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Review Article

From Knowledge Mapping to Evidence Synthesis: A Critical Path Model for Constructing Coherent Scientific Texts

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Abstract

Background. Contemporary academic writing practice is increasingly determined by standardized requirements for publication structure and typologies of review studies. At the same time, formal compliance with these standards does not guarantee the methodological coherence of a scientific text, as the logic of knowledge formation often remains unarticulated.

Purpose. To propose a critical path model of knowledge synthesis, within which the preparation of a scientific text is considered as a sequential cognitive process governed by an invariant logic of epistemological operations.

Materials and Methods. The study was conducted in the format of a conceptual narrative review involving methodological works on evidence synthesis, typologies of review studies, and academic writing. The analysis was aimed at reconstructing functional cognitive operations, establishing causal relationships between them, and formalizing their sequence in the form of a critical path.

Results. Five invariant cognitive nodes were identified: orientation, conceptualization, verification, evidence synthesis, and interpretation. It was shown that these nodes form a critical path that determines the methodological coherence of a scientific text regardless of the publication genre. It was established that different types of reviews correspond to individual segments of this path but do not determine its logic. Typical violations of the critical path were identified, including meta-analysis without conceptualization, narrative generalizations without verification, and systematic reviews without orientation in the scientific field, which lead to predictable methodological deformations.

Discussion. The obtained results indicate that methodological problems of contemporary scientific texts have a structural character and are associated with the substitution of the logic of cognition by genre-based and formal requirements. The proposed model makes it possible to interpret these violations as consequences of disruptions in causal relationships between cognitive operations.

Conclusions. The methodological correctness of a scientific text is determined not by its formal type, but by the consistency of the preparation trajectory with the critical path of knowledge synthesis. The proposed model provides a basis for improving the quality of academic writing, peer review, and editorial evaluation.

Keywords: critical path model, knowledge synthesis, evidence synthesis, academic writing, methodological framework, systematic review, physical education, sport science.

Introduction

In contemporary academic practice, the preparation of scientific texts is increasingly carried out under conditions of a high level of formalization of requirements for publication structure, reporting, and types of research, which is particularly evident in the standardization of review studies and evidence synthesis procedures (Grant & Booth, 2009; Page et al., 2021). However, such standardization does not eliminate, but often masks, problems of logical coherence in the process of knowledge formation. At the same time, the growth of formal standards is not always accompanied by a corresponding clarity regarding the logic of scientific knowledge formation, which precedes the choice of genre or type of article. As a result, scientific texts may comply with formal criteria while remaining conceptually unstable or methodologically ambiguous.

One manifestation of this situation is the emergence of hybrid texts that combine elements of narrative review,

systematic review, and meta-analysis without a clear distinction of their functional roles within the overall cognitive process, which had previously been conceptually differentiated in typologies of review studies (Grant & Booth, 2009). In such cases, genre forms de facto substitute the logic of sequential knowledge synthesis, leading to structurally unstable or methodologically inconsistent texts. This complicates both the interpretation of results and their evaluation in the peer-review process.

In contemporary philosophy of science and approaches to evidence synthesis, there is an increasingly clear understanding of scientific knowledge as the result of a stepwise cognitive process, within which different forms of synthesis perform specific functions—from orientation within the scientific field to verification and synthesis of evidence (Arksey & O'Malley, 2005; Levac et al., 2010; Higgins et al., 2019). In this context, bibliometric analysis serves as a formalized tool for mapping the structure of scientific knowledge, identifying thematic clusters, and research trends (Donthu et al., 2021). The evolution of review typologies confirms that these forms are not alternatives, but reflect different segments of a unified process of knowledge formation (Grant & Booth, 2009). At the same time, in academic writing practice, these functional distinctions are often reduced to genre templates, which complicates the reproduction of the internal logic of the cognitive process. Under these conditions, genre requirements and reporting standards begin to act as substitutes for methodological reflection, despite existing approaches that conceptualize writing as a tool for knowledge production (St. Pierre, 2007). This creates the need for formalizing a unified causal model that integrates different forms of knowledge synthesis into a coherent cognitive process.

As a result, problems of methodological quality in scientific publications are often interpreted as authors' errors or non-compliance with standards, whereas their causes are structural and related to the absence of a formalized connection between stages of knowledge synthesis. Under such conditions, individual methods may be applied formally correctly but yield methodologically unstable results, which is partly due to the fragmentation of methodological guidelines and reporting standards across types of review studies (Tricco et al., 2018; Page et al., 2021). This necessitates a conceptual understanding of scientific text preparation as a coherent cognitive process with an internally determined sequence of operations.

In this paper, a critical path model of knowledge synthesis is proposed, which interprets the preparation of a scientific text as a sequence of invariant cognitive operations linked by causal relationships.

In the field of physical education and sport, this problem becomes particularly relevant due to the interdisciplinary nature of research, the combination of pedagogical, biomedical, and behavioral approaches, and the rapid growth in the number of review publications. Under such conditions, violations in the logic of transitions between stages of knowledge synthesis lead to the emergence of formally correct but methodologically fragmented studies, including systematic reviews without a clear conceptual framework or meta-analyses without adequate orientation in the scientific field. This complicates the interpretation of results and reduces their practical value for specialists in physical education and sport.

The purpose of this study is to conduct a conceptual narrative review aimed at formalizing and conceptually substantiating the critical path of cognitive operations as an invariant model of knowledge synthesis in the process of scientific text preparation. Within this approach, genres of scientific publications are interpreted as functional segments of a unified cognitive process, while methodological correctness is determined by the consistency of the chosen trajectory with the causal logic of this process.

Achieving this goal involves:

(1) identifying invariant cognitive operations underlying scientific text preparation;

(2) formalizing their causal relationships in the form of a critical path;

(3) analyzing typical violations of this path and their methodological consequences.

Materials and Methods

Study Design

The study was conducted in the format of a conceptual narrative review aimed at the theoretical understanding of the logic of scientific text preparation in contemporary academic practice. The purpose of the methodological analysis was not to synthesize empirical results of individual studies, but to identify invariant cognitive operations and causal relationships that determine the methodological coherence of a scientific text.

The chosen format of a conceptual narrative review corresponds to contemporary approaches to the analysis of complex methodological phenomena, where the aim is not the aggregation of results of individual studies, but the reconstruction of the logic of the cognitive process. This approach is consistent with the interpretation of writing as a tool for research and knowledge production, rather than merely a means of its representation (St. Pierre, 2007).

Accordingly, the study does not belong to systematic reviews or meta-analyses and does not involve quantitative synthesis of data.

Research Material

The research material consisted of normative and methodological publications that define contemporary approaches to knowledge synthesis and the construction of review studies. The analysis included works that:

(a) describe functional differences between types of reviews and their methodological roles (Grant & Booth, 2009);

(b) substantiate the necessity of an orientation stage in expanding and fragmented scientific fields (Arksey & O'Malley, 2005; Levac et al., 2010);

(c) formalize requirements for verification and synthesis of evidence in systematic reviews and meta-analyses (Higgins et al., 2019; Page et al., 2021);

(d) conceptualize academic writing as a tool for cognition and the construction of scientific argument (St. Pierre, 2007).

These publications were considered not as empirical sources for result aggregation, but as methodological reference points reflecting the evolution of views on the logic

of knowledge synthesis and the status of different forms of review studies in scientific cognition.

Methodological Framework of Analysis

The methodological basis of the study was the interpretation of scientific text preparation as a sequential cognitive process that can be formalized in the form of a network model. Within this framework, genres of scientific publications were considered as forms of knowledge representation, while the main unit of analysis was functional cognitive operations.

The analysis was carried out through:

1. Conceptual comparison of different forms of knowledge synthesis with their cognitive functions.
2. Reconstruction of causal relationships between stages of scientific argument formation.
3. Identification of invariant nodes of the cognitive process, independent of the field and type of publication.

Procedure of Analysis

The research procedure included several interrelated stages:

1. Conceptual analysis of methodological sources to identify the evolution of views on the scientific text – from product to process of cognition.
2. Narrative synthesis of approaches to evidence synthesis with a focus on their functional role in the logic of knowledge formation.
3. Formalization of cognitive operations in the form of nodes of a network model and identification of logically necessary transitions between them.
4. Analysis of critical path violations, which made it possible to identify typical inadmissible trajectories of scientific text preparation and their methodological consequences.

The results of this stage formed the basis for the development of the critical path concept presented in the Results section.

Criteria of Conceptual Validity

The validity of the obtained conclusions was ensured not by statistical indicators, but by the internal logical consistency of the model and its ability to explain typical methodological deformations observed in academic practice.

The criteria of conceptual validity included:

- consistency of the model with contemporary views on the stepwise nature of scientific cognition;
- explanatory capacity with respect to identified inadmissible trajectories;
- coherence with the results and their interpretation presented in the Results and Discussion sections.

Methodological Limitations

The proposed approach is conceptual in nature and does not involve empirical verification on a corpus of specific publications. At the same time, it provides a methodological basis for further studies aimed at empirical analysis of scientific text preparation trajectories in different fields of knowledge.

Results

The analysis of contemporary approaches to evidence synthesis indicates that different forms of review studies historically developed not as alternatives to one another, but as responses to the limitations of previous approaches. Thus, the development of scoping approaches was driven by the need for orientation in expanding and fragmented scientific fields (Arksey & O'Malley, 2005; Levac et al., 2010), whereas systematic reviews and meta-analyses emerged as tools for increasing reproducibility and the strength of evidence (Higgins et al., 2019).

Logic of Scientific Text Preparation as a Network Cognitive Process

As a result of the conceptual narrative analysis of methodological approaches to knowledge synthesis, it was established that the preparation of a scientific text cannot be reduced to the choice of genre or type of publication. Instead, it follows an invariant logic of the cognitive process, which can be formalized in the form of a network model with clearly defined nodes and causal transitions between them.

These nodes correspond to functional cognitive operations, without which scientific generalization loses methodological stability.

Identification of Invariant Cognitive Nodes

The analysis of contemporary approaches to evidence synthesis, philosophy of science, and academic writing made it possible to identify five invariant cognitive nodes:

Orientation in the scientific field – provides an understanding of the structure of knowledge, thematic clusters, dominant approaches, and research gaps, including through bibliometric mapping techniques (Donthu et al., 2021).

Conceptualization of the problem – involves the formation of a theoretical framework, the logic of argumentation, and key concepts.

Verification of statements – is aimed at assessing the reliability and reproducibility of the empirical data and sources used.

Evidence synthesis – ensures the integration of results and the weighting of evidence, including quantitative synthesis.

Interpretation and projection – connects the obtained synthesis with theoretical positions and practical implications.

These nodes represent logically necessary states of cognition, regardless of the field of knowledge and the format of publication. The proposed logic has direct methodological relevance for the field of physical education and sport, where different forms of knowledge synthesis are often applied in isolation, outside their functional interconnection.

Critical Path of Scientific Text Preparation

In terms of network planning, the preparation of a scientific text has a critical path, the violation or omission of elements of which leads to methodological instability of the result.

The critical path has the following sequence:

Orientation → Conceptualization → Verification → Evidence synthesis → Interpretation

This path is epistemological rather than genre-based. It reflects the logic of scientific knowledge formation, whereas publication types represent only individual segments of this path.

The constructed network model of the critical path of knowledge synthesis is presented in Figure 1.

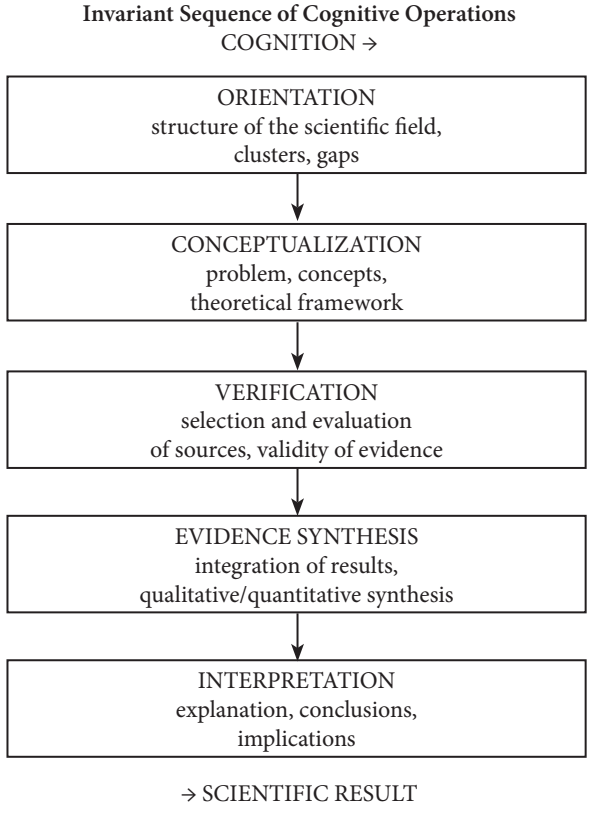

Fig. 1. Critical path of knowledge synthesis in scientific text preparation. Note. The critical path reflects an invariant, causally determined sequence of cognitive operations underlying knowledge synthesis. Violation or omission of individual stages of this path leads to predictable methodological deformations regardless of the formal type of publication.

Mapping of Cognitive Nodes to Forms of Knowledge Synthesis

Within the identified critical path, different forms of knowledge synthesis perform specific functions corresponding to individual cognitive nodes. This allows them to be considered not as alternative approaches, but as functionally interconnected elements of a unified process of knowledge formation. The correspondence between cognitive nodes and dominant forms of synthesis is summarized in Table 1.

Thus, forms of synthesis do not compete with each other, but functionally complement one another within a unified cognitive process.

Acceptable Trajectories of Scientific Text Preparation

The results of the analysis indicate that not all scientific texts are required to pass through the full critical path. At the same time, any acceptable trajectory must be consistent with its logic.

Table 1. Mapping of cognitive nodes to dominant forms of knowledge synthesis

Cognitive node	Dominant form of synthesis
Orientation	Bibliometric analysis; scoping review
Conceptualization	Narrative review
Verification	Systematic review
Evidence synthesis	Meta-analysis
Interpretation	Integrative conclusion

Note. Each form of synthesis corresponds to a specific functional stage within the critical path and does not substitute the overall epistemological sequence. Within these stages, specific tools may be applied; in particular, bibliometric analysis supports orientation in the scientific field by identifying knowledge structures and research trends (Donthu et al., 2021).

Examples of methodologically acceptable trajectories:

- Conceptual / theoretical work:
  Orientation → Conceptualization → Interpretation
- Systematic review without meta-analysis:
  Orientation → Conceptualization → Verification → Interpretation
- Meta-analysis:
  Orientation → Verification → Evidence synthesis → Interpretation
  (provided that a stable conceptual framework exists in the scientific field)

Violations of the Critical Path and Their Methodological Consequences

As a result of the conceptual narrative analysis, it was established that methodological problems of contemporary scientific texts are determined not by the choice of individual methods or genres, but by violations of the logic of the critical path of cognitive operations. Such violations have predictable consequences that manifest regardless of the field of knowledge and the formal type of publication.

The analysis made it possible to identify typical inadmissible trajectories of scientific text preparation that arise from omission or substitution of individual cognitive nodes. It was established that such violations are systemic and lead to predictable methodological deformations independent of the formal type of publication. The systematization of critical path violations and their methodological consequences is presented in Table 2.

The identified inadmissible trajectories are consistent with contemporary standards of evidence synthesis, within which the functions of conceptual justification, selection procedures, and interpretation of results are clearly differentiated (Page et al., 2021). Violation of this differentiation leads to formally correct but methodologically unstable results.

Conceptual Significance of Identified Violations

The identified violations are not individual author errors and cannot be reduced to non-compliance with formal standards. They are structural in nature and result from the identification of publication genres with the methodology of cognition. In such cases, individual stages of knowledge synthesis are applied in isolation, outside the logic of their functional interconnection.

Table 2. Typical violations of the critical path and their methodological consequences

Critical path violation	Methodological consequence
Meta-analysis without conceptualization	Statistically correct results lacking scientific meaning
Narrative conclusions without verification	Speculative generalizations
Interpretation without evidence synthesis	Essay-like reasoning without scientific validity
Systematic review without field orientation	Technical compilation without conceptual novelty

Note. Violations reflect disruptions in the causal sequence of cognitive operations rather than improper application of individual methods.

Thus, inadmissible trajectories reflect not the "weakness" of individual methods, but violations of causal relationships between cognitive operations, which leads to methodological instability of the scientific text.

Generalized Result

The obtained results indicate that the quality and scientific validity of a text are determined not by the completeness of applied methods and not by the formal type of publication, but by the consistency of the chosen trajectory of text preparation with the critical path of the cognitive process. Violations of this path lead to predictable and typical methodological deformations that can be identified at the stages of peer review and editorial analysis.

Discussion

Interpretation of Identified Violations of the Critical Path

The obtained results indicate that methodological deformations of scientific texts have a structural character and reflect disruptions in the logic of the cognitive process. The identified inadmissible trajectories specify the mechanisms of their occurrence, in particular the substitution of methodology by genre forms. In such cases, individual stages of knowledge synthesis are applied in isolation, without taking into account their functional role in the integral structure of scientific argument formation.

In particular, the emergence of meta-analyses without a clear conceptual framework is explained by the orientation toward formal criteria of evidence, while issues of meaningful interpretation are placed outside the scope of methodological analysis. Similarly, narrative generalizations without verification procedures are often the result of mixing theoretical reflection with empirical statements without proper differentiation of their status.

The identified violations of the critical path should be considered in the context of the fragmentation of methodological recommendations across publication types. The development of reporting standards for systematic reviews and scoping studies (Tricco et al., 2018; Page et al., 2021) has significantly increased the transparency of individual stages of knowledge synthesis, but at the same time has intensified the risk of their isolated application without a conceptual connection to other cognitive operations.

Structural Causes of Methodological Failures

They are formed within a broader context of contemporary academic practice, in which individual elements of the process of scientific text preparation are regulated unevenly and in isolation. In particular, this context includes:

- the spread of templated requirements for the structure of scientific articles, arising from the standardization of reporting forms for specific types of review studies and contributing to the identification of genre with methodology (Grant & Booth, 2009; Tricco et al., 2018);
- the growing role of formal quality indicators within evaluation procedures for review studies, where compliance with reporting standards is used as a proxy indicator of methodological rigor (Page et al., 2021);
- the fragmentation of methodological recommendations across publication types, as a result of which individual stages of knowledge synthesis (orientation, verification, synthesis) are regulated independently of one another (Grant & Booth, 2009; Arksey & O'Malley, 2005; Levac et al., 2010);
- the shift of emphasis toward the rapid reproduction of formally correct results, which is reinforced by requirements for accelerated publication cycles and reduces the space for conceptual reflection at the stage of text preparation.

Under such conditions, the genre of a scientific article often begins to function as a methodological surrogate, substituting the logic of cognition, which correlates with the fragmentation of standards of review studies across publication types (Grant & Booth, 2009; Tricco et al., 2018).

The Significance of the Critical Path as an Interpretative Framework

The proposed critical path model makes it possible to interpret these phenomena not as a set of "errors," but as consequences of violations of causal relationships between cognitive operations. Such an approach removes normative tension and shifts the analysis into the domain of methodological reflection.

In this context, the critical path does not function as a mandatory procedural scheme, but rather as an invariant logic with which different trajectories of scientific text preparation must be aligned. It is this alignment, rather than the completeness of applied methods, that determines methodological correctness and the scientific validity of results.

Implications for Academic Writing Practice and Evaluation

From the perspective of the obtained results, it becomes possible to reinterpret typical difficulties of peer review and preliminary editorial screening. Instead of evaluating

compliance with formal publication types, there emerges the possibility of analyzing the logic of the trajectory followed by the author.

For authors, this opens the space for the conscious selection of acceptable reduced trajectories without loss of methodological coherence. For reviewers, it provides a tool for identifying structural failures that are not always evident in superficial evaluation. For editorial boards, it creates a basis for explaining editorial policy without resorting to rigid normative prescriptions.

In the context of physical education and sport, this has direct practical implications. In particular, the use of systematic reviews and meta-analyses without proper conceptualization or orientation in the scientific field leads to the formation of generalizations that are difficult to integrate into educational practice or training programs. The proposed critical path model makes it possible to interpret these problems not as isolated methodological shortcomings, but as manifestations of violations in the logic of knowledge synthesis within the field.

Limitations and Future Directions

The discussed model is conceptual in nature and does not replace discipline-specific methodological standards. At the same time, it can serve as a meta-level for their coordination, as well as a basis for further research aimed at empirical verification of typical processes of scientific text preparation across different disciplines.

General Statement

Thus, the results and their discussion allow us to state that the problems of contemporary scientific texts are related not to a lack of methods or standards, but to insufficient articulation of the logic of the cognitive process, which precedes the choice of genre and determines the possibility of coherent knowledge synthesis.

Conclusions

Within the framework of a conceptual narrative review, it is substantiated that the preparation of a scientific text follows an invariant logic of the cognitive process that does not coincide with the traditional typology of scientific publications.

It is shown that genres of scientific articles reflect individual segments of this process, but do not determine its causal structure.

The formalization of the critical path of cognitive operations made it possible to identify typical inadmissible trajectories of scientific text preparation and the predictable methodological consequences of their violation.

The identified violations have a structural character and are caused by the substitution of methodology with genre and formal requirements of academic writing, which is consistent with typologies and standards of review studies (Grant & Booth, 2009; Page et al., 2021).

The proposed critical path model is not a normative instruction, but performs the function of an interpretative framework for analyzing the methodological coherence of scientific texts.

Methodological correctness is determined by the correspondence of the trajectory of text preparation to the logic of the cognitive process.

The obtained conclusions create a basis for the further development of tools for academic writing, peer review, and editorial evaluation oriented toward coherent knowledge synthesis.

Ethics approval and consent to participate

This study is conceptual in nature and did not involve human participants, animals, or the collection of primary data. Therefore, ethical approval and informed consent were not required.

Consent for publication

Not applicable.

Availability of data and materials

No datasets were generated or analyzed during the current study. All sources used are publicly available academic publications.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the conceptualization of the study, development of the methodological framework, analysis and interpretation of the results, and drafting and revision of the manuscript. All authors approved the final version of the manuscript.

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Notes on methodology

This article presents a conceptual narrative review and does not aim to provide prescriptive guidelines or empirical validation. The proposed framework is intended as an interpretative tool for understanding the logic of scientific text construction.

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Від картографування знань до синтезу доказів: модель критичного шляху побудови цілісних наукових текстів

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 2 табл., 1 рис., 8 джерел.

Вступ. Сучасна практика академічного письма дедалі більше визначається стандартизованими вимогами до структури публікацій і типологіями оглядових досліджень. Проте формальна відповідність цим стандартам не гарантує методологічної валідності, оскільки логіка формування знання часто залишається неявною або підміняється жанровими шаблонами, що призводить до системних спотворень синтезу доказів.

Мета дослідження. Формалізувати модель критичного шляху синтезу знань, у межах якої підготовка наукового тексту інтерпретується як послідовний пізнавальний процес, підпорядкований інваріантній логіці епістемологічних операцій.

Матеріали і методи. Дослідження виконано у форматі концептуального наративного огляду з використанням підходів синтезу доказів, типології оглядових досліджень і теорії академічного письма. Аналіз передбачав функціональну декомпозицію пізнавальних операцій, реконструкцію причинно-наслідкових зв'язків між ними та формалізацію їх послідовності у вигляді критичного шляху.

Результати. Виокремлено п'ять інваріантних пізнавальних вузлів: орієнтація (формулювання проблеми), концептуалізація (побудова моделі), верифікація (оцінка доказів), узагальнення доказів (синтез), інтерпретація (теоретичне пояснення). Показано, що ці вузли формують критичний шлях, який визначає методологічну цілісність наукового тексту незалежно від жанру. Встановлено, що типи оглядових досліджень відповідають окремим ділянкам цього шляху, але не визначають його логіку. Ідентифіковано типові порушення, зокрема мета-аналіз без концептуалізації, наративні узагальнення без верифікації та систематичні огляди без орієнтації, що призводить до передбачуваних методологічних деформацій.

Обговорення. Результати свідчать, що проблеми сучасних наукових текстів мають системний характер і зумовлені розривом причинно-наслідкових зв'язків між пізнавальними операціями та підміною логіки пізнання формальними вимогами. Запропонована модель дозволяє інтерпретувати ці порушення як прояви епістемологічної неузгодженості.

Висновки. Методологічна коректність наукового тексту визначається не його жанровою формою, а узгодженістю траєкторії підготовки з критичним шляхом синтезу знань. Модель може бути використана як інструмент підвищення якості академічного письма, рецензування та редакційного оцінювання.

Ключові слова: модель критичного шляху, синтез знань, синтез доказів, академічне письмо, методологічна рамка, систематичний огляд, фізичне виховання, спортивна наука.

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Review Article

From Motivation to Sustained Engagement: A Dual-Process Framework of Self-Regulation in Physical Literacy. A Systematic Review

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Abstract

Background. Physical literacy (PL) has emerged as a central outcome of contemporary physical education, reflecting a shift toward holistic approaches that integrate physical, cognitive, and affective domains. However, existing research often examines motivational and behavioral factors in isolation, limiting understanding of how sustained engagement in physical activity develops.

Objectives. This study aims to provide a thematically grounded synthesis of how non-cognitive attributes and self-regulatory processes interact to shape physical literacy outcomes in educational contexts.

Materials and Methods. A systematic review was conducted following PRISMA 2020 guidelines. Literature was retrieved from the Scopus and Web of Science databases using predefined search criteria. A total of 36 studies met the inclusion criteria and were analyzed using thematic synthesis.

Results. Four key themes were identified: (1) non-cognitive foundations, (2) self-regulatory mechanisms, (3) pedagogical and social contexts, and (4) digital and hybrid learning pathways. The findings indicate a consistent pattern in which non-cognitive attributes—particularly motivation, confidence, and self-efficacy—function as initiators of engagement, while sustained participation is supported by self-regulatory processes such as goal-setting, self-monitoring, and behavioral adjustment. These processes facilitate the transition from initial intention to more stable participation over time. In addition, pedagogical and digital contexts shape this relationship by structuring and supporting the interaction between motivational and regulatory processes.

Conclusions. The findings support a dual-process perspective in which motivation initiates engagement and self-regulation stabilizes behavior over time. This study contributes by clarifying how engagement in physical activity can be both initiated and sustained, providing a basis for designing physical education programs that integrate motivational and self-regulatory development.

Keywords: physical literacy, self-regulation, motivation, physical education, systematic review, student engagement, digital learning.

Introduction

Physical literacy (PL) has increasingly been recognized as a central outcome of contemporary physical education (PE), reflecting a shift from performance-oriented approaches toward a more holistic understanding of human movement. As a multidimensional construct, PL encompasses motivation, confidence, physical competence, knowledge, and understanding that collectively support lifelong engagement in physical activity (Dlugonski et al., 2022; Mota et al., 2021). This perspective positions PL not only as an educational objective but also as a foundation for sustained health, well-being, and active lifestyles across the lifespan (Edwards et al., 2016; Stoddart & Humbert, 2021; van Wyk et al., 2022).

A growing body of literature highlights that the development of PL is shaped by the interaction of cognitive,

affective, and social domains. Early engagement in meaningful physical experiences contributes to long-term participation and psychological well-being (Cornish et al., 2020; Edwards et al., 2016; Lloyd et al., 2024). Within this framework, non-cognitive attributes—such as motivation, self-efficacy, confidence, and emotional resilience—play a critical role in initiating engagement and shaping individuals' willingness to participate in physical activity (Houser & Kriellaars, 2023; Ma et al., 2021). However, while these attributes are consistently associated with increased participation, existing research rarely explains how motivational states are translated into sustained behavioral engagement over time.

This limitation points to the importance of self-regulatory processes as mechanisms that enable individuals to convert motivation into consistent action. Skills such as goal setting, self-monitoring, and behavioral planning support learners in regulating their participation and maintaining engagement across contexts (Jefferies et al., 2019; Liu & Chen, 2022; Quitério, 2018). Importantly, motivation alone does not necessarily lead to sustained participation, highlighting the need for regulatory capacities that stabilize behavior beyond initial engagement.

Despite these advances, research on physical literacy remains conceptually fragmented. Existing studies have typically examined pedagogical approaches, psychological constructs, or behavioral outcomes in isolation, resulting in a limited understanding of how these dimensions interact within authentic educational settings. In particular, insufficient attention has been given to how non-cognitive attributes and self-regulatory processes function as interconnected mechanisms that shape sustained participation in physical activity. This gap constrains both theoretical development and the design of integrated pedagogical models in physical education.

This limitation becomes increasingly relevant in the context of digital and hybrid learning environments, where learners are required to regulate their engagement more independently. While technology-enhanced PE has been associated with increased accessibility and engagement (Bond et al., 2020; Estevan et al., 2023), limited research has examined how digital environments influence the interplay between motivation and self-regulation in supporting long-term participation.

Given these gaps, there is a need for a systematic synthesis that integrates non-cognitive attributes, self-regulatory processes, and pedagogical contexts within a coherent analytical framework. Therefore, this study aims to examine how these dimensions interact to shape physical literacy outcomes in physical education settings. Specifically, the review explores how non-cognitive attributes and self-regulatory processes are conceptualized and operationalized, how pedagogical and learning environments influence these mechanisms, and which contextual conditions strengthen or constrain these relationships.

This study addresses this gap by advancing a theoretically grounded synthesis that integrates non-cognitive and self-regulatory constructs within established frameworks, particularly Self-Determination Theory (SDT) and Social Cognitive Theory (SCT). Building on this integration, the review proposes a dual-process perspective in which motivation functions as an initiator of engagement, while self-regulation acts as a stabilizing mechanism that sustains behavior over time. Accordingly, this study conceptualizes physical literacy as the result of dynamic interactions between affective, behavioral, and contextual processes, rather than isolated components.

Materials and Methods

Study Design

This study employed a systematic review design with thematic synthesis to integrate empirical and conceptually relevant evidence on the role of non-cognitive attributes and self-regulatory processes in shaping physical literacy outcomes in educational contexts. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency and methodological rigor.

Information Sources and Search Strategy

The literature search was performed using two major electronic databases, Scopus and Web of Science, to ensure comprehensive coverage of peer-reviewed publications in physical education, health, and educational psychology.

The search strategy was developed iteratively to identify studies examining physical literacy in relation to non-cognitive and self-regulatory constructs within educational settings. The primary search query included terms such as: ("physical literacy" OR "physical activity participation") AND ("grit" OR "perseverance" OR "self-regulated learning" OR "self-regulation") AND ("physical education")

To ensure broader coverage, the search process was supplemented by iterative refinement of keywords and citation tracking, allowing inclusion of studies addressing related constructs such as motivation, self-efficacy, confidence, and autonomy support. An expanded set of related terms was considered during refinement, although the core query structure remained consistent across databases.

Searches were conducted in Scopus and Web of Science on 12 March 2026. The strategy was adapted to the syntax requirements of each database. In Scopus, the search was conducted within title, abstract, and keywords fields, whereas a comparable topic-based strategy was applied in Web of Science. The search was limited to peer-reviewed journal articles published in English between 2015 and 2025. Backward and forward citation tracking was also conducted to identify additional relevant studies.

Eligibility Criteria

Studies were included if they:

1. Examined physical literacy or physical activity participation within educational settings;
2. Addressed non-cognitive attributes such as motivation, self-efficacy, confidence, grit, or perseverance and/or self-regulatory processes such as goal setting, self-monitoring, and self-regulated learning;
3. Employed empirical quantitative, qualitative, or mixed-methods designs;
4. Were published in peer-reviewed journals.

Studies were excluded if they lacked clear relevance to physical literacy outcomes, were not situated in educational

or pedagogical contexts, were not written in English, or did not report empirical findings.

Although the primary analytical focus was on empirical studies, a limited number of conceptually relevant review-based studies were retained to support theoretical interpretation and contextualize patterns emerging from the empirical evidence. These studies were not treated as primary analytical units.

Study Selection

The study selection process followed the PRISMA 2020 framework. The initial search identified 1,167 records, including 1,063 from Scopus and 104 from Web of Science. After duplicate removal, 1,000 unique records remained.

Title and abstract screening resulted in the exclusion of 780 records, leaving 220 articles for full-text assessment. Following full-text review, 184 articles were excluded because of insufficient relevance to physical literacy outcomes, lack of alignment with the educational focus of the review, or insufficient conceptual fit with the review objectives. A total of 36 studies met the inclusion criteria and were retained for the final synthesis. The study selection process is illustrated in Figure 1.

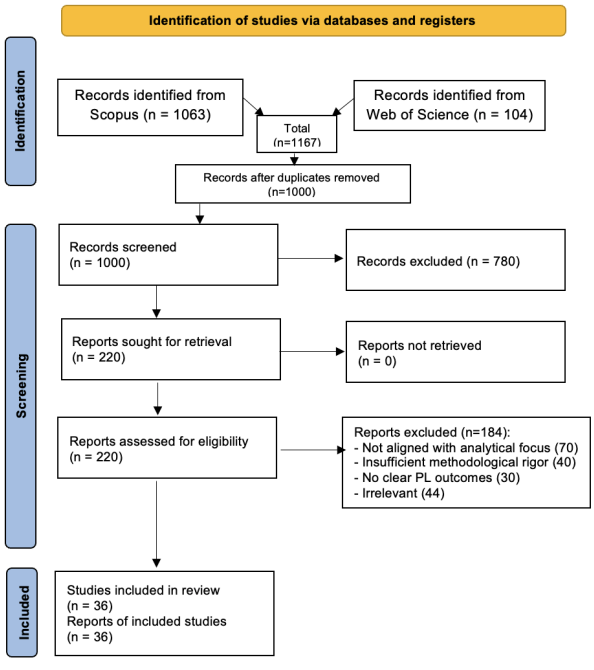

Fig. 1. The PRISMA flow diagram detailing the screening and selection process of literature

Selection was conducted in two stages: (1) title and abstract screening and (2) full-text assessment. The screening process was conducted by the author using predefined eligibility criteria.

Data Extraction

Data from the included studies were extracted using a standardized extraction form capturing study design, sample characteristics, key variables, measurement approaches, and principal findings.

To ensure analytical consistency, an additional verification step was conducted during extraction and synthesis by re-checking consistency between extracted data and thematic categorization. Studies that did not provide sufficient alignment with the analytical framework or lacked extractable data relevant to the identified themes were not emphasized in the tabular presentation.

Accordingly, Tables 1–4 present the most analytically salient studies grouped by thematic categories, while all included studies informed the overall synthesis and interpretation.

Quality Considerations

Because the review aimed to synthesize conceptually heterogeneous evidence across multiple study designs, no formal critical appraisal tool was applied. Instead, studies were evaluated based on relevance to the review questions, clarity of methodological reporting, and contribution to the thematic synthesis. This approach was considered appropriate for the interpretive purpose of the review and the diversity of the included evidence.

Data Synthesis

The analysis was conducted using thematic synthesis. Through iterative coding and categorization, four overarching themes were identified:

1. Non-cognitive foundations of physical literacy;
2. Self-regulatory mechanisms;
3. Pedagogical and social contexts;
4. Digital and hybrid learning pathways.

These themes guided the organization of the results and supported the development of a conceptual framework integrating affective and behavioral dimensions of physical literacy.

Result

Non-Cognitive Foundations of Physical Literacy

The review of the literature demonstrates that non-cognitive attributes play a central role in the development of physical literacy (PL), particularly through motivation, confidence, and affective engagement. As summarized in Table 1, these constructs are consistently positioned as foundational drivers of participation across diverse educational contexts.

The reviewed literature indicates that non-cognitive attributes play an important role in the development of physical literacy (PL), particularly through motivation, confidence, and affective engagement. As summarized in Table 1, these constructs were consistently emphasized across diverse educational contexts, suggesting that affective readiness remains a central concern in current PL research.

Motivation and confidence emerged as the most consistently reported PL-related domains, each appearing in 100% (9 out of 9) of the studies summarized in Table 1. In contrast, knowledge and understanding were identified in only 22% (2 out of 9) of the studies, typically in conjunction with affective dimensions. This distribution indicates that current PL research remains strongly oriented toward

Table 1. Non-Cognitive Foundations of Physical Literacy in Physical Education

Study / Context	Core Construct / Mechanism	Operationalization / Measure	PL-Related Domain / Outcome	Key Finding
(Malmström & Öqvist, 2025) / Elementary PE teachers	Self-efficacy; social support; motivation	Teacher self-efficacy scale; social support; SEM	Motivation; confidence	Teacher self-efficacy and social support were associated with stronger motivation and leadership behaviors supportive of PL-related environments
(Behzadnia et al., 2025) / High-school PE	Autonomy support; need satisfaction; autonomous motivation	SDT-based questionnaires; gameplay assessment	Motivation; confidence	Autonomy-supportive teaching was associated with need satisfaction and autonomous motivation, alongside improved performance relevant to PL
(Khairani & Zhang, 2025) / Chinese universities	Self-efficacy; outcome expectations; social support	SCT scales; PLS-SEM	Motivation; confidence	Self-efficacy was identified as a strong predictor of physical activity engagement, supporting confidence-related dimensions of PL
(Qiu et al., 2025) / College students	Psychological resilience; self-efficacy	IPAQ-S; CD-RISC; PSES-CS	Motivation; confidence	Physical activity and resilience were linked to enhanced self-efficacy, indicating affective pathways relevant to PL
(Pavlovic et al., 2025) / Youth sport	Emotions; climate perceptions	Survey; focus groups	Motivation; confidence	Positive emotional climates were associated with social-emotional development and affective outcomes relevant to PL
(White et al., 2025) / Informal school PA	Enjoyment; social belonging; confidence	Qualitative interviews	Motivation; confidence	Informal exercise opportunities were associated with improved confidence and social well-being beyond formal PE
(Cashman et al., 2025) / Primary schools	Well-being perceptions; relationships	PhotoVoice; interviews	Motivation; knowledge and understanding	Students highlighted relationships and learning experiences as important to well-being and holistic interpretations of PL
(Frikha et al., 2024) / Female PE students	Enjoyment; need satisfaction	SDT scales; mediation analysis	Motivation; relatedness	Enjoyment and need satisfaction were associated with institutional integration and motivational outcomes relevant to PL
(Costa et al., 2025) / PE empathy review*	Empathy; prosocial emotions	PRISMA scoping review	Motivation; affective domain	Emotional and social learning strategies in PE were reported to support affective dimensions relevant to PL

Note. IPAQ-S = International Physical Activity Questionnaire (Short Form); CD-RISC = Connor–Davidson Resilience Scale; PSES-CS = Physical Self-Efficacy Scale for College Students; SDT = Self-Determination Theory; SEM = Structural Equation Modeling; PLS-SEM = Partial Least Squares Structural Equation Modeling.

affective constructs, with comparatively limited integration of cognitive components.

Among the non-cognitive constructs, self-efficacy and related confidence constructs (5/9), autonomy support (3/9), and emotional factors (3/9) were most frequently identified. Self-efficacy and closely related constructs were frequently reported as important predictors of physical activity engagement, often interacting with social support and motivational processes. However, their effects were rarely presented as independent; rather, they tended to emerge in relation to broader contextual supports.

Motivational processes were commonly linked to autonomy-supportive environments, where instructional practices facilitated intrinsic motivation and engagement. Emotional and social constructs—such as enjoyment, belonging, and resilience—were particularly evident in informal and primary education contexts, where they were associated with increased confidence and well-being.

Across studies, motivation, confidence, and self-efficacy were rarely reported as isolated attributes. Instead, they appeared most clearly when supported by favorable social and instructional conditions, suggesting that affective readiness for participation is not purely individual but shaped through interaction with the learning environment. Taken together, these findings suggest that non-cognitive attributes primarily function as initiators of engagement, establishing the affective conditions necessary for participation but not, on their own, fully explaining sustained behavior over time.

Self-Regulation as a Mechanism for Physical Literacy

Building on these affective foundations, the reviewed studies identify self-regulation as a key mechanism that supports sustained engagement over time. As shown in Table 2, self-regulatory processes were identified across diverse contexts, including formal instruction, blended learning, and informal physical activity settings.

Among the identified mechanisms, self-monitoring (3/7) was the most frequently reported, followed by goal-setting (2/7), self-management (2/7), and persistence-related constructs (2/7). These processes were typically supported through pedagogical strategies such as structured reflection, digital feedback, and autonomy-supportive instruction.

Evidence from experimental and quasi-experimental studies suggests that interventions incorporating self-monitoring and goal-setting are associated with increased physical activity engagement and intrinsic motivation. Technology-supported interventions, including pedometer-based programs and fitness applications, were also linked to improved behavioral regulation and participation consistency.

Several studies indicate that self-regulation functions as more than an accompanying factor; it appears to connect initial willingness to participate with repeatable action. Psychological constructs such as motivation and resilience may influence participation indirectly through regulatory processes, suggesting that self-regulation links affective drivers with behavioral outcomes.

More specifically, the reviewed evidence suggests that motivation becomes behaviorally sustained when learners are provided with regulatory supports such as goal-setting, self-monitoring, structured feedback, and opportunities for behavioral adjustment. In this sense, self-regulation does not replace motivation, but converts initial willingness into repeatable action. Some studies also suggest potential transferability, with self-regulatory skills developed in informal settings supporting independent engagement beyond structured physical education environments. Overall, self-regulation appears to function as a stabilizing mechanism, complementing the initiating role of non-cognitive attributes.

Pedagogical and Social Contexts for Physical Literacy

Pedagogical and social contexts were consistently identified as key structural factors shaping both motivational and regulatory processes. As summarized in Table 3, instructional design and environmental support play a central role in influencing physical literacy outcomes.

Autonomy-supportive teaching (3/7) emerged as the most frequently reported approach, followed by social support (2/7) and student-centered pedagogical practices (2/7). These approaches were associated with increased motivation, confidence, engagement, and relatedness.

The reviewed studies indicate that autonomy-supportive teaching practices enhance psychological need satisfaction and

Table 2. Self-Regulation as a Mechanism for Physical Literacy Development in Physical Education

Study / Context	Core Self-Regulatory Skill / Mechanism	Operationalization / Intervention	PL-Related Domain / Outcome	Key Finding
(Huang et al., 2025) / School PE	Goal setting; self-monitoring	Cooperative learning and pedometer-based self-management	Behavioral engagement; autonomy	Self-management strategies were associated with increased physical activity engagement and greater autonomy in PE
(Ibragimova et al., 2025) / Blended learning	Self-monitoring; self-organization	Fitness app-supported PA program	Intrinsic motivation; activity habits	App-based feedback and gamification were associated with stronger motivation and more consistent physical activity habits
(Nie et al., 2025) / General PA context	Self-control	General physical activity participation	Self-control; well-being	Physical activity was associated with self-control, which partially explained life satisfaction outcomes relevant to PL
(Qiu et al., 2025)/ College students	Resilience; persistence	Regular physical exercise	Confidence; sustained engagement	Psychological resilience mediated the relationship between physical activity and self-efficacy, supporting sustained confidence
White et al. (2025) / Informal PA	Self-regulation transfer	Informal before-school exercise	Confidence; independent engagement	Informal PA settings appeared to support confidence transfer and self-directed engagement beyond PE
(Brown, 2024) / PE curriculum*	Self-management skills	Curriculum-focused PE pedagogy; SRL framework	Lifelong PA; self-management	Self-management was positioned as important for lifelong physical activity
(Zhang & Yun, 2025) / Online PE	Self-regulated engagement	Online gamified learning	Autonomy; learning engagement	Self-regulated engagement was associated with autonomy-supportive motivation and stronger learning engagement

Note. IPAQ-S = International Physical Activity Questionnaire (Short Form); SDT = Self-Determination Theory; SRL = Self-Regulated Learning.

Table 3. Pedagogical and Social Contexts Supporting Physical Literacy in Educational Settings

Study / Context	Pedagogical / Social Context	Core Mechanism	PL-Related Domain / Outcome	Key Finding
Behzadnia et al. (2025) / High-school PE	Teacher autonomy support	Need satisfaction leading to motivation	Motivation; confidence	Autonomy-supportive teaching was associated with intrinsic motivation and stronger engagement in PE
Frikha et al. (2024) / Female PE students	Peer and teacher support	Enjoyment; need satisfaction	Relatedness; confidence	Need satisfaction mediated the relationship between enjoyment and institutional integration
(Castillo-Retamal et al., 2024)/ Primary school PE	Student-centered pedagogy	Goal-setting; encouragement	Confidence; motivation	Goal-setting and emotional support were associated with increased student confidence and participation in PE
(Rech et al., 2025) / Preschool education	Teacher beliefs	Value of movement; activity provision	Confidence; enjoyment	Teachers' beliefs about movement influenced the frequency and quality of movement opportunities relevant to early PL development
(Saamong et al., 2025) / Early childhood education	Sociocultural values	Community attitudes; norms	Engagement; access	Cultural context shaped norms and expectations related to physical activity opportunities and PL experiences
(Malmström & Öqvist, 2025) / Elementary PE teachers	School climate	Motivational leadership	Confidence; engagement	Teacher self-efficacy and leadership climate were associated with motivational environments supportive of PL
Qiu et al. (2025) / University PE	Social support (peer/ instructor)	Resilience; motivation	Confidence; resilience	Social support was associated with motivation and self-efficacy through psychological resilience

Note. SDT = Self-Determination Theory; PA = Physical Activity.

intrinsic motivation, reinforcing the importance of learner-centered environments. Positive teacher-student relationships and supportive classroom climates were also associated with increased engagement and confidence, highlighting the role of social interaction in facilitating participation. Furthermore, student-centered approaches—such as goal-setting, personalized instruction, and reflective practices—were linked to both motivational and self-regulatory outcomes.

These findings suggest that pedagogy does more than support participation indirectly. Rather, it appears to structure the conditions under which affective and regulatory processes can operate together. In this sense, pedagogy functions not merely as a delivery mechanism, but as a structuring condition that shapes how motivation, confidence, and self-regulation become behaviorally meaningful in educational settings.

Institutional and sociocultural factors, including school climate, teacher beliefs, and community norms, were also identified as influencing PL development. However, variability across contexts indicates that the effectiveness of pedagogical strategies is contingent upon broader environmental conditions.

Digital and Hybrid Pathways for Physical Literacy

Extending beyond traditional instructional contexts, digital and hybrid learning environments were identified as emerging pathways supporting physical literacy development. As shown in Table 4, although the number of studies remains limited, consistent patterns can be observed across the available evidence.

The reviewed studies indicate that digital tools may support motivation, autonomy, and self-regulated engagement, particularly through features such as feedback, gamification, and activity tracking. Fitness applications and structured digital interventions were associated with increased engagement and more consistent participation behaviors.

Hybrid and online learning models were also linked to greater flexibility and opportunities for self-directed participation. These environments appear to facilitate self-monitoring and behavioral regulation, consistent with principles of self-regulated learning.

The reviewed evidence suggests that digital tools are most valuable when they extend pedagogical structure rather than act as independent interventions. Their contribution appears to lie in scaffolding monitoring, feedback, and continuity of participation rather than directly producing physical literacy outcomes on their own. Accordingly, the effectiveness of digital approaches depended on pedagogical alignment. Without structured guidance, digital tools alone were insufficient to sustain engagement, indicating that digital environments function more effectively as supporting mechanisms than as independent drivers of physical literacy.

Discussion

This systematic review provides a mechanism-based synthesis of how non-cognitive attributes and self-regulatory

Table 4. Digital and Hybrid Pathways Supporting Physical Literacy

Study / Context	Digital / Hybrid Strategy	Core Digital Mechanism	PL-Related Domain / Outcome	Key Finding
(Zhang & Yun, 2025)/ Online PE	Gamified online PE	Self-regulated engagement; autonomy support	Motivation; autonomy	Gamified platforms were associated with self-regulated engagement and stronger intrinsic motivation
Brown (2024) / Conceptual*	Online curriculum design	Digital-to-physical integration	Self-management; lifelong PA	Digital curriculum design was positioned as supporting self-management and lifelong physical activity
Ibragimova et al. (2025) / Experimental	Fitness app program	Gamification; feedback loops	Intrinsic motivation; engagement	Fitness app use was associated with stronger motivation and habit formation relevant to PL
Nie et al. (2025) / Digital PA participation	Behavioral feedback; affect tracking	Self-control mediation	Self-control; satisfaction	Self-control mediated the relationship between physical activity and life satisfaction, with implications for digitally supported participation

processes interact to shape physical literacy (PL) outcomes within educational contexts. Across the included studies, a consistent pattern emerges in which motivational constructs and self-regulatory mechanisms function as interdependent processes rather than independent predictors of physical activity engagement. This integrative pattern reflects the dynamic interaction between affective readiness, behavioral regulation, and contextual support observed across diverse learning environments (Huang et al., 2025; Ibragimova et al., 2025; Qiu et al., 2025).

A central contribution of this review lies in the refinement of a dual-process conceptualization of physical literacy. The findings indicate that non-cognitive attributes—particularly motivation, confidence, and self-efficacy—function as initiators of engagement, establishing the affective readiness required for participation. However, sustained participation is more consistently associated with self-regulatory processes such as goal-setting, self-monitoring, and behavioral adjustment. This distinction indicates that physical literacy development cannot be fully explained by affective readiness alone, but requires regulatory processes that enable behavioral continuity over time (Huang et al., 2025; Ibragimova et al., 2025).

Importantly, the findings clarify the mechanism underlying this relationship. Rather than functioning as parallel predictors, self-regulation operates as a bridging and stabilizing mechanism that connects psychological readiness with sustained behavioral engagement. In practical terms, this process reflects a sequence in which motivation facilitates intention formation, self-regulation structures behavior through monitoring and feedback, and sustained participation emerges through repeated and regulated action. Evidence across the reviewed studies indicates that individuals with higher levels of self-efficacy and intrinsic motivation are more likely to initiate physical activity; however, continued engagement depends on the presence of structured regulatory supports, including monitoring, feedback, and behavioral adjustment (Huang et al., 2025; Ibragimova et al., 2025). Furthermore, resilience-related constructs have been shown to mediate the relationship between participation and confidence, reinforcing the role of regulatory processes in maintaining behavioral consistency (Qiu et al., 2025). Taken together, these findings demonstrate that self-regulation is not merely supportive, but is essential in transforming initial engagement into sustained participation.

From a theoretical perspective, these findings reinforce the view that motivational and self-regulatory processes should be understood as interdependent components within the physical literacy framework. Evidence from the reviewed studies indicates that autonomy-supportive environments are associated with enhanced motivation and psychological need satisfaction (Behzadnia et al., 2025; Frikha et al., 2024), while self-efficacy and regulatory skills contribute to sustained behavioral engagement (Khairani & Zhang, 2025). Rather than functioning as separate explanatory domains, these processes operate in a complementary manner, jointly supporting both the initiation and maintenance of physical activity behavior.

The role of pedagogical and social contexts further strengthens this integrative interpretation. Evidence indicates that autonomy-supportive and student-centered instructional approaches are consistently associated with enhanced motivation, confidence, and engagement (Behzadnia et al., 2025; Castillo-Retamal et al., 2024). Similarly, supportive classroom climates and teacher-related factors facilitate both affective and behavioral dimensions of participation (Malmström & Öqvist, 2025; Pavlovic et al., 2025). This positions pedagogy not merely as a contextual influence, but as a critical structuring condition that determines whether psychological processes can be translated into observable and sustained behavior.

At the same time, the findings highlight the importance of contextual variability. Differences across educational levels, age groups, and learning environments indicate that the interaction between motivation and self-regulation is not uniform. Emotional and social constructs such as enjoyment, belonging, and well-being appear to play a more prominent role in informal and primary contexts (White et al., 2025; Cashman et al., 2025), whereas structured regulatory strategies are more evident in formal instructional settings (Huang et al., 2025). This suggests that physical literacy development is shaped by context-dependent interactions rather than fixed or universal relationships.

The emergence of digital and hybrid learning environments introduces an additional layer to this interaction. The reviewed studies indicate that digital tools—such as fitness applications and gamified platforms—can support motivation, self-monitoring, and engagement (Ibragimova et al., 2025; Zhang & Yun, 2025). However, these findings indicate that digital tools are not primary drivers of physical literacy, but are effective when they extend regulatory and pedagogical structures that support sustained engagement. Without such alignment, their contribution remains limited, highlighting that technology alone is insufficient without pedagogically grounded implementation.

Despite these contributions, several limitations of this review should be acknowledged. Variability in the operationalization and measurement of key constructs limits comparability across studies, while the predominance of cross-sectional and short-term designs restricts conclusions regarding long-term development. Differences in cultural and educational contexts may also limit generalizability. These limitations indicate the need for future research to adopt longitudinal and intervention-based designs that better capture the dynamic interaction between motivation and self-regulation over time.

From a practical perspective, the findings underscore the importance of designing physical education programs that explicitly integrate motivational and self-regulatory components. Strategies such as structured goal-setting, reflective practices, autonomy-supportive instruction, and digitally supported self-monitoring should be embedded within curriculum design rather than implemented as isolated interventions. This integrated approach enables the simultaneous development of engagement and behavioral persistence.

Conclusions

Physical literacy development is best explained through a dual-process model in which motivation, confidence, and self-efficacy initiate participation, while self-regulatory processes sustain long-term engagement.

Self-regulation functions as a key bridging mechanism that transforms initial readiness for participation into stable and repeated physical activity behavior.

Pedagogically supportive environments, particularly autonomy-supportive and student-centered approaches, strengthen both motivational and behavioral dimensions of physical literacy.

Digital tools can enhance engagement and self-monitoring, but their effectiveness depends on integration with sound pedagogical and regulatory frameworks.

Future research should prioritize longitudinal and intervention-based designs to better explain how motivation and self-regulation interact across diverse educational contexts over time.

Ethics Statement

This study did not involve human participants or animal subjects. Therefore, ethical approval was not required.

Data Availability Statement

All data analyzed in this study are derived from previously published articles and are available in the public domain. No new datasets were generated.

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Conflict of Interest

The authors declare no conflict of interest.

Authors Contributions

Conceptualization, methodology, analysis, and writing were performed by the authors.

AI Statement

The author used artificial intelligence tools (ChatGPT, OpenAI) to assist in language refinement and structuring of the manuscript. All content was critically reviewed and validated by the author, who takes full responsibility for the final version.

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Від мотивації до стійкої залученості: двопроцесна модель саморегуляції у фізичній грамотності. Систематичний огляд

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 4 табл., 1 рис., 31 джерело.

Обґрунтування. Фізична грамотність (PL) стала центральним результатом сучасної фізичної освіти, відображаючи перехід до цілісних підходів, що інтегрують фізичний, когнітивний та афективний компоненти. Однак наявні дослідження часто розглядають мотиваційні та поведінкові чинники ізольовано, що обмежує розуміння того, як формується стале залучення до фізичної активності.

Мета. Це дослідження має на меті надати тематично обґрунтований синтез того, як некогнітивні характеристики та процеси саморегуляції взаємодіють у формуванні результатів фізичної грамотності в освітніх контекстах.

Матеріали і методи. Систематичний огляд було проведено відповідно до рекомендацій PRISMA 2020. Літературу відібрано з баз даних Scopus та Web of Science за попередньо визначеними критеріями пошуку. Загалом 36 досліджень відповідали критеріям включення та були проаналізовані методом тематичного синтезу.

Результати. Визначено чотири ключові теми: (1) некогнітивні основи, (2) механізми саморегуляції, (3) педагогічні та соціальні контексти, (4) цифрові та гібридні траєкторії навчання. Результати свідчать про стійку закономірність, за якої некогнітивні характеристики — насамперед мотивація, упевненість і самоефективність — виступають ініціаторами залучення, тоді як стійка участь підтримується процесами саморегуляції, такими як постановка цілей, самоконтроль і поведінкове коригування. Ці процеси забезпечують перехід від початкового наміру до більш стабільної участі з часом. Крім того, педагогічні та цифрові контексти впливають на цей зв'язок, структуруючи та підтримуючи взаємодію між мотиваційними й регуляторними процесами.

Висновки. Отримані результати підтримують dual-process perspective, згідно з якою мотивація ініціює залучення, а саморегуляція стабілізує поведінку з часом. Це дослідження робить внесок у пояснення того, як залучення до фізичної активності може як ініціюватися, так і підтримуватися, створюючи основу для розроблення програм фізичної освіти, що інтегрують розвиток мотивації та саморегуляції.

Ключові слова: фізична грамотність, саморегуляція, мотивація, фізична освіта, систематичний огляд, залученість студентів, цифрове навчання.

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Review Article

Reconceptualizing Continuing Professional Development in Physical Education: A Systematic Review of Implementation, Mechanisms, and Pedagogical Transformation

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Abstract

Background. Continuing professional development (CPD) plays a critical role in improving teaching quality in physical education (PE); however, its effectiveness remains uneven and highly context-dependent.

Objectives. This study aims to systematically examine the forms of implementation, outcomes, and impacts of CPD in PE, while providing a more integrated understanding of how CPD functions as a professional learning process.

Materials and Methods. A systematic literature review was conducted in accordance with PRISMA guidelines, identifying 30 empirical studies published between 2015 and 2025 across major academic databases. Data were analyzed using thematic synthesis to identify patterns in implementation, duration, and outcomes.

Results. The findings indicate that CPD in PE is implemented through diverse models, including workshops, professional learning communities, and practice-based collaborative approaches. However, effectiveness is not determined solely by format or duration, but by the extent to which CPD fosters sustained engagement, reflective practice, and contextual relevance. CPD contributes to improvements in teachers' pedagogical knowledge, instructional practices, self-efficacy, and professional identity. Evidence of impact at the student and institutional levels suggests enhanced engagement, inclusivity, and learning environments, although these effects are indirect and mediated by implementation conditions.

Conclusions. CPD in PE should be understood as a dynamic, multi-level professional learning process shaped by interactions among individual, social, and institutional factors. These findings highlight the need for context-responsive and sustainable CPD designs that support meaningful pedagogical transformation.

Keywords: continuing professional development, physical education, teacher learning, pedagogical transformation.

Introduction

The role of the PE teacher has expanded beyond physical fitness to include a variety of skills, but has encompassed emotional intelligence, social skills, and cognitive development. PE involves a high level of behavioral interaction, educates students about morality, and facilitates certain prosocial behaviors, which are considered important goals of physical education (Wei et al., 2020). Therefore, strategic pedagogy in PE teaching is necessary to support students' holistic development. Hence, PE teaching should be implemented in a harmonious manner, providing positive sporting experiences, stimulating interest, and encouraging goal achievement (Guangxin et al., 2022). In addition, teaching in PE provides opportunities for students to achieve success, set expectations and build respectful relationships, thus strengthening life skills (Pozo et al., 2016).

Success in teaching PE relies significantly on the teacher taking an active role in the classroom, using direct and indirect behaviors and dialogue to support and extend learning (Goodyear & Dudley, 2015). In addition, the teacher is also the determinant of the success of the

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implementation of a model or theoretical construction in achieving teaching objectives (Casey et al., 2021). However, PE educators continue to face challenges in interpreting and applying the learning model in practice. A notable example is the challenge educators face in operationalizing the game-based approach within classroom settings (Goodyear, 2017). Teachers have limited pedagogical understanding, leading to deviations from the teaching practices recommended by the curriculum (Roshid & Haider, 2024). Furthermore, teachers find it difficult to change teaching methods that have already become habitual (Casey & MacPhail, 2018) and less skilled in keeping up with technological advances and collaborating with peers (Bodsworth & Goodyear, 2017).

Moreover, the teaching carried out by teachers is often driven not only by their understanding of the intricacies or effectiveness of the learning model, but also by encouragement from the principal and students (Cereda, 2023; Malinowski et al., 2024). Therefore, teacher training is needed as well as a concerted effort by researchers to create more scientific evidence based on classroom applications (Hernando-Garijo et al., 2021). The need for teacher training is reinforced by the study from (Casey & Bjørke, 2024) which highlights the importance of supporting frameworks for teachers in implementing pedagogical models focused on continuous learning and collaboration. In addition, strengthening pedagogical content knowledge is essential for teachers to be able to implement learning effectively (Iserbyt et al., 2017). For this reason, it is very important to develop teacher professionalism.

CPD allows for change through a sustainable community of practice (Kahts-Kramer & Wood, 2023). This can broaden teachers' understanding of inclusive pedagogy (Makopoulou et al., 2022) and improve knowledge and practice related to physical literacy (Edwards et al., 2019). CPD encourages teachers to apply teaching principles effectively by setting clear learning outcomes, differentiation and inclusion (Morgan et al., 2019). Despite the promising results of CPD, research shows that the effectiveness of these programs may vary depending on several factors, including the quality of the content, the level of teacher engagement, and the specific context in which the program is implemented (You et al., 2024). Therefore, continuous evaluation and improvement of CPD programs is essential to ensure that programs remain relevant and impactful. Further research is needed to understand the impact of CPD on teacher retention and the education system more widely, as well as to identify best practices for delivering CPD in different education settings (Tinning, 2020). Thus, an investigation into previous studies is needed to uncover the implementation of CPD in developing PE teachers' competencies.

Several studies have been conducted to investigate the application of CPD to improve teachers' teaching quality. Ambon et al. (2024) reviewed twenty-four articles related to the impact of CPD on the quality of teacher teaching in general. Further, Al-Omary et al. (2024) has reviewed thirteen articles relating to health professionals implementing their learning from CPD activities. Solomon, et, al. (Solomon et al., 2023) reviewed thirty-five articles related to conceptualization and related trends in staff CPD in higher education. Besides that, Parker et al (Parker et al., 2021) conducted an overview of 95 studies related to Learning Communities (LC) in physical education for professional development between 1990 and 2020. Based on these studies, the investigation related to CPD has covered many areas. However, this body of work remains conceptually fragmented, often emphasizing isolated aspects of CPD, such as program design or teacher outcomes, without offering an integrated understanding of how CPD operates as a complex, context-dependent professional learning process. Unlike other disciplines, PE teaching demands physical demonstration, interpersonal adaptability, and integration of social-emotional learning into movement activities (Goodyear & Dudley, 2015; Casey et al., 2021). Therefore, a dedicated synthesis is needed to understand how CPD programs are designed, delivered, and evaluated to meet these challenges. Furthermore, with global educational systems emphasizing inclusive, student-centered, and model-based pedagogies, understanding how CPD supports PE teachers in adapting to these demands remains underexplored.

In response to these gaps, a systematic review is needed that moves beyond program description to critically synthesize the types of CPD programs implemented, their pedagogical mechanisms, and their broader impacts on teaching and learning in PE. Such an approach can inform the development of contextually grounded, collaborative, and reflective professional learning frameworks that are more responsive to the unique demands of PE. This systematic review aims to map the forms of CPD implementation in physical education, analyze the impact of the program on teachers and students, and identify methodological and conceptual gaps in the existing literature. The focus of this review is not only on the description of CPD interventions, but also on the mechanisms by which CPD contributes to the development of professional identity, teacher agency, and the improvement of the quality of student learning experiences in the context of the unique, movement-based pedagogy of PE.

Materials and Methods

Search Strategy

A systematic literature review was conducted to identify empirical studies on the implementation of CPD programs for PE Teachers. In this systematic review emphasizes the systematic search process supported by three main steps: identification, screening, and eligibility, which aid researchers in conducting comprehensive article searches (Page et al., 2021). The search approach was designed to ensure comprehensiveness, reproducibility, and alignment with the review's objectives. Four online databases were selected for their relevance and comprehensiveness in the fields of education and sport pedagogy research: Scopus, Web of Science (WoS), ERIC, and EBSCOhost. The search, undertaken on 18 October 2025, was restricted to papers from 2015 to September 2025 to encompass recent advancements in CPD research.

The search query was built using Boolean operators and terms relevant to CPD and physical education. The ultimate search string utilized across databases was as follows: ("continuing professional development" OR "professional learning community" OR "teacher development" OR "continuous teacher learning") AND ("physical education"). The search in Scopus is performed on documents by examining titles, abstracts, and keywords. Subsequently, in

the WoS database, the search emphasises the pertinence of the study topic to the employed query. A search was performed in the EBSCOHost database within the available column, focusing on job compatibility. A search was conducted in the ERIC database using the search column to identify relevant educational resources. These criteria were used to ensure the sensitivity and specificity of the results.

Criteria for Inclusion and Selection of Studies

In compliance with PRISMA 2020 recommendations, this study used a structured, fully operationalized screening technique to ensure methodological rigor and transparency in the review process. The following criteria were established for inclusion: (a) studies that included in-service physical education (PE) teachers as participants; (b) studies that implemented a continuous professional development (CPD) intervention; (c) studies that specifically looked at how CPD affected pedagogical practices, teaching quality, teacher-related outcomes, or student learning outcomes; (d) empirical research designs, such as experimental, quasi-experimental, or action research; (e) articles published in peer-reviewed journals; (f) publications from September 2025; and (g) articles written in English.

The following criteria were used for exclusion: (a) studies that did not include PE teachers (e.g., general education contexts or other disciplines); (b) studies that did not include a CPD intervention component; (c) non-empirical publications (e.g., reviews, conceptual papers, editorials); (d) studies that were not published in peer-reviewed journals; and (e) articles that were not in their final published form. To ensure methodological traceability throughout the evaluation, the research selection procedure consisted of three consecutive steps: identification, screening, and eligibility assessment. A total of 699 entries were found through database searches during the identification phase. The dataset was then modified for screening after 233 duplicate records were eliminated.

Titles and abstracts were methodically assessed during the screening phase using the predetermined inclusion and exclusion criteria. At this point, studies that blatantly failed to satisfy the population, intervention, or study design requirements were eliminated. Full-text papers were then thoroughly evaluated in the eligibility step. After full-text review, 153 articles were excluded because they met at least one of the exclusion criteria. Furthermore, 283 papers were excluded for failing to meet the review's inclusion criteria. Thirty papers were included in the final qualitative synthesis after the selection procedure.

Procedures and Instruments

This research was qualitatively synthesised by two reviewers, focusing on the essential aspects of the studies: authors and year, location, sample size, intervention (kind, length, context, and format), and primary outcomes, adopted from (Taheri & Welsh, 2015). All included research were rigorously analysed according to these identified criteria. The topic synthesis in this study was executed systematically and aligned with the study objectives to achieve analytical rigour. The results from this analyse are discussed by all authors in accordance with the objectives of the paper.

This systematic review assesses the risk of bias in each study that has an assessment process. This decision was made because risk of bias (RoB) assessment is a key step in ensuring that the results of a systematic review or meta-analysis are truly reliable and not influenced by systematic errors. The RoB assessment uses the Cochrane Handbook for Systematic Reviews of Interventions guidelines (Boutron et al., 2019). This systematic review assessed the quality of the included studies based on the five main domains of ROBINS-I, i.e., selection bias, performance/intervention bias, outcome measurement bias, reporting bias, and conclusion bias. Each domain was assessed using the categories low risk of bias (+), uncertainty or unclear (?), and high risk of bias (–). A study is considered to have a low risk of bias if all domains are assessed as low risk or if there is one item assessed as high risk or uncertain. A study is considered to have a moderate risk of bias if two domains are assessed as high risk or if the risk of bias cannot be determined. Finally, a study is considered to have a high risk of bias if more than two domains are assessed as high risk.

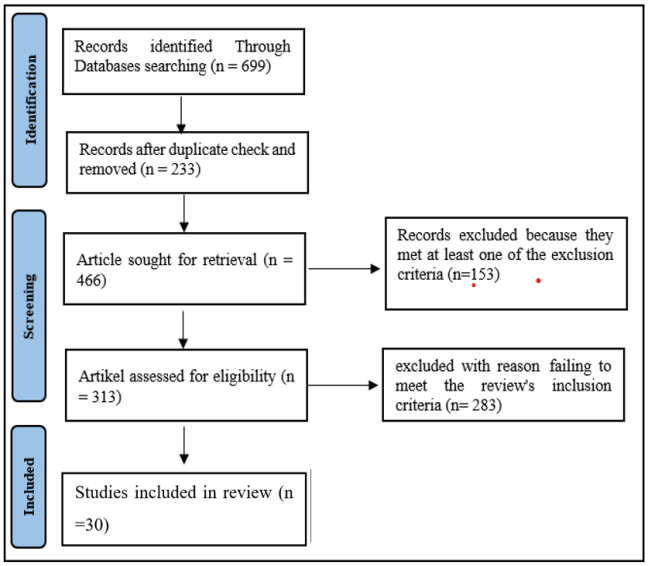

Fig. 1. Study selection flow diagram

Results

Risk of Bias Assessment

The results of the risk of bias assessment for the 30 studies are presented in Table 1. The risk of bias assessment shows that the majority of studies have a low to moderate risk of bias. Selection bias is the most common domain, mainly due to the use of purposive sampling and voluntary participation in the context of educational research. Most of the studies showed consistent implementation of interventions, use of standardized instruments, transparent reporting, and conclusions that were in line with the objectives. There were no indications of serious bias or selective reporting. Therefore, the overall methodological quality of the included studies was deemed adequate to support the thematic synthesis in this study.

Table 1. List of included studies with risk of bias result

Author & Year	Selection Bias (Randomisation)	Intervention Bias	Measurement Bias	Reporting Bias	Conclusion Bias
Hemphill et al. (2015)	-	+	+	+	+
Miller et al. (2015)	+	+	–	+	+
García-Calvo et al. (2016)	-	+	+	+.	+.
Braga et al. (2017)	-	+	+	+	+
Gore et al. (2017)	+	+	+	+	+
Miller et al. (2017)	+	+	?	+	+
Makopoulou (2018)	?	+	+	+	+
Sum et al. (2018)	-	+	+	+	+
Hünük et al. (2019)	?	+	+	+	+
Morgan et al. (2019)	+	+	+	+	+
Makopoulou et al. (2021)	?	+	+	+	+
Peralta et al. (2020)	+	+	+	+	+
Gonçalves et al. (2021)	?	+	+	+	+
Sum et al., (2022)	?	+	+	+	+
Deng et al. (2022)	-	+	+	+	+
Gonçalves et al. (2022)	+	+	+	+	+
Gonçalves et al. (2022)	?	+	+	+.	+.
Muarifin et al. (2022)	+	+	+	+	+
Bjørke et al. (2023)	+	+	+	+	+
Ferreira et al. (2023)	-	+	+	+	+
Kahts-Kramer & Wood (2023)	-	+	+	+	+
Lee et al. (2023)	?	+	+	+	+
Colburn et al. (2024)	?	+	+	+	+
Latino et al. (2024)	-	+	+	+	+
Yoon et al. (2024)	?	–	+	+	+
Beddoes et al. (2025)	?	+	+	+.	+.
Marcelino (2025)	+	?	+	+	+
Milton et al. (2025)	?	+	+	+.	+.
Ní Chróinín et al. (2025)	?	+	+	+.	+.

Findings Overview

The 30 studies (see table 2) that advanced to the final selection stage demonstrate that the implementation of Continuous Professional Development (CPD) in physical education occurs across diverse national and institutional contexts, including the United States, Australia, Spain, England, Hong Kong, Turkey, Brazil, Indonesia, Norway, South Africa, South Korea, Italy, Portugal, Ireland, and Wales. This geographical distribution suggests that the focus on continuing professional development for physical education instructors is a global concern, rather than a phenomenon confined to a particular school system. The evaluated studies exhibit considerable variability from the participants' perspective, ranging from small-scale investigations involving 3–10 teachers to extensive programs involving hundreds of teachers and thousands of students. Some studies not only concentrate on educators but also link CPD to student results. This variation shows that CPD in PE has been implemented both as a micro-intervention focused on deeply changing teacher practices and as a systemic intervention aimed at strengthening pedagogical capacity across schools.

Implementation's Form and Structure

The review findings indicate that CPD implementation in physical education is not uniform but rather encompasses a diverse array of methods. On the one hand, there exist structured, course-oriented programs, such as short-course CPD in inclusive physical education, that aim to enhance awareness and self-efficacy within a brief timeframe (Makopoulou, 2018; Makopoulou et al., 2021) day-long courses or workshops features prominently in teachers' continuing professional development (CPD. Conversely, the majority of research indicates the adoption of more collaborative and sustainable frameworks, including professional learning communities (PLC), communities of

practice (CoP), lesson study, video-based CPD, participatory action research, critical action learning, and student voice-driven methodologies (Gore et al., 2017; Peralta et al., 2020; Ferreira et al., 2023; Colburn et al., 2024).

These studies consistently indicate a transition from a unilateral training model to a professional learning approach that is social, reflective, and practice-oriented. Initiatives such as PLUNGE and QTR prioritize reflection and peer observation as fundamental components of learning (Miller et al., 2015, 2017), whereas CoP and PLC serve as collaborative environments for addressing practical challenges and collectively enhancing pedagogical knowledge (Hünük et al., 2019; Gonçalves et al., 2021). The implementation of CPD in PE demonstrates a pronounced inclination towards a model that regards teachers as active participants in the professional learning process.

Program Duration and Intensity

The examined papers indicate considerable disparity in the length of CPD implementation. Short-term programs range from one day to several weeks, including one-day short-course CPD (Makopoulou, 2018) or collaborative workshops spanning 3–5 weeks (Miller et al., 2015; Braga et al., 2017). Concurrently, other programs operate over a medium to long duration, spanning several months to over a year, and perhaps extending to a decade within the framework of sustainable professional communities (Yoon et al., 2024; Beddoes et al., 2025).

Short-term programs typically result in initial enhancements in knowledge, awareness, and self-efficacy (Morgan et al., 2019), while long-term programs are more frequently associated with profound pedagogical transformations, the establishment of professional communities, and the sustainability of collaborative practices (Deng et al., 2022; Bjørke et al., 2023; Lee et al., 2023). Nevertheless, numerous studies suggest that an extended length does not inherently ensure effectiveness, particularly in the absence of program modifications and sufficient support systems (Yoon et al., 2024). Consequently, time seems to be a significant aspect, albeit not the sole driver of CPD success.

Output at the Teacher Level

The results reveal that the effects of CPD at the teacher level can be categorized into several primary domains: enhancement of pedagogical competence, augmentation of self-efficacy and confidence, alterations in pedagogical beliefs, advancement of professional reflection, and reinforcement of teacher identity and agency. In the educational domain, CPD promotes a transition from conventional methodologies to more student-centered, inquiry-driven, and game-oriented methods. The adoption of PLUNGE (Miller et al., 2015) and programs focused on physical literacy and life skills (Sum et al., 2018; Sum et al., 2022)there remains limited empirical evidence for the effect of teacher participation in CPD on student learning outcomes. In light of this void, the purpose of this study was to examine the influence of an eight-month PE-CPD program on students' perceived physical literacy, motivation and enjoyment of physical education. A randomized control trial design was used to assign a sample of 65 physical education teachers from Hong Kong to the CPD and control intervention groups. Students' (n = 1,485 enhances teachers' capacity to create more relevant and contextualized learning experiences.

Numerous studies indicate an enhancement in teachers' self-efficacy, confidence, and perceived competence in the psychological-professional domain (Braga et al., 2017; Peralta et al., 2020; Latino et al., 2024)including enhanced cardiorespiratory endurance, improved academic performance, augmented cognitive functioning, as well as advancements in social and psychological well-being. Given that students participate in schooling for up to 200 days per annum, physical education (PE. Furthermore, CPD is linked to enhanced teacher agency, including the capacity to spearhead professional development, foster collaboration, and champion improvements in practice (Morgan et al., 2019; Gonçalves et al., 2022; Gonçalves et al., 2022; Kahts-Kramer et al., 2022; Ní Chróinín et al., 2025). This finding shows that CPD not only improves technical skills but also changes broader professional dimensions.

Impact on Students and the Learning Environment

The quality of the learning environment and the impact on pupils are also highlighted in several studies in this review, despite the primary focus of CPD being on teachers. The study by Studies by Sum et al. (2018) and Sum et al. (2022)there remains limited empirical evidence for the effect of teacher participation in CPD on student learning outcomes. In light of this void, the purpose of this study was to examine the influence of an eight-month PE-CPD program on students' perceived physical literacy, motivation and enjoyment of physical education. A randomized control trial design was used to assign a sample of 65 physical education teachers from Hong Kong to the CPD and control intervention groups. Students' (n = 1,485 showed that CPD is related to increased motivation, participation, and student engagement. Marcelino (2025)misaligning with contemporary educational paradigms prioritising holistic student development. This study examined the impact of a professional development intervention on classroom climates in PE, focusing on learning- and performance-oriented climates fostered by teachers and peers. Using a difference-in-differences approach with ordinary least squares regression models, data from 588 students across 43 classes in 12 Portuguese schools were analysed. The intervention involved a 25-h continuing professional development (CPD study indicates that student-centered CPD programs are associated with improvements in the learning environment and students' intrinsic motivation. Latino et al. (2024) including enhanced cardiorespiratory endurance, improved academic performance, augmented cognitive functioning, as well as advancements in social and psychological well-being. Given that students participate in schooling for up to 200 days per annum, physical education (PE indicated that CPD for PE teachers affects the physiological and cognitive health of school-aged children. These findings indicate that CPD in PE contributes to improvements in students' learning experiences, particularly through changes in teachers' pedagogical practices. Thus, the impact of CPD on students occurs indirectly through the transformation of learning design and classroom interactions.

Table 2. General overview of included studies

Author & Year	Location	Participants	Treatment Type	Duration	Primary Outcome
Hemphill et al. (2015)	Midwest, USA	3 PE teachers	Responsibility-based CPD protocol using Hellison's TPSR model.	4 months	Teachers showed increased awareness and integration of nine responsibility-based teaching strategies.
Miller et al. (2015)	New South Wales, Australia	7 primary schools	PLUNGE: Game-centered professional learning programme for PE teachers.	5 weeks + 2-week follow-up	Teachers shifted from skill-based to game-centered instruction; lessons became more engaging and inquiry-driven.
García-Calvo et al. (2016)	Spain	20 PE teachers	CPD on motivational and behavioural management strategies emphasizing need-supportive teaching.	5–6 weeks	Teachers improved positive behaviour support and fostered greater student motivation.
Braga et al. (2017)	Appalachian, USA	4 PE teachers	Collaborative hands-on workshops and reflection sessions.	3 weeks	Enhanced teachers' confidence, classroom management, and instructional routines related to safety and organization.
Gore et al. (2017)	New South Wales, Australia	192 teachers	Quality Teaching Rounds (QTR): collaborative CPD integrating PLC and instructional rounds.	6 months + 12-month follow-up	Improved teaching quality, morale, and sense of professional recognition across schools.
Miller et al. (2017)	Hunter Region, NSW, Australia	7 teachers	PLUNGE CPD focusing on the Game-Centered Approach (GCA).	5 weeks	Marked improvement in pedagogical understanding and delivery of game-based learning.
Makopoulou (2018)	England	40 tutors	CPD on Inclusive PE emphasizing practical and interactive approaches.	6-hour short course	Raised awareness of inclusive pedagogy but highlighted need for ongoing, context-specific training.
Sum et al. (2018)	Hong Kong	70 PE teachers, 6,300 students	Physical Literacy–based PE-CPD integrating teacher and 9student development.	8 months	Improved teachers' physical literacy knowledge and self-efficacy; students' motivation and participation increased.
Hünük et al. (2019)	Ankara, Turkey	6 PE teachers	Health-Related Fitness (HRF) Community of Practice (CoP).	10 weeks	Teachers engaged in collaborative reflection and peer challenge, supporting mutual professional growth.
Morgan et al. (2019)	Wales, UK	3 PE teachers	Collaborative PE-CPD with mentoring and reflective practice.	6–7 weeks	Teachers implemented inclusive pedagogies and felt empowered to lead in-service workshops.
Makopoulou et al. (2021)	England	1,604 teachers & assistants	One-day short-course CPD in inclusive PE.	6 hours	Positive short-term effects on teacher self-efficacy; limited evidence of sustained behavioural change.
Peralta et al. (2020)	Western Sydney, Australia	49 PE teachers	Video-based CPD grounded in Self-Determination Theory (SDT).	8 months	Improved theoretical understanding and perceived competence; valued authentic feedback and peer support.
Gonçalves et al. (2021)	Minas Gerais, Brazil	6 PE teachers	Maintenance of democratic CoP for social justice and equity in PE.	12 months	Teachers co-created practices addressing professional marginalization and built solidarity within CoP.
Sum et al., (2022)	Hong Kong	6 PE teachers	Customized PE-CPD tailored to teachers' contexts.	2.5 months	Immediate and intermediate improvements in teachers' physical literacy and teaching efficacy.
Deng et al. (2022)	United States	19 PE teachers	Full-semester CPD focused on healthful living and curriculum reform.	3 years (each semester)	Improved instructional quality and alignment between teaching and health-promoting curriculum.

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Table 2 (continued)

Author & Year	Location	Participants	Treatment Type	Duration	Primary Outcome
Gonçalves et al. (2022)	Minas Gerais, Brazil	6 PE teachers	Community of Practice (CoP) for professional empowerment in low-resource settings.	9 months	CoP served as an effective strategy for teacher learning and resilience under precarious conditions.
Gonçalves et al. (2022)	Governador Valadares, Brazil	6 PE teachers	Collaborative PLC for teacher empowerment and social transformation.	12 months	Supported teachers in seeking better working conditions and organizing collective action for change.
Muarifin et al. (2022)	East Java, Indonesia	74 PE teachers	Collaborative model-based CPD combining TPSR and TGfU.	13 sessions	Significantly improved teachers' cognitive ability and reflective teaching competence.
Sum et al. (2022)	Hong Kong	65 PE teachers & 1,485 students	Health-Based PE (HbPE) CPD.	8 months	Teachers' sustained participation improved affective learning outcomes and student engagement.
Bjørke et al. (2023)	Norway	3 PE teachers	Participatory Action Research (PAR) using Cooperative Learning as pedagogical innovation.	12 months	Collective reflection helped teachers move from directive to student-centered practices.
Ferreira et al. (2023)	Brazil	13 PE teachers	Online CoP for professional learning and mentoring.	11 months	Digital CoP expanded access to peer collaboration; "by teachers, for teachers" model proved effective.
Kahts-Kramer & Wood (2023)	Eastern Cape, South Africa	10 PE teachers	Critical Action Learning (CAL) integrated with Participatory Action Research (PALAR).	21 months	Created safe reflective spaces; enhanced teacher empowerment and contextual practice adaptation.
Lee et al. (2023)	South Korea	8 secondary PE teachers	Life-Skills-Oriented CPD programme (Project Change Up).	12 months	Identified four trajectories of teacher change (generative, delayed, fluctuated, stagnant) mediated by reflection and peer support.
Colburn et al. (2024)	United States	5 PE teachers	Online Andragogy-Based Lesson Study (AbLS) model for CPD.	2 years	AbLS deepened reflective inquiry and supported adult learning through structured collaborative cycles.
Latino et al. (2024)	Italy	50 PE teachers	Physical Literacy–based comprehensive CPD programme.	16 weeks	Significant gains in self-efficacy across seven pedagogical and technological domains.
Yoon et al. (2024)	South Korea	8 PE teachers	Long-term PE-CoP examining professional learning sustainability.	10 years	Professional learning effectiveness declined over time, emphasizing need for renewal and institutional support.
Beddoes et al. (2025)	New York City, USA	282 PE teachers	District-wide CPD through Professional Learning Communities (DPE-PLC).	~10 years	Improved teachers' content knowledge, collaboration, and curriculum coherence across schools.
Marcelino (2025)	Northwest Portugal	12 PE teachers, 588 students	Student-centered CPD programme emphasizing motivation and engagement.	25 hours (5 weeks)	Improved learning climate and intrinsic motivation among students.
Milton et al. (2025)	Wales, UK	8 staff members	Long-term CPD using CoP model with Duda's Integrated Motivational Framework.	18 months	Built sustainable and meaningful professional development communities in PE.
Ní Chróinín et al. (2025)	Ireland	10 PE teachers	Student-voice pedagogical CPD supported by PLC.	6 months	Fostered shared reflection, emotional support, and transformation of teachers' beliefs about PE teaching.

Institutional Impact and Pedagogical Reform

In addition to instructors and students, the review findings indicate that certain types of CPD influence the institutional level. The QTR study indicates improvements in teaching quality, morale, and professional recognition within schools (Gore et al., 2017). Beddoes et al. (2025) demonstrate that district-wide PLCs enhance content understanding, teamwork, and curriculum coherence among schools. Research in Brazil indicates CoPs and PLCs function as educational platforms for educators while also facilitating collective efforts to promote improved working conditions and foster professional solidarity in challenging circumstances (Gonçalves et al., 2021; Gonçalves et al., 2022; Gonçalves et al., 2022).

Discussion

The findings of this comprehensive literature review suggest that CPD in physical education should not be viewed as a homogeneous, technical training intervention, but rather as a multifaceted, contextual, and relational professional learning process. These data suggest that CPD is more precisely characterized as an ecology of professional learning established by the interplay of practice, reflection, cooperation, and institutional support. Nonetheless, these findings should not be construed solely as a modification in format, but rather as a transformation in the mechanics of professional learning. This conclusion is corroborated by a study by Altun & Yucel-Toy (2023) demonstrating that collaborative and reflective continuing professional development engenders improvements that signify a substantial transformation in professional comprehension, rather than only a modification in training format.

The subsequent finding regarding program duration indicates that time is not a definitive factor in CPD's efficacy. While long-term initiatives are sometimes linked to profound instructional transformations, they require integration with practice, ongoing reflection cycles, and institutional backing. According to Liebech- Lien et al. (2023), CPD programs must prioritize collaboration, reflection, and support structures rather than duration. The study conducted by Ventista & Brown (2023)the emergence of the school as learning organisation is vital. In this context, the aim of this systematic review was to explore what comprises effective professional development for educators: i.e. what forms of teacher professional development definitively lead to positive outcomes for students? A total of 125 studies were reviewed as part of the study; however only 11 studies with experimental or quasi-experimental design examined impact on students' learning. Analysis of these studies suggest that training, ongoing coaching, collaborative Continuous Professional Development (CPD further asserts that the efficacy of CPD depends on ongoing advancement, collaboration, and integration into the educational framework, rather than solely on the duration of participation. Nonetheless, it is crucial to acknowledge that the existing research does not clearly establish a consistent causal relationship between duration and effectiveness. Consequently, any interpretation of the importance of duration must be undertaken with prudence, considering additional elements such as practical integration and contextual support.

Moreover, this review's results demonstrate that CPD in PE enhances pedagogical competency and facilitates the reformation of teachers' professional identities. Several studies have indicated a transformation in educators' educational convictions and instructional methodologies. These data indicate that CPD influences not just technical dimensions but also instructors' comprehension and execution of pedagogy. The transition from conventional methods to more student-centered, inquiry-based, or experiential practices indicates that educators are altering not only their actions but also their comprehension of the objectives of PE. Study on meaningful physical education (Fletcher et al., 2021) and the transition from performance to learning orientation (Beni, 2017) suggests that CPD influences the reformation of teachers' pedagogical frameworks. However, changes in deeper dimensions, such as professional identity, are still limited to a small number of studies; therefore, any generalization of these findings must be made with due caution.

The review findings indicate that participatory CPD programs offer additional opportunities for teachers' active engagement in the professional development process. In addition to identification, this analysis highlights that teacher agency is a crucial factor in the efficacy of CPD. This finding is supported by the study by Zhang et al. (2024), which demonstrates that educators' proactive involvement strongly predicts CPD outcomes. Moreover, McMillan et al. (2016) emphasize the importance of active engagement rather than passive reception for educators to think, interrogate, and incorporate theory into practice. Consequently, it indicates that teachers' active participation is a pivotal factor in enhancing the efficacy of CPD, but the degree of its impact may vary across contexts.

Numerous studies have documented the influence of CPD on students, notably through enhanced motivation, engagement, and the quality of the educational experience. Study by Sum et al. (2022)there remains limited empirical evidence for the effect of teacher participation in CPD on student learning outcomes. In light of this void, the purpose of this study was to examine the influence of an eight-month PE-CPD program on students' perceived physical literacy, motivation and enjoyment of physical education. A randomized control trial design was used to assign a sample of 65 physical education teachers from Hong Kong to the CPD and control intervention groups. Students' (n = 1,485 indicates that the efficacy of physical literacy-based pedagogy depends on instructors' ability to incorporate it into their instruction. Nonetheless, these results are typically indirect and contingent upon modifications in educators' instructional methodologies. Thus, the connection between CPD and student learning outcomes should be perceived as a mediated interaction, rather than a direct consequence of the intervention.

These findings suggest that CPD in PE is most effective when structured as a collaborative, reflective, contextual, and institutionally endorsed learning process. Under these circumstances, CPD not only augments pedagogical proficiency but also cultivates professional identity, broadens teacher agency, and elevates the quality of student learning experiences (Ambon et al., 2024; Ncube & Ajani, 2025). Consequently, CPD must be recognized as a tool for pedagogical reform that functions at various levels, linking practice, reflection, professional communities, and institutional contexts. The ramifications of these findings suggest that the next CPD development should prioritize designs that are connected with practice, facilitate ongoing

reflection, and enhance teacher professional communities. Moreover, subsequent research should prioritize investigating change mechanisms rather than solely focusing on outcomes to facilitate a deeper understanding of the relationship among CPD, pedagogical practices, and student learning experiences.

This systematic review possesses numerous methodological flaws that warrant acknowledgment. The included studies demonstrate significant heterogeneity regarding research design, context, and methodological approaches, including experimental, quasi-experimental, qualitative, and action research studies. Although thematic synthesis was used to address this diversity, this variability may affect the consistency and generalisability of the findings. The risk-of-bias assessment employed an adapted domain-based approach to accommodate the mixed-method nature of the evidence. While this facilitated consistent evaluation across studies, it may lack the precision of design-specific appraisal tools. It should be regarded as a general indication of study quality rather than a conclusive measure of rigor. Ultimately, potential publication bias cannot be ruled out, as the review focused on peer-reviewed journal papers, which may disproportionately feature research with positive outcomes while neglecting null or negative results. Notwithstanding these constraints, this review provides a thorough, methodical synthesis of existing literature on CPD in PE, offering significant insights into its implementation, outcomes, and foundational mechanisms.

Conclusions

This systematic study indicates that CPD in PE should not be viewed as a uniform training intervention, but as a multifaceted, context-sensitive professional learning process. The results indicate that CPD operates within a dynamic ecosystem shaped by the interplay among practice, reflection, collaboration, and institutional support. Their structure or duration does not solely dictate the usefulness of varied CPD formats, but rather by their capacity to foster sustained engagement, facilitate meaningful collaboration, and align with instructors' pedagogical realities.

This review emphasizes the need for future research to move beyond mere descriptive assessments of CPD programs and focus on the fundamental mechanisms of change. Longitudinal and multi-level studies are essential for comprehending the impact of CPD on teaching practice, professional identity, and student learning over time. These initiatives will foster a more thorough, theoretically informed understanding of CPD as a catalyst for instructional innovation in physical education.

Ethics Approval and Informed Consent:

As this study is based solely on the analysis of previously published studies and does not involve direct interaction with human participants, ethical approval and informed consent were not applicable.

Data Availability Statement

Extended data supporting this study are publicly available via Zenodo at: ILMAWATI, H. (2026). Data Set of A Systematic Review of Implementation, Mechanisms, and Pedagogical Transformation [Data set]. Zenodo. https://doi.org/10.5281/zenodo.19404224. The extended data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

AI Transparency Statement

The authors declare that artificial intelligence (AI) tools were used solely to assist in language refinement and manuscript editing. All intellectual content, including conceptualization, data analysis, interpretation, and conclusions, was developed by the authors. The authors take full responsibility for the integrity and originality of the work.

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Conflicts of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Переосмислення безперервного професійного розвитку у фізичному вихованні: систематичний огляд впровадження та механізмів педагогічної трансформації

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 13 с., 2 табл., 1 рис., 63 джерела.

Актуальність. Безперервний професійний розвиток (БПР) відіграє ключову роль у підвищенні якості викладання фізичного виховання (ФВ); однак його ефективність залишається нерівномірною та значною мірою залежить від контексту.

Мета. Це дослідження спрямоване на систематичне вивчення форм реалізації, результатів і впливів БПР у ФВ, а також на формування більш цілісного розуміння того, як БПР функціонує як процес професійного навчання.

Матеріали і методи. Систематичний огляд літератури проведено відповідно до рекомендацій PRISMA; відібрано 30 емпіричних досліджень, опублікованих у 2015–2025 роках у провідних наукових базах даних. Дані проаналізовано за допомогою тематичного синтезу для виявлення закономірностей у реалізації, тривалості та результатах.

Результати. Отримані дані свідчать, що БПР у ФВ реалізується через різноманітні моделі, зокрема семінари, професійні навчальні спільноти та практико-орієнтовані колаборативні підходи. Водночас ефективність визначається не

лише форматом чи тривалістю, а насамперед тим, наскільки БПР забезпечує стійку залученість, рефлексивну практику та контекстуальну релевантність. БПР сприяє підвищенню педагогічних знань учителів, удосконаленню навчальних практик, зростанню самоефективності та формуванню професійної ідентичності. Докази впливу на рівні учнів та інституцій вказують на підвищення залученості, інклюзивності та якості освітнього середовища, хоча ці ефекти є опосередкованими і залежать від умов реалізації.

Висновки. БПР у ФВ доцільно розглядати як динамічний багаторівневий процес професійного навчання, що формується у взаємодії індивідуальних, соціальних та інституційних чинників. Отримані результати підкреслюють необхідність розроблення контекстно чутливих і сталих моделей БПР, здатних забезпечити змістовну педагогічну трансформацію.

Ключові слова: безперервний професійний розвиток, фізичне виховання, навчання вчителів, педагогічна трансформація

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Review Article

The Role of Physical Education in Developing Students' Motivation and Lifelong Physical Activity: A Pedagogical Perspective

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Abstract

Objectives. This conceptual narrative review examines how motivation functions as a structural mechanism linking pedagogical approaches in physical education to lifelong physical activity.

Materials and Methods. Through a selective and interpretive synthesis of theoretical and empirical literature grounded in Self-Determination Theory (SDT) and models-based practice, this review develops an integrative conceptual model.

Results. The synthesis demonstrates that specific features of pedagogical models (e.g., autonomy support in TGfU, affiliation in Sport Education, and peer support in Cooperative Learning) satisfy the basic psychological needs for autonomy, competence, and relatedness. Simultaneous satisfaction of these needs facilitates the internalization of motivational regulation—from controlled to more autonomous forms (identified, integrated, and intrinsic regulation)—which, in turn, promotes sustained engagement in physical activity beyond the school context. Hybrid integrative models demonstrate greater potential because they create coherent learning environments that reinforce these processes, whereas traditional and single-model approaches often lead only to short-term compliance and limited behavioral transfer.

Conclusions. Transitioning toward system-oriented hybrid frameworks, with motivation positioned as a central organizing mechanism, is essential for physical education to promote autonomous motivation and lifelong physical activity habits. The review identifies the conditions under which this mechanism operates effectively or fails, thereby providing a conceptual foundation for curriculum reform and future research.

Keywords: physical education, student motivation, lifelong physical activity, Self-Determination Theory, models-based practice, hybrid pedagogical models, pedagogical integration, sport pedagogy.

Introduction

Physical inactivity remains a major global public health challenge, with evidence consistently showing that physical activity patterns established during school years exert a significant influence on lifelong habits. Physical education occupies a unique position within educational systems, offering not only opportunities for physical development but also a critical context for shaping students' motivation and long-term behavioral choices (Bailey, 2006; Kirk & Haerens, 2014).

Nevertheless, a persistent gap exists between the stated goals of physical education and actual long-term participation rates in physical activity (Telama, 2009; Trudeau & Shephard, 2008). This discrepancy suggests that traditional instructional approaches often fall short in fostering the motivational foundations required for sustained engagement beyond the school environment. This gap indicates a need for a system-level reconceptualization rather than incremental pedagogical adjustments.

Contemporary sport pedagogy emphasizes that the quality of pedagogical interactions and learning environments, rather than the sheer volume of physical activity, determines the long-term impact of physical education (Quennerstedt et al., 2011; Casey & MacPhail, 2018). Research grounded in Self-Determination Theory highlights that educational

experiences supporting autonomy, competence, and relatedness are associated with higher intrinsic motivation and greater likelihood of continued physical activity in adulthood (Chen, 2014; Chatzisarantis & Hagger, 2009). However, many school-based programs continue to rely on teacher-centered and performance-oriented models that prioritize short-term compliance over autonomous motivation (Kirk, 2013; Perlman, 2012).

A critical review of the literature reveals a fundamental fragmentation: motivational theories, pedagogical models, and long-term behavioral outcomes are frequently examined in isolation rather than as interconnected components of a unified system (Hastie & Wallhead, 2016; Harvey et al., 2020). This lack of systemic integration limits the capacity of physical education to translate positive school experiences into enduring physical activity habits.

The present conceptual narrative review addresses this gap by synthesizing contemporary pedagogical and motivational literature. Its primary aim is to explicate how specific pedagogical models, through targeted motivational processes rooted in Self-Determination Theory, influence student motivation and promote (or fail to promote) lifelong physical activity under defined conditions. Rather than treating motivation as a peripheral outcome, this synthesis repositions it as a structural mechanism that organizes the relationship between learning environments, behavioral internalization, and long-term engagement. Particular attention is given to the potential of hybrid integrative models that combine elements of Sport Education, Teaching Games for Understanding, and Cooperative Learning while embedding SDT principles. This review develops a mechanism-based conceptual model that explains the specific processes through which these pedagogical features lead to (or fail to produce) lifelong physical activity under defined conditions. Accordingly, this review explicitly develops a mechanism-based conceptual model that integrates pedagogical features, motivational processes, and behavioral outcomes within a unified analytical framework.

Materials and Methods

This study is designed as a conceptual narrative review aimed at developing a theoretical understanding and an integrative conceptual model of the relationship between pedagogical approaches, motivational processes, and lifelong physical activity. It does not claim to be a systematic review; therefore, no formal PRISMA protocol, flow diagram, or quality appraisal of studies was applied. Instead, the review is based on a selective and interpretive synthesis of key theoretical and empirical literature grounded in Self-Determination Theory (SDT) and models-based practice in physical education.

Results

Theoretical Background and Comparative Synthesis of Pedagogical Approaches

Physical education has evolved from a performance-oriented discipline toward a pedagogically driven field that emphasizes motivational and behavioral outcomes. Early frameworks primarily focused on skill acquisition and physical performance, whereas contemporary research highlights the role of pedagogical processes in shaping long-term engagement in physical activity (Bailey, 2006; Kirk & Haerens, 2014).

Analysis of motivation-related studies demonstrates that student engagement is strongly associated with intrinsic motivational factors rather than external performance pressures. Environments supporting autonomy, competence, and relatedness lead to higher levels of participation and persistence (Chen, 2014; Chatzisarantis & Hagger, 2009). However, traditional teaching models continue to dominate practice, often prioritizing control and standardized outcomes, which negatively affect students' motivational responses (Perlman, 2012; Kirk, 2013).

Further analysis of pedagogical models shows that student-centered teaching and model-based practice significantly enhance engagement and learning outcomes by promoting active participation, decision-making, and personal relevance (Hastie & Wallhead, 2016; Casey & MacPhail, 2018). Nevertheless, these models are frequently applied in isolation, resulting in context-dependent and inconsistent effectiveness. This fragmentation results in limited scalability and reduced transferability across educational contexts.

Longitudinal studies confirm that positive experiences in physical education are associated with higher levels of physical activity in adulthood, although such outcomes depend heavily on pedagogical quality rather than mere participation (Telama, 2009; Trudeau & Shephard, 2008).

Although individual pedagogical models demonstrate positive effects on student motivation and engagement, their isolated application results in only partial satisfaction of basic psychological needs, leading to inconsistent long-term outcomes. This fragmentation highlights the need for a system-level synthesis that integrates specific pedagogical features with motivational processes to explain not only what works, but why and under which conditions it leads to lifelong physical activity.

A synthesis of existing studies reveals a fundamental fragmentation within the field: motivational theories, pedagogical models, and long-term behavioral outcomes are often examined separately rather than as interconnected elements of a unified system. This lack of integration limits the transformative potential of physical education. The present analytical synthesis, therefore, seeks to address this gap by examining the structural role of motivation and the advantages of hybrid integrative models in bridging theory and practice.

The categorization presented in Table 1 is derived from recurring patterns identified across the reviewed studies and reflects a comparative analytical synthesis rather than isolated evaluation.

Conceptual Mechanism of Pedagogical Influence

The present review conceptualizes motivation as a structural mechanism that links pedagogical approaches in physical education to lifelong physical activity through three specific processes: (1) specific pedagogical features of the models shape the learning climate; (2) these features satisfy or frustrate the basic psychological needs of autonomy, competence, and relatedness as defined by Self-Determination

Table 1. Comparative Evaluation of Pedagogical Models Based on Motivational and Behavioral Outcomes

Approach	Strengths	Limitations	Impact on Student Motivation	Impact on Lifelong Physical Activity
Traditional Approach	Structured lessons, easy management, skill focus	Low engagement, passive learning, performance pressure	Low (mainly extrinsic)	Low (weak transfer)
Student-Centered Approach	High engagement, autonomy, and personal relevance	Requires advanced teacher training	High (autonomy & competence)	Moderate to High
Sport Education (SE)	Team affiliation, responsibility, and holistic development	Time-consuming, may favor competitive students	Very High (relatedness & belonging)	High (sport culture)
Teaching Games for Understanding (TGfU)	Tactical learning, problem-solving, decision-making	Needs basic game knowledge	Very High (cognitive autonomy + competence)	High (enjoyment & transfer)
Cooperative Learning (CL)	Social skills, inclusivity, peer support	Grouping and monitoring challenges	High (strongly relatedness)	Moderate to High
Hybrid Integrative Models (SE + TGfU + CL with explicit SDT principles)	Coherent outcomes address all SDT needs	Complex planning, high teacher demand	Very High (simultaneous need satisfaction)	Highest potential

Note: Synthesized by the authors based on Casey & MacPhail (2018), Hastie & Wallhead (2016), and Harvey et al. (2020)

Theory; and (3) the degree of need satisfaction determines the internalization of motivational regulations along the SDT continuum (from external and controlled regulation toward identified, integrated, and intrinsic regulation). This internalization process, in turn, promotes behavioral internalization, whereby physical activity becomes personally endorsed and is maintained voluntarily beyond the school context. More specifically, the mechanism operates through distinct and model-dependent pathways:

- autonomy-supportive instructional strategies (e.g., choice provision, student leadership in Sport Education) primarily facilitate autonomy satisfaction;
- tactical problem-solving tasks (as in TGfU) enhance perceived competence through cognitive engagement;
- and structured peer interaction (as in Cooperative Learning) strengthens relatedness via social interdependence.

These differentiated pathways jointly regulate the depth and quality of motivational internalization, thereby determining whether behavioral engagement is transient or sustained beyond the school context.

Specific pedagogical models contribute differently to this mechanism. Sport Education primarily supports relatedness through team affiliation, persisting roles, and seasonal structures, while also offering autonomy via student leadership opportunities. Teaching Games for Understanding (TGfU) mainly enhances competence and cognitive autonomy by emphasizing tactical problem-solving and decision-making rather than rote skill drills. Cooperative Learning strengthens relatedness and social competence through structured group interdependence and peer accountability.

When these models are implemented in isolation, need satisfaction remains partial, often resulting in only moderate internalization (e.g., identified regulation) and limited transfer to out-of-school physical activity. In contrast, hybrid integrative models (combining elements of SE, TGfU, and CL with explicit SDT principles) enable simultaneous satisfaction of all three needs within a coherent learning climate. This simultaneous satisfaction creates synergistic effects and mutual reinforcement, leading to deeper motivational internalization and a higher likelihood of lifelong physical activity.

The mechanism fails or produces only short-term compliance when need frustration occurs (for example, under controlling teaching styles, excessive performance pressure, or lack of student choice) or when only one or two needs are addressed. Figure 1 presents the proposed conceptual mechanism linking pedagogical design, motivational processes, and long-term behavioral outcomes.

As illustrated in Figure 1, the mechanism operates through sequential and interdependent processes:

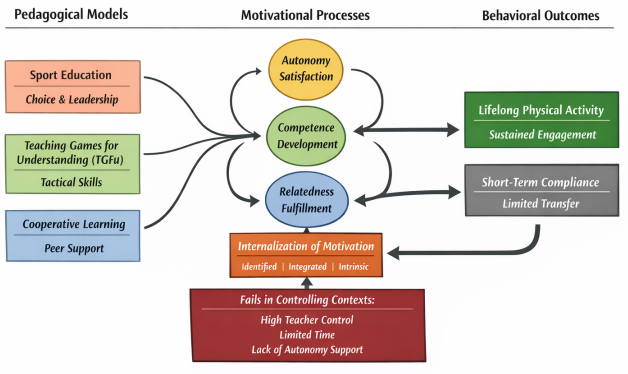

Fig. 1. Conceptual mechanism linking pedagogical models, motivational processes, and lifelong physical activity

pedagogical features influence the satisfaction or frustration of basic psychological needs, which subsequently affects the internalization of motivational regulation and the development of autonomous motivation. These processes determine whether students demonstrate sustained engagement in physical activity or only temporary compliance within instructional settings. In the long term, stable autonomous regulation increases the likelihood of lifelong physical activity participation.

Pedagogical Features → Basic Psychological Need Satisfaction/Frustration → Internalization of Motivational Regulation and Autonomous Motivation → Sustained Engagement in Physical Activity → Lifelong Physical Activity (or short-term compliance).

Discussion

The analytical synthesis challenges the dominant activity-based paradigm in physical education by demonstrating that sustained participation is less a direct outcome of lesson volume and more a consequence of how pedagogical structures systematically support student motivation (Bailey, 2006; Kirk & Haerens, 2014; Chen, 2014). This interpretation shifts the focus toward the qualitative design of learning environments, where motivation serves as a structural mechanism that facilitates or constrains long-term behavioral continuity.

The proposed structural mechanism is visually summarized in Figure 1 (see Conceptual Mechanism of Pedagogical Influence section).

A deeper examination reveals that the relationship between pedagogical approaches and lifelong physical activity is inherently non-linear and mediated by the degree of internalization of motivational regulations. When Self-Determination Theory principles are deliberately integrated with model-based approaches, they promote not only immediate engagement but also the development of motivational competence — a critical precursor to lifelong participation (Ryan & Deci, 2017; Chatzisarantis & Hagger, 2009; Chen, 2014).

Hybrid or integrative models emerge as particularly promising because they allow simultaneous addressing of autonomy, competence, and relatedness within a coherent system (Hastie & Wallhead, 2016; Casey & MacPhail, 2018). This synergistic integration creates mutual reinforcement between motivational processes and instructional strategies, producing more robust and transferable outcomes than additive combinations of single models. Importantly, this effect is not additive but systemic: the simultaneous satisfaction of psychological needs generates nonlinear amplification of motivational internalization, which cannot be achieved through isolated pedagogical interventions (Gil-Arias et al., 2017; Correia et al., 2019; Renshaw & Chow, 2019).

From a practical standpoint, these findings imply that curriculum designers should prioritize hybrid frameworks embedding motivational support mechanisms. Teacher education programs must develop teachers' capacity to scaffold autonomy, design meaningful tasks, and foster positive peer relationships (Iserbyt et al., 2016). For instance, teachers may begin by implementing Sport Education's seasonal structure, integrate tactical problem-solving tasks from TGfU within lessons, and incorporate Cooperative Learning for group goal-setting and reflection to ensure consistent satisfaction of all three basic psychological needs. School policies should reconceptualize physical education as a strategic context for building lifelong motivational foundations rather than short-term physical activity participation (Ennis, 2017; Whitehead, 2010).

Theoretically, this analysis advances a system-oriented perspective that positions motivation as an organizing structural element rather than a peripheral variable. By explicating the specific processes through which pedagogical features influence motivational regulation and behavioral internalization, this review offers a conceptual bridge between motivational theories and pedagogical practice (Ryan & Deci, 2017; Casey & MacPhail, 2018). It opens avenues for future intervention studies testing different hybrid configurations across diverse educational contexts and age groups.

Conditions of Effectiveness and Limitations

The effectiveness of this mechanism is not universal and depends on several contextual conditions. Beyond these general conditions, the applicability of the proposed mechanism is bounded by specific structural and contextual factors. At the educational level, the mechanism is most effective in secondary school settings where students possess sufficient cognitive and social maturity to engage in cooperative, tactical, and autonomy-supportive learning environments. In contrast, in early primary education, where structured guidance and basic skill acquisition dominate, the mechanism may operate only partially (Durden-Myers et al., 2018; Whitehead, 2010).

At the institutional level, its effectiveness depends on curriculum flexibility, class size, and resource availability. Highly standardized curricula, limited lesson time, and large class sizes constrain the implementation of hybrid pedagogical models and reduce opportunities for meaningful autonomy and interaction. Similarly, in contexts with limited teacher professional development, the capacity to apply need-supportive strategies remains restricted (Iserbyt et al., 2016; Casey & MacPhail, 2018).

At the socio-cultural level, the mechanism may be weakened in environments where hierarchical teacher–student relationships, performance pressure, or externally driven achievement norms dominate. In such contexts, autonomy-supportive practices may be constrained, leading to controlled forms of motivation and reduced long-term transfer (Ryan & Deci, 2017; Perlman, 2012).

Taken together, these boundaries indicate that the mechanism is not universally transferable but contingent upon alignment between pedagogical design, institutional conditions, and socio-cultural context.

However, the proposed mechanism may fail under certain conditions. Controlling teaching styles, excessive performance pressure, lack of student autonomy, large class sizes with limited resources, low teacher training, or unsupportive socio-cultural environments can prevent the transition from controlled to autonomous motivation. In such cases, motivation remains mostly externally regulated, resulting in short-term compliance rather than sustained lifelong physical activity habits (Kirk, 2013; Chen, 2014; Ryan & Deci, 2017).

Conclusions

Traditional performance-oriented models prove insufficient because they rarely foster the autonomous motivation required for sustained participation beyond school years.

The central insight is that motivation should be understood and designed as a structural mechanism within pedagogical systems. Aligning Self-Determination Theory principles with hybrid integrative models offers a coherent pathway to simultaneously satisfy students' psychological needs while creating meaningful and transferable learning experiences.

By advocating a shift from fragmented implementations toward system-oriented hybrid frameworks, this synthesis provides a conceptual foundation for curriculum reform, teacher professional development, and policy-making. Future research should empirically test different hybrid configurations across diverse educational contexts.

Ultimately, strengthening the connection between pedagogy and motivation is a practical necessity if physical education is to contribute meaningfully to combating global physical inactivity and supporting lifelong healthy behaviors. This reconceptualization positions physical education as a strategic domain for long-term public health intervention. The proposed mechanism should be interpreted as a conceptually grounded theoretical model rather than an empirically verified mechanism. It provides an integrative framework that requires further empirical validation across diverse educational contexts.

Data Availability Statement

No new data were created or analyzed in this study.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Transparency Statement

AI-assisted tools were used for language refinement and editing purposes only. The intellectual content and scientific interpretations are solely the responsibility of the authors.

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Роль фізичного виховання у формуванні мотивації учнів та звички до довічної фізичної активності: педагогічний аспект

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 1 табл., 1 рис., 20 джерел.

Мета. У цьому концептуальному наративному огляді розглядається, яким чином мотивація функціонує як структурний механізм, що пов'язує педагогічні підходи у фізичному вихованні з довічною фізичною активністю.

Матеріали і методи. На основі вибіркового та інтерпретативного синтезу теоретичної й емпіричної літератури, що ґрунтується на Теорії самодетермінації (Self-Determination Theory, SDT) та model-based practice, у роботі розроблено інтегративну концептуальну модель.

Результати. Синтез показав, що окремі характеристики педагогічних моделей (наприклад, підтримка автономії у TGfU, формування належності у Sport Education та підтримка однолітків у Cooperative Learning) забезпечують задоволення базових психологічних потреб в автономії, компетентності та пов'язаності. Одночасне задоволення цих потреб сприяє інтеріоризації мотиваційної регуляції — від контрольованих до більш автономних форм (ідентифікована, інтегрована та внутрішня регуляція), що, своєю чергою, підтримує стійке залучення до фізичної активності за межами шкільного контексту. Гібридні інтегративні моделі демонструють вищий потенціал, оскільки створюють цілісне освітнє середовище, яке підсилює зазначені процеси, тоді як традиційні та одномодельні підходи часто забезпечують лише короткочасну підпорядкованість вимогам і обмежене перенесення поведінкових ефектів.

Висновки. Перехід до системно орієнтованих гібридних моделей, у яких мотивація розглядається як центральний організуючий механізм, є необхідною умовою для того, щоб фізичне виховання сприяло формуванню автономної мотивації та звички до довічної фізичної активності. В огляді визначено умови, за яких цей механізм функціонує ефективно або зазнає порушення, що створює концептуальне підґрунтя для реформування навчальних програм і подальших досліджень.

Ключові слова: фізичне виховання, мотивація учнів, довічна фізична активність, Теорія самодетермінації, models-based practice, гібридні педагогічні моделі, педагогічна інтеграція, спортивна педагогіка.

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Review Article

Integrated Versus Cognitively-Enriched Physical Education: Differential Effects on Mathematics Performance in School-Aged Children

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Physical activity (PA) interventions are increasingly being studied due to their potential to improve academic performance, particularly in mathematics. However, it remains unclear whether specific approaches such as Mathematics Integrated Physical Education (Math-PE) are more effective than general approaches such as Cognitively Enriched PE.

Objectives. The purpose of this study is to demonstrate the effects of physical activity interventions on mathematics performance and compare the effectiveness of Mathematics Integrated Physical Education (Math-PE) and Cognitively Enriched PE.

Materials and Methods. This study employed a systematic review and meta-analysis. A literature search was conducted in the Scopus, PubMed, and Taylor & Francis Online databases in accordance with the PRISMA 2020 guidelines. The studies that met the criteria (N = 11 independent samples) consisted of randomized controlled trials and quasi-experiments. The analysis used a random-effects model to calculate the pooled standardized mean difference (SMD).

Results. The analysis revealed a significant and moderate overall effect of PA interventions on mathematics performance (SMD = 0.425; 95% CI [0.187; 0.663]; $p < 0.001$). Importantly, moderator analysis revealed no statistically significant difference between Integrated Math-PE (k = 7; SMD = 0.436) and Cognitively Enriched PE (k = 4; SMD = 0.427; Qb = 0.00; p = 0.974).

Conclusions. While both methods produce statistically similar results, their implementation needs to be tailored to specific pedagogical circumstances. Integrated Physical Education and Mathematics is most effective for introducing specific mathematical concepts in early grades, while Cognitively Enriched Physical Education is more appropriate for improving general problem-solving skills and calculation speed in older children. Therefore, educators must carefully select methods that are truly relevant to the developmental stage of the students and the learning objectives they wish to achieve, emphasizing that Physical Education is a crucial factor in mathematics achievement when applied in the right context.

Keywords: physical education, mathematics performance, integrated learning, embodied cognition.

Introduction

Global education systems currently face a paradoxical dual pressure: the need to improve mathematical literacy amidst stagnant academic achievement, often met by reducing PE time in favor of more classroom time (Donnelly & Lambourne, 2011; Resaland et al., 2016). This sedentary approach has been sharply criticized for ignoring neurophysiological evidence showing that physical activity is not simply a biological necessity but a crucial catalyst for the development of brain structure and cognitive plasticity during childhood and adolescence (Hillman et al., 2008;

Tomporowski et al., 2015). Furthermore, reduced PA in schools is linearly correlated with declines in executive functions-such as working memory, inhibition, and cognitive flexibility-which are fundamental predictors of successful logical-mathematical reasoning (Diamond, 2015; F. Egger et al., 2019).

Theoretically, physical activity interventions in mathematics learning are based on two distinct but complementary frameworks. First, the Cognitive Stimulation perspective argues that complex physical exercise (e.g., Cognitively-Enriched PE) triggers physiological arousal and the secretion of neurotrophic factor (BDNF), which prepares the brain's neural networks for more efficient learning (Egger et al., 2019; Pesce et al., 2016; Schmidt et al., 2015). Second, the Embodied Cognition theory proposes that cognition is rooted in the body's sensorimotor interactions with the environment (Kiefer & Trumpp, 2012; Wilson, 2002). In this context, abstract mathematical concepts become more concrete when mapped through physical body movements (Integrated PE), such as jumping to understand a number line or manipulating objects for geometry (Mavilidi et al., 2018; Mullender-Wijnsma et al., 2016).

Although previous meta-analyses have confirmed a positive association between PA and academic achievement in general (Alvarez-Bueno et al., 2017; Singh et al., 2019), the existing literature often fails to distinguish specific effectiveness based on intervention type. Many systematic reviews conflate Integrated PE (learning through movement) with Enriched PE (moving to stimulate the brain), yet the two operate through distinct cognitive mechanisms (Schmidt et al., 2019; Vetter et al., 2020).

This ambiguity creates a significant knowledge gap: whether improvements in math performance are driven more by integrating curriculum content into movement (domain-specific) or by the general cognitive stimulation of physical activity (domain-general). This study aims to fill this gap through a systematic review and meta-analysis of recent randomized controlled trials (RCTs) and quasi-experiments Desains (QEDs). Specifically, the study compares the efficacy of Integrated Math-PE and Cognitive-Enriched PE approaches on math learning outcomes. Understanding these nuances is crucial for policymakers designing time-efficient future curricula in which physical health and academic excellence are no longer viewed as trade-offs but rather as mutually reinforcing elements.

Materials and Methods

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). All methodological procedures—including the search strategy, inclusion criteria, and analytical plan—were predetermined to minimize potential bias.

Eligibility Criteria (PICO)

Study eligibility was determined using the PICOS framework (Population, Intervention, Comparator, Outcome, Study design) (Richardson et al., 1995). We included controlled trials evaluating physical activity interventions specifically, those classified as either integrated math content or cognitively enriched PE on the mathematics achievement of school-aged children. Detailed inclusion and exclusion criteria are provided in Table 1.

Information Sources and Search Strategy

A systematic literature search was conducted in three electronic databases (Scopus, PubMed, and Taylor & Francis Online). The search strategy used a combination of predetermined keywords related to the topic, linked using structured Bolean operators (AND, OR). The complete search syntax and specific queries for each database are detailed in Supplementary Table 1.

Study Selection Process

The selection process followed the PRISMA 2020 flow diagram (Page et al., 2021). After removing duplicates, two independent reviewers screened titles and abstracts against the eligibility criteria, followed by a full-text assessment of potentially relevant records. Disagreements regarding inclusion were resolved through consensus or consultation with a third investigator. Complete workflow, including exception reasons at the full text stage

Table 1. PICOS criteria for inclusion and exclusion of studies

Criterion	Inclusion Criteria	Exclusion Criteria
Population	School-aged children (kindergarten to lower secondary level).	Children with specific learning disabilities (e.g., dyscalculia) or clinical conditions (e.g., ADHD), unless separable from typically developing peers.
Intervention	(1) Integrated Math: Physical tasks explicitly combined with academic content (e.g., math games).(2) Cognitively-Enriched PE: Motor tasks with high cognitive demands (e.g., executive function focus) without direct academic instruction.	Acute (single-bout) exercise sessions; pure aerobic/fitness training without cognitive engagement; after-school programs unrelated to the curriculum.
Comparator	Traditional physical education (active control) or sedentary classroom lessons (passive control).	Studies lacking a concurrent control group (e.g., pre-post single group designs).
Outcome	Quantitative mathematics performance (e.g., standardized tests, grades, procedural fluency).	Qualitative perceptions; self-reported grades without verification; math anxiety (without performance data).
Study Design	RCTs, Cluster-RCTs, and QEDs with a control group.	Cross-sectional studies, reviews, conference abstracts, or grey literature.

Data Extraction

Data extraction was conducted independently by two reviewers (AC and JT). The information collected included: (1) study characteristics (author, publication year, country); (2) participant characteristics (sample size, mean age, sex ratio); (3) intervention specifications (activity type, duration, frequency, and categorization as integrated vs. enriched); and (4) quantitative outcome data (mean, standard deviation, and sample size) for the experimental and control groups at post-intervention. Any discrepancies between reviewers were resolved through consensus discussions or adjudication by a third reviewer. For studies that did not report complete data, statistical conversions were performed using standard errors or confidence intervals, where possible.

Methodological quality assessment

We assessed risk of bias using the Cochrane RoB 2 tool for Cluster Randomized Trials (Sterne et al., 2019). Although some included studies were quasi-experimental, they used allocation at the classroom or school level; thus, treating them as cluster-randomized trials ensured a rigorous and comparable evaluation (Eldridge et al., 2016; Higgins et al., 2023). Two reviewers (JT and TAN) independently assessed five domains of bias (randomization, identification, bias, missing data, and measurement). Discrepancies were resolved through consensus or consultation with a third reviewer. Visualizations were generated using robvis (McGuinness & Higgins, 2021).

Data Synthesis and Statistical Analysis

The meta-analysis was conducted using JASP software (Version 0.16.3). Effect sizes were calculated as SMDs using Hedges' g to correct for bias in small samples (Hedges, 1981). A random-effects model with the Restricted Maximum Likelihood (REML) method was applied to accommodate inter-study variability (Borenstein et al., 2010). Heterogeneity was assessed using the I^2 statistic and the Cochrane's Q test, with I^2 values>50% indicating substantial heterogeneity (Higgins & Thompson, 2002). To address the primary research objective, subgroup moderator analyses were conducted by intervention type (Integrated Math vs. Enriched PE) to compare the effectiveness of the two approaches. Potential publication bias was evaluated visually through a symmetric funnel plot and quantified using Egger's regression test (Egger et al., 1997) and Begg & Mazumdar's rank correlation test (Begg & Mazumdar, 1994).

Results

Study Selection

An initial literature search retrieved 46,700 records from three electronic databases. After removing duplicates and screening titles and abstracts, 16 full-text articles were assessed in detail for eligibility.

Five studies were excluded at this stage for not meeting eligibility criteria, primarily because they used non-equivalent comparators (e.g., artificial control activities or active video games) or lacked a control group. Ultimately, 11 studies met all inclusion criteria and were included in the systematic review and meta-analysis. The complete selection process is illustrated in Figure 1.

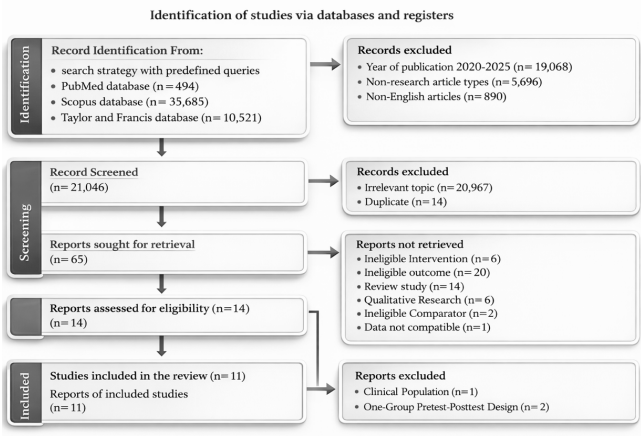

Fig. 1. PRISMA flow diagram showing the study identification and selection process.

Study Characteristics

Table 2 outlines the characteristics of the 11 included studies. The studies were conducted across diverse geographic settings, predominantly in Europe (n=8), followed by North America (n=1), South America (n=1), and North Africa (n=1). The sample comprised school-aged children aged approximately 6 to 14, with a primary focus on elementary education grades. Methodologically, the review incorporated a mix of RCTs, cluster-RCTs, and quasi-experimental designs.

Effect size, SMD (Hedges' g); random-effects model (REML); CI, confidence interval; PI, prediction interval; Qe, heterogeneity test; I^2, heterogeneity (%); τ^2, between-study variance. Main subgroup differences: Qm(1)=0.00, p=.974; Sensitivity subgroup differences: Qm(1)=0.00, p=.979; tatistical significance was set at $p < 0.05$. The sensitivity analysis excluded studies with passive (sedentary) control .

Interventions were stratified into two distinct modalities: (1) Integrated Math-PE (n=7), where academic concepts were explicitly embedded within physical tasks (e.g., 'Eduball', geometry treasure games, or fraction courts); and (2) Cognitively-Enriched PE (n=4), which targeted executive functions through complex motor circuits without direct mathematical instruction. Intervention duration exhibited significant heterogeneity, ranging from short-term exposures (2–3 weeks) to longitudinal programs spanning a full school year. Regarding comparators, most studies used an active control group (traditional physical education), while others used sedentary classroom instruction.

Risk of Bias Assessment

The risk of bias assessment using the RoB 2 Cluster instrument showed a varied quality profile (see Figure 2). Overall, two studies (18%) were classified as having a low risk of bias, five studies (45%) as having some concerns, and four studies (36%) as having a high risk. The main sources of bias were structural and centered in Domain 1 (Randomization),

Table 2. Characteristics of included studies (N = 11)

Study ID (Country)	Study Design	Sample Characteristics	Intervention Group (Description)	Control Group	Duration & Dosage	Math Domain
(Bustamante et al., 2022) (USA)	Cluster-RCT	N analyzed=158 Age: 4th-6th Grade Female: 52%	Fraction Ball Basketball games with court markings modified to represent fractions/decimals to teach rational numbers.	Active Control: Regular PE classes (Business-as-usual)	3 weeks2x / week50 min / session (Total 6 sessions)	Rational Numbers (Overall Composite: Fractions & Decimals)
(Wawrzyniak et al., 2022) (Poland)	Cluster-RCT	N=70 Age: 6-7 yrs (First Grade) Female: 44% (Pooled)	Eduball Integrated PE using balls with letters/ numbers. Conducted by varying teachers (Classroom/PE teachers).	Active Control: Standard PE program (no educational balls).	10 months (1 School Year) 2x / week 45 min / session	Early Numeracy (TUNSS: Numbers, space, shape, relationships)
(Chikha et al., 2024) (Tunisia)	Randomized Crossover Trial	N=24 Age: 6.1 ± 0.7 yrs (Grade 1) Female: 41.7% (14 Boys, 10 Girls)	Treasure Game (TG) Integrated PE where students run/walk on a 12×12m grid to form geometric shapes based on topological coordinates.	Passive Control: Sedentary conventional geometry lessons.	2 weeks (Experimental Phase) During PE Sessions (Frequency not specified, typical PE)	Geometry (Van Hiele Level 1: Visualization & Shape Identification)
(Romero-Martínez et al., 2025) (Spain)	Cluster-RCT	N=332 Age: 10-11 yrs (Grade 5) Female: 51.8%	ALPHYL Intervention Combination of classroom-based Physically Active Learning (PAL) and Quality PE. Teachers integrated movement into academic lessons (e.g., math) using SAAFE principles.	Active Control: Standard PE lessons + Regular sedentary curriculum.	9-10 weeks Daily PAL (≥ 30 min/day)	Arithmetic Fluency (Woodcock-Johnson III: Addition, subtraction, multiplication speed)
(Cecchini & Carriedo, 2020) (Spain)	QEDs	N=46 Age: 6.4 yrs (77 mos) Female: 58.7%	ITU Group (Integrated Teaching Unit) Interdisciplinary approach combining PE and Math content (subtraction) in unified sessions.	Active Control: Traditional curriculum (separate PE and Math lessons).	3 weeks 5 hours / week (Total 15 hours)	Arithmetic (Single-digit Subtraction Fluency)
(Ruiz-Hermosa et al., 2025) (Spain)	QEDs	N=77 Age: 12-14 yrs (Secondary School) Female: 57.1%	ACTIVE CLASS Integrated PAL (Physically Active Learning) lessons where math content is taught through movement (e.g., running, jumping) in outdoor areas.	Passive Control: Sedentary mathematics lessons in the classroom.	4 weeks1x / week60 min / session	Arithmetic Fluency (Woodcock-Muñoz III: Math Fluency Test)
(Cichy et al., 2020) (Poland)	QEDs	N=47 Age: 7 yrs (First Grade) Female: 45%(12 IG, 9 CG)	Eduball Integrated PE classes using educational balls with letters/numbers/signs.(Replaced 2 of 3 weekly PE lessons)	Active Control: Regular PE classes (no educational balls).	1 school year (10 months) 2x / week45 min / session	General Math Knowledge (Comprehensive Test: Sets, Arithmetic, Geometry, Measurement)
(García-Hermoso et al., 2020) (Chile)	Cluster-RCT	N analyzed=158 Age: 10 yrs (Range 8-10) Female: 43%	Active-Start Before-school PA program involving moderate-to-vigorous games and cognitive engagement (no math content).	Passive Control: Sedentary routine (no before-school activity).	8 weeks5x / week 30 min / session (Daily)	General Mathematics (School Grades / GPA, Scale 1-7)

Table 2 (continued)

Study ID (Country)	Study Design	Sample Characteristics	Intervention Group (Description)	Control Group	Duration & Dosage	Math Domain
(Latino et al., 2025) (Italy)	Cluster-RCT	N=200 Age: 11.5 ± 0.5 yrs (Early Adolescence) Female: 49%	DCC Program Cognitively-Enriched PE involving motor circuits combined with executive function tasks (e.g., 1-back motor chain, stroop-like agility) without explicit math instruction.	Active Control: Standard PE curriculum (sports techniques/free play).	12 weeks 2x / week 60 min / session	Problem Solving (AC-MT 11-14 Standardized Test)Also reported: Math Grades
(De Bruijn et al., 2020) (Netherlands)	Cluster-RCT	N=891 Age: 9.17 yrs (Grade 3-4) Female: 50.6%	Cognitively-Engaging PE Exercises with complex coordination and changing rules (e.g., tag games with cognitive tasks) to challenge executive functions, without explicit math content.	Active Control: Standard PE curriculum.	14 weeks 4x / week 30 min / session	General Mathematics (CITO Mathematics Test)
(Kliziene et al., 2020) (Lithuania)	Cluster-RCT	N=178 Age: 6-7 yrs (Grade 1) Female: 49.4%(88/178)	Innovative PE Program Combined physical exercises with cognitive tasks (spatial perception, logical tasks) using a specialized textbook during PE lessons.	Active Control: Standard PE lessons (unmodified) without the innovative program/textbook.	8 months 2x / month (Program intensity) 45 min / session	General Mathematics (Diagnostic Progress Tests: 5 Curriculum Areas)

N, number of participants; RCT, randomized controlled trial; QEDs, quasi-experimental design; PE, physical education; PA, physical activity; PAL, physically active learning; IG, intervention group; CG, control group; SAAFE, Supportive, Active, Autonomous, Fair, and Enjoyable principles; ITU, Integrated Teaching Unit; TG, Treasure Game; DCC, Dual-Challenge Circuit; GPA, grade point average; CITO, Centraal Instituut voor Toetsontwikkeling (Central Institute for Test Development); AC-MT, Test of Calculation Ability and Problem Solving (Abilità di Calcolo e Soluzione di Problemi); TUNSS, Test of Understanding of Number Systems and Structures.

where the high risk classification was due to the use of a quasi-experimental design or a limited number of clusters (e.g., k=2), which hindered effective allocation concealment.

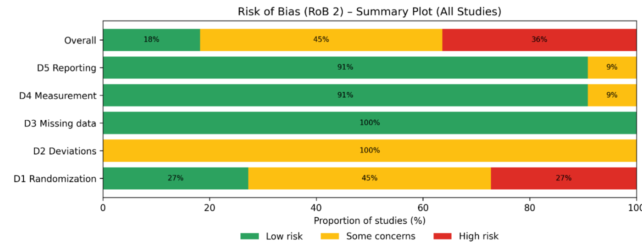

Fig. 2. Summary plot of Risk of Bias (RoB 2) across studies (D1–D5)

Although the lack of blinding for physical interventions raises consistent concerns in Domain 2, the internal validity of the studies remains intact. This is supported by strong data integrity, with 100% of studies having a low risk of missing data (Domain 3), and the majority of studies minimizing detection bias through the use of objective, standardized math tests (Domain 4).

Primary Outcomes and Moderator Analysis

Random-effects (REML) meta-analysis using SMD (Hedges' g) showed a significant overall improvement in mathematics performance (SMD = 0.425, 95% CI [0.187, 0.663], $p < .001$). Heterogeneity was substantial ($Qe(10) = 59.15$, $p < .001$; $I^2 = 82.28$; $\tau^2 = 0.121$), and the prediction interval crossed zero (95% PI [−0.297, 1.147]), indicating significant between-study variability in the magnitude of effects.

Both subgroups showed significant positive effects: Integrated Math Content (SMD = 0.436, 95% CI [0.089, 0.782], p = .014) and Cognitive-Enriched PE (SMD = 0.427, 95% CI [0.074, 0.780], p = .018), with high residual heterogeneity in each subgroup (I^2 = 78.61% and 86.64%). The subgroup difference test was not significant ($Qm(1) = 0.00$, p = .974), providing no evidence that one approach outperformed the other (see Table 3).

Sensitivity Analysis

To test the robustness of our findings, we conducted a sensitivity analysis excluding studies with a passive (sedentary) control group. Even under these more stringent conditions, the combined effect of the cognitively engaged physical education intervention remained statistically significant (SMD = 0.42, 95% CI [0.06, 0.78], p = 0.029). This suggests that the academic benefits are not solely due to increased levels of physical activity relative to sedentary behavior, but rather stem from the additional cognitive component of the intervention.

Interestingly, moderator analysis in this sensitivity subset revealed no significant difference between Math-Integrated Physical Education and Cognitively Enriched Physical Education (Qb = 0.00, p = 0.98). Both approaches yielded nearly identical medium effect sizes (SMD = 0.42 and SMD = 0.43, respectively). This suggests that cognitive engagement—regardless of content integration—is the primary driver of academic improvement compared to standard aerobic physical education.

Table 3. Summary of meta-analytic results for primary outcomes, moderator analysis by intervention type, and sensitivity analysis

Analysis	Group	k	g (SMD)	95% CI	p	95% PI	Qe(df)	p(Q)	I^2 (%)	τ^2
Primary Outcomes and Moderator Analysis	Overall	11	0.425	[0.187, 0.663]	<.001	[−0.297, 1.147]	59.15(10)	<.001	82.28	0.121
	Integrated Math Content	7	0.436	[0.089, 0.782]	0.014	[−0.423, 1.294]	31.15(6)	<.001	78.61	0.16
	Cognitively-Enriched PE	4	0.427	[0.074, 0.780]	0.018	[−0.314, 1.169]	27.15(3)	<.001	86.64	0.111
Sensitivity Analysis	Overall	8	0.42	[0.056, 0.784]	0.029	[−0.576, 1.417]	52.55(7)	<.001	87.11	0.154
	Integrated Math Content	5	0.424	[−0.193, 1.041]	0.129	[−0.956, 1.804]	25.37(4)	<.001	83.3	0.198
	Cognitively-Enriched PE	3	0.433	[−0.632, 1.498]	0.223	[−1.632, 2.497]	26.08(2)	<.001	91.58	0.169

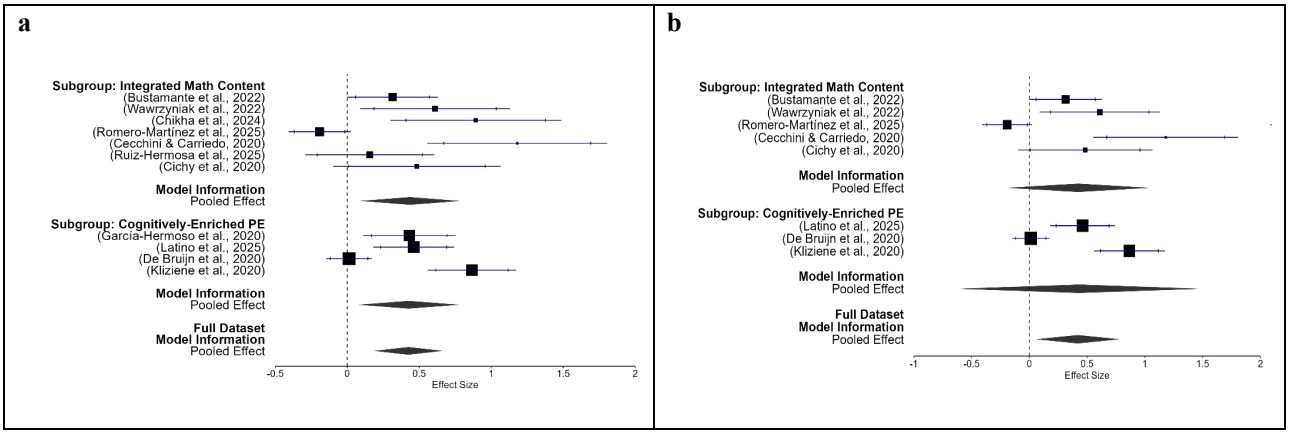

Fig. 3. Forest plot a) comparing the effects of Integrated vs. Enriched PE on math achievement, b) sensitivity analysis forest plot comparing cognitively-engaging PE interventions versus active control groups only

Publication Bias

Based on weighted regression (Egger-type), there is an indication of asymmetry/small-study effects in the funnel plot (supplementary figure S2) ($t(9) = 3.029$, $p = .014$; $\mu = -0.317$, 95% CI [−0.773, 0.139]). However, in supplementary table S2, the rank correlation (Begg-type) is not significant (Kendall's $\tau = 0.382$, $p = .121$), indicating inconsistent evidence of asymmetry across trials.

Discussion

This study aimed to analyze the effectiveness of physical activity interventions on students' mathematics performance through a systematic review and meta-analysis, specifically comparing the impact between Integrated Math and Cognitively-Enriched PE approaches. This meta-analysis confirmed a moderate positive impact of physical activity interventions on mathematics performance, refuting concerns that time allocation for physical activity is detrimental to academic achievement (Alvarez-Bueno et al., 2017; Donnelly et al., 2016). However, the most crucial and distinctive finding of this study is the statistical equivalence between Integrated Math and Cognitively-Enriched PE. This absence of significant disparity indicates that embodiment (content integration) and cognitive priming (neural stimulation) pathways have equal potential to amplify learning outcomes, providing significant pedagogical flexibility for school curricula.

The effectiveness of Integrated Math is validated by Embodied Cognition Theory, where physical movement facilitates the processing of abstract concepts by reducing intrinsic cognitive load (Mavilidi et al., 2018; Wilson, 2002). Sensorimotor manipulation of numerical content (e.g., jumping on a number line) creates multimodal memory traces that strengthen long-term retention (Beck et al., 2016; Liang et al., 2023). Conversely, the efficacy of Cognitively-Enriched PE is supported by the Cognitive Stimulation Hypothesis. Complex coordinative activities stimulate the prefrontal cortex and executive function, triggering BDNF secretion that prepares the neural architecture for academic learning without the need for explicit math instruction (Best, 2010; Diamond & Lee, 2011; Schmidt et al., 2015).

The novelty of this study lies in a methodological disaggregation often overlooked in previous meta-analyses that tend to generalize across physical activity modalities (Singh et al., 2019). By separating and comparing them head-to-head, this study fills a gap in the literature by demonstrating that improvements in math achievement can be achieved through both domain-specific (Integrated) and domain-general (Enriched) mechanisms. These findings have significant practical implications. Rather than using one approach for all, educators need to wisely select intervention methods that best suit students' developmental stages, specific mathematical objectives, and timing, ensuring the difficulty of the physical tasks aligns with the learning targets.

Importantly, the significant statistical variation observed in this meta-analysis should not be viewed solely as a flaw in the method, but rather as an important indicator of differing conditions of effectiveness. These differences reflect the various ways in which these interventions are driven by different implementation contexts, intervention dosages, and participant ages. For example, the effectiveness of these interventions depends largely on the precise match between the program duration, which varied from 2 weeks to 10 months across the included studies and the specific academic outcomes of interest. Therefore, this variation suggests that physical interventions need to be precisely tailored to instruction to achieve the best academic benefits. Furthermore, the preponderance of short-term studies limits conclusions about the durability of effects on academic performance over the long term. The relatively small sample sizes of some of the studies used also require caution in extending the findings due to potential bias in assessment.

Conclusions

Overall, this systematic review and meta-analysis indicates that Integrated Mathematics Physical Education and Cognitive Enhanced Physical Education both improve mathematics performance with statistically similar results. Rather than finding one strategy that is better for all, our results suggest that the choice of the best method depends largely on the specific circumstances in which it is implemented, including the students' developmental stage and the type of mathematics task being addressed. For younger students (such as 6–8 years old) or if the goal is to help them understand new and abstract concepts such as geometry or fractions, Integrated Mathematics Physical Education is preferable because it uses a concrete learning experience to reduce the burden of complex thinking. On the other hand, for older children (such as 10–14 years old) or if the goal is to improve their abilities in general arithmetic and solve more complex problems, Cognitive Enhanced Physical Education is very effective in stimulating their thinking skills. Furthermore, the appropriateness of implementing these methods depends on the context in which they are implemented; Schools with tight schedules may benefit from using Integrated Physical Education to combine academic and physical education time, while schools focused on long-term neurocognitive development may want to implement enhanced motor tasks within regular physical education classes. Future curricula need to go beyond simple choices and instead provide educators with the tools to make dynamic decisions about implementing active learning approaches in line with evolving educational goals.

Data Availability Statement

The datasets generated and analyzed during this research are available from the corresponding author upon reasonable request.

Conflict of Interest Statement

The authors declare no conflicts of interest regarding the publication of this article.

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AI Transparency Statement

The artificial intelligence (AI) tool, in this case Grammarly, was used solely to assist with language correction and improve the readability of the manuscript. The authors are solely responsible for the content, data analysis, and integrity of the final article.

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Інтегроване та когнітивно збагачене фізичне виховання: диференційований вплив на математичну успішність дітей шкільного віку

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 3 табл., 3 рис., 43 джерела.

Передумови. Втручання, засновані на фізичній активності (PA), дедалі частіше досліджуються через їхній потенціал покращувати академічну успішність, зокрема з математики. Однак залишається незрозумілим, чи є специфічні підходи, такі як інтегроване фізичне виховання та математика (Math-PE), більш ефективними, ніж загальні підходи, такі як когнітивно збагачене фізичне виховання.

Мета. Метою цього дослідження є демонстрація впливу втручань, заснованих на фізичній активності, на математичну успішність та порівняння ефективності інтегрованого фізичного виховання та математики (Math-PE) і когнітивно збагаченого фізичного виховання.

Матеріали та методи. У дослідженні використано систематичний огляд та метааналіз. Пошук літератури проводився в базах даних Scopus, PubMed і Taylor & Francis Online відповідно до рекомендацій PRISMA 2020. До аналізу були включені дослідження, що відповідали критеріям відбору (N = 11 незалежних вибірок) і мали дизайн рандомізованих контрольованих досліджень та квазіекспериментів. Для розрахунку об'єднаного стандартизованого середнього ефекту (SMD) застосовано модель випадкових ефектів.

Результати. Аналіз виявив статистично значущий помірний загальний ефект втручань, заснованих на фізичній активності, на математичну успішність (SMD = 0.425; 95% CI [0.187; 0.663]; $p < 0.001$). Важливо, що модераторний аналіз не виявив статистично значущої різниці між інтегрованим Math-PE (k = 7; SMD = 0.436) та когнітивно збагаченим фізичним вихованням (k = 4; SMD = 0.427; Qb = 0.00; p = 0.974).

Висновки. Хоча обидва методи демонструють статистично подібні результати, їх впровадження має бути адаптоване до конкретних педагогічних умов. Інтегроване фізичне виховання та математика є найбільш ефективними для введення конкретних математичних понять у молодших класах, тоді як когнітивно збагачене фізичне виховання є більш доцільним для покращення загальних навичок розв'язування проблем і швидкості обчислень у старших дітей. Отже, педагоги повинні ретельно обирати методи, які дійсно відповідають віковим особливостям учнів і навчальним цілям, яких вони прагнуть досягти, підкреслюючи, що фізичне виховання є важливим чинником математичної успішності за умови його застосування у відповідному контексті.

Ключові слова: фізичне виховання, математична успішність, інтегроване навчання, втілене пізнання.

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Review Article

Health Literacy, Physical Activity, and Education: Integrating Healthcare and Pedagogical Perspectives

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Abstract

Background. Health literacy (HL) is a multidimensional construct recognized as a key determinant of health outcomes, influencing individuals' ability to access, understand, and apply health information. However, existing literature predominantly describes associations between HL and health behaviours, while the mechanisms through which HL produces behavioural change, particularly in physical activity, remain insufficiently specified. In addition, the contextual conditions under which these effects operate, weaken, or fail have not been clearly defined.

Objective. This narrative review aims to develop a mechanism-based and condition-sensitive conceptual model integrating healthcare, pedagogical, and physical activity perspectives to explain how, why, and under which conditions HL influences health behaviour, with specific reference to physical activity.

Materials and Methods. A structured narrative review was conducted using the PubMed, Scopus, and Web of Science databases. Studies published between 2000 and 2025 were selected based on predefined inclusion and exclusion criteria. The analysis followed a theory-driven synthesis approach aimed at identifying causal pathways, mediating processes, and contextual moderators.

Results. The synthesis identifies a multilevel mechanism through which HL influences physical activity and health behaviours via cognitive, motivational, and behavioural regulation processes. However, this mechanism is conditional rather than universal: its effectiveness depends on contextual factors such as educational level, socio-economic status, healthcare system complexity, and digital access. HL effects are strengthened in supportive environments, attenuated in complex communication contexts, and may fail in the presence of structural constraints.

Conclusions. HL should be conceptualized not only as a determinant but also as a conditional mechanism of behaviour change operating across healthcare, educational, and social systems. The proposed model provides a theoretically grounded framework with defined causal pathways, mediators, and boundary conditions, offering guidance for the design of integrated interventions to improve health outcomes, promote active lifestyles, and reduce health inequalities.

Keywords: health literacy, patient education, health promotion, physical activity, physical education, sport, empowerment, healthcare systems, public health.

Introduction

Health literacy (HL) is increasingly recognized as a central determinant of health and a key component of healthcare systems. Originally it was defined as the ability to read and understand basic health information; in more recent times, the concept has evolved into a multidimensional construct that affects different aspects, such as cognitive, social, and critical skills required for informed decision-making (Nutbeam, 2008).

In recent Public Health research, HL is not considered a static individual attribute but a dynamic interaction between individuals and healthcare, educational, and social systems.

The growing importance attributed to HL is closely linked to the transformations in healthcare, including aging populations, the rise of chronic diseases, etc. In this context,

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patients are expected to take a more active role in managing their health, and in making decisions (Kickbusch & Maag, 2008).

Despite its recognized importance, current research on HL remains fragmented. Indeed, HL has been predominantly investigated within clinical and Public Health settings, while parallel developments in educational sciences and physical activity research have often evolved independently. As a result, there is limited integration between healthcare-oriented HL models, pedagogical theories of learning and empowerment, and behavioural frameworks related to physical activity and sport participation.

Furthermore, HL is also related to lifestyle behaviours, including physical activity and sport participation. Adequate levels of HL enable individuals to better understand the benefits of regular exercise, interpret public health guidelines, and adopt active lifestyles, as highlighted by the World Health Organization (2018). Conversely, limited HL may contribute to sedentary behaviours and poor engagement in preventive practices, including unhealthy lifestyle patterns such as poor diet and physical inactivity (Paasche-Orlow & Wolf, 2007; Calella et al., 2024). In this perspective, physical activity represents not only a determinant of health but also an educational context in which individuals develop skills related to self-management, body awareness, and informed decision-making. Participation in sport and physical education has been associated with improved physical, psychological, and social outcomes, reinforcing its relevance within health promotion strategies (Bailey, 2006).

At the same time, HL is associated to social determinants such as education, socioeconomic status, and cultural background, that could contribute to health inequalities (Paasche-Orlow & Wolf, 2007).

Despite the considerable clinical implications, HL has also a pedagogical dimension. Indeed, it involves learning processes, communication strategies, and the development of competencies during lifetime. Therefore, healthcare workers (HCWs) are required not only to provide care but also to facilitate understanding and promote patient empowerment (World Health Organization, 2013).

In addition, the rapid expansion of digital technologies has led to the emergence of digital health literacy (DHL), which refers to individuals' ability to seek, understand, and use health information from electronic sources. DHL is increasingly recognized as a key determinant of health in contemporary societies, influencing access to care, self-management, and health-related decision-making.

Despite the expansion of HL research across healthcare, education, and behavioural domains, current literature predominantly establishes associative relationships rather than explanatory mechanisms. Systematic reviews by Berkman et al. (2011) and conceptual analyses by Baker (2006) consistently demonstrate strong associations between HL and health outcomes, yet they do not fully explain how these relationships are produced. While HL is linked to physical activity and preventive behaviours (World Health Organization, 2018), there is limited understanding of how HL translates into behavioural change through identifiable causal pathways. Moreover, the conditions under which these relationships operate, weaken, or fail remain insufficiently specified.

This limitation constrains both theoretical advancement and practical application, as interventions based on HL often assume linear effects without accounting for mediating processes and contextual dependencies. Paasche-Orlow and Wolf (2007) proposed one of the few causal pathway models linking HL to health outcomes, emphasizing intermediate factors such as access, communication, and self-management; however, these mechanisms have not been fully integrated with educational and behavioural frameworks. Similarly, Sørensen et al. (2012) conceptualize HL as a multidimensional construct shaped by individual and systemic factors, but without explicitly operationalizing its behavioural pathways.

In the context of physical activity, this gap is particularly evident. Although higher HL is associated with increased engagement in active lifestyles (World Health Organization, 2018), the processes through which knowledge is transformed into sustained behaviour, such as motivation, self-efficacy, and behavioural regulation are not systematically incorporated into HL models. Educational theories (Knowles et al., 2012) and communication-based approaches (Street et al., 2009) suggest that learning and interaction processes are central, yet these perspectives remain only partially connected to HL research. Furthermore, structural and contextual factors, including educational level and socio-economic conditions, are known to influence HL (Sørensen et al., 2012), but their role as moderators of behavioural outcomes is rarely explicitly defined.

Therefore, this study aims to move beyond descriptive synthesis by developing a mechanism-based and condition-sensitive conceptual model of HL. Specifically, the review seeks to: 1) identify the causal pathways linking HL to health behaviour, with particular focus on physical activity; 2) analyse the mediating processes through which HL influences behaviour; 3) define the contextual conditions under which these mechanisms operate, weaken, or fail.

By addressing these aspects, this study proposes an operational framework that integrates healthcare, educational, and behavioural perspectives, contributing to a more theoretically grounded and practically applicable understanding of HL.

Materials and Methods

Study design

This study was conducted as a structured narrative review with a theory-driven synthesis approach. Although narrative in structure, the review follows systematic principles of transparency, study selection, and theory-driven synthesis to enhance reproducibility and analytical rigor. The review was designed not only to summarize existing literature but to identify causal pathways, mediating mechanisms, and contextual conditions linking HL to health behaviour, particularly physical activity. This approach combines elements of scoping reviews with conceptual model development, ensuring both breadth of coverage and analytical depth.

Literature search strategy

A comprehensive literature search was conducted in PubMed, Scopus, and Web of Science databases. The search covered studies published between 2000 and 2025. Search terms were combined using Boolean operators and included: ("health literacy") AND ("physical activity" OR "sport" OR

"lifestyle") AND ("health education" OR "patient education" OR "physical education").

The search strategy was designed to capture studies addressing HL across healthcare, educational, and behavioural domains. Reference lists of key articles were also screened to identify additional relevant studies.

Eligibility criteria and study selection

Studies were included if they met the following criteria: 1) peer-reviewed articles; 2) focus on HL in relation to healthcare, education, or physical activity; 3) contribution to understanding mechanisms, processes, or outcomes related to HL; and 4) published in English.

Studies were excluded if they were non-scientific publications, did not explicitly address HL, or lacked relevance to the conceptual integration of HL across domains.

The selection process was conducted in two stages: 1) title and abstract screening to identify potentially relevant studies; and 2) full-text assessment based on inclusion criteria. Although the review does not follow a formal systematic review protocol, the selection process was conducted to ensure transparency and reproducibility. To enhance consistency, the selection process was guided by predefined conceptual criteria focusing on the relevance of studies for identifying mechanisms, mediating processes, and contextual conditions. Emphasis was placed on studies providing explanatory insights rather than purely descriptive associations. The selection process resulted in a focused set of studies that met the inclusion criteria and were considered sufficiently relevant for the development of the conceptual synthesis. Consistent with the narrative and theory-driven nature of the review, emphasis was placed on conceptual relevance and explanatory contribution rather than on quantitative reporting of study flow.

Data extraction and synthesis

Data were extracted focusing on three analytical dimensions: 1) reported relationships between HL and health outcomes or behaviours; 2) identified mediating processes (e.g., comprehension, self-efficacy, communication); and 3) contextual factors influencing these relationships.

The synthesis followed a theory-driven approach aimed at moving from descriptive aggregation to explanatory modelling. Studies were analysed to identify recurring causal patterns, which were then integrated into a mechanism-based conceptual framework specifying pathways, mediators, and boundary conditions.

Rather than aggregating results, the analysis aimed to construct a mechanism-based explanation by linking observed relationships to underlying processes and conditions. This approach supports the development of a conceptual model that is theoretically grounded while remaining open to empirical validation.

Results

Study selection and overview of included literature

The literature search yielded a heterogeneous body of literature across healthcare, educational, and physical activity domains. A focused subset of studies meeting the inclusion criteria was selected and analysed using a theory-driven synthesis approach. The selected literature reflects heterogeneous methodological approaches, including systematic reviews, observational studies, theoretical frameworks, and intervention studies, highlighting the multidimensional nature of HL.

Across the included studies, HL was conceptualized as a multidimensional construct involving healthcare systems, individual competencies, and educational contexts (Nutbeam, 2000; Sørensen et al., 2012).

Mechanism-based synthesis of health literacy

The synthesis of the included studies moves beyond thematic aggregation to identify a mechanism-based explanation of how HL influences health behaviour, particularly physical activity. Across the literature, HL does not operate as a direct determinant of behaviour, but rather through a set of interacting cognitive, motivational, and behavioural regulation processes.

At the cognitive level, HL enables individuals to access, understand, and interpret health information. Berkman et al. (2011) demonstrate that limited HL is associated with misunderstanding of medical instructions and poor disease knowledge, while Baker (2006) highlights its role in shaping healthcare decision-making. These findings suggest that comprehension represents a primary mechanism through which HL affects subsequent processes.

Limited HL is also associated with increased healthcare costs, reflecting inefficient use of services and poorer disease management (Eichler et al., 2009).

At the motivational level, HL contributes to the development of self-efficacy, risk perception, and outcome expectations. Osborn et al. (2011) show that HL influences patients' confidence in managing their health, while educational theories (Knowles et al., 2012) emphasize the role of learning processes in fostering autonomy and motivation. These elements are critical in translating knowledge into intention.

At the behavioural level, HL affects self-management, adherence, and lifestyle choices. Paasche-Orlow and Wolf (2007) propose that HL influences health outcomes through intermediate pathways including access to care, patient–provider interaction, and self-care behaviours. In the context of physical activity, the World Health Organization (2018) indicates that individuals with higher HL are more likely to engage in preventive behaviours, although this relationship is not linear or universal.

The concept of physical literacy further supports this interpretation, integrating cognitive, motivational, and behavioural dimensions of lifelong physical activity engagement (Whitehead, 2010). This multidimensional perspective is supported by systematic evidence linking physical literacy to motivation, competence, and long-term engagement in physical activity (Edwards et al., 2017).

Taken together, these findings support a multilevel mechanism in which HL influences behaviour through a sequential pathway: cognitive processing (comprehension); motivational activation (self-efficacy and intention); behavioural regulation (action and maintenance).

Conditions of operation

The analysis further indicates that the effect of HL on behaviour is conditional rather than universal. Specifically,

three patterns can be identified: conditions under which HL operates effectively, conditions under which its effect weakens, and conditions under which it fails.

HL operates effectively when individuals are supported by enabling environments, including accessible healthcare systems, clear communication, and adequate educational background. Sørensen et al. (2012) emphasize that HL emerges from the interaction between individual capacities and system demands, suggesting that alignment between these elements is necessary for effective outcomes.

The effect of HL weakens in contexts characterized by complexity and limited support. Street et al. (2009) show that ineffective communication between healthcare providers and patients can reduce comprehension and limit the impact of HL. Similarly, low motivation or lack of reinforcement may prevent the translation of knowledge into sustained behaviour, particularly in physical activity contexts.

HL may fail to produce behavioural change in the presence of structural barriers. Socio-economic constraints, low educational attainment, and limited access to resources can inhibit the application of health knowledge, even when HL levels are adequate. In such cases, HL alone is insufficient to generate change, as behavioural outcomes are constrained by external conditions rather than individual competence.

Integrative model

Based on these findings, HL can be conceptualized as a conditional mechanism linking healthcare systems, educational processes, and behavioural outcomes. The proposed model integrates three core components: 1) causal pathways (cognitive, motivational, behavioural), 2) mediating processes (comprehension, self-efficacy, regulation), and 3) contextual moderators (education, socio-economic conditions, system complexity).

This model moves beyond illustrative representations by specifying how HL produces effects and under which conditions these effects vary, providing an operational framework for future research and interventions.

Table 1 synthesizes the mechanism-based structure of the included studies, highlighting main component, mechanism, and implications.

Table 1 synthesizes the findings according to a mechanism-based framework, identifying the core processes through which HL influences health behaviour. Rather than organizing evidence into thematic domains, the table highlights the sequential pathways (cognitive, motivational, and behavioural), the key mediating elements, and the contextual conditions that shape the strength and direction of these relationships.

Figure 1 presents the operational framework of this model, illustrating the sequential pathways through which HL influences behaviour and the contextual conditions under which these processes operate. The proposed framework conceptualizes HL as a conditional mechanism integrating causal pathways, mediating processes, and contextual moderators

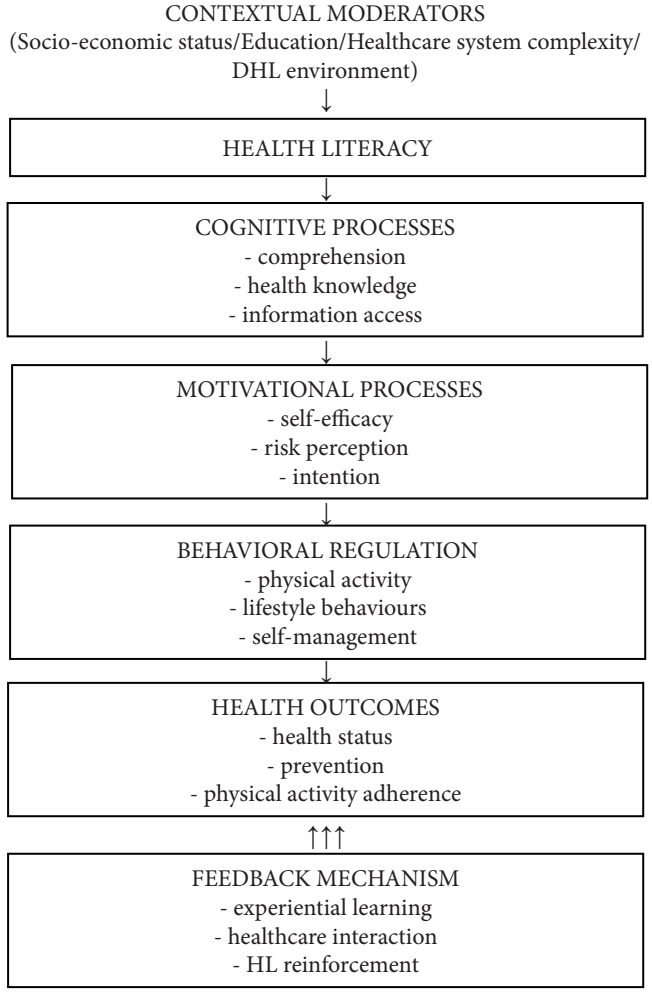

Fig. 1. Conceptual model of HL

Table 1. Synthesis of HL literature across domains

Component	Mechanism	Key elements	Supporting evidence
Cognitive processes	Access, understanding, and interpretation of health information	Comprehension, health knowledge	Berkman et al. (2011); Baker (2006)
Motivational processes	Transformation of knowledge into intention	Self-efficacy, risk perception, motivation	Osborn et al. (2011); Knowles et al. (2012)
Behavioral regulation	Translation of intention into action	Physical activity, self-management, adherence	Paasche-Orlow & Wolf (2007); World Health Organization (2018)
Contextual moderators	Conditions influencing the strength of the relationship	Education, socio-economic status, healthcare system complexity, digital access	Sørensen et al. (2012); Street et al. (2009)
Boundary conditions	Conditions of effectiveness, weakening, or failure	Supportive vs constrained environments	Derived from theory-driven synthesis

Discussion

This review moves beyond a descriptive synthesis by integrating evidence on HL across healthcare, educational, and physical activity domains. The main contribution of this study lies in framing HL as an interdisciplinary and dynamic construct that operates across systems rather than as an isolated individual competency.

The findings suggest that HL should be interpreted as a multilevel construct emerging from the interaction between individual abilities, healthcare system demands, and educational contexts. This perspective aligns with existing theoretical models that conceptualize HL as both an individual and a systems-level attribute (Nutbeam, 2000; Sørensen et al., 2012).

This study advances the literature by moving from associative descriptions of HL to a mechanism-based and condition-sensitive explanation of its effects on health behaviour. The findings indicate that HL does not act as a direct determinant of outcomes, but as a multilevel mechanism operating through cognitive, motivational, and behavioural regulation processes. This interpretation extends previous models, such as that proposed by Paasche-Orlow and Wolf (2007), by explicitly integrating educational and behavioural dimensions within a unified framework.

From a theoretical perspective, the results support the conceptualization of HL as a conditional mechanism rather than a static individual attribute. Specifically, HL enables behavioural change only when cognitive understanding is translated into motivation and subsequently into action. This sequential process highlights the central role of mediators such as comprehension and self-efficacy, which bridge the gap between knowledge and behaviour. Importantly, the proposed mechanism should not be interpreted as a strictly linear sequence, but as a dynamic and recursive system of interactions. HL not only influences cognitive, motivational, and behavioural processes, but is also progressively reshaped by individual lived experiences in health-related and physical activity contexts. In this sense, behavioural outcomes may generate feedback effects that contribute to the refinement of health-related knowledge, self-efficacy, and future decision-making capacity. This bidirectional perspective suggests that HL operates within a continuous learning loop rather than a unidirectional causal pathway.

Based on this synthesis, the following theoretical statements are proposed:

Statement 1: HL is associated with health behaviour through sequential mediating processes involving cognitive comprehension, motivational activation (e.g., self-efficacy), and behavioural regulation; however, these pathways are non-linear and may vary across contexts.

Statement 2: The relationship between HL and health behaviour is moderated by contextual factors such as educational level, socio-economic conditions, healthcare system complexity, and digital access, which influence the strength and direction of effects.

Statement 3: HL alone is insufficient to ensure sustained behavioural change when environmental, organisational, or structural constraints limit the translation of knowledge into action.

Statement 4: The translation of HL into physical activity behaviour is a dynamic process influenced by the interaction between individual capacities and contextual opportunities, and it may be reinforced or weakened over time through feedback from behavioural experiences.

These statements define a set of boundary conditions that clarify when and how HL operates. In particular, the findings indicate that HL operates effectively in contexts characterized by accessible information, supportive communication, and adequate educational resources. Conversely, its effect weakens in complex or poorly structured systems and may fail entirely in the presence of structural barriers such as socio-economic disadvantage or limited access to resources.

This perspective has important implications for both theory and practice. From a theoretical standpoint, it contributes to the advancement of HL research by providing an operational model that specifies causal pathways and conditions of applicability. From a practical standpoint, it suggests that interventions should not focus solely on improving individual HL levels, but also on modifying contextual factors that enable or constrain behaviour.

Healthcare systems should adopt health-literate organizational models that reduce complexity and enhance communication (Brach et al., 2012), while educational systems should integrate HL as a core competence linked to critical thinking and lifelong learning (Nutbeam, 2008). In the domain of physical activity, interventions should explicitly target both HL and its mediating processes, such as motivation and self-regulation, in order to facilitate sustained engagement.

An additional implication concerns the role of DHL, which may amplify both opportunities and inequalities. While digital tools can enhance access to health information, they also require advanced critical evaluation skills and may exacerbate disparities among populations with limited resources or competencies. These dynamics introduce further challenges, including information overload, exposure to misinformation, and digital inequality.

These challenges may amplify existing disparities in HL and health outcomes if not addressed through targeted educational and system-level interventions.

The findings of this review could have several practical implications. For healthcare systems, HL should be integrated into organizational design through health literate healthcare systems that improve communication and navigation (Brach et al., 2012). For educational systems, HL should be incorporated into curricula as a lifelong learning competence linked to critical thinking and empowerment (World Health Organization, 2013). For physical activity and sport, interventions should explicitly integrate HL components to enhance understanding of health benefits, motivation for active lifestyles, and adherence to physical activity guidelines (World Health Organization, 2018; Bailey, 2006).

HCWs, educators, and sport practitioners should therefore be considered joint stakeholders in HL development.

Study limitations

This review has several limitations related to its non-systematic approach and the potential for selection bias in the included literature. As a structured narrative review, it is subject to heterogeneity of included study designs, and absence of quantitative synthesis. Indeed, future research should focus on development and validation of integrated HL models, and longitudinal studies assessing HL impact on physical activity and health outcomes.

Conclusion

HL is a fundamental determinant of health and a component of modern healthcare systems. Its integration with pedagogical approaches provides a powerful framework for improving health outcomes and contrasting inequalities. Rather than being confined to a single disciplinary domain, HL should be conceptualized as a dynamic mechanism influencing how individuals access, understand, and apply health information across contexts.

Efforts to enhance HL should involve people, HCWs, and healthcare systems, with the adoption of more comprehensive and interdisciplinary approaches.

The integration of HL with pedagogical approaches and physical activity frameworks provides a promising direction for improving health outcomes and reducing health inequalities. This review contributes to the field by proposing a synthesized conceptual interpretation and highlighting the need for an integrated model capable of guiding future research and practice.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethics Statement

Ethical approval was not required because this study is a narrative review and did not involve human participants, personal data, or experimental procedures.

Data Availability Statement

No new datasets were generated or analyzed in this study.

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Медична грамотність, фізична активність та освіта: інтеграція медичних і педагогічних підходів

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 1 табл., 1 рис., 18 джерела.

Передумови. Медична грамотність (HL) є багатовимірним конструктом, який розглядається як ключовий чинник результатів здоров'я, оскільки впливає на здатність людини отримувати, розуміти та застосовувати інформацію про здоров'я. Однак наявна література переважно описує зв'язки між HL і поведінкою, пов'язаною зі здоров'ям, тоді як механізми, через які HL забезпечує поведінкові зміни, особливо у сфері фізичної активності, залишаються недостатньо визначеними. Крім того, контекстуальні умови, за яких ці ефекти проявляються, послаблюються або не спрацьовують, також не були чітко окреслені.

Мета. Це наративне оглядове дослідження спрямоване на розроблення механізм-орієнтованої та чутливої до умов концептуальної моделі, що інтегрує медичні, педагогічні та фізкультурно-оздоровчі підходи для пояснення того, як, чому та за яких умов HL впливає на поведінку, пов'язану зі здоров'ям, з особливим акцентом на фізичну активність.

Матеріали і методи. Проведено структурований наративний огляд із використанням баз даних PubMed, Scopus та Web of Science. Дослідження, опубліковані у 2000–2025 роках, відбиралися відповідно до попередньо визначених критеріїв включення та виключення. Аналіз здійснювався на основі теоретично орієнтованого синтезу, спрямованого на виявлення причинно-наслідкових шляхів, опосередковувальних процесів і контекстуальних модераторів.

Результати. Синтез дозволив виявити багаторівневий механізм, через який HL впливає на фізичну активність і поведінку, пов'язану зі здоров'ям, за допомогою когнітивних, мотиваційних і поведінково-регуляторних процесів. Водночас цей механізм має умовний, а не універсальний характер: його ефективність залежить від таких контекстуальних чинників, як рівень освіти, соціально-економічний статус, складність системи охорони здоров'я та цифрова доступність. Вплив HL посилюється у сприятливих середовищах, послаблюється в умовах складної комунікації та може не реалізуватися за наявності структурних обмежень.

Висновки. HL слід розглядати не лише як детермінанту, а й як умовний механізм поведінкових змін, що функціонує в системах охорони здоров'я, освіти та соціального середовища. Запропонована модель формує теоретично обґрунтовану основу з визначеними причинно-наслідковими шляхами, медіаторами та граничними умовами, що може бути використана для розроблення інтегрованих втручань, спрямованих на покращення результатів здоров'я, популяризацію активного способу життя та зменшення нерівності у сфері здоров'я.

Ключові слова: медична грамотність, навчання пацієнтів, зміцнення здоров'я, фізична активність, фізичне виховання, спорт, розширення можливостей, системи охорони здоров'я, громадське здоров'я.

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Review Article

The Role of Sport in Promoting Mental Health Among Adolescents

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Objective. Adolescence, a critical transitional phase of life, is characterised by biological, psychological, and social changes that may increase vulnerability to mental health problems. This review aims to provide an integrative synthesis of the role of sport and physical activity in promoting mental health among adolescents, with a specific focus on biological, psychological, and social mechanisms.

Materials and Methods. A narrative review was conducted using studies retrieved from major scientific databases, including PubMed, Scopus, and Web of Science. Relevant articles were selected based on their focus on adolescents (aged 10–24 years), physical activity or sport participation, and mental health outcomes. The evidence was analysed using a thematic approach to identify patterns, relationships, and inconsistencies across studies.

Results. The review identified four main domains: neurobiological, psychological, social, and contextual. Overall, the evidence indicates that physical activity contributes to adolescent mental health through multiple interconnected pathways, including neurobiological mechanisms (e.g., regulation of neurotransmitters such as serotonin and dopamine), psychological mechanisms (e.g., improved self-esteem), and social mechanisms (e.g., peer interaction). However, the magnitude and direction of these effects appear to be strongly moderated by contextual and environmental factors.

Conclusions. Sport represents a multidimensional factor in promoting mental health during adolescence. Its effects should be interpreted within an integrated framework in which biological, psychological, and social mechanisms interact dynamically. Rather than being universally beneficial, sport participation may produce both positive and negative outcomes depending on the quality of the environment and the level of competitiveness. Future research should focus on clarifying causal pathways and contextual moderators, as well as on developing context-sensitive and mechanism-informed interventions.

Keywords: adolescent, mental health, sport, physical activity, health promotion.

Introduction

Adolescence is a transitional stage of development characterised by profound biological, psychological, and social changes that influence mental health trajectories into adulthood. According to the World Health Organisation (WHO), mental health is a state of well-being that enables people to cope with life's stresses, realise their potential, learn effectively, work and contribute to their community; health, therefore, is more than the mere absence of illness. It is a multidimensional construct influenced by biological, psychological, and social factors, particularly during adolescence (WHO, 2021).

Anyone can experience mental health problems at any stage of their life. No single factor contributes to the development of a mental health condition: this is the result of a complex interaction of factors within the individual and their social environment. In adolescence, a crucial aspect of mental health is prevention and early intervention. There is considerable evidence to suggest that the timely identification of signs of psychological distress (such as social withdrawal, a decline in academic performance, sleep disturbances or behavioural changes) helps to reduce the risk of mental health disorders becoming chronic. School-based interventions, which include social-emotional learning programmes, life skills promotion and psychological support, have proven effective in improving psychological well-being and reducing symptoms of anxiety and depression (WHO, 2021; OECD 2025).

The prevalence of mental health disorders continues to rise at an alarming rate. In the European Region, one in six people (around 140 million) lives with a mental health disorder, with an impact on daily life ranging from mild to severe (WHO, 2024). Furthermore, adolescents' mental health is also strongly influenced by the social determinants of health, including socioeconomic status, family background, access to health services and educational opportunities. Adolescents from disadvantaged backgrounds are at greater risk of developing mental health disorders, partly due to chronic stress and fewer opportunities for social participation. Such inequalities require structural interventions and equity-oriented policies.

The WHO also draws attention to technology and electronic devices: "The use of technology affects young people's mental health in complex and contradictory ways. It can connect, inspire and educate, but it can also expose young people to serious risks. The most common online dangers include cyberbullying, unrealistic body ideals, self-harming content, harmful marketing and invasive data collection" (WHO, 2024). Another factor that is often underestimated but can be crucial for mental health in adolescence is the quality and quantity of sleep. Sleep deprivation, which is increasingly common partly due to the evening use of electronic devices, is associated with an increased risk of anxiety, depression, irritability and cognitive difficulties. Ensuring adequate sleep habits is therefore an important protective factor for psychological well-being. Recent data from studies conducted on Italian populations confirm the high prevalence of sleep disorders among young people, highlighting a close association between poor sleep quality, use of digital devices and a deterioration in psychological well-being (Gallè et al., 2025).

The latest CENSIS report indicates that 74.1% of Italians say they have had direct or indirect experience of mental health issues (34.2% personally, 36.3% through family members or friends); 29.4% of people say they think about their mental health every day or often (41.9% among young people) and 44.3% at least occasionally (CENSIS, 2026).

During childhood and adolescence, anxiety disorders are the most common psychiatric condition, and it is estimated that, by the age of 18, one third of adolescents will meet the criteria for an anxiety disorder (Merikangas et al., 2010). Anxiety disorders have a multifactorial origin, with genetic and neurobiological factors, environmental and social factors, and temperamental factors all potentially contributing.

According to Masi, children of a parent with an anxiety disorder are seven times more likely to develop the same condition during childhood (Masi et al., 2000). In children, anxiety generally manifests in connection with school or sporting performance, or the anticipation of social engagements which the child experiences with a sense of tension and anticipatory agitation, due to situations they foresee or perceive as unpleasant or even threatening. In pre-adolescence and adolescence, anxiety is instead linked above all to exposure to social judgement and the avoidance of situations that might expose them to negative judgements.

'Drop-out', i.e. the early abandonment of sport and a retreat into a sedentary lifestyle, is a common phenomenon in adolescence. The reasons are linked to psychological factors of demotivation and rejection of an environment too often focused on performance, excessive competition, and results as the sole objective.

Adolescence is the period of life, lasting approximately 10 years, that marks the transition from childhood to adulthood, that is, from the onset of puberty to the age of 24 (Sawyer et al., 2018). During this ontogenetic period, profound physical, physiological and neuropsychological changes occur, which are responsible for the vulnerability specifically associated with adolescence; these changes can influence behaviour and mental health in adulthood. It is during this phase that the brain refines its efficiency in processing information and acquires speed of communication between neurons whilst remaining particularly plastic ('brain plasticity') and thus becoming highly sensitive and receptive to stimuli from the external environment (Giedd et al., 1999; Andrews et al., 2021).

Adolescence, following childhood, can be considered the 'second critical period' of neurobehavioral development which, as regards the central nervous system, particularly affects certain brain areas involved in the processing of gratification (deriving from pleasant and fulfilling experiences) and emotional states, such as fear, anger, happiness, sadness and aggression. In adolescents, these emotional states manifest with extremely variable intensity, often with moments of extreme happiness rapidly alternating with others of profound distress or depression.

Experimental and clinical evidence suggests that temperament and certain behavioural traits characteristic of adolescence, such as high emotional reactivity, risk underestimation and a strong propensity for novelty seeking (the pursuit of new experiences and sensations), are partly attributable to a delayed physiological maturation of the neural circuits in the prefrontal cortex that underlie executive functions such as: the ability to reason critically, control impulses and inhibit inappropriate behaviour. Whilst novelty-seeking behaviour has significant adaptive value-as it drives adolescents to separate from their parents, motivating them to explore the world beyond the family sphere and to construct their own identity-it can also lead to the pursuit of risky activities that strongly stimulate the brain's reward mechanisms, such as extreme sports and, more generally, danger-defying behaviour, or the use of psychoactive substances.

During adolescence, a period in which the ability to feel empathy and understand the intentions and perspectives of others is refined, socialisation plays an important role in the construction of one's identity. Being socially connected is a fundamental human need, rooted in our evolutionary history and therefore crucial for survival and emotional well-being. Younger individuals may be more vulnerable to negative social experiences at a stage of life when identity, social skills and emotional regulation abilities are developing (Lamblin et al., 2017). Indeed, extensive evidence shows that, in the case of children and adolescents, the number of friends, the quality of these relationships, and peer relationships act as protective factors for mental health (Schwartz-Mette et al., 2020), whilst early school leaving (and the consequent loss of peer socialisation processes) and social isolation represent significant risk factors (Egger et al., 2003; Finning et al., 2019). This evidence highlights how the promotion of protective social connections (support networks) and the fight against stigma and discrimination are crucial actions in the early stages of development and can act as a buffer against the

emergence of mental health disorders. Conversely, negative peer experiences, such as bullying, represent a significant risk factor for psychological well-being. Recent studies highlight how victimisation is associated with a poorer perception of oneself and one's physical appearance, particularly in adolescents who are overweight or obese, contributing to reduced self-esteem and increased emotional distress (Ballarin et al., 2023). However, despite the large body of literature supporting the positive role of sport, findings are not always consistent. While many studies report beneficial effects on mental health, others highlight neutral or even negative outcomes, particularly in highly competitive or performance-oriented contexts. This inconsistency suggests that the relationship between sport participation and mental health is dependent on multiple factors.

Therefore, an issue in the literature is the lack of a multidimensional model explaining how physical activity influences adolescent mental health considering biological, psychological, and social domains. This gap limits the ability to design effective and targeted interventions for mental health promotion. Moreover, existing studies often examine isolated outcomes, and as a result, it remains unclear how different mechanisms interact.

Therefore, the aim of this narrative review is to provide an integrative synthesis of the role of sport and physical activity in promoting mental health among adolescents, with particular attention to the biological, psychological, and social mechanisms underlying these effects. This narrative review addresses the following research questions: 1)What are the main biological, psychological, and social mechanisms through which physical activity influences adolescent mental health? 2) How do different types of sport participation moderate these effects? 3) What are the main inconsistencies in the current literature?

Materials and Methods

Study design

This study was conducted as a narrative review aimed to provide an integrative synthesis of the relationship between sport participation and mental health among adolescents. Given the heterogeneity of study designs, outcomes, and conceptual approaches in the existing literature, a narrative approach was considered appropriate to explore and interpret the complex biological, psychological, and social mechanisms underlying this association. A systematic review approach was not considered appropriate due to the high heterogeneity of study designs, outcome measures, and conceptual frameworks, which limits the feasibility of quantitative synthesis and requires an interpretative approach. However, to enhance transparency and reproducibility, explicit criteria for study selection, analytical boundaries, and synthesis procedures were defined a priori. This review adopted a structured narrative synthesis approach, informed by established methodological guidance, to ensure transparency in study identification, selection logic, and interpretation. Although not designed as a systematic review, efforts were made to reduce selection bias by applying consistent inclusion criteria and prioritising studies that contributed to the understanding of underlying mechanisms rather than simple associations.

Literature search strategy

The literature search was carried out using major scientific databases, including PubMed, Scopus, and Web of Science. Additional sources were identified through manual screening of reference lists of relevant articles. The search was conducted between January and March 2026 and included combinations of the following keywords: "adolescents", "youth", "sport", "physical activity", "mental health", "well-being", "anxiety", and "depression". Search strings were adapted for each database using Boolean operators (e.g., "adolescent AND (sport OR physical activity) AND (mental health OR well-being OR anxiety OR depression)").

The search focused on studies published between 2010 and 2025, in order to capture the most recent and methodologically robust evidence on adolescent mental health and physical activity. Earlier seminal studies were included when considered theoretically relevant to the interpretation of mechanisms. The initial search yielded a broad pool of records, which were progressively refined through screening procedures. The selection process followed a structured and iterative logic aimed at identifying conceptually relevant and methodologically sound studies.

Study selection and analytical boundaries

Studies were selected based on predefined inclusion and exclusion criteria. Inclusion criteria were: 1) studies involving adolescents aged 10–24 years; 2) studies examining sport participation or physical activity as the main exposure; 3) studies reporting mental health outcomes (e.g., anxiety, depression, well-being, self-esteem); 4) peer-reviewed articles published in English; 5) empirical studies, systematic reviews, or meta-analyses.

Exclusion criteria were: 1) studies focusing exclusively on adults; 2) studies not addressing mental health outcomes; 3) editorials, commentaries, conference abstracts, or non-peer-reviewed publications; 4) studies lacking sufficient methodological clarity.

Adolescence was defined as the age range of 10–24 years, in line with recent developmental frameworks that extend adolescence to include young adulthood due to prolonged social and neurodevelopmental transitions. However, variability in age definitions across studies was considered during the interpretation of findings.

The study selection process was conducted in two stages. First, titles and abstracts were screened to exclude clearly irrelevant studies. Second, full texts of potentially eligible articles were assessed according to the inclusion and exclusion criteria. The selection process followed a structured and iterative logic aimed at ensuring conceptual relevance and coverage of the main domains. Priority was given to systematic reviews, meta-analyses, and longitudinal studies, while cross-sectional studies were included when they contributed to the identification of specific mechanisms or contextual factors.

The analytical boundaries of the review were defined to focus on mechanisms linking sport participation to mental health outcomes, rather than on clinical treatment effects or diagnostic processes. Studies were included if they contributed to understanding at least one of the following domains: neurobiological, psychological, social, or contextual mechanisms.

Data synthesis and analytical approach

The selected literature was analysed using a thematic and interpretative approach.

Initially, the selected studies were grouped according to the type of mechanisms and outcomes investigated. Subsequently, studies were compared to identify recurring patterns, convergences, and inconsistencies across the literature (e.g., differences related to type of sport, intensity, and context), to move beyond descriptive reporting toward analytical interpretation).

This process allowed the identification of four main analytical domains:

1) neurobiological mechanisms;
2) psychological mechanisms;
3) social mechanisms;
4) contextual and behavioural factors.

Rather than providing a purely descriptive summary, the analysis aimed to interpret how these domains interact and under which conditions sport participation may influence mental health outcomes. Attention was given to identifying variations in findings related to type of sport, intensity, and contextual factors.

Results

The analysis of the included literature resulted in the identification of four main domains through which sport participation influences adolescent mental health: 1) neurobiological mechanisms; 2) psychological mechanisms; 3) social mechanisms; 4) contextual and behavioural factors. Across the included studies, evidence consistently converges on the multidimensional nature of the relationship between sport and mental health, although the strength and direction of effects vary depending on contextual and individual factors.

These domains interact dynamically, shaping mental health outcomes through complex interactions between individual and environmental conditions. Across the analysed literature, three overarching evidence patterns emerged: 1) a consistent positive association between sport participation and mental health outcomes; 2) significant variability in effect size and direction depending on contextual and individual factors; and 3) the presence of conditional or adverse effects in highly competitive or unsupportive environments. These patterns indicate that the relationship between sport and mental health is not uniform, but conditional upon multiple interacting variables.

Sedentary behaviour and lifestyle factors

The WHO report from 2020 states that only 19% of adolescents worldwide get enough physical activity (WHO, 2020). A 2021 ISTAT survey showed that, in Italy, the situation is better; around 70% of adolescents aged between 11 and 17 take part in sport regularly, an increase from 67% in 2019 (ISTAT, 2021), supporting the growing awareness of the benefits of sport and physical activity in general.

Across studies, there is strong convergence in identifying sedentary behaviour as a risk factor for poorer mental health outcomes. However, the direction of causality remains unclear, as several studies suggest a bidirectional relationship in which lower mental well-being may also lead to increased sedentary behaviour. Taking part in sport during adolescence plays a relevant role for physical and mental health. A consistent pattern across studies indicates that sedentary behaviour is associated with poorer mental health outcomes, particularly increased symptoms of anxiety and reduced well-being. Importantly, several studies suggest that lifestyle behaviours (e.g., physical activity, diet, sleep and screen time) tend to cluster, creating cumulative effects on both physical and mental health. Furthermore, adolescents who play sport develop better cardiovascular endurance, muscle strength and flexibility, promoting balanced physical development and preventing chronic diseases such as type 2 diabetes and cardiovascular disease (Janssen & LeBlanc, 2010).

Regular physical exercise is also associated with better stress regulation and healthier behavioural patterns. In adolescents, it has been observed that engaging in regular physical activity promotes the adoption of healthy behaviours, including good eating habits and abstaining from alcohol and smoking. Furthermore, recent studies conducted among the Italian population highlight how a sedentary lifestyle is frequently associated with unhealthy eating habits, creating a combined risk pattern that can negatively affect both physical and mental health (Calella et al., 2024). In parallel, digital behaviours represent a growing component of sedentary lifestyles. Media use among adolescents has increased significantly over the last decade, facilitated by constant access to mobile devices and the internet. Across studies, increased screen time is consistently associated with poorer mental health indicators, whereas sport participation appears to act as a protective factor. However, the direction of causality remains unclear, as physically active adolescents may already differ in baseline psychosocial characteristics.

This finding is confirmed by the latest national Health Behaviour in School-aged Children (HBSC) survey from 2022, which shows that, as children get older, both boys and girls spend more time on social media and watching online content, while patterns of gaming differ by age and gender (HBSC, 2022).

Overall, these findings suggest that sedentary and digital behaviours should be interpreted as part of a broader lifestyle pattern, interacting with physical activity and contributing to mental health outcomes. Sport participation may therefore represent a potentially protective behavioural alternative, reducing excessive screen time and promoting more adaptive daily routines. Taking part in sport can be a powerful strategy for preventing internet and video game addiction, as sport offers an active and engaging alternative to time spent online, reducing the risk of digital addiction (García-Ortiz et al., 2025). This suggests that sedentary behaviour should not be interpreted as an isolated factor, but as part of a broader behavioural pattern in which physical activity, digital engagement, and lifestyle habits interact cumulatively.

Neurobiological mechanisms

Physical activity also has a positive influence on emotional well-being: regular exercise helps, for example, to reduce levels of aggression and tension (Cantoia et al., 2017). This effect is partly attributable to the release of endorphins,

molecules naturally produced by the brain that act in a similar way to antidepressants, promoting a general sense of well-being. Evidence across experimental and observational studies suggests a convergent association between physical activity and neurobiological regulation mechanisms, particularly involving neurotransmitter systems related to mood and reward.

Among the main neurotransmitters involved in regulating physical and mental well-being are:

- serotonin, associated with mood regulation and the perception of happiness;
- dopamine, linked to reward and motivation mechanisms;
- endorphins, which help to generate feelings of relaxation and calm;
- oxytocin, which promotes the development of interpersonal trust and positive emotions.

These neurobiological processes represent underlying mechanisms through which physical activity exerts its effects, interacting with psychological and social dimensions.

Across the literature, evidence on neurobiological mechanisms shows a general convergence in short-term experimental findings, particularly regarding neurotransmitter regulation. However, inconsistencies emerge in relation to the long-term stability and magnitude of these effects, largely due to the limited availability of longitudinal and directly measured neurobiological data.

However, the magnitude and persistence of these effects remain uncertain, as many studies rely on indirect measures and short-term observations rather than longitudinal neurobiological data.

Psychological mechanisms

Evidence suggests that regular physical activity improves mood and can reduce symptoms of depression and anxiety (Biddle & Asare, 2011). A robust and recurrent finding across the literature is the positive association between sport participation and self-esteem, emotional regulation, and reduction of depressive symptoms. However, some studies report null or context-dependent effects, indicating that psychological benefits are not universal and may depend on factors such as motivation, perceived competence, and type of sport. However, evidence also highlights that sport participation may produce adverse psychological outcomes under specific conditions. In particular, highly competitive and performance-oriented environments have been associated with increased levels of stress, performance anxiety, burnout, and reduced self-esteem. These findings indicate that the psychological effects of sport are not universally beneficial, but rather depend on the interaction between individual characteristics and contextual factors such as coaching style, motivational climate, and perceived pressure. Participating in team sports, moreover, helps develop social skills, self-esteem and a strong sense of belonging (Eime et al., 2013). At a stage of life full of emotional and social challenges, these benefits are particularly valuable. Indeed, sport is an important vehicle for teaching adolescents to work proactively and constructively within a group sharing the same objectives. Furthermore, according to Eccles and Barber, "Participation in sport and other extracurricular activities has been associated with lower levels of delinquent behaviour and other problematic behaviours in adolescents" (Eccles & Barber, 1999). Taking part in sporting activities therefore provides a positive environment where young people can form friendships and receive social support, reducing the risk of isolation. These psychological benefits are closely linked to both biological regulation and social experiences within sport contexts.

Social mechanisms

Taking part in sport not only improves physical and mental health, but also school life. Indeed, by acquiring discipline, young athletes learn to manage their time better, as they must balance study and training. This organisational skill often translates into greater efficiency in their studies and fewer late submissions.

There is strong and consistent evidence supporting the mediating role of social factors, particularly peer relationships and sense of belonging. However, the strength of these effects varies depending on the quality of the social environment, indicating that not all sport contexts equally promote positive social outcomes.

Social mechanisms emerge as a central pathway, with consistent evidence showing that peer interaction, sense of belonging, and social support mediate the relationship between sport and mental health.

Some research has highlighted how physical activity contributes to improved brain function by increasing blood and oxygen supply and promoting neurogenesis in the hippocampus, a key area of the brain for learning and memory processes. These findings suggest that social factors not only have a direct effect, but also reinforce psychological and emotional benefits, indicating a mediating and moderating role.

Jacquelynne Eccles has demonstrated that students involved in sporting activities tend to achieve better academic results than their sedentary peers. These results are said to stem not only from the development of good time management but also from the enhancement of problem-solving skills and the ability to work under pressure (Fredericks & Eccles, 2006). Social mechanisms therefore play a mediating role, reinforcing or attenuating the psychological effects of sport participation.

Potential negative effects of sport participation

The analysis also revealed that sport participation is not universally beneficial and may produce adverse outcomes under specific conditions. An important inconsistency in the literature concerns the dual nature of sport participation: while most studies report beneficial effects, others highlight adverse outcomes under specific conditions. Although the benefits of sport are well documented, it is also important to consider certain potential risks, particularly when it is characterised by excessive competitive pressure or unsupportive environments. In such contexts, adolescents may develop stress, performance anxiety, burnout or reduced self-esteem. Therefore, it is essential to promote educational and inclusive sporting models, focused on the individual's overall well-being. In particular, highly competitive and performance-oriented environments are more frequently associated with stress, anxiety, and burnout, whereas

recreational and autonomy-supportive contexts tend to produce positive outcomes.

Adolescents who play sport regularly tend to develop a greater sense of belonging and are less likely to become isolated (Eime et al., 2013). In particular, team sports, by promoting social interaction and interpersonal skills, are thought to be more effective in countering social withdrawal. A further benefit of participating in sport, in addition to improving physical, mental, social and academic health, is its significant contribution to preventing 'addiction' and dysfunctional behaviours associated with technology. Society, parents and educators should therefore always promote physical activity among young people, given its crucial role in their overall development.

Among the variables associated with psychological well-being, self-esteem plays an important role; it is a complex component linked to cognitive aspects (the image people have of themselves or the way they describe themselves), affective aspects (how satisfied people are with themselves) and social aspects, namely the assessment people make of themselves in relation to the groups to which they belong, and the extent to which they receive approval from the members of those groups. Self-esteem has the fundamental characteristic of being a purely subjective, dynamic and changeable perception. It has been shown that physical activity, particularly sport, as well as promoting social integration, can boost self-esteem by helping to build community relationships, involving everyone-each according to their abilities, skills and knowledge-in the creation of collective well-being. The link between physical activity and self-esteem is not direct but stems from the individual's perception of improvement in skills and abilities, as well as in physical appearance and fitness. Therefore, an important responsibility of sports and physical education teachers is to help individuals who are new to physical activity and sport, or who practise it regularly, to perceive these improvements.

Sport and mental health in contextual conditions

Across the world, the recent COVID-19 pandemic has had a significant impact on people's mental health and social well-being (Francia et al., 2023; Valeriani et al., 2023). Contextual disruptions such as the COVID-19 pandemic provide further evidence that the relationship between sport and mental health is highly context-dependent and sensitive to environmental constraints. In addition to large-scale contextual disruptions, evidence also indicates that sport-specific environments play a crucial moderating role. In particular, factors such as coaching style, motivational climate, and levels of competitive pressure can either enhance psychological well-being or contribute to adverse outcomes such as anxiety, burnout, and dropout. The strict social distancing measures (including school closures) and restrictions on peer-based sporting and recreational activities, implemented to curb infections, have consequently led to disruptions in teaching/learning and socialisation processes. Children, adolescents and young adults around the world have experienced disruptions to their daily routines and have been exposed to various risk factors for mental health – including social isolation, loss of income and family stress – which, as has long been noted, lead to a consequent increase in levels of anxiety and depression (Egger et al., 2003; Finning et al., 2019). During lockdown, in our country too, there was an increase in requests for help from parents regarding their children's mental health issues, confirming the many negative effects of prolonged quarantine on adolescents' lives: difficulty concentrating, boredom, irritability, restlessness, nervousness, feelings of loneliness, distress and worry. As might be expected, adolescents spent more time using screens and digital devices and engaged in less physical activity (Caffo et al., 2020; Gallè et al., 2020; Orgilès et al., 2020; Muzi et al., 2021; Gallè et al., 2022). Lockdown has also been linked to the adoption of unhealthy lifestyles (poor diet, alcohol and cannabis use, physical inactivity and prolonged screen time), which represent a risk factor for adolescents' growth and development (Calella et al., 2024). The pandemic and social containment measures have not only exposed adolescents and young adults to particularly worrying risks (especially given that most mental health disorders typically emerge during this stage of life) but have also worsened the condition of those already suffering from mental health issues.

International organisations and institutions are increasingly focusing on the promotion and prevention of mental health for what has been termed the 'COVID Generation', including initiatives to encourage greater participation within communities, schools, workplaces and families.

Adolescents and young adults who engage in outdoor activities and spend time in green spaces (including sporting activities) build resilience to environmental stressors, thereby mitigating their potential long-term consequences. A study conducted by the Reference Centre for Behavioural Sciences and Mental Health (SCIC) at the Italian National Institute of Health examined the behaviours and habits of Italians regarding their use of green spaces during the pandemic. Contrary to expectations, changes in leisure habits appeared more significant among younger people, for whom, in particular, a decrease in time spent outdoors and in green spaces was observed. Older people, by contrast, were less likely to give up outdoor activities, socialising and the use of green spaces (Medda et al., 2021). Promoting psychological well-being and socio-emotional skills and ensuring access to early interventions for adolescents and young adults, are public health priorities, particularly given that mental health problems and social exclusion can extend into adulthood, compromising health and limiting opportunities for a healthy and peaceful life (UNICEF, 2021).

Based on the identified domains, a structured synthesis of the main mechanisms linking sport participation and adolescent mental health is summarized in Table 1.

Overall, these results highlight that the relationship between sport and mental health is multidimensional and context-dependent, emerging from the interaction between biological, psychological, and social processes rather than from a single causal pathway. Importantly, the synthesis suggests that sport participation should be conceptualised not as a uniform exposure, but as a context-sensitive system whose effects depend on the interaction between individual, social, and environmental factors.

Discussion

This narrative review provides an integrative synthesis of the relationship between sport participation and mental health

Table 1. Thematic synthesis of mechanisms about sport participation and mental health in adolescents

Domain	Mechanism	Evidence pattern	Inconsistencies	Implications
Neurobiological domain	Neurotransmitter regulation (serotonin, dopamine, endorphins, oxytocin)	Convergent evidence of short-term effects of physical activity on neurochemical regulation	Limited longitudinal and direct neurobiological measurement data	Need for longitudinal and mechanistic studies to confirm causal pathways
Psychological domain	Self-esteem, emotional regulation, anxiety and depression reduction	Strong and consistent association between sport participation and improved psychological well-being	Effects vary according to motivation, perceived competence, and sport type	Promote autonomy-supportive and psychologically safe sport environments
Social domain	Peer interaction, social support, sense of belonging	Consistent evidence for mediating role of social relationships in mental health benefits	Variation depending on quality of social environment and group dynamics	Enhance inclusive, cooperative, and socially supportive sport contexts
Contextual domain	Coaching style, motivational climate, competitive pressure, sedentary behaviour, digital/screen use, sport drop-out risk	Strong evidence that contextual factors moderate both positive and negative outcomes	High heterogeneity across sport settings and digital exposure patterns	Design interventions focused on quality of experience rather than participation alone
Contextual domain (adverse effects)	Performance pressure, burnout, overtraining, anxiety, dropout	Evidence of negative outcomes in high-performance or controlling environments	Highly dependent on competitive level and psychosocial climate	Implement safeguarding strategies in youth sport systems

among adolescents, highlighting the multidimensional and context-dependent nature of this association. This synthesis is structured around a 4-domain model (neurobiological, psychological, social, and contextual), which emerged from the thematic analysis of the included studies. Overall, the findings suggest that sport participation should be conceptualised not as a uniform protective factor, but as a complex and context-sensitive exposure, whose effects emerge from the interaction between biological, psychological, and social mechanisms (Biddle & Asare, 2011; Eime et al., 2013). A key contribution of this review is the conceptual integration of evidence into a multidimensional framework, in which biological, psychological, and social mechanisms interact dynamically rather than operating as independent pathways. This integrative perspective supports the conceptualisation of sport participation as a dynamic and context-sensitive system, rather than a uniform behavioural exposure. Within this system, mental health outcomes emerge from the interaction between neurobiological regulation, psychological processes, and social experiences, moderated by contextual and environmental factors (Lamblin et al., 2017; Schwartz-Mette et al., 2020).

Rather than representing a uniformly protective factor, sport emerges as a context-dependent exposure whose effects vary according to environmental, motivational, and relational conditions. However, the evidence also highlights that these benefits are not automatic or universal but are strongly influenced by contextual and organisational factors. This variability represents one of the central findings of the present review.

The literature analysed indicates that the mental health benefits of sport are mediated by multiple mechanisms. Across studies, three main interacting pathways emerge: 1) neurobiological regulation; 2) psychological processes; and 3) social integration (Biddle & Asare, 2011; Eime et al., 2013; Lamblin et al., 2017). These pathways should be interpreted as interdependent rather than additive.

These findings are consistent with previous systematic reviews indicating a positive association between physical activity and mental health in young populations (Biddle & Asare, 2011; Eime et al., 2013). However, compared to previous reviews, the present study explicitly highlights the interactions between mechanisms and the role of contextual moderators.

At the same time, the literature shows variability in effect size and consistency, suggesting that not all forms of sport are equally beneficial (Eime et al., 2013; Francia et al., 2023). This heterogeneity suggests that the relationship is not linear, but conditional. In particular, the evidence suggests that the same sport participation may produce divergent outcomes depending on the quality of the environment in which it occurs, highlighting the central role of contextual moderators (Eccles & Barber, 1999; Fredericks & Eccles, 2006).

In particular, competitive and performance-oriented environments may attenuate psychological benefits or even contribute to stress-related outcomes. This may be explained by increased external pressure and reduced autonomy, which are known to negatively affect intrinsic motivation.

A key finding of this review is that the relationship between sport and mental health is dependent on the context. Factors such as motivational climate, peer relationships, and perceived pressure significantly influence outcomes. More specifically, contextual variables act as moderators that can

either enhance or reverse the expected benefits of sport participation.

Supportive and autonomy-oriented environments tend to enhance psychological benefits, whereas overly competitive or controlling contexts may increase anxiety, burnout, and dropout risk (Eime et al., 2013; Francia et al., 2023). This supports a socio-ecological interpretation, in which individual outcomes are shaped by interactions between personal and environmental factors (WHO, 2021; OECD, 2025).

Socioeconomic and structural factors further influence both access to sport and its potential benefits, reinforcing health inequalities. Although sport is generally associated with positive outcomes, this review also highlights potential adverse effects. These include performance anxiety, overtraining, burnout, and early dropout, particularly among adolescents exposed to highly competitive pressure (Francia et al., 2023; Eime et al., 2013). This distinction is essential for both research interpretation and intervention design.

Therefore, the assumption that sport is inherently beneficial for mental health should be reconsidered, as its effects are contingent upon specific contextual and organisational conditions.

These findings underline the importance of distinguishing between recreational, educational sport and elite, performance-driven sport when evaluating mental health outcomes (Biddle & Asare, 2011; Eime et al., 2013).

Building on this synthesis, sport participation can be conceptualised as a dynamic system of interacting pathways rather than a single behavioural factor. This model contributes to advancing the literature by explaining not only whether sport is beneficial, but under which conditions and through which mechanisms these benefits occur. The findings have implications for the design of sport-based interventions targeting adolescent mental health. Interventions should therefore prioritise quality of experience (e.g., supportive environments, autonomy) over mere participation rates. In particular, school-based programmes represent a key setting for implementing such approaches (WHO, 2021; OECD, 2025).

Overall, this review contributes to advancing the literature by shifting the focus from whether sport is beneficial to how, for whom, and under which conditions it may promote or hinder mental health outcomes (Biddle & Asare, 2011; Eime et al., 2013; Francia et al., 2023). This perspective enables a more nuanced interpretation of existing evidence and supports the development of targeted, context-sensitive interventions.

Limitations

This narrative review has limitations related to its non-systematic approach and the potential for selection bias in the included literature. Additionally, the narrative nature of this review does not allow for quantitative estimation of effect sizes, which should be addressed in future systematic research. Indeed, future research should aim to clarify causal pathways using longitudinal designs and to differentiate more clearly between types of sport, competitive levels, and contextual conditions.

Conclusion

This narrative review highlights that sport participation represents a relevant and multidimensional factor influencing adolescent mental health through biological, psychological, and social mechanisms. However, its effects are not uniform and depend strongly on contextual conditions such as the motivational climate, type of sport, and level of competitiveness.

Overall, sport should not be considered a universally protective factor, but rather a complex intervention that can either enhance or hinder psychological well-being in adolescence.

An active and healthy lifestyle is a key determinant of psychological and physical well-being, particularly when supported by positive social and environmental conditions. Furthermore, when physical activity is undertaken collectively, its beneficial effects on mental health are enhanced by social interaction and peer support.

Maintaining regular physical activity from an early age may contribute to long-term cognitive, emotional, and behavioural benefits across the life course. These findings highlight the need for integrated, context-sensitive approaches to sport promotion that prioritise psychological well-being alongside physical health. Future interventions should focus on creating supportive, inclusive, and non-competitive environments that maximise the positive effects of sport while minimising potential risks such as burnout, anxiety, and dropout.

Reframing sport as a context-dependent system rather than a universally protective factor represents a critical step toward more effective and evidence-informed mental health promotion strategies in adolescence.

Conflicts of Interest

The authors declare no conflicts of interest.

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Not applicable.

Data Availability Statement

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Роль спорту у зміцненні психічного здоров'я підлітків

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 1 табл., 35 джерел.

Мета. Підлітковий вік, як критичний перехідний етап життя, характеризується біологічними, психологічними та соціальними змінами, що можуть підвищувати вразливість до психічних розладів. Метою цього огляду є інтегративний аналіз ролі спорту та фізичної активності у зміцненні психічного здоров'я підлітків із особливим акцентом на біологічних, психологічних і соціальних механізмах.

Матеріали та методи. Наративний огляд проведено на основі досліджень, відібраних із провідних наукових баз даних, зокрема PubMed, Scopus і Web of Science. До аналізу включалися статті, присвячені підліткам (віком 10–24 роки), фізичній активності або участі у спортивній діяльності, а також показникам психічного здоров'я. Доказову базу аналізували із застосуванням тематичного підходу для виявлення закономірностей, взаємозв'язків і суперечностей між дослідженнями.

Результати. У результаті огляду визначено чотири основні домени: нейробіологічний, психологічний, соціальний і контекстуальний. Загалом отримані дані свідчать, що фізична активність сприяє психічному здоров'ю підлітків через декілька взаємопов'язаних механізмів, зокрема нейробіологічних (наприклад, регуляція нейромедіаторів, таких як серотонін і дофамін), психологічних (наприклад, підвищення самооцінки) і соціальних (наприклад, взаємодія з однолітками). Водночас вираженість і спрямованість цих ефектів значною мірою залежать від контекстуальних і середовищних чинників.

Висновки. Спорт є багатовимірним чинником зміцнення психічного здоров'я у підлітковому віці. Його вплив слід розглядати в межах інтегрованої моделі, у якій біологічні, психологічні та соціальні механізми динамічно взаємодіють. Участь у спортивній діяльності не є універсально корисною, оскільки може мати як позитивні, так і негативні наслідки залежно від якості середовища та рівня змагальності. Подальші дослідження мають бути спрямовані на уточнення причинно-наслідкових механізмів і контекстуальних модераторів, а також на розроблення контекстно чутливих і механізм-орієнтованих втручань.

Ключові слова: підлітки, психічне здоров'я, спорт, фізична активність, зміцнення здоров'я.

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Effects of an 8-Week Physical Education Training Program on Physical Fitness in U17–U18 Students

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Abstract

Objective. The effectiveness of physical education programs often varies because the specific contribution of exercise sequencing and load progression to fitness outcomes remains insufficiently understood. This study examined how deliberate control of exercise order and progressive load distribution in an 8-week program affects speed, agility, explosive power, and endurance in U17–U18 students.

Materials and Methods. Fifty male students aged 17–18 years were randomly assigned to an experimental group (n = 25) and a control group (n = 25). The experimental group completed the structured program three times per week for eight weeks. Physical fitness was assessed using the 30-m sprint, Illinois agility test, standing long jump, and Cooper 12-minute run test.

Results. The experimental group showed statistically significant improvements in all four parameters ($p < 0.05$), with large effect sizes (Cohen's d = 0.83–1.10), whereas the control group showed no significant changes.

Conclusions. The improvements resulted from the sequencing in which speed and agility drills preceded explosive strength exercises, while endurance activities concluded each session, together with progressive load distribution across three microcycles. When this specific order and load progression are followed, substantial gains across multiple fitness components can occur simultaneously. These findings demonstrate that deliberate changes in exercise sequencing and load parameters can influence the magnitude and balance of fitness development, indicating that outcomes are determined by the structured interaction of training components rather than by isolated exercises.

Keywords: physical education, physical fitness, adolescents, exercise sequencing, load distribution, speed, agility, explosive power, endurance.

Introduction

Physical education is widely recognized as a fundamental component of adolescent health and development (Janssen & LeBlanc, 2010; Ortega et al., 2008). Numerous studies have demonstrated that regular participation in physical activity improves various components of physical fitness, including speed, agility, muscular power, and endurance (Kriemler et al., 2011; Lubans et al., 2018).

However, despite the widespread implementation of school-based physical education programs, their effectiveness remains inconsistent across different contexts and populations (Lai et al., 2014). In many cases, standard physical education programs are applied without a clearly defined internal structure or controlled interaction between training components. As a result, improvements in physical fitness are often uneven, unpredictable, or limited to specific abilities.

This reveals a fundamental contradiction in the current system: physical education programs are broadly implemented in schools, yet they do not consistently ensure balanced and predictable development of multiple physical fitness components. The core problem lies in the insufficient understanding of how specific training structure parameters — particularly the sequencing of exercise modalities and the progression of load — determine physical fitness outcomes (Granacher & Borde, 2017; Lonsdale et al., 2013).

The aim of this study was to investigate the effects of a structured 8-week physical education training program,

in which the sequencing of exercise modalities (speed and agility drills preceding explosive strength exercises, with endurance concluding each session) and progressive load distribution were deliberately controlled, on speed, agility, explosive power, and endurance in U17–U18 students.

From this perspective, the object of the study is physical education training programs in adolescents, whereas the subject concerns the influence of specific training structure parameters — exercise sequencing and load progression — on multiple components of physical fitness. The contradiction lies in the fact that physical education programs are widely implemented in school settings, yet they do not consistently produce balanced and predictable improvements across fitness components. Accordingly, the research problem concerns the insufficient understanding of how exercise sequencing and load progression determine physical fitness outcomes.

Materials and Methods

Study Design

This study employed an experimental pre-test and post-test design to examine the effects of an eight-week general physical education training program on selected physical fitness parameters.

Participants

A total of 50 male students aged 17–18 years studying in the coaching specialization voluntarily participated in this study. The participants were randomly divided into an experimental group (n = 25) and a control group (n = 25). All participants were physically active and regularly attended practical physical education classes. None of the participants had medical conditions that could restrict participation in physical activity.

Training Program

The experimental group participated in an eight-week physical education training program conducted three times per week. Each session lasted 45–60 minutes and consisted of warm-up (10 min), main training activities (30–40 min), and cool-down (5–10 min). The control group continued with their regular physical education classes without additional structured intervention.

The training program was structured by deliberately manipulating specific parameters: exercise sequencing, load progression, and rest intervals.

Control variables were: (1) Sequencing of exercise modalities within each session: speed and agility drills → explosive strength exercises → endurance-oriented activities; (2) Progressive load distribution across the 8 weeks, divided into three microcycles (weeks 1–3: familiarization with moderate volume and intensity; weeks 4–6: increased exercise density and complexity; weeks 7–8: consolidation phase with higher intensity while maintaining balance); (3) Rest intervals between training blocks (2–3 minutes) to support sequential interaction of stimuli.

Dependent variables (outcome measures):

- sprint speed (30-m sprint time);
- agility performance (Illinois test time);
- explosive power (standing long jump distance);
- endurance capacity (Cooper test distance).

Interaction scheme and expected effect pathway: Speed and agility drills at the start of each session increase performance readiness and rate of force development, which modifies the response conditions for subsequent explosive strength stimuli. This change enhances the response to the following explosive strength exercises, leading to greater improvements in force production. The resulting improvement in power and coordination then improves running economy during the endurance component, allowing greater distance to be covered in the Cooper test. The effect is cumulative: each component alters the effectiveness of the next one through changes in performance conditions and movement efficiency. The effect emerges from a sequential dependency, where each training component modifies the initial conditions of the subsequent stimulus, thereby determining its effectiveness.

System model:

- Inputs: Manipulated training structure (sequencing of modalities + progressive volume/intensity parameters + controlled rest intervals).
- Transformation: Sequential interaction that produces cumulative changes in force production efficiency and movement economy.
- Outputs: Concurrent improvements in 30-m sprint time, Illinois agility time, standing long jump distance, and Cooper 12-minute run distance.

Established regularity: If training sessions are organized with speed and agility exercises preceding explosive strength work and endurance activities concluding the session, combined with progressive and balanced load distribution over 8 weeks, then U17–U18 students show simultaneous large improvements (Cohen's d = 0.83–1.10) in speed, agility, explosive power, and endurance. Disruption of this sequencing or unbalanced load distribution reduces the magnitude or balance of these gains.

The warm-up phase included light jogging and dynamic mobility exercises. The main training phase incorporated speed drills (e.g., 10–30 m accelerations), agility exercises (e.g., change-of-direction patterns), body-weight strength exercises (squats, lunges, plyometric jumps), and interval running. Exercise volume and intensity progressed according to the microcycle plan. Rest intervals and exercise order were strictly controlled. The cool-down consisted of static stretching and breathing exercises.

Testing Procedures

Physical fitness parameters were measured before and after the eight-week intervention.

Sprint speed was assessed using the 30-m sprint test. Agility was evaluated using the Illinois Agility Test. Explosive power was measured using the standing long jump test. Endurance capacity was assessed using the Cooper 12-minute run test.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics software. Descriptive statistics were expressed

as mean ± standard deviation (SD). The normality of the data distribution was examined using the Shapiro–Wilk test. Within-group pre-test and post-test differences were analyzed using paired samples t-tests. Effect sizes were calculated using Cohen's d. Statistical significance was set at $p < 0.05$.

Results

Participant Characteristics

The anthropometric characteristics of the participants are presented in Table 1. No significant differences were observed between the experimental and control groups at baseline, indicating that both groups were homogeneous before the intervention.

Table 1. Participant characteristics (Mean ± SD)

Variable	Experimental (n = 25)	Control (n = 25)
Age (years)	17.4 ± 0.5	17.5 ± 0.4
Height (cm)	174.2 ± 6.1	173.8 ± 5.9
Weight (kg)	66.5 ± 7.2	65.9 ± 6.8

Changes in Physical Fitness Parameters

Pre-test and post-test values of all measured physical fitness variables in the experimental and control groups are presented in Table 2.

Overall, statistically significant improvements were observed only in the experimental group, while the control group showed no significant changes across the measured variables.

Sprint Performance

Sprint performance improved significantly in the experimental group following the eight-week training program. The mean sprint time decreased from 4.62 ± 0.21 s in the pre-test to 4.45 ± 0.18 s in the post-test ($p = 0.003$). In contrast, the control group did not demonstrate a statistically significant change in sprint performance ($p > 0.05$).

Agility Performance

A significant improvement in agility performance was observed in the experimental group. The Illinois agility test results decreased from 16.20 ± 0.60 s to 15.45 ± 0.55 s ($p = 0.001$). However, no significant differences were detected in the control group ($p > 0.05$).

Explosive Power

Explosive power assessed by the standing long jump test increased significantly in the experimental group. The average jump distance improved from 205 ± 15 cm to 218 ± 16 cm ($p = 0.002$). The control group did not show significant improvements in this parameter ($p > 0.05$).

Endurance Performance

Endurance capacity measured by the Cooper 12-minute run test also showed a significant improvement in the experimental group. The mean running distance increased from 2400 ± 180 m to 2570 ± 190 m ($p = 0.001$). No statistically significant changes were observed in the control group ($p > 0.05$).

Effect Size

Effect size analysis indicated large effects of the training program on the measured physical fitness parameters. Cohen's d values were 0.83 for sprint performance, 1.10 for agility, 0.85 for standing long jump, and 0.92 for endurance performance, indicating substantial improvements following the intervention.

In addition to statistically significant within-group improvements, descriptive comparisons indicated that the magnitude of change was consistently greater in the experimental group than in the control group across all measured variables. These effect sizes indicate that the observed improvements were not only statistically significant but also practically meaningful.

Discussion

The present study revealed statistically significant improvements with large effect sizes (Cohen's d = 0.83–1.10) across speed, agility, explosive power, and endurance in the experimental group, while the control group showed no meaningful changes (Ardoy et al., 2011; Andrade et al., 2014; Kriemler et al., 2011). Importantly, the magnitude of improvement was not uniform: agility and explosive power demonstrated the largest gains, whereas endurance

Table 2. Pre-test and post-test comparison of physical fitness variables in experimental and control groups

Test	Group	Pre-test	Post-test	p
30 m sprint (s)	Experimental	4.62 ± 0.21	4.45 ± 0.18	0.003
30 m sprint (s)	Control	4.63 ± 0.22	4.60 ± 0.20	0.214
Agility (s)	Experimental	16.20 ± 0.60	15.45 ± 0.55	0.001
Agility (s)	Control	16.18 ± 0.58	16.10 ± 0.60	0.187
Standing long jump (cm)	Experimental	205.00 ± 15	218.00 ± 16	0.002
Standing long jump (cm)	Control	204.00 ± 14	206.00 ± 15	0.261
Cooper test (m)	Experimental	2400.00 ± 180	2570.00 ± 190	0.001
Cooper test (m)	Control	2410.00 ± 175	2435.00 ± 180	0.173

showed comparatively moderate but still substantial progress (Castro-Piñero et al., 2010; Hachana et al., 2013; Ortega et al., 2008). This differentiated pattern suggests that adaptations were shaped by the internal organization of the training session rather than by a general training stimulus (Granacher & Borde, 2017; Lonsdale et al., 2013).

The proposed mechanism — sequencing speed and agility drills at the beginning of each session to create performance readiness, followed by explosive strength exercises, and concluding with endurance activities — is directly supported by the observed results (Ardoy et al., 2011; Granacher & Borde, 2017). Early neuromuscular activation likely enhanced force production efficiency and rate of force development, which amplified the effectiveness of subsequent strength stimuli (evidenced by notable gains in standing long jump) (Castro-Piñero et al., 2010; Ruiz et al., 2009). The resulting improvements in power and coordination then contributed to better movement economy during the endurance component (Lang et al., 2018; Ortega et al., 2008). This sequential dependency explains why concurrent development across multiple fitness domains was achieved without the interference effects commonly reported in unstructured concurrent training programs (Duncombe et al., 2022; Martin-Smith et al., 2020; Cao et al., 2019).

These findings are consistent with previous research showing that exercise order significantly influences training adaptations (Granacher & Borde, 2017; Lonsdale et al., 2013). Studies have demonstrated that performing high-velocity or skill-based exercises in a non-fatigued state produces superior gains in power and speed compared to fatigued conditions (Castro-Piñero et al., 2010; Hachana et al., 2013). Concurrent training literature further indicates that simultaneous improvements in strength and endurance are possible when training stimuli are carefully ordered, but interference often occurs when endurance precedes strength work (Cao et al., 2019; Duncombe et al., 2022; Martin-Smith et al., 2020). In contrast to many school-based interventions that report isolated or uneven gains (e.g., Ardoy et al., 2011; Granacher & Borde, 2017), the present study achieved large concurrent effects by explicitly controlling sequencing and load progression. Thus, this work contributes to the literature by showing that the structure of interaction between components, rather than their mere combination, determines the balance and magnitude of fitness development in adolescents (Kriemler et al., 2011; Lai et al., 2014; Neil-Sztramko et al., 2021).

Alternative explanations, such as increased overall training volume, progressive overload alone, or heightened participant motivation, cannot be entirely ruled out (Lonsdale et al., 2013; Lubans et al., 2018). Progressive overload is a well-established driver of adaptation, and adolescents generally respond positively to structured physical activity (Dobbins et al., 2013; Neil-Sztramko et al., 2021). However, the control group, which maintained regular physical education classes with similar weekly exposure, exhibited no significant changes (Andrade et al., 2014; Kriemler et al., 2011). Moreover, if volume or general intensity were the dominant factors, more uniform improvements across all components would be expected (Lai et al., 2014; Huhtiniemi et al., 2023). The component-specific variation observed here (larger gains in agility and power) supports the primacy of the sequencing mechanism over non-structural factors (Castro-Piñero et al., 2010; Hachana et al., 2013).

In summary, the results validate the proposed mechanism: the training outcome functioned as a direct consequence of the manipulated structure (exercise order and load progression) (Ardoy et al., 2011; Granacher & Borde, 2017; Lonsdale et al., 2013). When this structure was maintained, predictable concurrent gains occurred; any deviation would be expected to reduce transfer between components (Duncombe et al., 2022; Pérez-Ramírez et al., 2024; Pérez-Ramírez et al., 2025). These findings highlight that physical fitness development in physical education can be made more controllable by focusing on the organization of training stimuli rather than on content alone (Kriemler et al., 2011; Dobbins et al., 2013; Neil-Sztramko et al., 2021).

Despite these strengths, limitations should be noted. The 8-week duration limits conclusions about long-term retention, the sample was restricted to male adolescents aged 17–18, and the program relied primarily on body-weight exercises (Lai et al., 2014; Huhtiniemi et al., 2023). Future research should examine whether similar structural effects hold in females, younger age groups, and programs incorporating external loads (Olsen et al., 2024; Pérez-Ramírez et al., 2024; Pérez-Ramírez et al., 2025).

Conclusion

The 8-week training program led to statistically significant improvements with large effect sizes in speed, agility, explosive power, and endurance in U17–U18 students. These gains were determined by the specific sequencing of exercise modalities and the progressive distribution of training load. Speed and agility drills performed at the beginning of each session increased the effectiveness of subsequent explosive strength exercises, while the resulting improvements in power and coordination contributed to better endurance performance.

When training sessions are organized with speed and agility preceding explosive strength, with endurance activities concluding the session, and with balanced progressive load distribution, concurrent large improvements across multiple fitness components occur. Disruption of this sequencing or load balance limits the magnitude or the concurrent nature of the gains.

The results indicate that physical fitness outcomes in physical education can be made more predictable and modifiable through deliberate control of exercise order and load parameters. This confirms that the training outcome is a controllable function of program structure rather than a result of isolated exercises.

Ethics Approval

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. The research was carried out within regular educational practice using non-invasive physical fitness assessments. According to institutional regulations, formal approval by an ethics committee was not required.

Informed Consent

All participants were informed about the purpose, procedures, and voluntary nature of the study. Written

informed consent was obtained from all participants prior to participation.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors used AI-assisted tools for language editing only and take full responsibility for the content of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Вплив 8-тижневої програми фізичного виховання на фізичну підготовленість учнів U17–U18

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 2 табл., 22 джерела.

Мета. Ефективність програм фізичного виховання часто варіює, оскільки специфічний внесок послідовності вправ і прогресії навантаження у формування показників фізичної підготовленості залишається недостатньо з'ясованим. Це дослідження вивчало, як цілеспрямоване керування порядком виконання вправ і прогресивним розподілом навантаження впродовж 8-тижневої програми впливає на швидкість, спритність, вибухову силу та витривалість учнів U17–U18.

Матеріали та методи. П'ятдесят учнів чоловічої статі віком 17–18 років були випадково розподілені на експериментальну групу (n = 25) і контрольну групу (n = 25). Експериментальна група виконувала структуровану програму тричі на тиждень протягом восьми тижнів. Фізичну підготовленість оцінювали за допомогою бігу на 30 м, Іллінойського тесту на спритність, стрибка в довжину з місця та 12-хвилинного тесту Купера.

Результати. В експериментальній групі виявлено статистично значуще покращення за всіма чотирма показниками ($p < 0,05$) із великими розмірами ефекту (Cohen's $d = 0,83–1,10$), тоді як у контрольній групі статистично значущих змін не зафіксовано.

Висновки. Покращення були зумовлені такою послідовністю виконання вправ, за якої вправи на швидкість і спритність передували вправам на вибухову силу, а вправи на витривалість завершували кожне заняття, у поєднанні з прогресивним розподілом навантаження впродовж трьох мікроциклів. За дотримання саме такого порядку вправ і прогресії навантаження можливе одночасне суттєве покращення кількох компонентів фізичної підготовленості. Отримані результати свідчать, що цілеспрямовані зміни послідовності вправ і параметрів навантаження можуть впливати на величину та баланс розвитку фізичних якостей, що вказує на визначальну роль структурованої взаємодії компонентів тренування, а не окремих вправ.

Ключові слова: фізичне виховання, фізична підготовленість, підлітки, послідовність вправ, розподіл навантаження, швидкість, спритність, вибухова сила, витривалість.

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Improving Long-Pass Performance in Youth Football Players Through the BLAST Training Model

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Abstract

Background. The long-pass kicking technique is a fundamental skill in football that can significantly influence match dynamics and contribute to team success. However, this technique remains a major challenge for youth football athletes, as it is often insufficiently emphasized in training programs. Therefore, an effective and structured training model is needed to improve long-pass performance.

Objectives. This study aimed to examine the effectiveness of the BLAST training model in improving long-pass kicking technique among youth football athletes.

Materials and Methods. This study employed a quasi-experimental design with a pretest–posttest control group approach. A total of 50 participants were divided into an experimental group (n = 25), which received the BLAST training model, and a control group (n = 25), which underwent conventional training provided by their coaches. The Rumi long-pass test was administered during both the pre-test and post-test to assess performance. Data were analyzed using descriptive statistics, the Shapiro–Wilk normality test, Levene's test of homogeneity, ANCOVA, independent samples t-tests, and N-gain score analysis.

Results. The findings revealed that both groups showed improvements in long-pass kicking performance after the intervention. However, the experimental group demonstrated significantly greater improvement than the control group ($p < 0.05$). The experimental group achieved an average N-gain score of 62.56% (moderately effective), whereas the control group reached only 22.99% (low effectiveness).

Conclusions. The results indicate that the BLAST training model is more effective than conventional training methods in improving long-pass kicking technique among youth football athletes.

Keywords: BLAST model, long-pass kicking, football training, youth athletes, skill development.

Introduction

Football is one of the most widely played and globally popular sports, characterized by complex interactions between technical skills, tactical strategies, and team coordination. Team success is closely linked to players' technical proficiency and the effectiveness of structured training programs that support optimal performance. As a collective sport, football requires continuous interaction among players to achieve shared objectives (Baroni et al., 2020), where individual technical skills directly influence overall team performance (Kvas-Cabral et al., 2022).

Among fundamental technical skills, kicking plays a central role in determining both individual and team effectiveness. In particular, passing is a dominant component of gameplay, functioning not only to maintain possession but also to connect defensive and offensive phases (Burcak, 2015). Passing can be broadly categorized into short and long passes, each serving distinct tactical purposes (Marsyanurdin et al., 2023). Previous studies have demonstrated a strong relationship between passing activity and team success, with passing accuracy identified as a key determinant of technical performance (Belete, 2023).

Long passes, although less frequently used than short passes, have strategic importance in creating scoring opportunities, especially in counterattacks or when breaking defensive lines (Cordón-Carmona et al., 2023). They are

commonly executed by goalkeepers and central defenders as part of tactical play (Lisenchuk et al., 2021). Effective long-pass execution requires mastery of several technical components, including foot placement, ball contact, body posture, and follow-through. In modern football, the ability to deliver accurate and powerful long passes is essential for achieving tactical efficiency and competitive advantage (Fernandez-Navarro et al., 2016).

Despite its importance, mastering long-pass technique remains a significant challenge, particularly among youth athletes (Nusri, 2018). Prior studies indicate that this skill is often insufficiently emphasized in training programs (Power et al., 2017), which tend to integrate passing drills without structured and specialized approaches (Goes et al., 2019). As a result, young athletes frequently demonstrate low levels of long-pass proficiency, particularly in terms of accuracy and distance control. This issue is supported by preliminary findings showing that most athletes fall within fair to poor performance categories, highlighting a substantial gap between training practices and skill requirements.

This gap reflects a broader limitation in existing training approaches, where the lack of focus and structured intervention may lead to suboptimal skill development and reduced motivation. Effective training programs should be designed based on systematic principles, incorporating both technical and physiological aspects to enhance performance outcomes (Paixão et al., 2015). Therefore, there is a clear need for an evidence-based training model that specifically targets the development of long-pass technique in youth football athletes.

In response to this need, the Bagus Long-pass Football Training (BLAST) model was developed based on the Research and Development framework proposed by Gall et al. (1996). This model is designed to stimulate physiological adaptation through the overcompensation principle while simultaneously improving technical execution during training. However, empirical evidence regarding the effectiveness of this model in improving long-pass performance remains limited.

Therefore, this study aims to examine the effectiveness of the BLAST training model in improving long-pass kicking technique among youth football athletes, thereby contributing to the development of more structured and effective training approaches in football.

Materials and Methods

Study Participants

This study was conducted at Lampung Provincial Football School and involved 50 youth football athletes aged 14–17 years who actively participated in regular training sessions. Participants were assigned into an experimental group (n = 25) and a control group (n = 25). All participants provided informed consent prior to participation. Ethical approval was obtained from State University of Jakarta (No. 47/UN39.14/PT.01.05/I/2026).

Study Design and Procedures

This study employed a quasi-experimental design using a pretest–posttest control group approach. The experimental group received the BLAST training model, while the control group followed conventional training conducted by their respective coaches (Table 1)..

The intervention was carried out over six weeks, consisting of 16 training sessions, with each session lasting 60 minutes. The BLAST training model was developed through a systematic process, initially comprising 40 training variations that were refined into 30 models following expert

Table 1. Blast Training Program Protocol (High-Level Design)

Session	Training Models	Distance	Sets	Repetitions	Duration (min)	Intensity (RPE)	Rest Interval	Progression
1	M3, M4, M17, M29	15–25 m	3	8–10	60	5–6 (Moderate)	60–90 sec	Technical adaptation
2	M5, M6, M18, M30	15–25 m	3	8–10	60	5–6 (Moderate)	60–90 sec	Technical adaptation
3	M9, M10, M19	15–20 m	3	10–12	60	6 (Moderate)	60 sec	Volume increase
4	M14, M15, M20	20 m	3	10–12	60	6 (Moderate)	60 sec	Stability phase
5	M16, M18, M19, M35	20–25 m	4	8–10	70	6–7 (Moderate–High)	60 sec	Load progression
6	M15, M20, M23, M36	20–25 m	4	8–10	70	6–7 (Moderate–High)	60 sec	Load progression
7	M14, M24, M25, M37	20–25 m	4	8–10	70	6–7 (Moderate–High)	60 sec	Load progression
8	M13, M26, M27, M38	20–25 m	4	8–10	70	6–7 (Moderate–High)	60 sec	Load progression
9	M3, M28, M39	15–25 m	4	10–12	75	7 (High)	45–60 sec	Intensity increase
10	M4, M27, M18, M40	15–25 m	4	10–12	75	7 (High)	45–60 sec	Intensity increase
11	M5, M26, M19, M30	15–25 m	4	10–12	75	7 (High)	45–60 sec	Intensity increase
12	M6, M25, M20, M33	15–25 m	4	10–12	75	7 (High)	45–60 sec	Intensity increase
13	M9, M24, M35, M3	15–20 m	4	10–12	80	7–8 (High)	45 sec	Performance phase
14	M10, M23, M36, M5	15–20 m	4	10–12	80	7–8 (High)	45 sec	Performance phase
15	M9, M24, M37, M9	15–20 m	4	10–12	80	7–8 (High)	45 sec	Performance phase
16	M10, M23, M39, M14	15–20 m	4	10–12	80	7–8 (High)	45 sec	Performance phase
17	M9, M24, M40	15–20 m	3	12–15	75	8 (Very High)	30–45 sec	Peak phase
18	M10, M23, M20, M26	15–20 m	3	12–15	75	8 (Very High)	30–45 sec	Peak phase

Note: M = Model, RPE = Rate of Perceived Exertion (scale 1–10), Program duration = 18 sessions, Frequency = 3 sessions/week (recommended), Each session includes warm-up (10–15 min) and cool-down (5–10 min)

judgment evaluation. The expert validation involved football coaching specialists with experience in technical training development. The model was structured progressively based on passing distance to enhance technical adaptation and performance.

The validity of the instrument was assessed using the corrected item–total correlation method. The results indicated that all items across the pre-test and post-test in both experimental and control groups had correlation coefficients exceeding the critical value (r table = 0.396, n = 25, α = 0.05). Therefore, all items were considered valid and suitable for measuring long-pass performance (Table 2).

Table 2. Item Validity Results

Group	Item	r-value	r-table	Decision
Pre-Test Experimental	Test 1	0.60	0.396	Valid
	Test 2	0.56	0.396	Valid
	Test 3	0.62	0.396	Valid
	Test 4	0.58	0.396	Valid
	Test 5	0.64	0.396	Valid
Post-Test Experimental	Test 1	0.73	0.396	Valid
	Test 2	0.70	0.396	Valid
	Test 3	0.75	0.396	Valid
	Test 4	0.72	0.396	Valid
	Test 5	0.76	0.396	Valid
Pre-Test Control	Test 1	0.55	0.396	Valid
	Test 2	0.53	0.396	Valid
	Test 3	0.59	0.396	Valid
	Test 4	0.56	0.396	Valid
	Test 5	0.61	0.396	Valid
Post-Test Control	Test 1	0.65	0.396	Valid
	Test 2	0.62	0.396	Valid
	Test 3	0.67	0.396	Valid
	Test 4	0.63	0.396	Valid
	Test 5	0.69	0.396	Valid

The reliability of the instrument was evaluated using Cronbach's Alpha. The results demonstrated high to excellent internal consistency, with Cronbach's Alpha values of 0.86 for the pre-test experimental group, 0.91 for the post-test experimental group, 0.84 for the pre-test control group, and 0.88 for the post-test control group. These findings confirm that the instrument is both valid and reliable for assessing long-pass kicking performance among youth football athletes (Table 3).

Table 3. Reliability Test Results

Group	Cronbach's Alpha	Interpretation
Pre-Test Experimental	0.86	High Reliability
Post-Test Experimental	0.92	Excellent Reliability
Pre-Test Control	0.83	High Reliability
Post-Test Control	0.87	High Reliability

Both groups underwent pre-test and post-test using the Rumi Long Pass Test to measure long-pass accuracy (Doewes et al., 2022). Each participant performed five long-pass attempts toward a designated target area. The testing procedure involved three officials responsible for start coordination, target supervision, and score recording. Scoring was based on accuracy within concentric target zones: 50 points (≤1 m), 40 points (2 m), 30 points (3 m), 20 points (4 m), and 10 points (5 m) (Fig. 1).

Statistical Analysis

Data were analyzed using descriptive statistics and inferential tests at a significance level of 0.05. The Shapiro–Wilk test and Levene's test were used to assess normality and homogeneity assumptions, respectively. Paired sample t-tests were applied to examine within-group differences, while independent sample t-tests were used to compare between-group differences. In addition, N-gain analysis was conducted to evaluate the effectiveness of the intervention. All statistical analyses were performed using SPSS version 25.

Results

The effectiveness of the BLAST training model was evaluated by comparing pre-test and post-test results between the experimental and control groups. The descriptive statistics are presented in Table 4.

Table 4. Descriptive Statistics of Long-Pass Performance

Group	N	Min	Max	Mean	SD
Pre-test (Experimental)	25	100	170	139.60	18.59
Post-test (Experimental)	25	150	220	189.20	18.01
Pre-test (Control)	25	100	170	138.00	18.03
Post-test (Control)	25	130	190	157.20	14.87

As shown in Table 4, both groups demonstrated improvements in long-pass performance after the intervention.

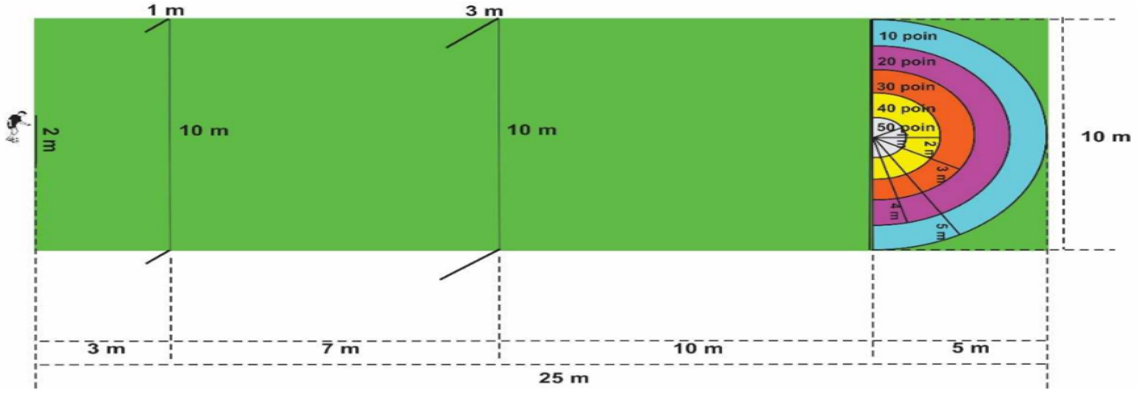

Fig. 1. Rumi Long Pass Test

However, the increase in the experimental group was substantially higher compared to the control group.

Prior to hypothesis testing, normality and homogeneity assumptions were examined. The results in Table 5 indicated that the data were normally distributed and homogeneous ($p > 0.05$), fulfilling the requirements for parametric analysis.

Table 5. Normality Test (Shapiro–Wilk)

Variable	N	Sig.
Pre-test (Experimental)	25	>0.05
Post-test (Experimental)	25	>0.05
Pre-test (Control)	25	>0.05
Post-test (Control)	25	>0.05

The Levene's test result in Table 6 ($p = 0.699$) confirmed that the variance between groups was homogeneous.

Table 6. Homogeneity Test (Levene's Test)

Variable	F	Sig.
Long-pass	0.152	0.699

Hypothesis testing using independent sample t-test showed a significant difference between the experimental and control groups after the intervention ($p < 0.05$). The results indicate that the BLAST training model produced a significantly greater improvement in long-pass kicking performance compared to conventional training.

Table 7. ANCOVA Results

Source	SS	df	MS	F	Sig.
Pre-test (Covariate)	2150.32	1	2150.32	9.87	0.003
Group	7420.55	1	7420.55	34.62	0.000
Error	10078.44	47	214.44		

The ANCOVA results revealed a significant effect of group on post-test long-pass performance ($F = 34.62$, $p < 0.001$), indicating that the experimental group performed significantly better than the control group after controlling for pre-test scores. To further examine the magnitude of the effect, Cohen's d was calculated. The analysis showed a large effect size ($d = 1.92$), indicating a substantial practical impact of the BLAST training model. Additionally, the 95% confidence interval (CI) for the mean difference ranged from 22.50 to 41.50, confirming the robustness of the observed effect.

For comparison purposes, an independent samples t-test was also conducted, which showed a significant difference between groups ($t = 6.852$, $df = 48$, $p < 0.001$), with a mean difference of 32.00.

Table 8. Independent Sample t-Test Results

Variable	t	df	Sig. (2-tailed)	Mean Difference
Long-pass	6.852	48	0.000	32.00

To further assess the effectiveness of the intervention, N-gain analysis was conducted, as presented in Table 9.

Table 9. N-Gain Score Results

Group	Mean (%)	Min (%)	Max (%)	Category
Experimental Group	62.56	29.70	98.36	Moderately Effective
Control Group	22.99	12.35	49.18	Low Effectiveness

The N-gain results show that the experimental group achieved a higher improvement level (62.56%) compared to the control group (22.99%). This indicates that the BLAST training model is more effective in enhancing long-pass kicking technique among youth football athletes.

Discussion

The results of this research provide strong empirical evidence that the BLAST training model is not only possible but also much more successful than conventional training techniques when it comes to enhancing the performance of youth football players in terms of long pass kicking. The experimental group showed a much improvement (62.56% compared to 22.99%) in post-test mean scores and N-Gain values, indicating that training that is structured and consistently planned achieves better performance results. In addition to showing effectiveness these results show a system of learning processes that controls the occurrence of such changes.

Mechanistically speaking, the BLAST model's effectiveness is explicable in terms of how one acquires motor skills. Structured repetition, increasing task complexity, and continuous feedback are all components of the paradigm that work together to help with neuromuscular adaptation but also stabilise movements (Kaliukhovich et al., 2013; Kennefick et al., 2018; Wang et al., 2024). High involvement and swift mistake correction help athletes quickly go from cognitive knowledge to fundamental coordination in early training. Training moves toward the associative stage, when consistency and efficiency of movement are developed, and improvements become more gradual as a result. This sequential learning process explains why the experimental group outperformed the control group, who did not receive any structured feedback or development, and maintained their superior performance over time. Accordingly, the discrepancies are more than simply statistical; they point to a real causal process with its origins in the design of structured learning.

However, the BLAST model should not be viewed as a static training approach; rather, it should be interpreted as a dynamic element whose functional role develops during the process of learning. At the beginning, BLAST is mostly used to generate stimuli, which speed up the acquisition of motor skills and the correction of errors via systematic repetition and instant feedback. As athletes go into the intermediate stage, BLAST takes on a stabilising function, helping to ensure that their movements are consistent and that their performance is less variation. This is achieved by controlled task progression. Excessive repetition without increasing complexity might inhibit further adaptation in subsequent phases, thus it is necessary to change the same structure to avoid this limitation. The BLAST model's effectiveness varies from one athlete's developmental stage to another, and this variation is explained by this functional transformation.

Because this procedure is time-dependent, we now know exactly when to use the BLAST model. Athletes are most receptive to technical adjustments and learning via repetition in the early and middle stages of training, when they experience the biggest performance increases (Quinzi et al., 2016). The need for more complicated and context-driven training stimuli arises because the pace of progress

inevitably decreases with increasing skill levels. This suggests that the BLAST model works best for young players when they are still growing into their sport, when fundamental technical abilities like long passing are very adaptable. Conventional training methods, on the other hand, miss this crucial opportunity since they rarely incorporate focused growth (Deuker et al., 2024).

The temporal performance limitations of the BLAST model provide for a more exact understanding of the effectiveness of the model. This is most noticeable when athletes are still in the early to mid-stages of their training and are very receptive to feedback and structured repetition. A steady pace of advancement indicates a shift toward more consistent and sophisticated execution, which occurs naturally as skill learning advances (Vanderka et al., 2020). If training stimuli are not well modified or athletes reach a performance plateau, especially at advanced levels when tactical and environmental elements become more important, the impact could decrease. The BLAST model's effectiveness changes with time as a result of interactions between training plan, athlete development stage, and the progress of learning stimuli, as seen by this dynamic pattern.

Additionally, the functional transformation accomplished by the BLAST model is explained by this system-level interpretation. The BLAST system organises training sessions that were previously unstructured, which is a significant improvement over conventional approach. As a result of this change, players gain self-assurance, consistency, and pinpoint precision while passing the ball long distances. When training design, learning processes, and performance results are well linked, as is the case in the experimental group, the effectiveness of this transformation process is reflected in the much larger N-Gain.

Nevertheless, this system's effectiveness is conditional and not applicable in all cases. Athletes in the process of skill development benefit most from the application of the model in supervised training settings with regular exposure. For more experienced players, when tactical complexity and decision-making matter more than technical progress alone, its effect may be less noticeable (Lex et al., 2015). These limits show that the BLAST model may not always be applicable to every situation; rather, its performance depends on how training design and contextual elements interact with one another.

When seen from a tactical point of view, the expansion of game tactics may also be connected to the increase in long pass performance (Wu, 2022). Direct play, which prioritises quick ball advancement and effective use of space, relies heavily on long passing (Tenga et al., 2010). Teams may avoid midfield pressure and adjust to possession-dominant opponents with better long pass execution (Fernandez-Navarro et al., 2016). Thus, the BLAST method improves tactical flexibility and performance beyond skill development.

The statistical findings provide further support for these notions. The intervention effect is confirmed to be resilient by the substantial differences seen in independent t-tests ($p < 0.05$) and the improvements shown in paired sample analyses. Crucially, the N-Gain analysis differentiates between structured and unstructured training results, offering more insight into the effectiveness of learning. Conventional approaches do not achieve the same level of learning efficiency as the BLAST model, which optimises the interaction between training variables. This discrepancy may be explained by different levels of system structure. These results are in line with previous studies that found a correlation between good passing and better attacking results (Rein et al., 2017).

A transparent decision rule was implemented across several performance measures to guarantee a uniform interpretation of the outcomes. N-Gain was considered the main statistic for effectiveness since it shows how much learning improved compared to starting performance levels. The observed differences were not attributed to random changes, as shown by statistical significance ($p < 0.05$) from t-tests. The convergence of these indicators allowed us to draw the final conclusion on the BLAST model's performance. We found that there were statistically significant changes, and the N-Gain values were moderate to high, which indicates a substantial and practically important improvement. By using this method, it is ensured that the findings are not constructed merely on the basis of statistical results, but rather on the basis of an integrated assessment of both the significance and the learning effect.

The research provides a system-based training model that has been verified and is ready for direct use by coaches and practitioners, which is a practical implication. Effective learning environments that speed up skill acquisition may be created using the BLAST model, which integrates progression, repetition, and feedback into an integrated framework. Since football performance is complicated and arises from the interplay of technical, tactical, and situational elements, this is especially pertinent (Delibas et al., 2019; Estephan et al., 2017). In addition to enhancing technical performance, coaches may use this approach to better match training methods with overall performance goals.

It is important to recognise a number of limitations notwithstanding these achievements. This research does not require contextual factors like player placement, opponent pressure, and in-game decision-making into account; instead, it mainly looks at the technical parts of long passing. Because technical execution and tactical context combine to produce real-game effectiveness, this is just a partial representation of performance from a systemic viewpoint. More integrative methods that capture both technical and contextual aspects of performance should be used in future research, according to recent innovations like the passing disruptiveness notion (Goes et al., 2021).

It is beneficial for future studies to investigate if the training can be maintained over time. The impact of structured training methods on real-game performance may be better understood with continuous integration of physical, technical, and tactical analysis which remains essential for advancing both theoretical development and practical application in football training (Andrzejewski et al., 2018).

Conclusion

At the early to intermediate stages of skill development, when motor learning and performance improvement are most facilitated by structured repetition and progressive task design, this study shows that the BLAST-based long pass training model works well for youth football players. Both statistical significance and N-Gain analysis show that the model outperforms traditional training under these

circumstances, demonstrating meaningful and practically relevant learning results.

BLAST model effectiveness depends on training situation and athlete development stage. For highly skilled players, the importance of tactical complexity decision-making, and contextual adaptability over technical repetition to increase performance may diminish. Furthermore, the current investigation has limitations due to its exclusive emphasis on technical performance, which does not adequately account for tactical and situational factors that impact actual game effectiveness.

Accordingly, the effectiveness of the BLAST model needs to be understood within a controlled environment, whereby the training plan, athlete attributes, and performance metrics are matched appropriately. The concept works best as a structured learning system during certain developmental periods, not as a general training solution. This paradigm should be expanded by adding tactical, contextual, and match-based performance indicators to better assess effectiveness of training.

Ethics Approval

This study was conducted in accordance with established ethical standards. Ethical approval was granted by The State University of Jakarta (No. 47/UN39.14/PT.01.05/I/2026) prior to data collection, and all procedures involving human participants complied with institutional and international guidelines.

Informed Consent

Informed consent was obtained from all participants involved in this study. For participants under the age of 18, consent was obtained from their parents or legal guardians, along with participant assent where appropriate.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors used AI-assisted tools for language editing only and take full responsibility for the content of this manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Удосконалення виконання довгого пасу у юних футболістів засобами тренувальної моделі BLAST

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 9 табл., 1 рис., 28 джерел.

Актуальність. Техніка довгого пасу є однією з базових навичок у футболі, яка може суттєво впливати на динаміку гри та сприяти успіху команди. Однак ця техніка залишається серйозною проблемою для юних футболістів, оскільки їй часто приділяється недостатньо уваги у тренувальних програмах. Тому існує потреба в ефективній та структурованій моделі тренування для вдосконалення виконання довгого пасу.

Мета дослідження. Метою дослідження було вивчити ефективність тренувальної моделі BLAST у вдосконаленні техніки виконання довгого пасу у юних футболістів.

Матеріали і методи. У дослідженні застосовано квазіекспериментальний дизайн із підходом «передтест–післятест» із контрольною групою. Загалом у дослідженні взяли участь 50 спортсменів, яких було розподілено на експериментальну групу (n = 25), що тренувалася за моделлю BLAST, та контрольну групу (n = 25), яка проходила традиційне тренування під керівництвом тренерів. Для оцінювання результатів під час передтесту та післятесту використовувався тест довгого пасу Rumi. Дані аналізували за допомогою описової статистики, тесту Шапіро–Вілка на нормальність розподілу, тесту Левена на однорідність дисперсій, ANCOVA, t-тестів для незалежних вибірок та аналізу N-gain.

Результати. Результати показали, що після втручання обидві групи продемонстрували покращення техніки виконання довгого пасу. Однак експериментальна група продемонструвала статистично значуще більше покращення порівняно з контрольною групою ($p < 0.05$). Середній показник N-gain в експериментальній групі становив 62.56% (помірна ефективність), тоді як у контрольній групі — лише 22.99% (низька ефективність).

Висновки. Отримані результати свідчать про те, що тренувальна модель BLAST є ефективнішою за традиційні методи тренування у вдосконаленні техніки виконання довгого пасу у юних футболістів.

Ключові слова: модель BLAST, довгий пас, футбольне тренування, юні спортсмени, розвиток навичок.

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Original Scientific Articles. Pedagogical Models and Instructional Design

Baskin as an Inclusive Educational Laboratory in University Sport Sciences Education

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Abstract

Background. Social inclusion is a central priority in educational and sport policies, aiming to create participatory environments that value diversity. Baskin, an innovative inclusive sport, enables individuals with and without disabilities to participate together through differentiated roles and adapted rules, fostering interaction and cooperation.

Objectives. This study aimed to evaluate the educational and social impact of a Baskin laboratory implemented within a university Sport Sciences course, with particular attention to students' perceived inclusion, relational dynamics, and professional development.

Materials and Methods. A mixed-methods design was adopted. Quantitative data were collected using the Perceived Inclusion Questionnaire (PIQ), administered before (T0) and after (T1) the intervention. Qualitative data were gathered through systematic observations, reflective journals, and semi-structured interviews. The sample included 175 university students and 13 individuals with motor disabilities. Quantitative data were analyzed using paired-samples t-tests and Cohen's d, while qualitative data were examined through thematic analysis.

Results. The results showed a statistically significant increase in perceived inclusion, social acceptance, and relational support ($p < .001$), with a large effect size ($d = 0.82$). Qualitative findings highlighted changes in students' perceptions of disability, increased empathy, the development of professional competencies, and enhanced group cohesion. The laboratory promoted cooperative behaviors and reduced relational barriers.

Conclusions. The Baskin laboratory proved to be an effective pedagogical tool for inclusive education in Sport Sciences. It supports the development of relational, reflective, and professional skills while fostering meaningful inclusion through structured experiential learning.

Keywords: inclusive sport, baskin, sport sciences, inclusive education, adapted physical activity, university education.

Introduction

Over the past decades, social inclusion has become one of the main priorities of educational and sports policies at the international level. Supranational organizations such as UNESCO and the United Nations have highlighted the need to promote educational systems capable of recognizing and valuing diversity as a resource, moving beyond models based on exclusion or mere formal integration (Unesco, 2020). From this perspective, inclusion is not limited to ensuring access to educational and social opportunities, but also implies the creation of participatory contexts in which every individual can actively contribute to community life, as highlighted in studies on sport-based inclusion and sustainability (Di Palma et al., 2025). Within this theoretical framework, sport represents a particularly effective tool for promoting inclusive processes. Participation in shared physical activities fosters the development of social skills, cooperative attitudes, and po Parthenope University of Naples sitive relationships among individuals with different abilities and backgrounds, also in relation to body expression and ludic interaction (Raiola, 2015). The literature highlights how sport can help reduce stereotypes and social barriers related to disability, promoting contexts of interaction based on mutual respect and collaboration (Di Palma & Tafuri, 2016; Darcy et al., 2016). From a psychological perspective, participation in inclusive physical activities can support the development of intrinsic motivation and self-efficacy. According to Self-Determination Theory (Deci et al., 2000)

individuals' motivation increases when three fundamental psychological needs are satisfied: competence, autonomy, and social relationships. In educational environments characterized by cooperation and active participation, these needs can be fulfilled, fostering genuine engagement in the proposed activities, in line with studies showing how physical activity contexts can enhance self-efficacy and academic development (Latino et al., 2023). Among the inclusive sports practices developed in recent years, Baskin represents one of the most innovative models in the field of educational sport. Created in Italy in the early 2000s, Baskin is a team sport derived from basketball but specifically designed to enable the simultaneous participation of people with and without disabilities. The game system includes differentiated roles assigned to players according to their motor and cognitive abilities, baskets positioned at different heights, and specific rules that ensure the active participation of all team members. Unlike many adapted sports, Baskin does not simply modify an existing sport to include people with disabilities, but redesigns the entire structure of the game according to a principle of functional equity. Each player assumes a specific role that enhances their individual abilities, making diversity a functional element for the success of the team. Scientific literature highlights how Baskin promotes the development of social, relational, and cooperative skills in school contexts (Tafuri, 2025). However, there are still relatively few studies examining the potential of this discipline in the university education of students in Sport Sciences. University programs in Sport Sciences are increasingly required to train professionals capable of working in heterogeneous contexts, where the presence of people with disabilities requires specific competencies in the field of adapted physical activity. In this regard, learning experiences based on direct contact with people with disabilities represent a fundamental component in the training of future professionals in movement and sport.

Knowledge develops through a process that integrates concrete experience, reflection, and conceptualization, as also highlighted by research on outdoor and experiential learning approaches in physical activity contexts (Latino, 2023). Inclusive sport laboratories therefore represent privileged contexts for fostering this type of learning, allowing students to develop professional competencies through direct experience. In light of these considerations, the present study analyzes the educational impact of a Baskin laboratory conducted with first-year students enrolled in a Sport Sciences degree program at a university in Naples. The project involved university students and individuals with motor disabilities in shared sports activities, with the aim of promoting processes of inclusion, relational learning, and professional development, as well as contributing to cognitive functioning and mental well-being (Latino, 2025).

Research objective

The main objective of the study is to evaluate the educational and social impact of a Baskin laboratory implemented with university students in Sport Sciences and individuals with motor disabilities.

Specifically, the study aims to:

- analyze changes in university students' perceptions of social inclusion through the Perceived Inclusion Questionnaire (PIQ);
- observe the relational dynamics between students and participants with disabilities during sports activities;
- explore students' representations of disability and inclusive sport;
- assess the pedagogical value of Baskin in the training of future Sport Sciences professionals.

Materials and Methods

Research Design

The study adopted a mixed-methods research design, integrating quantitative and qualitative approaches. This type of design makes it possible to combine statistical analysis of data with an in-depth understanding of participants' lived experiences (Creswell, 2017).

The laboratory intervention took place over a period of two months and involved inclusive sports activities based on Baskin. The sessions were supervised by two qualified instructors with experience in inclusive sport and adapted physical activity.

The project was structured into three main phases:

Initial phase (T0)

- administration of the PIQ questionnaire;
- collection of socio-demographic data;
- preliminary observations of relational dynamics;
- Intervention phase;
- implementation of Baskin laboratory activities;
- systematic observation of group dynamics;
- completion of students' reflective journals.

Final phase (T1)

- second administration of the PIQ questionnaire
- semi-structured interviews
- qualitative analysis of participants' experiences

Participants

The study sample consisted of:

- 175 university students enrolled in the first year of a Sport Sciences degree program at a university in Naples;
- 13 individuals with motor disabilities involved in the inclusive sports activities.

The university students had an average age of 19.4 years (SD = 1.3).

Participants with motor disabilities presented different functional conditions, including spinal cord injuries, cerebral palsy, and neuromotor disorders.

Quantitative and Qualitative Instruments

Quantitative Instruments

The Perceived Inclusion Questionnaire (PIQ) developed by Venetz, Zurbriggen, and Eckhart (Venetz, 2015) was used. The questionnaire measures three main dimensions:

- social acceptance;
- participation;
- relational support.

The data were analyzed using paired-samples t-tests and effect size calculation (Cohen's d).

Qualitative Instruments

The qualitative component included:

- systematic observations of game sessions;
- semi-structured interviews with students;
- reflective journals completed by students.

Qualitative data were analyzed through thematic analysis according to the model proposed by Braun and Clarke.

Educational Activities: Baskin as an Inclusive Pedagogical Tool

In recent years, international literature in physical education and sport pedagogy has highlighted the importance of integrating experiential learning and active student participation within university curricula (Braun et al., 2006). In particular, in Sport Sciences education, laboratory activities represent a privileged context for fostering professional competencies related to the design, management, and evaluation of inclusive physical activities.

Several studies have shown that the direct involvement of university students in practical experiences with people with disabilities can contribute to modifying attitudes, representations, and professional competencies in the field of Adapted Physical Activity (APA) (Haegele et al., 2016). In this sense, inclusive sport laboratories represent educational environments in which theoretical learning can be integrated with concrete experience, promoting the development of relational, pedagogical, and organizational competencies.

The Baskin laboratory described in this study was designed as an experiential educational device aimed at promoting a concrete understanding of inclusion through movement and sport.

The intervention consisted of 16 teaching sessions, each lasting approximately 90 minutes, distributed over a period of two months. The activities were conducted by two instructors specialized in Baskin and adapted physical activity, with the support of the university lecturer responsible for the laboratory.

Each session followed a recurring pedagogical structure consisting of four main phases:

- relational warm-up;
- progressive learning of Baskin rules;
- matches and game situations;
- final reflective debriefing.

This structure allowed the integration of motor activity, social interaction, and pedagogical reflection, elements considered central in the recent literature on inclusive physical education (Creswell., 2017; Haegele et al., 2016).

Relational Warm-Up

The first phase of each laboratory session was dedicated to relational warm-up, lasting approximately 15–20 minutes. The main objective of this phase was to create a positive group climate and facilitate interaction between university students and participants with motor disabilities.

According to the literature on inclusive physical education, the motivational and relational climate represents a key variable in promoting active student participation and the development of cooperative relationships (Haegele et al., 2016). In inclusive contexts, the quality of social relationships significantly influences participants' sense of belonging and perceived competence.

The activities proposed during the relational warm-up included cooperative motor exercises, ice-breaking games, and coordination activities carried out in small mixed groups composed of students and participants with disabilities. Among the most frequently used activities were ball-passing exercises in circles, movement games based on cooperation between pairs, and simple motor coordination tasks adapted to participants' different abilities.

These activities served a dual pedagogical function. On the one hand, they allowed participants to gradually prepare for the subsequent physical activity. On the other hand, they promoted the construction of interpersonal relationships through cooperative situations and informal communication.

In several cases, students reported in their reflective journals that this initial phase helped reduce the sense of embarrassment or uncertainty experienced during the first sessions of the laboratory.

The use of cooperative games during the warm-up is supported by pedagogical literature on cooperative learning, which highlights how collaboration-based activities can foster positive relationships and the development of social skills in educational contexts (Creswell, 2017; Dyson et al., 2004).

Progressive Learning of Baskin Rules

The second phase of the session focused on learning the rules of Baskin and understanding the different player roles. This phase lasted approximately 20 minutes and followed a progressive teaching approach that allowed students to gradually become familiar with the structure of the discipline.

Baskin differs from traditional basketball in that it includes differentiated roles assigned to players according to their motor and functional abilities. Each role has specific possibilities for action within the game, allowing the simultaneous participation of individuals with different levels of motor ability.

During the first sessions, instructors focused on explaining the fundamental principles of the game, including role distribution, the use of side baskets, and collaboration strategies among different players.

Students then participated in technical exercises designed to explore the specific characteristics of the different roles. For example, some activities involved passing and shooting exercises differentiated according to the characteristics of each role, while others aimed to understand cooperation strategies among players with different functions within the team.

From a pedagogical perspective, this phase was particularly significant because it allowed students to observe how the organization of sports rules can either facilitate or limit participation for individuals with different abilities. According to studies in the field of Adapted Physical Activity, the design of rules and the game environment is one of the key elements in promoting inclusion in physical activities.

Through these activities, students were able to understand that inclusion in sport does not depend solely on the individual characteristics of participants, but also on how activities are designed and organized.

Baskin Matches

The central phase of each session consisted of Baskin matches, lasting approximately 40 minutes. During this phase, students and participants with disabilities were divided into mixed teams, ensuring the presence of different player roles within each group.

Matches represented the moment when participants could concretely experience the dynamics of Baskin and apply the skills developed during the previous phases. During gameplay, instructors carefully observed interactions among players, intervening only when necessary to facilitate cooperation and respect for the rules.

The structure of Baskin naturally encourages collaboration among team members, since each role has specific possibilities for action and the success of a play depends on the coordinated participation of different players. This feature creates a form of positive interdependence, a key element in cooperative learning models applied to physical education (Creswell, 2017; Dyson et al., 2004).

Throughout the sessions, a gradual evolution of relational dynamics among participants was observed. During the initial sessions, students tended to focus mainly on the technical aspects of the game. Over time, however, an increase in cooperative strategies and communication among team members was observed.

For example, several students began actively encouraging teammates during gameplay, suggesting passing strategies, or supporting players with greater motor difficulties in more complex situations. These behaviors represent important indicators of the development of relational and cooperative competencies within the group.

Reflective Debriefing

The final phase of each session was dedicated to reflective debriefing, lasting approximately 10–15 minutes. This phase represented an essential component of the pedagogical structure of the laboratory, as it allowed students to reflect on the experience lived during the activities and to attribute meaning to the relational and inclusive dynamics that emerged during the session.

The debriefing usually took place at the end of the match or training activities, with all participants seated in a circle in the gymnasium to facilitate open communication and active participation in the discussion.

In Sport Sciences education, guided reflection is considered a fundamental element of experiential learning processes. Studies in sport pedagogy and physical education highlight that participation in practical activities alone is not sufficient to generate meaningful learning unless accompanied by structured moments of reflection and analysis (Creswell, 2017).

Through guided reflection, students were encouraged to critically analyze their actions, recognize the relational dynamics observed during the activity, and connect the practical experience with the theoretical knowledge acquired during their university studies.

In the Baskin laboratory, the debriefing aimed to stimulate shared reflection on the inclusive dynamics observed during gameplay. Instructors guided the discussion through open-ended questions such as:

- What difficulties did you encounter during the game?
- Which strategies facilitated collaboration among team members?
- How did the rules of Baskin influence the participation of different players?
- Which game situations required greater cooperation among teammates?

These questions encouraged students to reflect not only on the technical aspects of the activity but also on the social and relational dynamics of inclusive sport.

Students were also invited to share their emotions, including feelings of enthusiasm, surprise, or initial uncertainty when interacting with participants with disabilities. The expression of these experiences helped increase awareness of the learning process and contributed to building a climate of trust within the group.

Reflections emerging during the debriefing were later expanded through individual reflective journals, in which students described meaningful situations observed during the game, difficulties encountered, and collaboration strategies that supported team functioning.

Overall, reflective debriefing played a central role in transforming the sports activity into a structured educational experience.

The Laboratory as an Inclusive Learning Environment

Overall, the organization of the laboratory sessions created a learning environment in which motor activity, social relationships, and pedagogical reflection were closely integrated. This integration is considered a central element in contemporary models of Sport Sciences education, which emphasize the importance of educational experiences capable of linking theoretical knowledge and professional practice through authentic learning contexts (Creswell, 2017).

The Baskin laboratory functioned as an educational space where students could directly experience the concrete implications of inclusion in sport. Unlike traditional theoretical lessons, in which inclusion is often addressed mainly at a conceptual level, the laboratory allowed students to engage in real interactions with individuals with motor disabilities.

Through participation in Baskin activities, students developed several professional competencies relevant to their future roles in Sport Sciences. In particular, the laboratory experience contributed to the development of skills related to observing individual differences among participants, adapting motor strategies to different abilities within the group, and designing sports activities aimed at inclusive participation.

Another significant aspect concerns the role of direct contact with disability in students' training processes. Studies in inclusive physical education highlight that direct interaction with individuals with disabilities can help modify attitudes and social representations, fostering greater openness toward diversity and a deeper understanding of the potential of people with disabilities in sports contexts (Haegele et al., 2016).

Within the laboratory, the cooperative structure of Baskin also promoted the development of positive relationships among participants. The game requires

collaboration among players with different roles, creating a form of interdependence among team members. This dynamic encourages communication and cooperation strategies aimed at achieving shared goals, elements considered fundamental in cooperative learning contexts (Creswell, 2017).

Throughout the sessions, a gradual evolution of group dynamics was observed: students increasingly adopted collaborative communication strategies and gameplay approaches that valued the abilities of different team members. This process contributed to the creation of an educational climate characterized by mutual support, respect for differences, and a strong sense of group belonging.

From this perspective, the Baskin laboratory can be interpreted as an example of situated learning, in which knowledge develops through concrete experience and social interaction among participants. The integration of sports practice, interpersonal relationships, and pedagogical reflection made the laboratory a particularly meaningful context for the education of Sport Sciences students, contributing to the development of technical, relational, and educational competencies essential for working in inclusive sports environments.

Results

Quantitative Results

The quantitative analysis of the data collected through the Perceived Inclusion Questionnaire (PIQ) revealed a significant improvement in university students' perception of social inclusion after participating in the Baskin laboratory. The comparison between the mean scores recorded in the pre-intervention phase (T0) and those in the post-intervention phase (T1), conducted using a paired-samples t-test, showed a statistically significant increase both in the overall perceived inclusion score and in the individual dimensions measured by the questionnaire.

Table 1. Quantitative results (PIQ)

Variable	T0 (Mean ± SD)	T1 (Mean ± SD)	p	Effect size (Cohen's d)
Perceived inclusion	3.44 ± 0.56	4.20 ± 0.61	.001	0.82
Social acceptance	3.51 ± 0.60	4.25 ± 0.58	.001	0.82
Relational support	3.37 ± 0.64	4.10 ± 0.62	.001	0.82

Table 2. Structural interpretation

Variable	Direction of change	Pedagogical interpretation
Perceived inclusion	Increase	Enhanced perception of belonging through cooperative participation
Social acceptance	Increase	Reduction of social distance and greater recognition of peers' abilities
Relational support	Increase	Strengthening of collaborative interactions and mutual support

Overall, the quantitative results suggest that participation in the Baskin laboratory significantly strengthened students' perception of social inclusion, promoting higher levels of mutual acceptance and relational support among participants. The experience of shared sports practice between university students and individuals with motor disabilities therefore appears to have generated a more inclusive and cooperative relational context, confirming the educational potential of inclusive sport within university Sport Sciences education.

Qualitative Results

The qualitative analysis of the data collected through systematic observations of the game sessions, students' reflective journals, and semi-structured interviews allowed for an in-depth exploration of the educational, relational, and formative processes activated during the Baskin laboratory. The thematic analysis conducted according to the model proposed by Braun and Clarke identified four main interpretative themes: transformation of representations of disability; development of empathy and relational sensitivity; professional learning and pedagogical awareness, and strengthening of group cohesion and the creation of an inclusive climate.

The first emerging theme concerns the change in students' representations of disability. During the initial phases of the laboratory, observations and notes recorded in the reflective journals revealed a certain hesitation in interacting with participants with motor disabilities. Some students reported an initial sense of uncertainty, related to the fear of adopting inappropriate behaviors or not being able to manage the dynamics of the game correctly. This condition was often accompanied by an implicit perception of disability as a limitation or fragility. However, as the activities progressed, these representations evolved significantly. The concrete experience of the game allowed students to directly observe the motor and strategic abilities of teammates with disabilities, promoting a redefinition of their initial perceptions. In many final interviews, students emphasized how Baskin makes it possible to "see the person before the disability," as the structure of the game assigns each participant a specific and necessary role within the team. The presence of differentiated roles and rules designed to value different abilities contributed to transforming disability from a perceived obstacle into a functional element within the organization of the game.

A second particularly relevant theme concerns the development of empathy and relational sensitivity. Observations during the game sessions showed a progressive increase in spontaneous interactions between students and participants with disabilities. In the first sessions, communication was mainly functional to the game, whereas over time social interactions expanded beyond the strictly sporting dimension. Students began to develop more attentive and collaborative forms of communication, characterized by mutual encouragement, positive feedback, and supportive strategies during gameplay. Some students reported in their reflective journals that the experience contributed to developing greater listening skills and a stronger ability to observe the needs of other team members. This process facilitated the construction of more authentic relationships and helped reduce relational barriers initially present. In several cases, students described specific moments during gameplay in which collaboration with teammates with

disabilities required a reorganization of their motor and communicative strategies, generating a greater awareness of the importance of cooperation.

The third theme concerns professional learning derived from the laboratory experience. Many students emphasized that the laboratory represented one of their first concrete opportunities to engage directly with the design and management of inclusive motor activities. Through participation in the Baskin sessions, students were able to observe how the structure of the rules, the organization of spaces, and the distribution of roles influence the participation of different players. This process fostered a deeper understanding of the principles underlying adapted physical activity, allowing students to connect the theoretical knowledge acquired during their university studies with practical educational interventions. In several interviews, students highlighted how the experience contributed to developing competencies useful for their future professional careers, including the ability to observe individual differences, adapt motor activities to different levels of ability, and design inclusive learning environments. Some participants also emphasized that Baskin represents an effective model for promoting the participation of heterogeneous groups, suggesting the possibility of applying similar principles in other educational and sports contexts.

The fourth theme concerns the strengthening of group cohesion and the construction of an inclusive climate. Observations of game dynamics showed that the cooperative structure of Baskin fosters the development of positive relationships among team members. Throughout the sessions, a progressive reduction in relational distance between students and participants with disabilities was observed, accompanied by an increase in behaviors of mutual support. Students began to develop gameplay strategies based on collaboration and interdependence among different roles. In several situations, spontaneous behaviors of encouragement, celebration of successful actions, and support during moments of difficulty were observed. These elements contributed to the creation of a group climate characterized by trust, respect, and a sense of belonging.

Another aspect emerging from the interviews concerns the emotional value of the experience. Many students described the laboratory as a particularly meaningful moment in their university journey, emphasizing that the experience generated positive emotions related to collaboration and satisfaction derived from achieving shared goals. In particular, some students highlighted that Baskin allowed them to experience a form of sports competition different from traditional models, based not only on individual performance but also on collective team success.

Overall, the qualitative results suggest that the Baskin laboratory acted as a transformative educational context, capable of influencing multiple dimensions of students' experiences: cognitive, relational, emotional, and professional. The integration of sports practice, social interaction, and guided reflection facilitated the development of new representations of disability and contributed to the acquisition of competencies essential for future Sport Sciences professionals. Baskin therefore emerges not only as an inclusive sport activity but also as a pedagogical tool capable of promoting processes of situated learning and personal and professional development.

Discussion

The results of this study support the initial assumption that a structured Baskin laboratory can enhance perceived inclusion, relational dynamics, and professional awareness among first-year Sport Sciences students. In particular, the significant increase in perceived inclusion scores (PIQ) indicates that participation in shared sport activities with individuals with motor disabilities improves students' perceptions of participation, social acceptance, and relational support, in line with studies showing how structured sport programmes can enhance both motor and social skills in educational contexts (Tafuri et al., 2026). However, beyond this descriptive evidence, the findings suggest that these outcomes are generated by specific pedagogical mechanisms embedded in the structure of Baskin.

First, the activity promotes functional interdependence, as the differentiated roles require active cooperation among participants, fostering meaningful participation rather than mere coexistence. Second, direct experiential contact with individuals with disabilities contributes to the transformation of initial representations, shifting from a deficit-based view of disability to the recognition of individuals as competent actors within the game. Third, the integration of guided reflection (through debriefing, observations, and interviews) allows students to process and internalize the experience, transforming action into learning. These mechanisms explain how the structure of the activity produces the observed outcomes and under which conditions they are more likely to emerge.

These results are consistent with an educational perspective that considers inclusion as active participation in social contexts, as emphasized by UNESCO guidelines, which highlight the need to transform educational relationships and remove barriers. In this sense, Baskin operationalizes inclusion through its rules and organization, aligning with principles of adaptive physical education and inclusive teaching strategies (Susanto et al., 2024). Compared to previous studies, which mainly emphasize the general benefits of inclusive sport (Di Palma & Tafuri, 2016; Darcy et al., 2016), the present findings provide a more detailed understanding of the mechanisms through which inclusion is generated.

From a pedagogical perspective, the active involvement of students as participants rather than observers appears to be a key condition for the effectiveness of the intervention. This is consistent with literature highlighting the role of direct interaction with individuals with disabilities in modifying attitudes and fostering relational competencies (Haegele et al., 2016). Similarly, the development of professional awareness observed in the qualitative data confirms the relevance of experiential learning approaches in Sport Sciences education, particularly in relation to adapted physical activity and its connections with lifestyle and cognitive functioning (Tafuri et al., 2025).

The findings also align with cooperative learning theory, according to which learning is enhanced through positive interdependence and shared responsibility (Johnson, 2009). In Baskin, such interdependence is structurally embedded in the rules of the game, representing a distinctive element compared to traditional sport practices, with implications for psychosocial development and body perception (Latino

et al., 2019). Furthermore, the results can be interpreted through the lens of Self-Determination Theory (Deci & Ryan, 2000): the laboratory appears to satisfy the needs for competence (through role differentiation), relatedness (through cooperation), and autonomy (through active participation), thus explaining the high level of engagement and the improvement in perceived inclusion.

From a scientific perspective, the study contributes to the literature by moving beyond a purely descriptive claim ("Baskin improves inclusion") and identifying the structural and pedagogical conditions under which inclusive outcomes are produced. It also integrates empirical findings with theoretical frameworks, offering a more comprehensive understanding of inclusive sport as a learning environment.

Some limitations should be acknowledged. The short duration of the intervention limits the assessment of long-term effects; the use of the PIQ as the sole quantitative instrument restricts the analysis to perceived inclusion; and the absence of a control group reduces the possibility of establishing causal relationships. Future research should address these limitations through longitudinal designs, the inclusion of additional variables (e.g., self-efficacy, attitudes toward disability), and comparative studies across different contexts.

Despite these limitations, the findings indicate that Baskin represents a high-potential educational tool in university Sport Sciences programs. Its effectiveness lies not only in its inclusive intent but in its capacity to translate inclusion into a structured, embodied, and reflective practice, contributing to the development of ethically and socially aware professionals (Mazzeo et al., 2016).

Conclusion

In light of the results obtained, the Baskin laboratory can be considered a meaningful educational experience for first-year Sport Sciences students. Direct interaction with individuals with motor disabilities, mediated through a sports practice structured according to principles of cooperation and active participation, contributed to improving perceived inclusion and generated significant transformations at relational and professional levels.

The most significant aspect emerging from the study concerns the fact that Baskin did not merely function as an adapted sports activity but as a pedagogical context capable of generating learning. Students experienced direct contact with disability not mediated by an assistive or purely theoretical perspective, but embedded within a concrete situation of play, collaboration, and shared responsibility. This made it possible to redefine their representations of disability and to develop a more mature understanding of the educational value of inclusive sport.

From the perspective of university education, the findings suggest that experiences of this type can substantially contribute to the development of professional competencies that are increasingly necessary in the field of Sport Sciences: adaptability, observation of individual differences, design of inclusive activities, management of heterogeneous groups, and pedagogical reflection on practice. In this sense, Baskin represents a methodology aligned with the need to train professionals who are not only technically competent but also aware of the educational and social implications of their interventions.

From an institutional perspective, the results suggest the opportunity to integrate inclusive sport laboratories more systematically into Sport Sciences university curricula. Such activities could represent an effective bridge between theoretical education and professional practice, strengthening the quality of student preparation and contributing to the development of a university culture more attentive to inclusion.

Finally, future research should further explore this field through longitudinal studies, larger samples, and the use of multiple evaluation tools. In particular, it would be useful to examine whether the observed effects on perceived inclusion and professional awareness are maintained over time and to what extent such experiences influence students' future professional orientations.

Overall, this study suggests that Baskin, when used as a university laboratory, can represent a highly valuable pedagogical tool—not only because it enables the shared participation of people with and without disabilities, but because it transforms this participation into an opportunity for learning, reflection, and professional growth. In this sense, Baskin is not simply an inclusive sport, but a genuine educational experience of lived inclusion.

Ethics Approval and Consent to Participate

The study was approved by the Ethics Committee of the University of Naples Parthenope (DiSMMeB, Prot. No. 88779/2025). Written informed consent was obtained from all participants and/or their legal guardians prior to participation in the study.

Conflict of Interest

The authors declare no conflicts of interest.

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Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Baskin як інклюзивна освітня лабораторія в університетській освіті у сфері спортивних наук

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

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Актуальність. Соціальна інклюзія є одним із ключових пріоритетів освітньої та спортивної політики, спрямованих на створення середовища участі, у якому цінується різноманітність. Baskin як інноваційний інклюзивний вид спорту дає можливість особам з інвалідністю та без неї брати участь у спільній діяльності завдяки диференційованим ролям і адаптованим правилам, що сприяє взаємодії та співпраці.

Мета дослідження. Оцінити освітній і соціальний вплив лабораторії Baskin, реалізованої в межах університетського курсу спортивних наук, з особливою увагою до сприйняття студентами інклюзії, міжособистісної взаємодії та професійного розвитку.

Матеріали і методи. Використано змішаний дизайн дослідження. Кількісні дані збирали за допомогою опитувальника Perceived Inclusion Questionnaire (PIQ), який застосовували до (T0) та після (T1) втручання. Якісні дані отримували шляхом систематичних спостережень, рефлексивних щоденників і напівструктурованих інтерв'ю. У дослідженні взяли участь 175 студентів університету та 13 осіб із порушеннями опорно-рухового апарату. Кількісні дані аналізували за допомогою t-критерію для залежних вибірок і коефіцієнта d Коена, тоді як якісні дані опрацьовували методом тематичного аналізу.

Результати. Результати засвідчили статистично значуще підвищення рівня сприйняття інклюзії, соціального прийняття та міжособистісної підтримки ($p < .001$) із великим розміром ефекту ($d = 0.82$). Якісні результати виявили зміни у сприйнятті студентами інвалідності, зростання емпатії, розвиток професійних компетентностей і посилення групової згуртованості. Лабораторія сприяла формуванню кооперативної поведінки та зменшенню міжособистісних бар'єрів.

Висновки. Лабораторія Baskin виявилася ефективним педагогічним інструментом інклюзивної освіти у сфері спортивних наук. Вона сприяє розвитку міжособистісних, рефлексивних і професійних навичок, а також забезпечує змістовну інклюзію через структуроване практико-орієнтоване навчання.

Ключові слова: інклюзивний спорт, baskin, спортивні науки, інклюзивна освіта, адаптивна фізична активність, університетська освіта.

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Effects of Hybrid Training Combining Shadow, Dynamic Ball, Sensory, and Game Drills on Forehand Drive Performance in Young Table Tennis Players: A 2×2 Factorial Design

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Abstract

Background. Optimal training protocols for the forehand drive in young table tennis players (ages 6–9) are still under development. Although shadow drills, dynamic ball practice, sensory tools, and game-based activities each provide unique benefits, no research has integrated these methods into a hybrid model. Additionally, the moderating role of baseline EHC remains unclear, limiting the design of inclusive training programs.

Objectives. This study investigated the effect of a hybrid training model on forehand drive performance and assessed whether its effectiveness varied according to the athlete's baseline EHC level.

Materials and Methods. A 2×2 factorial quasi-experimental design was employed. Twenty-eight athletes from PTMSI Makassar were divided into experimental (n = 14) and control (n = 14) groups and further stratified by high or low EHC levels (measured using the Beery VMI). Forehand drive accuracy (maximum score = 50) was assessed before and after 14 training sessions (50 minutes each, three times per week). Data were analyzed using two-way ANCOVA while controlling for pretest scores.

Results. After adjustment, the hybrid group achieved significantly higher scores than the control group (M = 44.68 vs. 42.11; $p < 0.001$, partial $\eta^2 = 0.483$). Athletes with high EHC outperformed those with low EHC (M = 44.54 vs. 42.25; $p < 0.001$, partial $\eta^2 = 0.423$). The interaction between training and EHC was not significant ($p = 0.991$).

Conclusions. The hybrid training model significantly improved forehand drive performance compared to conventional training methods. Coaches are encouraged to incorporate all four training methods into daily practice programs. These findings highlight the importance of integrating diverse training approaches at an early age and suggest potential applications in pediatric physiotherapy and motor performance rehabilitation.

Keywords: table tennis, forehand drive, hybrid training, eye-hand coordination, early childhood.

Introduction

Modern table tennis demands high reaction speed, technical precision, and exceptional perceptual-motor coordination, especially in young athletes during their early developmental stages (ages 6–9). Among the basic strokes, the forehand drive is widely recognized as a key offensive technique, serving as the foundation for more advanced attacking shots, as demonstrated by Grycan et al. (2023) and Mao et al. (2023). According to Faber et al. (2021) and He et al. (2022), mastering the forehand drive at an early age is critical because it builds the technical foundation for acquiring subsequent skills.

Various training methods have been developed to enhance forehand drive performance. Shadow training improves movement patterns without ball contact interruptions (Gusman et al., 2025; Pratama, 2021). Dynamic ball training and multiball exercises increase repetition frequency and enhance the upper arm muscle stretch-shortening cycle (Asri et al., 2017). Sensory tools, such as target boards and auditory cues, provide feedback

that enhances shot accuracy and proprioceptive awareness (Basiri et al., 2020). Game-based training reinforces decision-making and adaptability in unpredictable match contexts (Pane et al., 2020). While each of these methods demonstrates benefits, the current literature remains at an impasse, primarily due to technical gaps rather than holistic approaches.

The primary limitation of the existing protocols is their fragmentation. When applied independently, these methods fail to address the holistic demands of motor learning in children, an approach increasingly recognized as essential for youth development (Martindale et al., 2007). For 6–9-year-olds, monotonous repetitive training, which is the default in many conventional settings, leads to premature technical consolidation without the necessary contextual variation for long-term skill retention and transfer (Schmidt & Lee, 2019). This concern is supported by research on contextual interference, which indicates that while blocked practice may lead to faster initial performance gains, it typically results in poorer retention and transfer to novel situations compared to more variable practice schedules (Krstulović et al., 2020). In contrast, relying solely on game-based play without sufficient technical repetition leads to higher error rates and reinforcement of flawed biomechanical patterns. This tension creates a pedagogical contradiction—developmental needs for high-volume, accurate repetitive training to consolidate motor pathways directly conflict with the psychological need for varied, engaging stimuli that maintain attention and prevent fatigue in young children.

Furthermore, the role of eye-hand coordination (EHC) as a potential moderator of intervention effects remains a critical unanswered question. EHC is not merely a correlate of performance; it is a fundamental perceptual-motor barrier that training stimuli must overcome (Hülsdünker et al., 2019; Utama et al., 2023). It is plausible that complex multimodal interventions may inadvertently benefit children with superior basic visuomotor integration, thus widening the performance gap (Matthew effect). The Matthew effect in this context would manifest as the "rich become richer" phenomenon, where small initial advantages in ability could accumulate and be amplified by a training program that is not sensitive to individual baseline differences (Bakermans-Kranenburg et al., 2005). Conversely, if the hybrid model provides adequate external scaffolding (e.g., enhanced feedback from sensory tools), it may narrow the gap, acting as a compensatory mechanism for children with low baseline EHC. The absence of empirical evidence regarding this interaction renders current coaching practices speculative. Coaches cannot ascertain whether the integrated training protocol is an inclusive tool for all athletes or a selective accelerator for those already well-coordinated and transform a potentially polarizing training tool into a universally effective and equity-promoting intervention (Plak et al., 2016).

This study is designed to resolve the specific pedagogical contradiction identified in the research question: the inherent tension between high-volume, accurate repetition required to consolidate motor pathways and the limited attentional capacity typical of children aged 6–9. Therefore, the objective is not merely to analyze the broad effects but to determine whether the sequential multimodal hybrid training protocol can reconcile this contradiction more effectively than conventional constant training. Furthermore, this study aims to clarify whether basic eye-hand coordination (EHC) moderates intervention effectiveness, for example, whether the hybrid model serves as an inclusive developmental tool or as a selective accelerator that differentially benefits those with higher early visuomotor capacity.

Three initial hypotheses were formulated: (1) The hybrid model will result in a significantly greater improvement in forehand drive accuracy compared to conventional training, based on contextual interference and part-to-whole transfer; (2) athletes with high EHC will outperform athletes with low EHC, regardless of training condition, reflecting the fundamental performance constraints imposed by visuomotor integration; and (3) a significant Training × EHC interaction will emerge, with competing predictions between compensatory mechanisms (narrowing the gap) versus Matthew effects (widening the gap) to be empirically tested. Based on the needs analysis, preliminary observations of PTMSI Makassar coaching, and the identification of forehand drive training methods and models previously applied by coaches, the researchers plan to further develop this training model by integrating several methods, including shadow training, dynamic ball exercises, sensory tools, and game-based play. The combination of these various training methods has been summarized into a structured training program.

Materials and Methods

Study Design

A 2×2 factorial, parallel group, quasi-experimental design was used to examine the main and interaction effects of the training model (hybrid vs. conventional) and eye-hand coordination level (high vs. low) on forehand drive performance. The study was conducted at the Table Tennis Training Center of PTMSI Makassar, Indonesia.

Table 1. The 2x2 Factorial Design

Training Model	High EHC	Low EHC
Experimental (Hybrid)	EH_H (n = 7)	EH_L (n = 7)
Control (Conventional)	CH_H (n = 7)	CH_L (n = 7)

Note: EH_H = Experimental group, High EHC; EH_L = Experimental group, Low EHC; CH_H = Control group, High EHC; CH_L = Control group, Low EHC. All four cells contain 7 participants, yielding a total sample of 28.

Sample and Allocation

A total of twenty-eight young table tennis athletes (ages 6–9) registered with PTMSI Makassar were recruited through purposive sampling. A priori power analysis conducted using GPower 3.1 (Faul et al., 2007) for a two-way ANOVA ($\alpha = 0.05$, power = 0.80, large effect size $f = 0.40$) indicated that a minimum total sample of 24 participants was necessary; thus, 28 participants were enrolled to account for potential attrition. The inclusion criteria included: (a) active PTMSI membership for at least one year; (b) the ability to perform a basic forehand drive; (c) no history of upper or lower extremity injury within the preceding six months; and (d) willingness to attend all 14 training sessions. The exclusion criteria were: (a) absence from more than two consecutive sessions and (b) any acute illness or injury occurring during the intervention.

Allocation procedure

Due to the need for coordinated access to specific training equipment and coaching schedules, participants were non-

randomly assigned to either the experimental group (hybrid training, n = 14) or the control group (conventional training, n = 14). The allocation was based on the convenience of training slots while ensuring that the groups were balanced in terms of age and initial performance level; subsequent pre-test analysis confirmed baseline equivalence (see Results). Within each group, the 14 athletes were further stratified into high (n = 7) and low (n = 7) eye-hand coordination subgroups based on their age-adjusted Beery VMI standard scores (high: ≥100, low: <100).

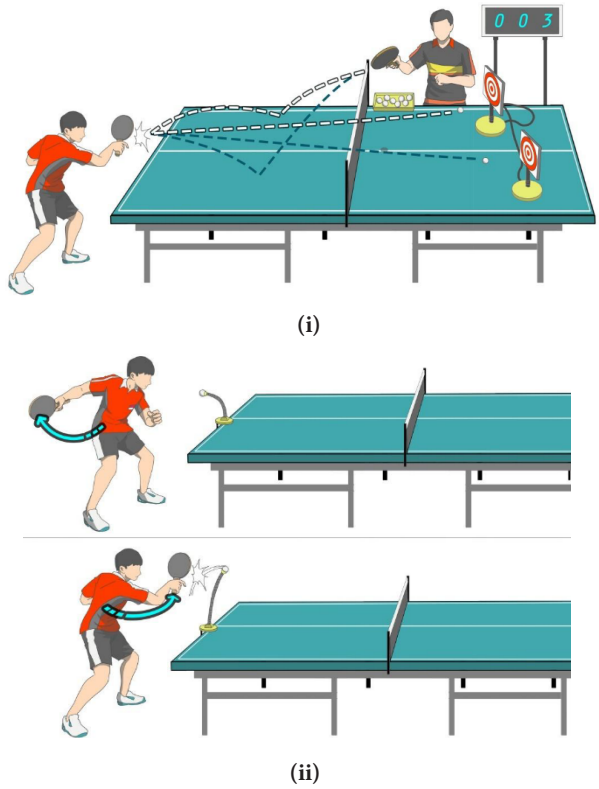

Fig. 1. Forehand Training using Dynamic Ball (i) and Sensory Tool (ii)

Procedure

Eye–Hand Coordination Assessment

Eye-hand coordination was assessed before the intervention using the Beery-Buktenica Developmental Test of Visual Motor Integration (Lim et al., 2015). The test requires children to copy 24 geometric forms of increasing complexity within 10–15 minutes. Raw scores were converted to age-adjusted standard scores (M = 100, SD = 15), and participants were classified as high (≥100) or low (<100) EHC.

Training Protocols

Both groups engaged in 14 training sessions (three sessions weekly, each lasting 50 minutes), overseen by certified table tennis coaches. The experimental group adhered to a structured hybrid model comprising: (1) ten minutes of shadow drills without a ball to enhance movement patterns and footwork; (2) fifteen minutes of dynamic ball training utilizing a suspended ball apparatus to promote high-volume repetitive strikes with intrinsic feedback; (3) ten minutes of sensory tools, including visual and auditory targets, designed to improve shot accuracy and proprioceptive feedback; and (4) fifteen minutes of game-based drills, such as modified small-sided matches, to facilitate the transfer of skills into representative contexts. Conversely, the control group underwent traditional training, characterized by repetitive forehand drive exercises devoid of any systematic advancement or integrated elements.

Evaluator and Concealment

All pre-test and post-test evaluations of forehand drive performance were administered by a sole certified table tennis coach possessing 10 years of coaching experience, who remained independent of the training intervention. The assessor was unaware of the participants' group assignments and did not know if any athlete belonged to the experimental or control group during both assessment sessions. Due to the nature of the physical intervention, it was impractical to blind either the coaches administering the training or the participants involved. Nonetheless, data analysts were unaware of group assignments during the statistical analysis phase.

Regulation of External Training Loads

To minimize extraneous variation, all participants and their guardians were instructed to abstain from any supplementary organized table tennis practice outside the designated study sessions throughout the 5-week intervention period. Compliance was assessed via a weekly self-report log; no participant indicated significant external training throughout the study.

Performance Indicator

The performance of the forehand drive was assessed utilizing the validated test established by Rihtiana and Tomoliyus (2014). Each athlete performed 10 forehand drives aimed at three concentric target zones (30×30 cm, 60×60 cm, and 60×60 cm), receiving scores of 5, 3, and 1, respectively, resulting in a maximum attainable score of 50. The instrument exhibits substantial test-retest reliability (ICC = 0.89) and content validity.

Statistical Analysis

Descriptive statistics were computed for each factorial cell. Baseline equivalence was assessed via one-way ANOVA on pre-test scores. To evaluate the intervention effect while controlling for initial differences, a two-way analysis of covariance (ANCOVA) was performed on post-test scores with pre-test scores as the covariate, training model and EHC level as fixed factors, and the two-way interaction term included. Effect sizes were reported as partial eta squared (η^2), interpreted according to Cohen's benchmarks (.01 small, .06 medium, .14 large). Assumptions of normality, homogeneity of variance, and homogeneity of regression slopes were checked and satisfied. All analyses were conducted in SPSS (version 26.0) with $\alpha = 0.05$.

Results

Descriptive analysis presents the mean scores and standard deviations of forehand drive skills in table tennis for athletes in both the experimental and control groups. The two groups were distinguished by their high and low eye-hand coordination abilities. Table 1 displays the average forehand drive scores and standard deviations for each of the four factorial cells. The forehand drive assessment has a maximum score of 50 points. No participant attained this maximum; nonetheless, the highest recorded score was 49 points. Consequently, this measure is sufficiently sensitive to detect changes without range limitations.

Table 2. Pretest and Posttest Forehand Drive Scores

Group	n	Pretest Mean (SD)	Posttest Mean (SD)	Mean Change
Experimental High (EH_H)	7	42.14 (3.67)	45.86 (2.41)	+3.71
Experimental Low (EH_L)	7	41.86 (2.48)	43.43 (1.13)	+1.57
Control High (CH_H)	7	42.71 (1.70)	43.57 (1.51)	+0.86
Control Low (CH_L)	7	41.57 (3.16)	40.71 (2.69)	–0.86

Note: Maximum score = 50 points. SD = standard deviation.

The descriptive analysis in Table 2 indicates that all groups commenced with similar baseline levels, with mean scores between 41.57 and 41.86 for the low category and between 42.14 and 42.71 for the high category. Post-intervention, the experimental groups exhibited more substantial positive changes (+3.71 for EH_H, +1.57 for EH_L) relative to the control groups (+0.86 for CH_H, –0.86 for CH_L). The raw change scores offer preliminary evidence of varying improvement, which was later examined through inferential analysis that considers baseline variance.

Baseline Equivalence

A one-way analysis of variance (ANOVA) was performed on the pre-test forehand drive scores to assess the comparability of the four groups prior to the intervention. The analysis indicated no statistically significant differences between the groups, $F_{(3, 24)} = 0.21$, $p = 0.892$, partial $\eta^2 = 0.026$. The minimal and inconsequential effect size suggests that any pre-existing disparities in forehand drive performance were trivial. Consequently, the assumption of baseline equivalence is fulfilled, thereby enhancing the internal validity of subsequent causal inferences concerning the effects of the intervention. To ensure thoroughness and facilitate comparison with studies presenting basic post-test analyses, a two-way factorial ANOVA was performed on post-test forehand drive scores, utilizing Training Model (Experimental vs. Control) and Eye–Hand Coordination (High vs. Low) as between-subjects variables. The assumptions of normality (Shapiro–Wilk, $p > 0.05$) and homogeneity of variance (Levene's test, $F_{(3,24)} = 0.52$, $p = .672$) were satisfied.

There was a significant difference between the group receiving the hybrid training model and the group receiving conventional training, regardless of eye-hand coordination level ($F_{(1, 24)} = 10.53$, $p = 0.003$, partial $\eta^2 = 0.305$). Additionally, a significant effect of eye-hand coordination level on forehand drive performance was observed: athletes with high EHC consistently scored higher than athletes with low EHC, regardless of the training group ($F_{(1, 24)} = 11.77$, $p = 0.002$, partial $\eta^2 = 0.329$). However, the interaction was not significant. This means that the difference in scores between the hybrid and conventional training groups was not dependent on the child's eye-hand coordination level ($F_{(1, 24)} = 0.08$, $p = 0.783$, partial $\eta^2 = 0.003$), with the hybrid model showing benefits for both high and low EHC children.

In this study, the correlation between pre-test and post-test scores was moderate and positive, $r_{(26)} = 0.52$, $p = 0.005$, which meets the key condition for the effective use of ANCOVA. Therefore, a two-way ANCOVA was performed on post-test forehand drive scores, with pre-test scores as the covariate, training model (Experimental vs. Control), and eye-hand coordination level (EHC High vs. Low) as between-subjects factors, including the two-way interaction term.

Before interpreting the ANCOVA results, the underlying assumptions were tested. The assumption of normality was assessed using the Shapiro-Wilk test for the residuals of each factorial cell; all p values exceeded 0.05, indicating no significant departure from normality. Levene's test confirmed the homogeneity of variances across the four groups, $F_{(3, 24} = 0.52$, $p = 0.672$. The assumption of homogeneity of regression slopes was satisfied, as the interactions between the covariate and each independent variable were not significant: Pre-test × Training Model, $F_{(1, 22)} = 0.06$, $p = 0.814$; Pre-test × EHC, $F_{(1, 22)} = 0.30$, $p = 0.592$. Thus, all assumptions underlying ANCOVA were satisfied.

A significant main effect of eye-hand coordination (EHC) was also observed, $F_{(1, 23)} = 16.90$, $p < 0.001$, partial $\eta^2 = 0.423$, with high EHC athletes ($M = 44.54$, $SE = 0.39$) outperforming low EHC athletes ($M = 42.25$, $SE = 0.39$). The interaction between the training model and EHC was not significant, $F_{(1, 23)} = 0.001$, $p = 0.991$, partial $\eta^2 < 0.001$, indicating that the magnitude of the hybrid training model's advantage over conventional training did not differ significantly between high and low coordination participants within the constraints of the current sample. To further explore the differences between individual factorial cells, Tukey's Honestly Significant Difference (HSD) post-hoc tests were conducted (Table 5).

The only statistically significant pairwise difference was identified between the Experimental High EHC group

Table 3 (Alternative). TwoWay ANOVA Results for Posttest Forehand Drive Scores

Source	Type III SS	df	MS	F	p	partial η^2
Training Model (T)	43.75	1	43.75	10.53	.003	.305
Eye–Hand Coordination (EHC)	48.89	1	48.89	11.77	.002	.329
T × EHC Interaction	0.33	1	0.33	0.08	.783	.003
Error	99.72	24	4.16			

Note. $R^2 = .48$ (Adjusted $R^2 = .42$).

Table 4. TwoWay ANCOVA Results Forehand Drive Scores

Source	Type III SS	df	MS	F	p	partial η^2
Corrected Model	102.96	4	25.74	11.95	<.001	0.675
Intercept	24.25	1	24.25	11.26	0.003	0.329
Pretest	38.24	1	38.24	5.89	0.023	0.204
Training	46.32	1	46.32	21.50	<.001	0.483
EHC	36.40	1	36.40	16.90	<.001	0.423
Training × EHC	0.0003	1	0.0003	0.001	0.991	0.000
Error	49.53	23	2.15			
Total	53107.00	28				
Corrected Total	152.49	27				

Note. R^2 = .66 (Adjusted R^2 = .60). Partial η^2 benchmarks: small ≈ .01, medium ≈ .06, large ≈ .14 (Cohen, 1988).

Table 5. Tukey's HSD PostHoc Comparisons Between Factorial Cells

(I) Group	(J) Group	Mean Difference (I–J)	SE	p	95% CI Lower	95% CI Upper
EH_H	EH_L	2.43	1.09	0.145	−0.62	5.48
EH_H	CH_H	2.29	1.09	0.186	−0.76	5.34
EH_H	CH_L	5.14	1.09	<0.001	2.09	8.19
EH_L	CH_H	−0.14	1.09	0.999	−3.19	2.91
EH_L	CH_L	2.71	1.09	0.081	−0.34	5.76
CH_H	CH_L	2.86	1.09	0.060	−0.19	5.91

Note. SE = 1.09 (pooled from oneway ANOVA MS_within = 4.155, df = 24). Bold text indicates a significant pairwise difference (p-value < .05). All pvalues are adjusted for multiple comparisons.

(EH_H, M = 45.86) and the Control Low EHC group (CH_L, M = 40.71), resulting in a difference of 5.14 points. No further comparisons reached statistical significance. This pattern corresponds with the principal effects observed in the ANCOVA and highlights the synergistic benefit of hybrid training and enhanced baseline coordination in the most favorable condition compared to the least favorable one. However, owing to the absence of substantial interaction in the comprehensive factorial model, these cell-wise comparisons should not be overinterpreted.

Illustration of the Insignificant Interaction

An interaction plot was created to demonstrate the absence of a significant interaction (Figure 2). The graph depicts the mean forehand drive scores for the experimental and control groups at two tiers of eye-hand coordination. The lines representing the two training models are nearly parallel, suggesting that the influence of the hybrid training model was unaffected by the athletes' initial eye-hand coordination. Figure 2 depicts parallel lines, signifying a non-significant interaction.

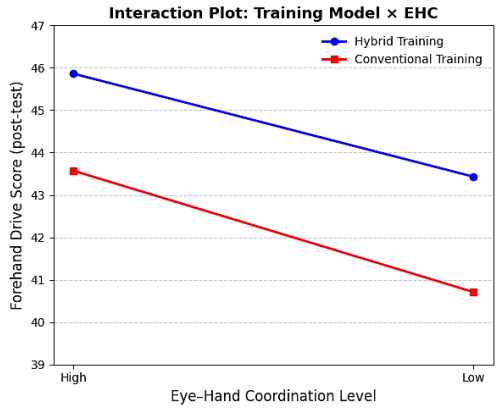

Fig. 2. Interaction Plot of Training Model × EyeHand Coordination on Forehand Drive

Discussion

This study investigated the impact of a sequentially integrated hybrid training model comprising shadow drills, dynamic ball exercises, sensory apparatus, and game-based activities. The influence on forehand drive performance was evaluated in young table tennis players aged 6 to 9 years, considering the significance of eye-hand coordination (EHC). This study's findings can be encapsulated in three principal results: (1) the hybrid training model yielded a statistically and practically significant enhancement in forehand drive accuracy relative to traditional training, after adjusting for pre-test scores; (2) elevated EHC was independently correlated with improved post-test performance; and (3) no significant interaction was observed between the training model and EHC level.

The substantial primary effect of the training model, indicated by a large effect size partial η^2 = .483, aligns with research highlighting the advantages of diverse and

organized training. All elements of this hybrid protocol conform to established principles of motor learning. Shadow training deconstructs movement patterns and diminishes the cognitive burden associated with ball tracking (Gusman et al., 2025; Robin & Dominique, 2025; Pratama, 2021). Dynamic ball exercises offer the necessary repetition volume to improve motor pathways while incorporating intrinsic feedback (North et al., 2019; Asri et al., 2017). The sensory apparatus offers supplementary feedback aimed at enhancing spatial precision (Basiri et al., 2020), which is crucial for athletes to accurately track and respond to moving objects during dynamic ball exercises. Game-based training exposes participants to progressively distracting contextual conditions, which has been demonstrated to improve skill retention and transfer (Vaghetti et al., 2023; Pane et al., 2020; Galatti et al., 2019; Schmidt & Lee, 2019). By amalgamating these elements into a unified session, the hybrid model may have fulfilled the requirement for engaging, repetitive practice for youth while maintaining balance. The Beery VMI test employed in this study assesses visual perception, motor planning, and fine motor control, all pertinent to the demands of striking small, rapidly moving targets. The recent discovery that EHC can autonomously predict the precision of the forehand drive aligns with prior research and indicates that EHC assessment may serve as an effective instrument for identifying young athletes (Susetyorini et al., 2019) who might gain from enhanced motor-perceptual training.

Research by Basiri et al. (2020) demonstrates that visual training, when combined with forehand practice, improves reaction time, anticipation-coincidence timing, and eye-hand coordination, as well as the acquisition and retention of the forehand drive in novice players. This corresponds with the study's findings, indicating that enhancing EHC capabilities through visual training can aid in the acquisition of technical skills, such as the forehand drive in table tennis. This study illustrates that integrating varied visual and motor exercises into a hybrid training model validates the importance of visual-based training, especially eye-hand coordination, in the enhancement of complex motor skills. Extensive research by Johor & Rahmadiky (2020) and Kurniawan & Rangkuti (2020) demonstrated that eye-hand coordination and arm strength significantly correlate with forehand drive proficiency, each accounting for over fifty percent of the variance in this skill within their respective samples. These findings correspond with the study's results, indicating that EHC functions as an independent predictor of forehand drive accuracy. This study found no significant interaction between training models and EHC levels; however, the results substantiate the claim that EHC significantly affects technical performance. The positive correlation between eye-hand coordination and arm strength with stroke proficiency suggests that these elements are crucial for the development of motor skills in table tennis (Sharma et al, 2024).

Mongsidi et al. (2023) illustrate that focused eye-hand coordination training significantly improves forehand drive skills in children. The findings endorse the training methodology utilized in the hybrid model, indicating that exercises focused on repetition and reinforcement of motor coordination with a dynamic ball can improve the precision of the forehand drive movement. The results correspond with current literature, indicating that enhancing fine motor coordination and visual perception in a sports context can accelerate the acquisition of intricate technical skills. Shinkai et al. (2024) demonstrated that during a forehand rally with a moving ball, the coordination of the eyes, head, and arm is markedly temporally synchronized, revealing correlations between the head and arm, as well as between the eyes and arm. Research indicates that hand-eye coordination, a component of perceptuo-motor skills, can predict future competitive performance and reduce dropout risk in youth table tennis, highlighting its importance in long-term athlete development (Faber et al., 2023). This indicates a strong correlation between integrated visual and motor movements in the forehand technique of table tennis. This study suggests that improved visuomotor coordination, marked by better synchronization of eye, head, and arm movements, may substantially enhance forehand skills. These findings provide a framework for enhancing motor coordination training in forehand instruction, as head and eye movements, in conjunction with arm movements, are crucial for refining the accuracy and timing required for this technical skill (Warzuqni et al, 2025).

This study offers initial evidence on the efficacy of the hybrid training model and the independent function of EHC; however, the lack of a significant interaction between the training model and low-level EHC indicates the necessity for additional research with a larger sample size. The interaction effect between training model and eye-hand coordination (EHC) level on forehand drive performance was non-significant with a negligible effect size. Any alternative interpretation of this interaction is erroneous. Future research should examine moderating variables or non-linear relationships that could elucidate the connection between eye-hand coordination and technical skills within the framework of table tennis training. Moreover, research incorporating biomechanical or neurophysiological assessments, such as those performed by Shinkai et al. (2022), will yield enhanced understanding of the mechanisms driving skill enhancement.

Limitation

Multiple facets of the study design must be contemplated when analyzing the results. The sample size (n = 28; 7 per cell) was established through a priori power analysis and was adequate for detecting large main effects with high precision; however, the statistical power to discern small or moderate interactions was constrained. The study lacked kinematic or physiological measures that could clarify the mechanisms behind any training effects, and the sample was sourced from a single training center, potentially limiting external validity.

Conclusions

The hybrid training model, integrating shadow drills, dynamic ball equipment, sensory devices, and game-based activities, significantly improves forehand drive performance in children aged 6–9 years compared to conventional repetitive training, with a substantial effect size (partial $\eta^2 = 0.483$). Higher baseline eye-hand coordination is associated with better forehand drive accuracy. The interaction between training model and EHC level was non-significant with a negligible effect size.

Ethics Approval and Consent to Participate

Ethical approval for the research protocol was obtained from the Research Ethics Committee of Universitas Negeri

Jakarta (Approval No: 2716/UN39.6.Ps/LT/2023. Informed consent was obtained from all individual participants included in the study prior to their involvement.

Data Availability Statement

Data are available from the corresponding author upon reasonable requestю

AI Transparency Statement

The authors used AI-assisted tools for language editing and for generating the code used in Figure 2. The authors take full responsibility for the content of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Вплив гібридного тренування, що поєднує імітаційні вправи, динамічні вправи з м'ячем, сенсорні вправи та ігрові завдання, на результативність удару справа у юних гравців у настільний теніс: факторний дизайн 2×2

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 5 табл., 2 рис., 32 джерела.

Передумови. Оптимальні протоколи тренування удару справа у юних гравців у настільний теніс (6–9 років) усе ще перебувають на стадії розроблення. Хоча імітаційні вправи без м'яча, динамічні вправи з м'ячем, сенсорні засоби та ігрові вправи мають окремі переваги, жодне дослідження не інтегрувало ці методи в єдину гібридну модель. Крім того, модифікувальна роль вихідного рівня координації «око–рука» (EHC) залишається нез'ясованою, що обмежує можливості розроблення інклюзивних тренувальних програм.

Мета. Дослідження мало на меті вивчити вплив гібридної моделі тренування на результативність виконання удару справа та оцінити, чи залежить її ефективність від вихідного рівня координації «око–рука» спортсмена.

Матеріали та методи. Було застосовано квазіекспериментальний дизайн 2×2. Двадцять вісім спортсменів із PTMSI Makassar були розподілені на експериментальну (n = 14) та контрольну (n = 14) групи, а також стратифіковані за висо-

ким або низьким рівнем координації «око–рука» (визначеним за допомогою тесту Beery VMI). Точність виконання удару справа (максимальний бал — 50) оцінювали до та після 14 тренувальних занять (по 50 хвилин, тричі на тиждень). Аналіз даних проводили за допомогою двофакторного ANCOVA з контролем показників попереднього тестування.

Результати. Після коригування результатів гібридна група продемонструвала достовірно вищі показники порівняно з контрольною групою (M = 44.68 проти 42.11; $p < 0.001$, partial $\eta^2 = 0.483$). Спортсмени з високим рівнем координації «око–рука» показали кращі результати, ніж спортсмени з низьким рівнем координації «око–рука» (M = 44.54 проти 42.25; $p < 0.001$, partial $\eta^2 = 0.423$). Взаємодія між типом тренування та рівнем координації «око–рука» не була статистично значущою ($p = 0.991$).

Висновки. Гібридна модель тренування достовірно покращила результативність виконання удару справа порівняно з традиційними методами тренування. Тренерам рекомендується інтегрувати всі чотири методи тренування у щоденні програми підготовки. Отримані результати підкреслюють важливість інтеграції різноманітних тренувальних підходів у ранньому віці та свідчать про потенційні можливості їх застосування у дитячій фізіотерапії та реабілітації рухових функцій.

Ключові слова: настільний теніс, удар справа, гібридне тренування, координація «око–рука», ранній дитячий вік.

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Sex Differences in Gross Motor Quotient among Students: Evidence from TGMD-2 Assessment

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Abstract

Objectives. This study aims to assess and compare Fundamental Motor Skills (FMS) using gender-based Gross Motor Quotient (GMQ) scores in elementary school students.

Materials and Methods. The study involved 24 fourth-grade elementary school students (12 boys, 12 girls; M±SD = 10.21±0.41) to assess gross motor skills using the TGMD-2. The locomotor and object-control subtests were assessed in two trials using binary criteria and then converted into standard scores and GMQ values. The analysis included descriptive statistics, normality tests, independent t-tests or Mann-Whitney U tests, and effect size calculations to compare motor skills between genders.

Results. Gross Motor Quotient (GMQ) analysis showed that most students had low gross motor skill levels. The boys' group was in the very poor category (GMQ 58-67) for both locomotor and object-control skills, indicating low uniformity across subtests. The girls' group showed greater variation (GMQ 61-82), but the majority were still classified in the very poor or poor categories. Independent-samples t-tests on the locomotor and object-control subtests showed no significant differences between genders, except for the slide subtest, in which girls performed better ($p = 0.038$). A Mann-Whitney U test on the GMQ confirmed a significant difference between the groups, with girls outperforming boys ($p = 0.005$; effect size = 0.57). These findings confirm the low level of gross motor skills among students and emphasize the need for structured motor learning interventions to improve locomotor and object-control competencies.

Conclusions. Future research should explore game-based adaptive learning models, optimal exercise dosage, and the integration of sensorimotor and motivational approaches to improve elementary school students' GMQ.

Keywords: locomotor, object control, gross motor quotient, fundamental motor skills, differentiated physical education.

Introduction

Fundamental Motor Skills (FMS), which include locomotor skills and object control, are the foundation of students' physical, cognitive, and social development (Piotrowski et al., 2025). While essential, FMS development does not occur automatically with age; children require systematic instruction, sufficient practice, and feedback from trained teachers (Nobre et al., 2018; Valentini et al., 2016). In many schools, physical education instruction still emphasizes free play and general fitness activities, with little focus on specific motor skills, resulting in children often not achieving age-appropriate standards (Barnett et al., 2016). Optimal motor learning requires physical and mental practice, instructional reinforcement, sensorimotor adaptation, variety and frequency of practice, structured feedback, and student motivation (Bates et al., 2026; Leech et al., 2022). This gap underscores the urgency of identifying underdeveloped FMS in elementary school students as a first step to assess students' Gross Motor Quotient (GMQ) and understand the extent of their motor delays. Without systematic evaluation, interventions may be poorly targeted and fail to improve children's motor competence.

Empirical data demonstrate variation in FMS abilities in elementary school students. Students aged 7-9 years show improved locomotor abilities compared to younger ages, but most still fall within the "average" or "below average" category

for locomotor skills, and "poor" to "below average" for object control (Lin & Yang, 2015; Mukherjee et al., 2017). In Indonesia, the average locomotor score is 78.7, while object-control skills are much lower, at around 8% (Oktarifaldi et al., 2024). Another study also confirmed that despite high student participation, 90% boys and 92% girls, traditional physical education still fails to provide sufficient motor learning experiences to address children's developmental delays (Makaruk et al., 2025). These data indicate that even though children participate in physical education, their FMS competencies do not meet normative standards, underscoring the need for a comprehensive evaluation before designing interventions. Identification of FMS using the GMQ is an important indicator for understanding motor strengths and weaknesses and for determining development priorities, both in locomotor and object-control aspects.

School environment factors, facilities, gender, and training opportunities also influence the FMS gap in students. Boys tend to show higher FMS scores than girls, particularly in object-control skills, due to a higher frequency of practice and greater interest in ball games (Komaini et al., 2023; Razali et al., 2025). Conversely, girls students face physical barriers and activity preferences that are less conducive to their motor development. Systematically identifying FMS through the GMQ enables teachers to understand each student's individual needs, reduce gender disparities, and determine more appropriate physical education learning strategies. Children with low GMQ in locomotor and object control are at risk of experiencing difficulties in daily physical activities and not achieving age-appropriate developmental standards (Mukherjee et al., 2017; Oktarifaldi et al., 2024). Therefore, measuring the GMQ in elementary school students is a crucial step in designing evidence-based interventions, such as targeted exercises, explicit instruction, and adjustments to the physical education curriculum, to improve children's motor skills optimally.

The purpose of this study was to assess and compare gender-based physical education (FMS) in elementary school-aged children using the GMQ. Systematic evaluation of FMS in elementary school students is a critical step to ensure interventions have a real and sustainable impact. The results of this study support teachers and policymakers in designing effective physical education programs.

Materials and Methods

Study participants

This study involved 24 elementary school students (M±SD = 10.21±0.41) from an elementary school in Bandung, West Java, Indonesia. Participants were 12 boy and 12 girl students. Inclusion criteria included: (1) actively enrolled students, (2) no physical or neurological disorders affecting movement, and (3) written consent from a parent or guardian. Students who were injured or absent during data collection were excluded from the study.

Study organization

This study used a quantitative descriptive-comparative design to evaluate the gross motor skills of elementary school-aged children, specifically fourth-grade students, and to compare motor skills between boys and girl groups. The focus of this study was on measuring gross motor skills using the standardized Test of Gross Motor Development-Second Edition (TGMD-2) instrument developed by Ulrich (2000). The TGMD-2 was chosen for its high reliability and validity and for its ability to measure two main dimensions of gross motor skills: locomotor and object control.

Prior to the measurements, each participant was given a detailed explanation of the measurement procedure and asked to wear sports clothing suitable for physical activity. It was done to ensure participants could move freely and perform each motor skill optimally. Next, each participant completed all TGMD-2 subtests on the school sports field under the supervision of trained researchers who were familiar with the TGMD-2 assessment standards.

During the subtests, each skill was assessed based on predetermined performance criteria. For each criterion, scoring was conducted using a binary system: 1 if the criterion was met and 0 if it was not. Each skill was performed in two formal trials to increase assessment accuracy. All raw scores from each subtest (locomotor and object control) were systematically recorded for each participant and used to convert to standard scores and the Gross Motor Quotient (GMQ).

Instrument

Participants' gross motor skills were assessed using the Test of Gross Motor Development-Second Edition (TGMD-2) developed by Ulrich (2000). This instrument demonstrated good reliability and validity. The internal consistency coefficient for the locomotor subtest was $\alpha = 0.85$, while the coefficient for the object control subtest was $\alpha = 0.88$. The Gross Motor Quotient (GMQ) also demonstrated higher internal reliability ($\alpha = 0.91$). Furthermore, test-retest reliability results demonstrated high consistency, with coefficients of 0.88 for the locomotor subtest, 0.93 for the object control subtest, and 0.96 for the GMQ. It indicates that the TGMD-2 instrument has good measurement stability over time. In terms of construct validity, the loading factor values ranged from 0.49 to 0.75, indicating that each indicator contributes moderately to strongly to the construct being measured. Furthermore, the goodness-of-fit indices also demonstrated good fit, with a Goodness-of-Fit Index (GFI) of 0.96, an Adjusted Goodness-of-Fit Index (AGFI) of 0.95, and a Tucker-Lewis Index (TLI) of 0.90. Therefore, it can be concluded that the TGMD-2 measurement model adequately fits the empirical data.

The locomotor subtest consists of six skills: first, running with four performance criteria. Second, gallop with four performance criteria. Third, hop with five performance criteria. Fourth, leap with three performance criteria. Fifth, horizontal jump with four performance criteria. Finally, slide with four performance criteria.

Meanwhile, the object control subtest also includes six skills: first, striking a stationary ball with five performance criteria. Second, stationary dribble with four performance criteria. Third, catch with 3 performance criteria. Fourth, kick with 4 performance criteria. Fifth, overhand throw with 4 performance criteria. Finally, underhand roll with 4 performance criteria.

Statistical analysis

In the TGMD-2, the assessment of a child's motor skills begins with a raw score obtained through direct observation

of locomotor and object-control skills. This score is calculated based on the number of correctly performed movement criteria and does not account for age factors or population norms. Next, the raw locomotor and object control scores are converted into standard scores using normative tables based on age and gender, specifically for students aged 10-11 years, with girl norms used for girls and boy norms for boys. This stage aims to compare children's abilities with their age group more objectively.

The two standard scores from each subtest were then summed and converted back to a GMQ using the TGMD-2 conversion table (Ulrich, 2000) (see Table 1). The GMQ is normative, with a mean of 100 and a standard deviation of 15, allowing for the classification of children's abilities into categories such as below average, average, or above average. Differences between raw scores and the GMQ arise from the gradual conversion process from raw scores to standard scores and then to the GMQ. Furthermore, the use of age- and gender-specific norms can result in children with the same raw score having different standard scores and GMQ scores. The GMQ is also based on a normal distribution, reflecting a child's relative position within the population, not simply the sum of the scores obtained.

Table 1. Descriptive ratings for subtest standard scores and Gross Motor Quotient

Subtest standard scores	Gross motor quotient	Descriptive ratings	Percentage included
17-20	>130	Very superior	2.34
15-16	121-130	Superior	6.87
13-14	111-120	Above average	16.12
8-12	90-110	Average	49.51
6-7	80-89	Below average	16.12
4-5	70-79	Poor	6.87
1-3	<70	Very poor	2.34

Descriptive statistics were calculated for raw scores, standard scores, total standard scores, and GMQ. A normality test was performed to determine the appropriate inferential analysis. For normally distributed data, an independent-samples t-test was performed on the locomotor and object-control subtests. Meanwhile, the Mann-Whitney U test was used to analyze the GMQ between gender groups. Effect sizes were calculated using Cohen's (2013) formula, with the following interpretations: 0.2 (small), 0.5 (medium), and 0.8 (large).

Results

Description of Gross Motor Quotient

Gross Motor Quotient (GMQ) analysis of 12 boys students showed that their gross motor skills were classified as very low. Individual Gross Motor Quotients ranged from 58 to 67, categorized as very poor, in both locomotor and object control domains. Standard scores for each domain also showed uniformity, with locomotor scores ranging from 3 to 6 and object control scores ranging from 3 to 5 (see Table 2). This condition emphasizes the need for more structured motor learning interventions or programs aimed at improving students' locomotor and object control competencies.

Table 2. Gross Motor Quotient Profile of boy students

Participant	Total locomotor	Total object control	Raw score	Standard score locomotor	Standard score object control	Total standard score	Gross motor quotient	Descriptive ratings
1	33	30	63	5	3	8	64	Very poor
2	32	34	66	4	4	8	64	Very poor
3	35	31	66	5	3	8	64	Very poor
4	33	32	65	5	3	8	64	Very poor
5	30	36	66	4	5	9	67	Very poor
6	31	33	64	4	4	8	64	Very poor
7	27	30	57	3	3	6	58	Very poor
8	29	31	60	3	3	6	58	Very poor
9	36	32	68	6	3	9	67	Very poor
10	31	33	64	4	4	8	64	Very poor
11	30	30	60	4	3	7	61	Very poor
12	34	32	66	5	4	9	67	Very poor

Meanwhile, girl students (n = 12) showed greater variation in GMQ, ranging from 61 to 82, with the low category still predominating. Five participants were categorized as very poor, six as poor, and one as below average. Locomotor scores ranged from 24 to 38, while object control scores ranged from 28 to 38 (see Table 3). Interindividual variation was observed, but overall, it indicated that gross motor skills were still limited in most participants. This finding again emphasizes the need for structured motor intervention or learning programs to improve locomotor and object-control skills, so that students' GMQ can be placed in a more adequate category.

Table 3. Gross Motor Quotient profile of girl students

Participant	Total locomotor	Total object control	Raw score	Standard score locomotor	Standard score object control	Total standard score	Gross motor quotient	Descriptive ratings
1	34	30	64	5	5	10	70	Poor
2	36	38	74	6	8	14	82	Below average
3	24	30	54	2	5	7	61	Very poor
4	26	32	58	2	6	8	64	Very poor
5	32	28	60	4	4	8	64	Very poor
6	30	32	62	4	6	10	70	Poor
7	30	31	61	4	5	9	67	Very poor
8	28	33	61	3	6	9	67	Very poor
9	32	33	65	4	6	10	70	Poor
10	38	34	72	7	6	13	79	Poor
11	31	32	63	4	6	10	70	Poor
12	34	32	66	5	6	11	73	Poor

Independent samples t-test (locomotor and object control subtest)

Before conducting the mean difference test, a normality test was first performed on the research variables to ensure the data met the parametric assumptions for both the locomotor and object control (gender) subtests.

Table 4. Tests of normality

Variable	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Locomotor subtest (boys)	0.114	12	0.200*	0.985	12	0.997
Locomotor subtest (girls)	0.128	12	0.200*	0.985	12	0.996
Object control subtest (boys)	0.167	12	0.200*	0.912	12	0.224
Object control subtest (girls)	0.188	12	0.200*	0.912	12	0.249

*. This is a lower bound of the true significance
a. Lilliefors Significance Correction.

Table 5. Testing the locomotor subtest

No	Locomotor subtest	Group statistics (M±SD)		Independent samples t-test		
		Boys (n=12)	Girls (n=12)	t-value	Two sided p	Decision
1	Run	5.33 ± 1.37	4.08 ± 1.93	1.830	0.081	Not significant
2	Gallop	5.75 ± 1.71	4.83 ± 1.27	1.491	0.150	Not significant
3	Hop	6.75 ± 1.06	6.67 ± 0.78	0.220	0.828	Not significant
4	Leap	3.58 ± 0.67	3.92 ± 0.79	-1.113	0.278	Not significant
5	Horizontal jump	5.58 ± 1.44	5.92 ± 1.31	0.592	0.560	Not significant
6	Slide	4.75 ± 1.42	5.83 ± 0.94	-2.203	0.038	Significant
	Total	5.29 ± 1.60	5.21 ± 1.56	0.362	0.721	Not significant

Table 6. Testing the object control subtest

No	Subtest object control	Group statistics (M±SD)		Independent samples t-test		
		Boys (n=12)	Girls (n=12)	t-value	Two sided p	Decision
1	Striking a stationary ball	6.25 ± 1.42	5.92 ± 1.44	0.570	0.575	Not significant
2	Stationary dribble	5.58 ± 1.08	5.33 ± 1.23	0.528	0.603	Not significant
3	Catch	4.17 ± 1.34	4.17 ± 0.58	0.000	1.000	Not significant
4	Kick	5.17 ± 1.53	5.33 ± 1.07	0.309	0.760	Not significant
5	Overhead throw	5.33 ± 0.65	5.92 ± 1.51	-1.232	0.231	Not significant
6	Underhand roll	5.50 ± 0.65	5.42 ± 1.08	0.205	0.840	Not significant
	Total	5.33 ± 1.31	5.42 ± 1.08	-0.094	0.926	Not significant

The results of the normality tests using the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that all study variables did not deviate from normality. For the locomotor subtest, the Kolmogorov-Smirnov statistic values for the boys and girls groups were 0.114 and 0.128, respectively, with p values >0.05. At the same time, the Shapiro-Wilk test showed a value of 0.985 for both groups with p values >0.05 (see Table 4).

For the object control subtest, the Kolmogorov-Smirnov test yielded statistical values of 0.167 (boy) and 0.188 (girl) with p values >0.05, and the Shapiro-Wilk test yielded statistical values of 0.912 (girl) with p values >0.05. This finding indicates that the data meet the assumption of normality, so parametric tests, such as the independent samples t-test, can be applied.

The test results showed no significant differences in most locomotor subtests, including the run (t = 1.830, p = 0.081), gallop (t = 1.491, p = 0.150), hop (t = 0.220, p = 0.828), leap (t = -1.113, p = 0.278), and horizontal jump (t = 0.592, p = 0.560). Similarly, the total locomotor skill score showed no significant difference between boys and girl participants (t = 0.362, p = 0.721) (see Table 5).

However, the slide subtest showed a significant difference (t = -2.203, p = 0.038), with girls participants (M±SD = 5.83±0.94) scoring higher than boy participants (M±SD = 4.75±1.42). It suggests that, while overall locomotor abilities were relatively balanced between the two groups, there were differences in specific skills, such as slide movement.

These findings highlight the potential for more focused interventions to improve skills that show significant differences between the groups.

Further testing results showed no significant differences in any object-control subtests between boy and girl participants. The details are as follows: Striking a stationary ball (t = 0.570, p = 0.575), stationary dribble (t = 0.528, p = 0.603), catch (t = 0.000, p = 1.000), kick (t = 0.309, p = 0.760), overhead throw (t = -1.232, p = 0.231), and underhand roll (t = 0.205, p = 0.840). The total object control score also showed no significant difference between the boys and girls groups (t = -0.094, p = 0.926) (see Table 6).

These results indicate that object-control abilities were relatively equal between men and women in this sample. It confirms that, despite individual variation, there is no overall trend of gender differences in object control skills.

Mann-Whitney U test (differences between boys and girls GMQ)

The Shapiro-Wilk normality test indicated that the GMQ data in the boys group were not normally distributed

Table 7. Tests of normality

Variable	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Gross Motor Quotient (boys)	0.314	12	0.002	0.829	12	0.020
Gross Motor Quotient (girls)	0.234	12	0.070	0.926	12	0.341

*. This is a lower bound of the true significance
a. Lilliefors Significance Correction.

Table 8. Differences in Gross Motor Quotient of participant groups

Descriptive statistics and mean rank				
Variable	**Group**	**N**	**Mean rank**	**Sum of ranks**
Gross Motor Quotient	Boys	12	8.54	102.50
	Girls	12	16.46	197.50
Mann-Whitney U Test				
Variable	**U**	**Z**	**p-value (2-tailed)**	**Description**
Gross Motor Quotient	24.500	-2.814	0.005	Significant
Effect size				
Variable	**Z**	**N**	**Effect size**	**Category**
Gross Motor Quotient	-2.814	24	0.57	Medium

($p = 0.020 < 0.05$). In contrast, those in the girls group were normally distributed ($p = 0.341 > 0.05$). Therefore, a comparative analysis was performed using the non-parametric Mann-Whitney U test.

The Mann-Whitney U test results showed a significant difference in GMQ between boy and girl groups ($U = 24.500$; $Z = -2.814$; $p = 0.005$). Based on the mean rank value, the girls group (16.46) had a higher score than the boys group (8.54). It indicates that gross motor skills in the girls group were better than those in the boys group. The effect size value of 0.57 indicates that the difference is in the moderate category (see Table 8).

Discussion

Overview of the main objectives

The main findings indicate that the majority of students, both boy and girl, have low gross motor skills. Boy students predominantly fell into the very poor category on the GMQ, with subtest scores ranging from 3 to 5, indicating significant delays (see Table 2). Meanwhile, girl students also fell into the low category, although some reached the poor and below-average categories (see Table 3). The results showed that students' gross motor skills were below standard, with an average GMQ score of ($M \pm SD = 66.63 \pm 5.69$). Referring to the GMQ as a normative transformation based on age and gender (Ulrich, 2000), this score indicates the child's relatively low position relative to their peer group.

Regarding these quantitative findings, further analysis revealed no significant differences between boys and girls on the locomotor or object-control subtests (see Tables 5 and Table 6). However, there were differences in GMQ scores, with girl students performing slightly better, with a medium effect size according to the Mann-Whitney U test (see Table 8). Overall, these findings confirm that elementary school students' gross motor skills remain at a level that requires serious attention. Based on these data, it is important to understand how the FMS's structure explains patterns of student performance.

Fundamentals motor skills structure

The development of Fundamental Motor Skills (FMS) tends to slow after age 7. Although some skills, such as catching a ball, improve around age 10, performance in other skills—such as jumping and throwing—remains inconsistent. In fact, most skills remain at a low level until that age, with only a small number of children achieving mastery. The declining trend in FMS skills from 2000 to 2019 in children aged 6-10 further confirms that low gross motor skills are a global issue, not just a local phenomenon (Chen et al., 2024; Nobre et al., 2018; Valentini et al., 2016).

Given the FMS structure, which consists of two main components: locomotor and object control, the lack of significant differences in each subtest can be explained by the uniform quality of children's motor experiences. Various studies show that the majority of children, both boys and girls, have insufficient levels of FMS, both in school sports programs (72-77%) and traditional physical education (90-92%) (Makaruk et al., 2025). The training experience remains limited and unstructured, resulting in relatively uneven development of basic skills across both main components. As a result, differences in performance between genders at the subtest level are small and not statistically significant. Low physical literacy and a lack of interest in game-based physical education learning also exacerbate this condition, as suboptimal movement experiences hinder the development of overall motor skills (Friskawati & Stephani, 2021; Nugraha et al., 2022).

However, when these two components were integrated into a GMQ composite score, significant differences emerged. It confirms the hierarchical and composite structure of the FMS, in which the accumulation of small differences

across multiple aspects, such as coordination, balance, and motor control, can lead to more significant differences at the global level. In this study, girls demonstrated an advantage on the GMQ. Developmentally, girls tend to reach motor maturity earlier, including in coordination and consistency of performance, resulting in more stable performance on structured motor tasks (Toole & Kretzschmar, 1993). Other findings also support a girl advantage in manual dexterity and balance (Navarro-Patón et al., 2021; Smits-Engelsman et al., 2023), although some studies have shown a boy advantage in specific aspects of gross motor skills (Pahlevanian & Ahmadizadeh, 2014).

Behavioral factors such as conscientiousness, adherence to instructions, and better emotional regulation also contribute to the consistent performance of girls (Chaplin & Aldao, 2013). Furthermore, more frequent involvement in fine motor activities also supports improved motor control (Arifiyanti, 2020). Despite reports of boy superiority in manipulative skills (Razali et al., 2025), the accumulation of these factors still results in higher GMQ scores in girls.

Furthermore, environmental and lifestyle factors contribute to low performance on the two main components of the FMS. Children today tend to spend time in sedentary activities, such as more than four hours of screen time for education and one to two hours for recreation, often accompanied by snacking (Rocka et al., 2022; Vanderloo et al., 2022). It negatively impacts physical fitness, muscle strength, coordination, and balance by reducing opportunities for active play. Furthermore, limited sports facilities, safe play spaces, and green open spaces, especially in urban areas, limit children's opportunities to develop locomotor and object control skills optimally (Arufe-Giráldez et al., 2024; Bates et al., 2026).

The combination of a sedentary lifestyle and environmental constraints results in relatively uniformly low gross motor skills across both main components, so that differences at the subtest level are not significant. However, through integration into the GMQ as a more sensitive composite indicator, small variations between individuals can still accumulate and produce clearer differences at the overall level. Overall, these findings suggest that children's motor skills cannot be understood in parts but must be analyzed as a composite system within the FMS structure.

Decision role

To prevent misinterpretation, this study formulated a step-by-step decision rule. First, if locomotor and object control subtest scores do not show significant differences between boys and girls, the analysis should not stop at the subtest level. Second, researchers must proceed to evaluate the composite score, the GMQ, which is considered more representative of Ulrich (2000) version of the TGMD-2. Finally, this GMQ-based decision is crucial because the GMQ combines subtest scores via a normative transformation that accounts for age and gender.

The GMQ's characteristics allow for a more critical assessment of motor skills than raw subtest scores alone. The same raw score can have different standard scores depending on age and gender. For example, a raw locomotor subtest score of 34 can be converted to a standard score of 5 for children aged 9-0 to 10-11, 6 for ages 8-0 to 8-11, and 7 for ages 7-0 to 7-5. As children get older, their standard scores may increase or decrease for the same raw score, indicating that raw scores alone are not sufficient to assess ability relative to peers.

Conversion of object control scores also reveals gender-based differences. For example, a raw score of 34 for girls aged 10-11 to 10-11 translates to a standard score of 6, while a boy with the same score only gets a 4. Another example is a raw score of 36 for girls, a standard score of 7, while a boy gets a raw score of 6. Thus, similar subtest scores do not necessarily reflect similar abilities. The GMQ can reveal latent differences more accurately, thus providing a more critical and relevant basis for evaluating the design of pedagogical interventions.

Pedagogical projection model

Designing pedagogical interventions to improve FMS must be comprehensive and consider specific deficiencies identified through evaluations, ensuring they are not merely general but also target the most lagging skill areas. Research shows that subtests such as hop, leap, and some aspects of object control remain low, indicating the need for more focused training. This approach requires applying critical motor learning principles, including directed practice with systematic repetition and consistent, reflective feedback, enabling students to recognize errors and progressively improve movement technique (Leech et al., 2022; Seckel, 2026). Furthermore, teachers and coaches must be able to adjust the intensity, complexity, and variety of exercises to the student's individual abilities, ensuring the intervention is adaptive and inclusive. This strategy allows each child to develop comprehensive locomotor and object control skills while fostering sustained self-efficacy and motor awareness, rather than simply achieving short-term scores.

Furthermore, an effective pedagogical model must be designed with a clear structure and be adaptable to each student's individual needs. A differentiated instructional approach is crucial, as it allows teachers to identify each child's areas of weakness and tailor training to each child's needs, including duration, difficulty level, and teaching methods (Blegur & Hardiansyah, 2024; Fullerton, 2023; Razali et al., 2024). The application of innovative learning models, such as Teaching Game for Understanding (TGfU) (Gustian et al., 2024), Sport Education Model (SEM) (Tang et al., 2026), Project-based Learning (PjBL) (Simonton et al., 2021), small game competitions (Fizi et al., 2023; Hartati et al., 2022), and other models that offer a fun, contextual approach, thus encouraging student motivation and active participation in the structured motor learning process. By combining targeted practice, adaptive teaching strategies, and meaningful play experiences, the intervention not only targets improvements in locomotor and object-control skills but also strengthens the overall GMQ. This approach emphasizes the development of continuous motor skills, strategic thinking in movement, and active child engagement, ensuring a greater learning impact and avoiding a focus on short-term score achievement.

Practical constraints, such as limited learning time, facilities, equipment, and teachers' opportunities for ongoing competency development, pose significant barriers to the implementation of motor interventions in schools.

Previous research confirms that these limitations directly impact the effectiveness of systematic and targeted motor practice, preventing students from receiving consistent and optimal practice (Blegur, 2025; Hannah et al., 2025; Nielsen-Rodríguez et al., 2021; Oktarifaldi et al., 2024). To address this issue, school-based pedagogical interventions should use games, structured practice modules, and professional development programs to help teachers implement learning strategies adaptively and sustainably. This approach not only ensures the comprehensive development of FMS, both locomotor and object control, but also helps reduce the ability gap between students. Furthermore, planned and systematic motor learning experiences build a strong motor foundation, encourage active physical participation, and facilitate long-term skill acquisition, rather than simply achieving short-term scores.

Research limitations

This study has several limitations that should be considered when interpreting the results. First, the relatively small sample size of only 24 children limits statistical power and the ability to detect more subtle differences between groups. The limited sample size also increases the possibility that individual variability influences the results, so the findings may not fully reflect the broader population. Second, the study's local context, focusing only on elementary school students in one city, may limit the relevance of its findings to the geographic, cultural, and educational conditions in other regions. Environmental factors, curricula, and children's physical activity habits in other regions may differ, so the results cannot be directly generalized to the entire population of elementary school children in Indonesia. Third, the generalizability of this study is limited by its focus on a specific FMS subtest, so broader measures of motor skills or related variables such as motivation, health, and family support are not comprehensively covered. These limitations emphasize the need for further research with larger samples and more representative contexts.

Prospects for further research

This research opens the door to further studies that empirically test the effectiveness of motor interventions through experimental and longitudinal designs, for example, by evaluating changes in the GMQ following the implementation of a structured school- or community-based exercise program. Previous evidence suggests that motor interventions can improve basic skills in children with developmental delays, while functional training is effective in locomotor and balance (Goodway & Branta, 2003; Zhang et al., 2024). Furthermore, recreational physical activity programs have been shown to improve fitness and reduce body fat percentage (de Oliveira et al., 2022). Future research should explore the link between motor development and academic, cognitive, and psychosocial aspects, given the influence of sedentary lifestyles and obesity on low motor skills (Bremer & Cairney, 2018). Socioeconomic and environmental factors, including regional variations and the effectiveness of school programs, are also important to analyze (Makaruk et al., 2025). The development of an evidence-based curriculum that is adaptive, differentiated, and emphasizes physical literacy is a top priority to support children's motor development and holistic well-being (Barnett et al., 2016; Bates et al., 2026; Khudolii et al., 2025; Piotrowski et al., 2025; Razali et al., 2025).

Conclusions

This study revealed that locomotor and object control abilities, as measured by the GMQ of fourth-grade elementary school students in Bandung, were below standard (M±SD = 66.63±5.69), indicating significant and potentially systemic motor delays. These findings align with international studies and indicate weaknesses in physical education practices, low-quality learning, and limited exposure to meaningful physical activity. Based on these results, interventions need to be defined in line with the research findings, namely structured, evidence-based, and focused on the sustainable development of FMS. Practical implications include curriculum reformulation, teacher competency enhancement, and the implementation of inclusive school- and community-based physical activity programs. Future research should also explore determinants, including socioeconomic and environmental conditions, as well as the relationship between motor delays and academic, cognitive, and psychosocial development. Overall, these findings emphasize the need for a transformation of physical education that is adaptive, integrative, and oriented toward strengthening children's FMS.

Ethics Approval

This study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The study protocol was approved by the institutional ethics committee of Universitas Pendidikan Indonesia.

Informed Consent

Written informed consent was obtained from all participants' parents or legal guardians prior to participation in the study. Assent was also obtained from the children before testing procedures.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors used AI-assisted tools for language editing and manuscript preparation. The authors take full responsibility for the content of the article.

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Conflict of Interest Statement

The authors declare no conflict of interest.

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Статеві відмінності коефіцієнта загальної моторики серед учнів: дані оцінювання за тестом розвитку великої моторики

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 8 табл., 43 джерела.

Мета дослідження. Це дослідження спрямоване на оцінювання та порівняння фундаментальних рухових навичок у учнів початкової школи за показниками коефіцієнта загальної моторики з урахуванням статі.

Матеріали та методи. У дослідженні взяли участь 24 учні четвертого класу початкової школи (12 хлопців, 12 дівчат; M±SD = 10,21±0,41) для оцінювання грубих моторних навичок за допомогою тесту розвитку великої моторики. Субтести локомоторних навичок і контролю об'єкта оцінювалися у двох спробах із використанням бінарних критеріїв, після чого результати були перетворені у стандартні бали та значення коефіцієнта загальної моторики. Аналіз включав описову статистику, тести на нормальність розподілу, незалежні t-тести або тести Манна–Вітні, а також розрахунок величини ефекту для порівняння моторних навичок між статями.

Результати. Аналіз коефіцієнта загальної моторики показав, що більшість учнів мали низький рівень грубих моторних навичок. Група хлопців належала до категорії «дуже низький» (58–67 балів) як за локомоторними навичками, так і за контролем об'єкта, що свідчить про низьку однорідність між субтестами. Група дівчат продемонструвала більшу варіативність (61–82 бали), однак більшість також належала до категорій «дуже низький» або «низький». Незалежні t-тести для субтестів локомоторних навичок і контролю об'єкта не виявили статистично значущих відмінностей між статями, за винятком субтесту ковзного кроку, у якому дівчата показали кращі результати (p = 0,038). Тест Манна–Вітні для коефіцієнта загальної моторики підтвердив статистично значущу різницю між групами, причому дівчата перевищували хлопців за показниками (p = 0,005; величина ефекту = 0,57). Отримані результати підтверджують низький рівень грубих моторних навичок серед учнів та підкреслюють необхідність структурованих програм моторного навчання для покращення локомоторних навичок і контролю об'єкта.

Висновки. Подальші дослідження повинні бути спрямовані на вивчення ігрових адаптивних моделей навчання, оптимального дозування фізичних вправ та інтеграції сенсомоторних і мотиваційних підходів для покращення коефіцієнта загальної моторики учнів початкової школи.

Ключові слова: локомоторні навички, контроль об'єкта, коефіцієнт загальної моторики, фундаментальні рухові навички, диференційоване фізичне виховання.

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Digitalization of "Timed Up and Go" Test to Increase the Control Efficiency in Inclusive Physical Education

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Objectives. The purpose of this study was to establish the reliability and validity of the "Timed Up and Go" (TUG) test for students with disabilities who have undergone lower limb amputation using an intelligent software-controlled hardware complex in inclusive physical education.

Materials and Methods. The study was conducted at the theoretical and empirical levels. The following methods were used: analysis, synthesis, systematization, generalization, measurement, and mathematical statistics. Measurements were performed using the TUG test. The study sample included first-year male students with a left lower limb amputation (n = 23), provided there were no acute conditions, open wounds, or complications.

Results. The results of the study are presented in the developed intelligent software-controlled hardware system for implementing the TUG test. The structural composition of the system includes Bluetooth-enabled wireless sensors placed on the student and along the entire TUG trajectory. The signals received by the Xsens DOT sensors are transmitted to the latest Arduino Uno R3 microcontroller. Information display and control are provided through the use of a Liquid Crystal Display. A distinctive feature of the complex is the use of IoT technologies for analytics and forecasting in inclusive physical education. Automated acquisition of TUG results enables the recording of numerous gait parameters in students with disabilities and lower limb amputation, such as the amplitude of central oscillations, reaction time, and step length, which cannot be recorded when TUG results are measured using a stopwatch. Digital data processing transforms the reliability and validity of the TUG test from "average" when measured with a stopwatch to "high", ensuring accurate recording of numerous parameters down to the microsecond level.

Conclusions. The novelty of the developed intelligent programmable tool for implementing the "Get Up and Go" test ensures effective control in inclusive physical education and eliminates the influence of the human factor on test results.

Keywords: student, physical education, TUG test, control, reliability, validity.

Introduction

Inclusive education has become particularly relevant in Ukraine since the start of the full-scale russian invasion. As a result of rocket attacks and military operations, the number of students with disabilities in Ukrainian universities has increased significantly, creating new challenges for the education system (Klos, Blavt, & Kovalchuk, 2024).

According to statistics (Life In War, 2024), 65–70% of injuries in the russia-Ukraine war involve the limbs. Limb loss due to combat injuries among military personnel and civilians ranks among the leading causes of amputations

(Van Dongen et al., 2017). Over 17 months of full-scale war, approximately 50,000 Ukrainians have lost arms or legs (Radiosvoboda, 2024). Worldwide, amputation is one of the most common causes of disability: 30 million people globally live with the loss of a lower limb (Şahan & Erbahçeci, 2023).

The enormous number of wounds, injuries, and amputations sustained by students as a result of russian aggression necessitates the provision of conditions in higher education institutions for their full rehabilitation. Physical education, which fulfills this function, has taken on exceptional significance today, during the war in Ukraine.

Analysis of recent research and publications.

Studies have shown (Bastas et al., 2018; Eshraghi et al., 2018; Wong et al., 2020) that leg amputation leads to persistent functional impairments and significantly affects mobility (Premnath et al., 2021; Gaunaurd et al., 2020; Batten et al., 2019). It has been determined that a consequence of amputations is that the body shifts its center of mass during any activity (Eshraghi et al., 2018; Kark et al., 2012). This disrupts functional stabilization and dynamic stability (Bastas et al., 2018), which are important factors for safe mobility (Kendell et al., 2010). Consequently, movement patterns change (Vrieling et al., 2007; Premnath et al., 2021). It is argued (Kendell et al., 2010; Schmid et al., 2005; Chihuri, Youdan, & Wong, 2021) that this is particularly important for people with lower limb amputations, as they fall significantly more often (Vu et al., 2019; Dite, Connor, & Curtis, 2007). Therefore, gait restoration is recognized (Premnath et al., 2021; Gaunaurd et al., 2020; Batten et al., 2019) as the primary goal of post-amputation rehabilitation.

In higher education institutions, inclusive physical education is designed to support the rehabilitation process for students with disabilities (Karamani et al., 2024; Navas-Bonilla et al., 2025; Iedynak et al., 2025). Research focuses on the issue of the quality of inclusive PE (Penney et al., 2018; Kuntjoro et al., 2024; Marín-Suelves & Más, 2021).

A position has become established in the scientific discourse according to which judgments about the effectiveness of physical education for students with disabilities are formed based on the results of test-based assessment (Blavt et al., 2024a; Maher, van Rossum, & Morley, 2023; Fuentes-Nieto, López Pastor, & Palacios-Picos, 2022). The factors contributing to the effectiveness of assessment in physical education are recognized as the objectivity of evaluation, the timeliness of results, the specificity of the assessment, and the suitability of tests for a specific population (Marín-Suelves & Más, 2021; Moura et al., 2021; Iedynak et al., 2025; Blavt et al., 2024b).

It has been demonstrated (Archer, & Ellis, 2024; Fuentes-Nieto, López Pastor, & Palacios-Picos, 2022) that the challenge of ensuring the effectiveness of assessment in inclusive physical education cannot be resolved today without the use of modern innovative technologies. Such technologies allow for the transformation of subjective assessment into a precise process of quality control management in physical education (Müller & Wagner, 2025; Kuntjoro et al., 2024).

Based on data from the scientific literature, it has been established that the problem of monitoring the body's dynamic stability and the dynamics of its normalization under the influence of inclusive physical education for students with disabilities involving amputation remains entirely unresolved. In general, researchers note (Eshraghi et al., 2018; Lythgo, Marmaras, & Connor, 2010; Maikos et al., 2024) the limited progress in improving the rehabilitation process for individuals with disabilities involving amputation across various populations, aimed at enhancing gait and balance.

The need to ensure the effectiveness of the rehabilitation process based on the results of gait parameter testing during inclusive physical education for students with disabilities involving lower limb amputation prompted us to conduct this experimental study.

The purpose of the study was to establish the level of reliability and validity of the Timed Up and Go (TUG) test for students with disabilities involving lower limb amputation using an intelligent software-controlled hardware complex in the process of inclusive physical education.

Materials and methods

Research methods

The experimental study was conducted at both the theoretical and empirical levels. The theoretical level established the foundation for justifying the concept of scientific research.

Based on the results of the analysis and synthesis of existing experience, the logic for further research was developed, and key components were identified. Through abstraction, secondary factors were eliminated to focus on gait biomechanics. Through concretization, general principles of inclusion were applied to the specific conditions of higher education. Through induction, a transition was made from individual facts to general conclusions regarding the effectiveness of testing using a specific methodology. Deduction was used to apply general laws of pedagogy to a specific case – physical education for students with disabilities involving lower limb amputation.

At the empirical level, technical modeling was used to create an intelligent software-controlled hardware system. A natural pedagogical experiment was organized to test the hypothesis regarding the improvement of gait parameter monitoring. Testing was conducted using the TUG test. The TUG test is a reliable, cost-effective, safe, and time-efficient way to evaluate overall functional mobility with high correlation with other proven tests that measure pure balance and gait performance (Shirley Ryan Abilitylab).

The test procedure. The TUG test requires the student to rise from a standard armchair, walk to a marker 3 meters away, turn, walk back, and sit down again (Fig. 1). It is a simple, quick assessment that measures functional mobility, dynamic balance, and fall risk.

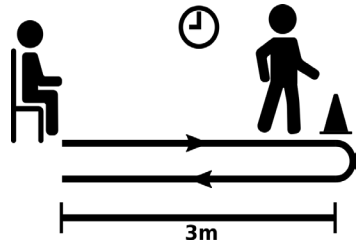

Fig. 1. Scheme of the TUG test (NeuroToolKit)

Study participants

The study sample consisted of male first-year students (23) with disabilities who had a left-sided transtibial amputation of the left lower limb. The sample was composed of individuals who had no clinical contraindications, such as acute conditions or inflammatory processes of the stump. Informed consent was obtained from the study participants.

The selection of participants with a left-sided limb deficiency was driven by the need to ensure homogeneity in the study sample. The selection criterion was the ability to walk independently with crutches and perform basic daily activities without external support.

Since the knee joint in the students of the study sample is intact, which significantly facilitates prosthesis control and ensures a higher level of mobility, the participants' functional status was characterized by the ability to perform self-care and move confidently using assistive devices (crutches).

Given that sample size affects conclusions in identifying study effects, recommendations were taken into account (Kemal, 2020). The results should be interpreted with consideration of the limited sample size, which is typical for the pilot phases of implementing innovative monitoring systems (Baumgartner et al., 2015).

The experiment is conducted with the anonymous written consent of the students. Students who agreed to participate in the study were given the right to withdraw from it at any time during its conduct.

The study was planned and carried out following the principles of bioethics set forth by the World Medical Association (WMA–2013) in the Helsinki Declaration «Ethical Principles of Medical Research Involving Humans» and UNESCO in the «General Declaration on Bioethics and Human Rights».

The sample size corresponds to a pilot-stage study focused on testing the applicability of the proposed monitoring approach.

Research organization

The study involved a comparison of methods for recording TUG results for students with lower limb amputations. The experimental work was based on a comparative analysis of two approaches to recording TUG results for students with lower limb amputations. A comparison was conducted between recording TUG results using a stopwatch and using a smart software-controlled hardware system.

A stopwatch was used to record the time taken to complete the TUG test. An intelligent software-controlled hardware system was used to record center oscillation amplitude, reaction time and stride length.

The students in the study sample were given detailed instructions on how to perform the test. The study was conducted in two sessions, during which the students completed two trials each.

Statistical analysis

Statistical information was obtained from the results of descriptive statistics. The reliability and validity of the methods were assessed using correlation analysis with correlation coefficient (rtt) (Mishra et al., 2019).

Mathematical statistics methods were used to process, analyze, and interpret the experimental data using SPSS Version 22.0 (IBM Corporation).

Results

We present the results of our research in the form of a custom-designed, software-controlled hardware system for implementing the TUG. The primary objective in developing the system was to record various gait parameters of students with lower-limb amputations and analyze them in real time.

The system's structural composition includes Bluetooth-enabled wireless sensors, which are placed on the student and along the entire TUG trajectory. The main computing module is a microcontroller that processes sensor data and performs real-time configuration. We display monitoring information using an LCD (Liquid Crystal Display), which serves as the main interface.

A schematic diagram of the connection of all elements of the intelligent software-controlled hardware complex has been developed, ensuring their proper interaction (Fig. 2). The system utilizes Bluetooth-enabled wireless sensors; the Xsens DOT (Mykytyuk et al., 2025) was selected, which consists of sensor modules that can be attached to the student's body segments to collect 3D data during the TUG test. Xsens DOT sensors provide detailed information about movement, including orientation, acceleration, angular velocity, step frequency, and more, enabling comprehensive and accurate motion analysis through real-time data streaming.

Xsens DOT implements an algorithm for fusing the student's motion sensors during the TUG test. Xsens DOT is resistant to magnetic field interference and equipped with the latest signal processing technology, easily enabling integration with mobile devices and compatibility with various software platforms.

The Arduino Uno microcontroller, the latest R3 model, was selected as the main computing module for the intelligent software-controlled hardware system to implement the TUG. The Arduino Uno has sufficient technical specifications to implement control algorithms and process data from sensors, as well as a simple programming structure and an easy-to-use USB interface for uploading. Communication between complex elements is provided by infrared communication lines.

The software for the intelligent software-controlled hardware complex for implementing TUG was developed using the Arduino IDE. A key feature of the complex is the use of IoT technologies. Consequently, connectivity to cloud platforms has been implemented, opening new possibilities for analytics, forecasting programs for inclusive physical education for students with disabilities, and optimizing energy consumption. It provides instant biofeedback, which is critical in rehabilitation for correcting a student's movements in real time. Thanks to the high measurement resolution (0.001 s), the student can feel the difference even in slight changes in walking pace.

Thus, the automated collection of TUG results provides numerous gait parameters for students with lower-limb amputations, such as center oscillation amplitude, reaction time and stride length, which cannot be recorded when TUG results are manually recorded by a teacher.

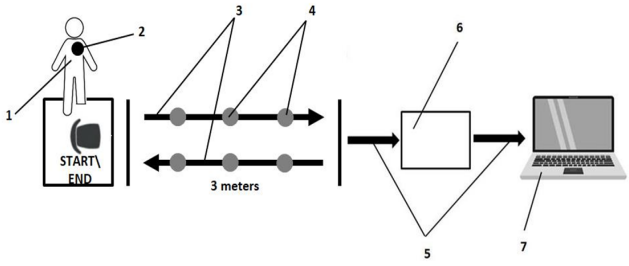

Fig. 2. Scheme of TUG test implementation using a: 1 – student, 2 – sensor modules, 3 – TUG test trajectory, 4 – Xsens DOT sensors, 5 – infrared communication lines, 6 – Arduino Uno microcontroller; 7 – PC

In the second stage of the empirical study the TUG was establish of the level of reliability and validity. The results are presented in Table 1-2.

According to the numerical data obtained from the intellectual software-controlled hardware complex, the TUG reliability (0,838-0,903) and validity (0,558-0.605) level is high. The detection of TUG performance results is carried out at the speed of the microprocessor, which ensures measurement accuracy down to the microsecond. The digitization of the process effectively «cleans» the data, ensuring the reliability of the test results.

In contrast, the use of a stopwatch reduces the test's validity and reliability to average values and levels deemed «acceptable for use». This is entirely expected, as the instructor's reaction is not constant and varies depending on fatigue, attention, and anticipation of the moment, leading to random errors in recording TUG results.

In addition, in manual mode, it is not possible to record and analyze numerous gait parameters (center oscillation amplitude, reaction time, stride length), that provide information about the progress of rehabilitation for students with disabilities involving lower limb amputation.

Discussion

Our study is based on the premise that the use of innovative technologies in physical education monitoring eliminates the influence of the human factor, ensuring high-quality monitoring and ease of use (Tohănean et al., 2025; Müller & Wagner, 2025; Blavt et al., 2024a). Consequently, the data (Navas-Bonilla et al., 2025; Karamani et al., 2024; Fuentes-Nieto, López Pastor, & Palacios-Picos, 2022) have been expanded, showing that improving the quality of monitoring holds significant potential for enhancing the quality of inclusive physical education.

The body of evidence has expanded (Hafner & Sanders, 2014; Clemens et al., 2020; Rietman, Postema, & Geertzen, 2002), indicating that the collection and use of objective data form the basis for objectively adjusting rehabilitation interventions following lower limb loss. At the same time, identifying mechanisms for correcting gait asymmetry

Table 1. The reliability and validity level of the TUG test for students with disabilities involving lower limb amputation using intellectual software-controlled hardware complex (n – 23)

Control parameter		(X ± m)	As	Me	V	(X ± m)	As	Me	V
Total test time (s)		16.5 ± 2.04	0.36	16.1	22.4	16.1 ± 1.96	0.38	15.9	22.1
Center oscillation amplitude (ms)	Straight-line gait	272.6 ± 12.7	2.99	270.8	24.5	265.8 ± 13.6	1.99	265.6	23.7
	Turning 180°	670.4 ± 22.3	8.91	670.8	25.3	645.7 ± 15.2	5.41	646.1	25.3
	Sit-to-Stand	420.1 ± 26.7	5.72	419.5	24.6	401.6 ± 21.3	3.82	400.8	24.5
	Stand-to-Sit	511.3 ± 21.2	9.1	509.5	22.5	515.7 ± 23.6	4.29	516.1	23.7
Step time (left, s)		0.45 ± 0.09	0.19	0.431	20.1	0.43 ± 0.11	0.18	0.415	22.3
Reaction time (ms)		730.4 ± 33.5	9.32	734.2	25.4	723.7 ± 29.2	7.29	725.1	24.5
Steps (number)		18.2 ± 2.3	0.72	18.5.	23.6	18.7 ± 2.9	0.39	17.5	21.5
Stride length (sm)		32.1 ± 2.01	0.88	32.5	25.1	31.5 ± 2.32	0.91	31.9	22.3
Velocity (m/s)		0.375 ± 0.034	0.17	0.373	21.4	0.372 ± 0.066	0.13	0.370	22.7
Reliability (rtt)			0, 838				0,902		
Validity (rtt)			0,558				0,612		

Table 2. The reliability and validity level of the TUG test for students with disabilities involving lower limb amputation using a stopwatch (n – 23)

Control parameter	(X ± m)	As	Me	V	(X ± m)	As	Me	V
Total test time (s)	17.4 ± 3.05	0.41	17.7	28.2	17.2 ± 2.88	0.44	17.4	27.9
Steps (number)	19.3 ± 2.6	0.62	19.1	30.1	19.1 ± 2.6	0.41	19.3	29.1
Stride length (sm)	31.1 ± 1.74	0.71	31.3	28.5	32.9 ± 2.55	0.68	32.7	31.1
Velocity (m/s)	0.341 ± 0.071	0.41	0.343	29.2	0.361 ± 0.083	0.43	0.365	28.5
Reliability (rtt)		0,512				0, 610		
Validity (rtt)		0,199				0,204		

following lower limb amputation can serve as a guide for understanding optimal strategies for the rehabilitation process (Maikos et al., 2024).

We were guided by the information (Kendell et al., 2010; Salih, Peel & Burgess 2016; Griffiths, Diment, Granat, 2021) that current assessment methods do not allow for characterizing the dynamic stability of individuals with lower limb amputations during walking. At the same time, as noted (Schmid et al., 2005; Rietman, Postema, & Geertzen, 2002; Bastas et al., 2018), one of the goals of gait rehabilitation after amputation is to restore step symmetry and variability (Sinitski et al., 2021; Vrieling et al., 2009) and gait stability on various surfaces (Premnath et al., 2021; Kark et al., 2012), including descents and ascents (Sturk et al., 2019; Vrieling et al., 2009; Lythgo, Marmaras, & Connor, 2010), walking speed (Gaunaurd et al., 2020; Batten et al., 2019), and step count (Chihuri, Youdan, & Wong, 2021).

Our study expands on the findings that artificial intelligence systems (Lex et al., 2023; Griffiths, Diment, Granat, 2021; Mahoney & Rhudy, 2019), electronic technologies (Jarchi et al., 2018; Chen et al., 2016; Kim et al., 2020), virtual reality (Şahan & Erbahçeci, 2023; Hao et al., 2023), and augmented reality (Vinolo Gil et al., 2021) are transforming the monitoring process in the implementation of rehabilitation for amputation, offering unprecedented accuracy in assessment.

Research (Grace Gaerlan et al., 2012) has shown that the TUG is reliable and valid for the quantitative assessment of functional mobility and for tracking clinical changes in walking ability. To date, the TUG has been validated for elderly individuals (Podsiadlo & Richardson, 1991; Alexandre et al., 2012; Herman, Giladi, & Hausdorff, 2011), in older adults with impaired mobility (Botolfsen et al., 2006), in patients with total hip arthroplasty (Yuksel et al., 2021; Özden, Coşkun, & Bakırhan, 2020); in frail and non-frail patients with prostate cancer (Feyzioğlu et al., 2025); in patients with knee osteoarthritis (Nalbant, Unver, & Karatosun, 2022); for children with Down syndrome (Martin et al., 2017; Nicolini-Panisson, & Donadio, 2014); in knee osteoarthritis (Gacto-Sánchez et al., 2023); in people with Parkinson's disease (Huang et al., 2011; Vance et al., 2015); in children (Verbecque et al., 2019); in children with cerebral palsy (Besios et al., 2018); in multiple sclerosis patients (Kalron, Dolev, & Givon, 2017; Hershkovitz et al., 2019); in older adults living with dementia (Chan et al., 2024).

To date, the TUG has been used for elderly patients with a lower limb amputation (Schoppen et al., 1999; Dite, Connor, & Curtis, 2007). The level of validation of individual tests for individuals with disabilities who have lower limb amputations has been determined: the Berg Balance Scale (Major, Fatone, & Roth, 2013), the Houghton Scale (Wong, Gibbs, & Chen, 2016), and the 2-Minute Walk Test (Wong et al., 2020).

However, no studies have assessed walking skills in a population of students with lower limb amputations. In our study, we were guided by the finding (Chen et al., 2016) that «gait analysis using wearable sensors must be evaluated in the target patient population to prove its clinical value, since algorithms developed from control subject data may not be generalizable to pathological gait».

For the first time, it has been substantiated and experimentally confirmed that the use of an intelligent software-controlled hardware system to record TUG results in students with lower limb amputations significantly enhances its validation.

The obtained detailed gait parameters (center oscillation amplitude, reaction time, stride length) extend the analytical capacity of the TUG test beyond time-based assessment. These parameters enable differentiation of motor deficits in students with lower limb amputation, particularly in terms of movement stability, coordination, and temporal organization of gait. This creates a basis for targeted pedagogical interventions in inclusive physical education, where exercise selection, load distribution, and corrective tasks can be individualized according to specific gait characteristics rather than general performance indicators. Thus, digitalization of the TUG transforms it from a screening tool into an instrument of pedagogical control and decision-making.

The results of our previous studies regarding the appropriateness of using technology to monitor inclusive physical education as a factor in ensuring its effectiveness have been confirmed (Blavt et al., 2024a; Blavt et al., 2024b).

Conclusions

The increasing number of students with disabilities resulting from lower limb amputations caused by prolonged hostilities in Ukraine necessitates improving the quality of their rehabilitation within the university course on inclusive physical education. This requires the use of modern innovative technologies in the monitoring process as a factor ensuring the effectiveness of the rehabilitation process.

An intelligent, software-controlled hardware system has been developed for the implementation of the TUG. Its structure integrates Xsens DOT sensors placed on the student's limbs and along the test trajectory, an Arduino Uno microcontroller of the latest R3 model, and an LCD display with an I^2C interface, which allows for the real-time display of current movement parameters. A distinctive feature of the system is the use of IoT technologies to connect to cloud platforms for analytics and forecasting.

An analysis of the reliability and validity of the TUG test among students with disabilities involving lower limb amputations confirmed a significant advantage of using the digital system for gait monitoring. Its application ensured a «high» level of reliability and validity of the methodology. At the same time, the use of the digital instrument allows for the recording of numerical gait parameters that cannot be obtained manually. In contrast, the use of a traditional stopwatch yielded only «average» and «acceptable» levels of reliability and validity for the TUG. This allows the digitized TUG to be considered a precision (high-accuracy) assessment tool with a high level of functionality, reliability, and effectiveness.

The study demonstrates that detailed digital recording of TUG parameters allows identifying specific characteristics of gait organization (e.g., instability phases, delayed motor response, asymmetry), which are not detectable using traditional timing methods. These characteristics can serve as a basis for targeted correction within the process of inclusive physical education.

The findings should be interpreted with caution due to the limited sample size and the specificity of the participant group.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

AI Transparency Statement

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Clarified Ethics Approval

This study was approved by the Research Ethics Committee Міжнародного Kamianets-Podilskyi National Ivan Ohiienko University (KPNU 2025-015) before the start of the study.

Conflicts of interest

No conflicts of interest exist.

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Цифровізація тесту «встань та іди» для підвищення ефективності контролю у інклюзивному фізичному вихованні

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

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Мета дослідження – установлення рівня надійності та валідності тесту «Встань та іди» для студентів з інвалідністю з ампутацією нижньої кінцівки з використанням інтелектуального програмно-керованого апаратного комплексу у процесі інклюзивного фізичного виховання.

Матеріал та методи. Дослідження реалізовано на теоретичному та емпіричному рівні. використано методи: аналізу, синтезу, систематизації, узагальнення, вимірювання та математичної статистики. Вимірювання реалізовано з використанням тесту «Встань та іди». У досліджувану вибірку увійшли 23 студенти І-го курсу навчання (чоловіки) з лівобічною трансгібіальною ампутацією нижньої лівої кінцівки за умови відсутності гострих станів, відкритих ран чи ускладнень.

Результати. Результати здійсненого наукового пошуку представляємо у розробленому інтелектуальному програмно-керованому апаратному комплексі для реалізації тесту «Встань та іди». Структурна композиція комплексу включає: бездротові датчики з підтримкою Bluetooth, які розміщуємо на студентові та по всій траєкторії виконання тесту «Встань та іди». Сигнали, отримані датчиками Xsens DOT, передаються на мікроконтролер Arduino Uno останньої моделі R3. Представлення інформації контролю забезпечуємо використанням РК-дисплей Liquid Crystal Display. Визначною особливістю комплексу є використання IoT-технологій для аналітики та прогнозування інклюзивного фізичного виховання. Автоматизоване отримання результатів тесту «Встань та іди» забезпечує отримання численних параметрів ходи студентів з інвалідністю з ампутацією нижньої кінцівки як амплітуда коливань центру, час реакції та довжина кроку, які не можливо зафіксувати з фіксацією результатів, секундоміром.

Цифрова обробка даних трансформує рівень надійності та валідності тесту «Встань та іди» з «середнього» при вимірюванні секундоміром, до «високого», що забезпечує точність фіксації числених параметрів до мікросекунд.

Висновки. Новизна розробленого інтелектуального програмованого інструменту для реалізації тесту «Встань та іди», полягає у забезпеченні ефективності контролю у інклюзивному фізичному вихованні та усунення впливу людського фактору на результати тестування.

Ключові слова: студенти, фізичне виховання, тест «Встань та іди», контроль, надійність, валідність.

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Functional Joint Mobility in Young Athletes Practicing Bocce Raffa: Implications for the Performance Model

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Abstract

Objectives. Bocce is a precision sport that requires coordination and technical control. In the Raffa specialty, upper limb coordination and postural control are particularly important. Despite its widespread practice, research on the functional characteristics of youth players remains limited. This exploratory analytical pilot study aimed to examine joint mobility as a functional configuration within the movement system underlying the Raffa technical gesture.

Materials and Methods. Twenty-five athletes aged 14–18 years were assessed during regional training events organized by the Campania Bocce Committee. Joint mobility was evaluated using three field tests: the Shoulder Mobility Test, a scapulo-humeral mobility test with stick rotation, and a seated forward trunk flexion test. Descriptive statistics, independent samples t-tests, and Pearson correlations were calculated. Bartlett's test of sphericity and an exploratory Cronbach's alpha were used to assess the integrative structure of mobility parameters.

Results. Significant differences emerged in scapulo-humeral mobility and spinal flexibility, whereas no differences were found in shoulder mobility. Correlation analyses revealed weak to moderate relationships among the variables. Bartlett's test ($\chi^2_{(3)}$=9.63, p=0.022) and a Cronbach's alpha of 0.65 supported the presence of an integrated mobility structure, indicating interdependence among segments.

Conclusions. Joint mobility acts as a non-linear, context-dependent resource, functioning as both a facilitator and a constraint depending on its integration within the movement system. Functional effectiveness in the Raffa gesture depends on the balance among shoulder, scapulo-humeral, and spinal components rather than on isolated maximal values. The study proposes a preliminary explanatory framework in which joint mobility mediates the relationship between movement amplitude and control.

Keywords: Raffa specialty, joint mobility, youth athletes, flexibility, sport performance.

Introduction

The game of bocce represents one of the most deeply rooted sporting disciplines in European and Mediterranean traditions, characterized by a long cultural history and by a progressive technical and regulatory evolution that has consolidated its identity within the contemporary sports landscape (Febrianingrum, & Diana, 2021). Today this discipline is recognized as a highly codified precision sport in which technical skills, motor control, and the management of environmental variables play a central role in determining performance outcomes. Within the international organizational framework, the sport of bocce is structured into three main specialties, Volo, Pétanque, and Raffa, each characterized by specific technical, regulatory, and biomechanical dynamics. Among these, the Raffa specialty represents one of the most widespread and practiced forms in Italy, distinguished by the particular technical complexity of the motor actions required and by the high level of precision demanded during the phases of play (Türkmen et al., 2018).

The growing attention toward the scientific analysis of sports performance has progressively involved disciplines traditionally considered less investigated compared with team sports or widely practiced Olympic disciplines. In this context, bocce is increasingly emerging as a field of interest within sport and exercise sciences, particularly with regard to the study of performance models and the physical and coordinative components that contribute to the effectiveness of the technical gesture. Despite the apparent simplicity of the actions involved, performance in bocce, and especially in the Raffa specialty, requires a sophisticated balance between motor precision, intersegmental coordination, postural control, and the management of force (Şimşek, & Kesilmiş, 2022). These elements become particularly evident during the phases of shooting and pointing, in which the player must accurately regulate the trajectory and velocity of the bowl while maintaining stability and fluidity of movement (Irawan et al., 2024).

Within this framework, one of the least investigated yet potentially relevant aspects for understanding performance concerns the role of joint mobility. Joint mobility represents a fundamental component of motor functionality, understood as the capacity of a joint to move within its physiological range of motion in a controlled and efficient manner. Joint mobility should not be considered as an isolated characteristic, but rather as a functional element within the kinetic chain, contributing to the coordination between proximal stability and distal movement control required for precise motor execution, and enabling the efficient transmission of forces along the movement sequence. In the context of sports technique, it contributes to the quality of motor execution, influencing coordination, movement economy, and injury prevention. In disciplines that require precision gestures and repetitive movements, such as bocce, joint mobility assumes particular significance because it allows the optimization of the kinetic chain involved in the execution of the technical gesture. However, in precision-based motor tasks, joint mobility should not be interpreted as a uniformly beneficial attribute, as both insufficient and excessive mobility may alter the balance between movement amplitude and control, potentially affecting the stability and reproducibility of the gesture. In the game of Raffa, the motor gesture that characterizes the principal actions of play involves a coordinated sequence of movements engaging several body segments, particularly the dominant upper limb, the trunk, and the lower limbs (Helmi, et al., 2024). During the execution of shooting or pointing actions, the player performs a coordinated movement that begins with body positioning and develops through a progressive activation of the kinetic chain, culminating in the release of the bowl. Within this motor sequence, the mobility of the shoulder, elbow, and wrist joints plays a decisive role in ensuring fluidity and precision of the gesture. At the same time, the mobility of the pelvis and lower limbs contributes to postural stability and to the correct distribution of forces during the execution phase (Gür et al., 2022). In this perspective, joint mobility assumes a regulatory role within the movement system, influencing the balance between movement amplitude and control, and determining the conditions under which the technical gesture can be executed with accuracy and consistency. Accordingly, joint mobility may be conceptualized as a resource operating under specific functional conditions, rather than as a linear determinant of performance.

Despite these biomechanical and functional considerations, the scientific literature dedicated to the analysis of the physical characteristics of bocce players still appears limited, particularly when compared with the large body of studies available in other sporting contexts (Firdaus, & Irfan, 2023). Most of the existing research mainly focuses on the technical and tactical aspects of the game or on competitive dynamics, while the physiological and motor components that characterize the athlete's performance model remain insufficiently explored (Hafidz et al., 2024). This gap becomes even more evident when attention shifts to the youth sector, an area in which knowledge of athletes' motor characteristics can represent a fundamental tool for guiding processes of sports training and the development of technical competencies (Latino et al., 2019).

The study of motor abilities in young athletes represents a field of considerable interest within sport sciences because it allows researchers to understand how processes of growth and maturation interact with motor learning and with the development of specific abilities required by a given discipline (Susanto et al., 2024). In the case of bocce, and particularly within the Raffa specialty, youth development represents a crucial phase for the acquisition of the technical and coordinative foundations of the game gesture. During this stage, joint mobility may play a particularly relevant role because it supports motor learning and the development of efficient movement patterns (Scamardella et al., 2025).

Joint mobility in young athletes is influenced by several factors, including biological age, level of physical activity, individual morphological characteristics, and previous motor experiences. During growth phases, the musculoskeletal system undergoes important structural and functional changes that may influence the movement capacity of the joints. A proper evaluation of joint mobility during this stage of development can therefore provide useful indications both for optimizing training programs and for preventing possible functional limitations that might negatively affect the quality of the technical gesture (Raiola et al., 2015).

Furthermore, the analysis of joint mobility in young bocce players may contribute to the definition of a more precise performance model for this sport discipline. The concept of a performance model represents a fundamental tool within training methodology because it allows the identification of the set of physical, technical, and psychological characteristics that contribute to the realization of effective performance. Through the identification of the variables that most strongly influence performance, it becomes possible to guide training processes and athlete development in a more targeted and evidence-based manner (Irawan, 2019). From this standpoint, joint mobility can be conceptualized as a functional variable within the performance model, interacting with coordination, postural control, and movement stability to influence the effectiveness and reproducibility of the technical gesture. In this sense, its contribution to performance should be interpreted in relation to its capacity to remain within functional limits compatible with control demands, rather than in terms of maximal range of motion alone.

In the specific case of bocce, the definition of a performance model appears particularly complex because the discipline lies at the intersection between precision sports and technical coordinative activities. Competitive success does not depend exclusively on traditional conditional abilities such as strength or endurance but rather on a combination of fine motor skills, neuromuscular control, concentration capacity, and the management of the playing space. Within this framework, joint mobility may represent a functional component capable of indirectly influencing the effectiveness of the technical gesture and the overall quality of performance (Eler, & Eler, 2018).

Another element of interest concerns the possibility of using joint mobility assessment as a monitoring tool within the developmental pathway of young athletes. The introduction of functional evaluation protocols within bocce schools and youth sectors could foster greater awareness of athletes' motor characteristics, enabling coaches to adapt training programs to the specific needs of individual players (Badruzaman, 2021).

In light of these considerations, there is a clear need to further investigate the motor characteristics of young practitioners involved in the Raffa specialty, with particular attention to joint mobility and its potential role in supporting the effectiveness of the technical gesture. The lack of systematic data in this field makes it necessary to initiate exploratory studies and pilot projects capable of providing initial indications useful for the construction of a more solid knowledge base (Yuan, & Li, 2022).

The present study is positioned within this exploratory perspective, with the aim of contributing to the understanding of joint mobility characteristics in young bocce players engaged in the Raffa specialty. Through the assessment of selected mobility parameters involving the shoulder complex and the spinal column, this research seeks to provide an initial functional profile of joint mobility in youth athletes practicing this discipline. In particular, the study aims to analyze joint mobility not only in terms of variability, but also in relation to its potential functional role within the movement system underlying the technical gesture of bocce. Furthermore, the study seeks to provide an initial interpretative framework for understanding how different mobility characteristics may influence movement control, coordination, and the balance between stability and mobility in young athletes. More specifically, the study adopts a functional systems perspective in which joint mobility is interpreted as an organized set of interdependent components within the movement structure of the Raffa technical gesture. Within this framework, shoulder mobility is considered to support distal segment orientation and fine modulation of the release phase, scapulo-humeral mobility contributes to the regulation of movement amplitude and trajectory continuity, and spinal flexibility plays a key role in postural organization and in the transmission of forces along the kinetic chain. The interaction among these components is hypothesized to determine the functional balance between movement amplitude and control, which is essential for ensuring accuracy, consistency, and reproducibility of the technical gesture. From this standpoint, the effectiveness of joint mobility depends on its capacity to operate within a functional range that simultaneously allows sufficient movement amplitude and adequate control, whereas deviations toward either insufficient or excessive mobility may compromise the stability and precision of the gesture. By framing joint mobility in terms of coordinated functional roles rather than isolated measures, the study seeks to move toward a preliminary explanatory model of how mobility operates within the movement system of young Raffa athletes.

In doing so, the study intends not only to address a gap in the existing literature but also to contribute to the development of greater scientific awareness surrounding a sporting discipline that, although deeply rooted in tradition, continues to evolve and offer new research perspectives within the field of sport and exercise sciences.

Materials and Methods

The present research was designed as a cross sectional exploratory analytical pilot study aimed at investigating joint mobility characteristics in young athletes practicing bocce in the Raffa specialty. The study sought to provide an initial functional interpretation of joint mobility parameters potentially associated with the technical gesture required in this precision sport. Rather than focusing exclusively on descriptive profiling, the study aimed to examine joint mobility as a functional configuration within the movement system underlying the execution of the technical gesture. Given the limited scientific literature focusing on the physical and functional characteristics of bocce athletes, particularly within youth categories, the study was conceived as an exploratory investigation intended to collect preliminary data useful for future research and for the development of a more structured performance model in this discipline. Within this framework, the study adopts an explanatory perspective by proposing a preliminary model in which joint mobility is interpreted as an intersegmental component contributing to movement organization and control.

The research focused on the evaluation of joint mobility through a set of field based motor tests commonly used in sport sciences for the assessment of shoulder complex mobility and trunk flexibility. The tests were selected for their simplicity of administration, their suitability for use in sports training environments, and their relevance to the biomechanical characteristics of the motor actions required in the Raffa specialty. In this context, the selected tests were intended to capture functionally relevant aspects of mobility related to the coordination between upper limb movement, trunk control, and the overall organization of the kinetic chain. Accordingly, each measure was considered not only as an isolated indicator of range of motion, but as a proxy of specific functional contributions within the coordinated movement system.

Data collection was carried out during regional training events organized by the Campania Bocce Committee, allowing the evaluation of athletes within a standardized sporting environment. The study design allowed the collection of objective measurements of joint mobility while minimizing interference with the athletes' regular training activities. This approach ensured that the observed mobility characteristics could be interpreted in relation to real training conditions, supporting their relevance within the practical movement context of the sport. This design supports the interpretation of mobility data not only as descriptive

measures, but as elements contributing to a preliminary explanatory framework of the movement system in young Raffa athletes.

Participants

The study involved a sample of twenty five young athletes practicing bocce in the Raffa specialty. All participants belonged to the junior category and were aged between fourteen and eighteen years. The sample included both male and female athletes, specifically fifteen males and ten females. This age range represents a critical developmental phase in which motor control, coordination, and mobility characteristics are still evolving and may influence the structuring of the technical gesture.

All athletes were actively involved in regional training programs and participated regularly in sporting activities related to the Raffa discipline. The participants were recruited during regional training stages organized by the Campania Bocce Committee, which represented collective technical training sessions involving selected youth players.

The inclusion criteria required that athletes were actively practicing the Raffa specialty and were regularly participating in training activities. All participants were physically able to perform the motor tests included in the study.

Procedures

The motor evaluations were conducted during regional training camps organized by the Campania Bocce Committee. All tests were performed in January 2026 within the context of these collective training sessions.

Before the administration of the tests, the athletes received clear instructions regarding the execution procedures. The tests were conducted under the supervision of trained evaluators in order to ensure consistency in the measurement procedures and to minimize potential execution errors. Each athlete performed the motor tests according to standardized protocols. When required by the test procedure, multiple attempts were allowed in order to obtain the best possible performance. Adequate recovery time was provided between attempts to avoid fatigue effects that could influence the results. The evaluation sessions were organized in a structured manner, allowing athletes to complete the different mobility assessments sequentially while maintaining comparable testing conditions for all participants.

The study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol was approved by the Institutional Review Board of the University of Naples "Parthenope" (DiSMMeB Prot. N. 88592/2024). Written informed consent was obtained from all participants and, in the case of minors, from their parents or legal guardians prior to participation in the study.

Measures

Three motor tests were administered in order to evaluate different aspects of joint mobility involving the shoulder complex and the spinal column. The selection of these tests was intended to capture functionally relevant components of mobility associated with the execution of the technical gesture in bocce, particularly in relation to upper limb coordination and trunk control. More specifically, each test was selected to represent a distinct functional component within the movement system underlying the Raffa technical gesture, allowing the identification of segment-specific roles related to distal control, movement amplitude regulation, and postural stabilization. In this perspective, the assessment protocol was designed not only to quantify joint mobility, but to capture functionally meaningful dimensions directly involved in the organization and control of the Raffa throwing gesture.

Shoulder Mobility Test

The Shoulder Mobility Test was used to assess the global mobility of the shoulder joint. The test was performed in a standing position with the athlete maintaining an upright posture, feet together, and fists closed with the thumbs placed inside the hands. One arm was positioned over the shoulder while the other was placed behind the back, and the athlete attempted to bring the fists as close as possible behind the back. The distance between the closest bony landmarks of the fists was measured in centimeters using a measuring tape. The test was performed three times for each side and the best result was recorded. This test provided an indication of the functional range of motion of the shoulder complex, which is involved in the execution and control of the throwing movement. From a functional perspective, this measure was interpreted as reflecting the capacity of the shoulder joint to support distal segment orientation and fine modulation of the release phase, contributing to the precision and directional control of the technical gesture. More specifically, adequate shoulder mobility allows the athlete to position the upper limb effectively during both the preparatory and release phases, facilitating fine adjustments of trajectory and enhancing the accuracy and repeatability of the gesture in a precision task such as Raffa.

Scapulo-humeral Girdle Mobility

The mobility of the scapulo humeral girdle was assessed through a stick rotation test. The athlete stood upright holding a stick with both hands positioned at its extremities and arms extended in front of the body. The movement consisted of a full circumduction of the arms performed forward, upward, backward, and downward until the stick touched the body, followed by a return to the starting position while maintaining the arms fully extended. During the test, the evaluator ensured that the movement of the arms remained symmetrical and that the elbows were not flexed. At each attempt the grip distance on the stick was progressively reduced. The final measurement corresponded to the minimum distance between the hands, expressed in centimeters, that allowed the athlete to perform the complete movement correctly. This measure reflects the coordination and mobility of the scapulo-humeral complex, which contributes to the control of movement amplitude and fluidity during the execution of the technical gesture. Within the functional model adopted in this study, this parameter was considered indicative of the ability to regulate movement amplitude and ensure continuity of the kinematic chain, supporting the generation of a smooth and

coordinated trajectory during the execution of throwing actions. Functionally, this component is particularly relevant in the Raffa gesture because it mediates the transition between proximal stability and distal control, allowing the athlete to generate sufficient movement amplitude without compromising trajectory continuity and coordination.

Spinal Flexibility

The flexibility of the spinal column was evaluated through a seated forward flexion test similar to the sit and reach protocol. The athlete sat with the feet fully placed against the testing bench and performed several preparatory stretching movements of the lower limb muscles. The arms were then raised upward and, at the signal, the athlete slowly bent forward attempting to reach the furthest possible point on the graduated measuring surface. The position was maintained for a few seconds before returning to the starting posture. Two attempts were performed and the best result was recorded. The measurement was expressed in centimeters based on the position reached by the fingertips. Values were recorded as negative when the athlete was unable to reach the toes and positive when the fingertips passed beyond them. This test provided an indication of trunk flexibility, which is functionally related to postural control and the transmission of forces along the kinetic chain. In the proposed functional framework, spinal flexibility was interpreted as a key component for postural organization and for the effective transmission of forces between lower and upper body segments, contributing to the stabilization of the movement and to the maintenance of control during the execution phase. In the context of the Raffa specialty, this dimension is crucial for maintaining postural stability during the execution phase, ensuring that the movement remains controlled and repeatable while allowing efficient force transfer along the kinetic chain.

The instruments used for the administration of the tests included a measuring tape, a graduated testing bench, a measuring wheel, spatial markers, and a graduated stick.

Statistical Analysis

The collected data were analyzed using descriptive statistical methods in order to summarize the mobility characteristics of the sample. For each test the maximum value, minimum value, mean score, and standard deviation were calculated separately for the male and female groups. These indicators were considered not only to describe variability, but also to identify potential functional ranges and distribution patterns relevant to movement execution.

In addition, frequency distributions were examined in order to identify the most recurrent values within each dataset. This approach allowed the identification of central tendencies that may reflect typical mobility conditions within the analyzed group. The descriptive statistical approach adopted in this study allowed the identification of general trends and variability patterns within the mobility performances of the athletes.

Independent samples t-tests were conducted in order to support a more analytical interpretation of the data. Differences between male and female groups were examined using independent samples t-tests. In addition to statistical significance, effect sizes (Cohen's d) were calculated to estimate the magnitude of between-group differences. Furthermore, correlation analyses (Pearson's r) were performed to explore the relationships between the different mobility parameters assessed.

To further examine whether the three mobility parameters could be interpreted as part of a common functional configuration, the correlation matrix was additionally assessed through Bartlett's test of sphericity. An exploratory estimate of internal coherence was also calculated using Cronbach's alpha. These analyses were intended to support the interpretation of shoulder mobility, scapulo-humeral mobility, and spinal flexibility as interrelated components of an integrated mobility profile.

Given the exploratory nature of the research and the relatively small sample size, the statistical analysis focused primarily on descriptive indicators intended to provide an initial overview of the joint mobility characteristics of young athletes practicing the Raffa specialty. Within this framework, the integration of descriptive and inferential analyses including effect size estimation was intended to support a preliminary functional interpretation of mobility parameters in relation to the organization of the movement system.

Results

The analyzed sample consisted of 25 young athletes practicing bocce in the Raffa specialty, belonging to the junior category (aged between 14 and 18 years). The group included 15 male and 10 female participants. All athletes were subjected to three joint mobility assessments: the Shoulder Mobility Test, the scapulo-humeral girdle mobility test, and the spinal flexibility test. The results are presented separately for the male and female samples. Comparisons between groups were performed using independent samples t-tests (Tab. 1), including effect size estimation (Cohen's d), and relationships among mobility variables were examined using Pearson's correlation analyses. Descriptive statistics for the total sample and by sex are summarized in Table 1.

Table 1. Descriptive statistics of joint mobility parameters.

Variable	Group	Min	Max	Mean	SD	Range
Shoulder Mobility	Total	0	23	6.2	5.8	23
	Male	0	23	8.0	6.8	23
	Female	0	10	3.5	3.6	10
Scapulo-humeral Mobility	Total	29	120	81.3	25.4	91
	Male	66	120	96.46	15.3	54
	Female	29	86	58.8	19.8	57
Spinal Flexibility	Total	-4	27	9.0	8.0	31
	Male	-4	22	7.0	7.41	26
	Female	5	27	12.0	8.42	22

Note. Values are reported for the total sample and by sex. Mean values are presented with standard deviations (SD). Range is calculated as the difference between maximum and minimum values.

Shoulder Mobility Test

In the male sample, the values recorded in the Shoulder Mobility Test ranged from a minimum of 0 cm to a maximum of 23 cm. The mean value was 8 cm with a standard deviation

of 6.8 cm. The most frequently observed values were 1 cm, 13 cm, and 16 cm, each with an absolute frequency of 2 (Fig. 1).

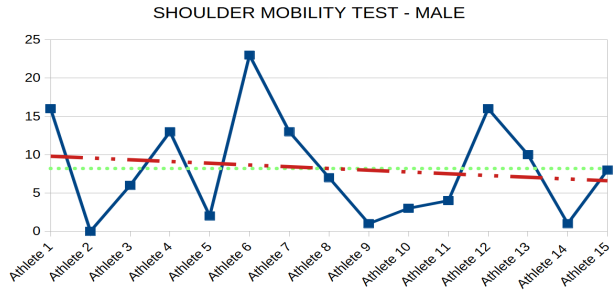

Fig. 1. Shoulder mobility – male sample.

In the female sample, the observed values ranged from a minimum of 0 cm to a maximum of 10 cm. The mean value was 3.5 cm with a standard deviation of 3.6 cm. The most frequently recorded values were 0 cm and 6 cm, both with an absolute frequency of 3 (Fig. 2).

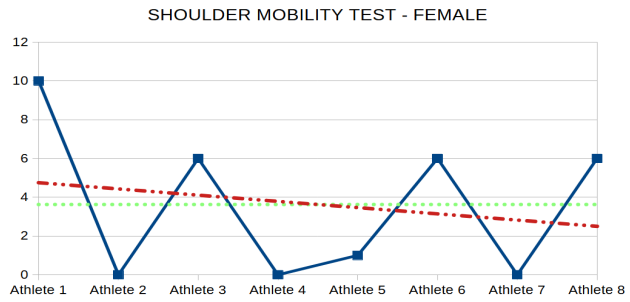

Fig. 2. Shoulder mobility – female sample.

The comparison between male and female groups did not show statistically significant differences in shoulder mobility ($t = 1.92$, $p = 0.067$), with a moderate effect size ($d = 0.85$), indicating a non-negligible magnitude of difference despite the lack of statistical significance.

Scapulo-humeral Girdle Mobility

Regarding the scapulo-humeral girdle mobility test, the values observed in the male sample ranged from a minimum of 66 cm to a maximum of 120 cm. The mean value was 96.46 cm with a standard deviation of 15.3 cm. The value most frequently observed was 120 cm, with an absolute frequency of 3 (Fig. 3).

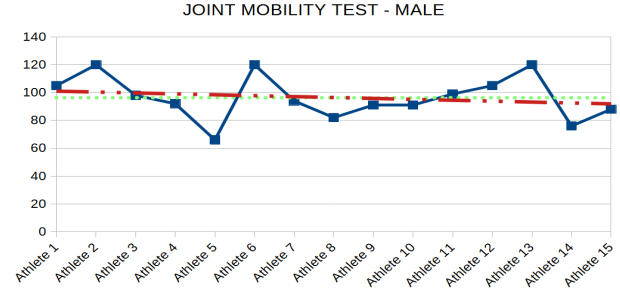

Fig. 3. Scapulo-humeral mobility – male sample.

In the female sample, the recorded values ranged from a minimum of 29 cm to a maximum of 86 cm. The mean value was 58.8 cm with a standard deviation of 19.8 cm. The values were evenly distributed, with an absolute frequency of 1 for each recorded value (Fig. 4).

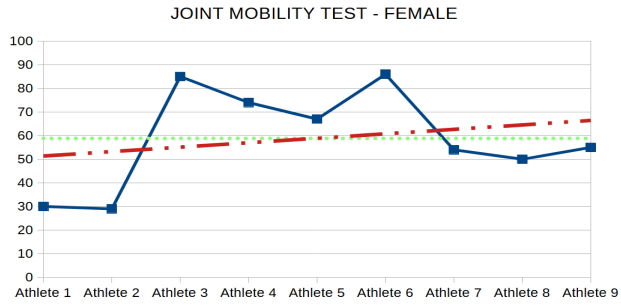

Fig. 4. Scapulo-humeral mobility – female sample.

The comparison between groups revealed statistically significant differences in scapulo-humeral mobility, with higher values observed in the male sample ($t = 5.12$, $p < 0.001$), with a large effect size ($d = 2.10$), indicating a substantial between-group difference.

Spinal Flexibility

In the spinal flexibility test, the male sample showed values ranging from a minimum of −4 cm to a maximum of +22 cm. The mean value was +7 cm with a standard deviation of 7.41 cm. The most frequently observed values were 0 cm and +12 cm, each with an absolute frequency of 3 (Fig. 5).

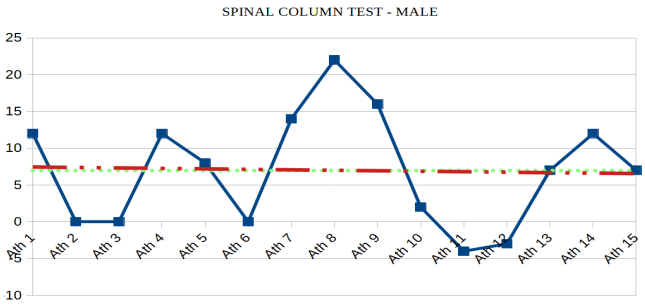

Fig. 5. Spinal flexibility – male sample.

In the female sample, all recorded values were positive and ranged from a minimum of +5 cm to a maximum of +27 cm. The mean value was +12 cm with a standard deviation of 8.42 cm. The most frequently observed value was +7 cm, with an absolute frequency of 3.

The comparison between male and female groups indicated statistically significant differences in spinal flexibility, with higher mean values in the female sample ($t = -2.12$, $p = 0.045$), with a moderate effect size ($d = 0.63$), suggesting a meaningful difference in trunk flexibility between groups (Tab. 2).

Pearson's correlation analyses

Pearson's correlation analyses were also performed to examine the relationships among the three mobility parameters assessed (Fig. 6). A moderate positive correlation

Table 2 - Summary of joint mobility parameters by gender.

Test	Male (Mean ± SD)	Female (Mean ± SD)	p-value	Cohen's d
Shoulder Mobility (cm)	8.0 ± 6.8	3.5 ± 3.6	0.067	0.85
Scapulo-humeral Mobility (cm)	96.46 ± 15.3	58.8 ± 19.8	< 0.001	2.10
Spinal Flexibility (cm)	7.0 ± 7.41	12.0 ± 8.42	0.045	0.63

Note. Values are presented as mean ± standard deviation. p-values refer to independent samples t-tests comparing male and female groups. Effect sizes are expressed as Cohen's d. Conventional thresholds for Cohen's d were applied (small = 0.2, medium = 0.5, large = 0.8).

Table 3. Correlation matrix among joint mobility parameters in young athletes practicing Raffa Bocce.

Variable	Shoulder Mobility	Scapulo-humeral Mobility	Spinal Flexibility
Shoulder Mobility	—	0.46* (p = 0.023)	0.28 (p = 0.174)
Scapulo-humeral Mobility	—	—	0.41* (p = 0.047)
Spinal Flexibility	—	—	—

Note. Values are reported for the upper triangular matrix to avoid redundancy. Diagonal elements (r = 1.00) are not shown. p < 0.05.

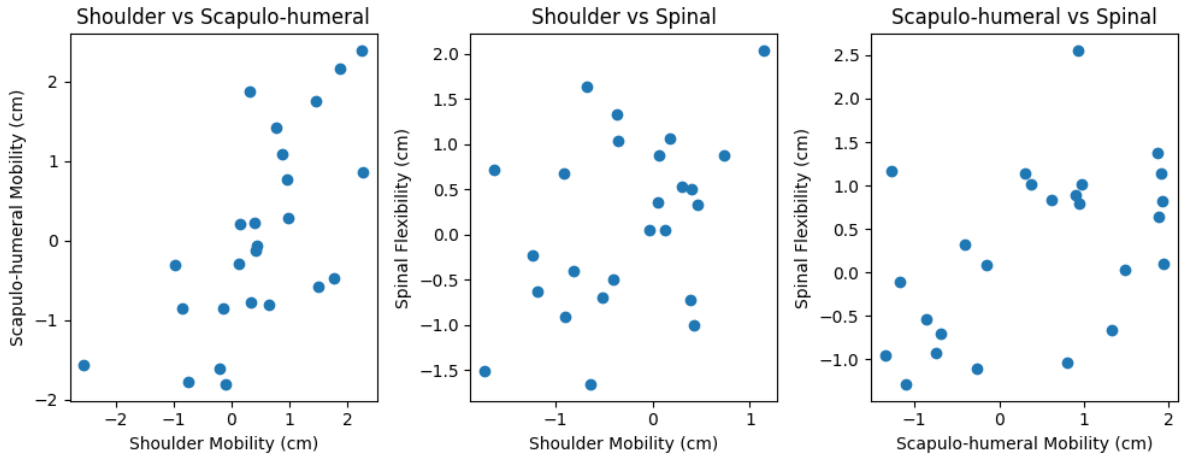

Fig. 6. Scatter plots illustrating the relationships between joint mobility variables in young bocce (Raffa specialty) athletes.

was observed between shoulder mobility and scapulo-humeral girdle mobility (r = 0.46, p = 0.023). A weak positive correlation was found between shoulder mobility and spinal flexibility (r = 0.28, p = 0.174). A moderate correlation was observed between scapulo-humeral girdle mobility and spinal flexibility (r = 0.41, p = 0.047). These findings indicate a pattern of interdependence among segmental mobility components, supporting their interpretation as functionally related rather than independent variables.

The correlation matrix is reported in Table 3.

Integrated analysis of joint mobility parameters

To verify whether the three mobility parameters could be interpreted as part of a shared functional configuration, the correlation matrix was additionally examined using Bartlett's test of sphericity. The test was statistically significant ((3) = 9.63, p = 0.022), indicating that the observed correlations were sufficient to reject the hypothesis of independence among variables. In addition, an exploratory estimate of internal coherence showed a Cronbach's alpha of 0.65, suggesting a moderate but meaningful degree of consistency among the three indicators. Taken together, these results support the interpretation of shoulder mobility, scapulo-humeral mobility, and spinal flexibility as components of a preliminary integrated mobility profile rather than as entirely separate parameters (Tab. 4). Overall, these results support the identification of a preliminary "mobility balance profile", in which the functional value of joint mobility emerges from the coherence among segmental contributions rather than from isolated parameter values.

Table 4. Integrative analysis of joint mobility parameters based on Bartlett's test of sphericity and Cronbach's alpha.

Analysis	Statistic	Value	p-value
Bartlett's test of sphericity	χ^2 (df = 3)	9.63	0.022
Internal consistency	Cronbach's α	0.65	–

Note. Bartlett's test evaluates whether the correlation matrix significantly differs from an identity matrix. Cronbach's alpha is reported as an exploratory estimate of internal coherence among mobility parameters.

An exploratory classification of functional mobility profiles is presented in Table 5.

Within this exploratory framework, mobility values were interpreted relative to the internal distribution of the sample. Lower values were considered indicative of

Table 5. Exploratory classification of functional mobility profiles in young Raffa Bocce athletes.

Profile Type	Description	N (Estimated)
Balanced profile	Comparable values across shoulder, scapulo-humeral, and spinal mobility	8
Upper limb dominant	Higher shoulder and scapulo-humeral mobility relative to spinal flexibility	7
Trunk dominant	Higher spinal flexibility relative to upper limb mobility	6
Unbalanced profile	Marked discrepancies among the three parameters	4

potentially insufficient mobility, intermediate and balanced values as functionally adequate, and disproportionately high values relative to other segments as potentially excessive. This classification does not define normative thresholds but provides a sample-based functional interpretation of mobility ranges.

Discussion

The present pilot study aimed to investigate joint mobility characteristics in young athletes practicing bocce in the Raffa specialty, with the intention of providing a preliminary functional profile of mobility parameters potentially related to technical performance in this precision sport. Beyond a purely descriptive approach, the study was oriented toward interpreting joint mobility as a functional component within the movement system underlying the technical gesture. Given the limited scientific literature specifically focused on the physical and functional characteristics of bocce players, particularly in youth categories, the study was conceived as an exploratory investigation designed to collect initial data useful for future research and for the development of a more structured understanding of the performance model associated with this discipline. Within this context, the study not only documents variability in joint mobility, but proposes a preliminary interpretation of joint mobility as an intersegmental functional configuration that mediates the relationship between movement amplitude and execution control in a precision-based task such as the Raffa gesture. Importantly, this interpretation is grounded in the observed variability, the pattern of between-group differences, and the interrelations identified among the assessed mobility parameters, rather than on direct measures of technical performance.

From a functional approach, the results of the present study can be interpreted within a system-based framework in which joint mobility operates as an organized set of interdependent components contributing to the control and reproducibility of the technical gesture. In this model, shoulder mobility primarily supports distal segment orientation and fine modulation of the release phase, scapulo-humeral mobility contributes to the regulation of movement amplitude and trajectory continuity, and spinal flexibility ensures postural organization and the effective transmission of forces along the kinetic chain. The interaction among these components determines the functional balance between movement amplitude and control, which is essential for achieving accuracy and consistency in the Raffa technical gesture. In the context of the present study, functional ranges should be interpreted as relative intervals within which mobility supports an effective balance between movement amplitude and control. Values below this range may limit movement adaptability, whereas values exceeding this range, particularly when not compensated by adequate control in other segments, may compromise movement stability. In this sense, joint mobility does not act as a single isolated factor, but as a coordinated system in which segmental contributions are functionally integrated. Crucially, within this system, joint mobility assumes a dual functional role, acting both as a facilitator of movement when it supports adequate amplitude and coordination, and as a potential constraint when excessive or insufficient levels disrupt the balance between control and stability. More specifically, the Raffa technical gesture requires a high level of repeatability, and such repeatability depends on maintaining a stable balance between movement amplitude and control; this balance is not generated by a single joint, but emerges from the coordinated interaction among shoulder, scapulo-humeral, and trunk mobility. Within the limits of the present design, this mechanism should be interpreted as a plausible functional explanation supported by the observed relationships among variables rather than as a directly tested causal pathway.

The main hypothesis underlying the research was that joint mobility, particularly at the level of the shoulder complex and spinal column, represents an important functional component for the execution of technical gestures in the Raffa specialty. In precision sports such as bocce, the quality of motor execution depends not only on technical skill and perceptual accuracy but also on the functional efficiency of the musculoskeletal structures involved in the movement. The throwing and pointing actions typical of the Raffa specialty require coordinated activation of the upper limb, trunk stabilization, and controlled movement amplitude, all of which may be influenced by joint mobility levels (Turkmen et al., 2013). In this perspective, joint mobility can be interpreted as a regulatory factor within the kinetic chain, influencing the balance between movement amplitude and control. More specifically, the effectiveness of the gesture may depend on the capacity of different joint segments to operate within a coordinated functional configuration, in which excessive or insufficient mobility in one segment may alter the overall organization of the movement. In this sense, insufficient mobility may limit movement amplitude and reduce the fluidity and adaptability of the gesture, whereas excessive mobility may compromise segmental stability and fine motor control, leading to reduced consistency and precision. Taken together, these elements support a functional interpretation in which the precision demands of the task require repeatable motor execution, repeatability depends on the balance between amplitude and control, and this balance is functionally mediated by the coordinated configuration of joint mobility across segments. However, this interpretation should be considered as a preliminary explanatory framework, as no direct performance outcomes were measured in the present study.

The results obtained in the present study indicate a certain degree of variability in joint mobility parameters among the young athletes examined. In the Shoulder Mobility Test, the male sample showed higher maximum values and greater variability compared with the female sample, while the female athletes generally presented lower average distances between the fists, suggesting relatively greater shoulder mobility. These findings may reflect differences in flexibility characteristics typically observed between male and female athletes during adolescence, as reported in several studies investigating joint mobility and flexibility in youth populations. Previous research in sport sciences has consistently highlighted that female athletes often display higher flexibility levels than males, particularly in movements involving the shoulder complex and posterior muscle chains (Şimşek et al., 2024). However, the absence of statistically significant differences in shoulder mobility between groups suggests that this parameter may fall within a functional range common to both sexes, rather than representing a discriminative factor for performance. Within the proposed functional model, this finding may indicate that shoulder mobility alone is not sufficient to determine movement effectiveness, but rather contributes to performance only when integrated with the functional behavior of other segments. This further supports the idea that mobility does not exert a linear effect on performance, but operates within a functional range in which both lower and higher values may have different implications depending on their interaction with other components of the movement system.

Regarding the assessment of scapulo-humeral girdle mobility, the results reveal a relatively wide range of values in both male and female samples. The variability observed in this test may be related to individual differences in training experience, motor coordination, and anthropometric characteristics. The scapulo-humeral joint complex plays a crucial role in the execution of throwing movements, as it contributes to the generation and control of movement amplitude and trajectory. Adequate mobility in this region allows athletes to perform smoother and more controlled arm movements, which may support the precision required in the technical gestures typical of bocce. In this perspective, the variability observed among participants may reflect different stages of motor development and technical adaptation to the sport. The statistically significant differences observed between male and female athletes indicate that this parameter may represent a more sensitive functional component, potentially influencing the organization of the upper limb movement within the kinetic chain. From a functional standpoint, scapulo-humeral mobility may represent a central regulatory element within the system, as it mediates the relationship between proximal stability and distal control, thereby influencing the continuity and efficiency of the movement trajectory. However, also in this case, an excessive increase in movement amplitude without adequate control may reduce movement consistency, highlighting again the non-linear contribution of mobility to performance.

The spinal flexibility test also revealed interesting patterns. While the male sample displayed both positive and negative values, indicating heterogeneous levels of trunk flexibility, the female sample showed exclusively positive values and a higher mean score. These results appear consistent with previous studies on flexibility development in adolescent athletes, which frequently report greater trunk flexibility among female participants. From a biomechanical perspective, adequate spinal mobility may contribute to improved postural control and balance during the execution of throwing movements, facilitating the transmission of force along the kinetic chain and allowing more efficient movement coordination (Costa, 2021). The presence of statistically significant differences between groups suggests that trunk mobility may play a differentiated functional role, particularly in relation to postural stabilization and force transmission during the technical gesture. Within the proposed model, spinal flexibility can be interpreted as the structural base that supports the integration of upper limb actions, ensuring that movement amplitude generated at the scapulo-humeral level is effectively controlled and transferred without compromising balance and stability. At the same time, excessive trunk mobility without sufficient neuromuscular control may reduce postural stability, potentially affecting the precision of the technical gesture.

The correlation analyses provide additional insight into the functional organization of joint mobility within the movement system. The moderate relationships observed between shoulder mobility and scapulo-humeral mobility, as well as between scapulo-humeral mobility and spinal flexibility, suggest the existence of coordinated functional interactions between different segments of the kinetic chain. In contrast, the weaker association between shoulder mobility and spinal flexibility indicates a more indirect relationship, highlighting the role of intermediate segments in linking upper limb movement and trunk function. These findings support the interpretation of joint mobility not as isolated parameters, but as interdependent components contributing to the overall organization of movement. In particular, the observed pattern of correlations supports the idea of a hierarchical and coordinated system, in which the scapulo-humeral complex acts as an intermediate functional link connecting distal control and proximal stabilization. The statistical assessment of the correlation matrix further strengthens this integrative interpretation. The significant result of Bartlett's test of sphericity indicates that the relationships among the three mobility parameters are not random, supporting the presence of an underlying functional structure. Moreover, the moderate Cronbach's alpha suggests a meaningful level of internal coherence among shoulder mobility, scapulo-humeral mobility, and spinal flexibility. Taken together, these findings support the identification of a preliminary "mobility balance profile", in which the functional value of joint mobility depends on the coherence among segmental contributions rather than on the isolated magnitude of individual parameters. This interpretation is further supported by the exploratory classification reported in Table 4, which illustrates how different combinations of segmental mobility give rise to distinct functional profiles, reinforcing the concept of joint mobility as an integrated and configuration-dependent system. Within this perspective, the profiles reported in Table 5 can be interpreted as reflecting different functional conditions, ranging from relatively insufficient to balanced and, in some cases, to relatively excessive mobility configurations. These distinctions are based on the internal distribution of the sample and should

be considered exploratory rather than normative thresholds. It is important to note that these profiles are derived from exploratory criteria and should not be interpreted as normative classifications.

When interpreting these findings, it is important to consider the specific characteristics of bocce as a precision sport. Unlike high-intensity or endurance-based sports, the success of performance in bocce relies heavily on the quality of fine motor control, the stability of body segments, and the ability to reproduce consistent movement patterns. Within this context, joint mobility does not necessarily act as a direct determinant of performance but rather as a functional prerequisite that may facilitate efficient motor execution (Geçitli et al., 2021). This implies the existence of functional ranges of joint mobility, within which movement execution is supported, whereas values outside these ranges, either excessive or insufficient, may compromise movement control and coordination. Adequate ranges of motion in the shoulder complex and trunk may allow athletes to adopt more stable and biomechanically efficient positions during technical actions, thereby supporting accuracy and repeatability (Helmi et al., 2024; Bălan et al., 2020). In this perspective, the effectiveness of joint mobility depends not on its absolute magnitude, but on its alignment with the functional requirements of the movement system, reinforcing the idea of mobility as a context-dependent resource rather than a universally beneficial attribute. Accordingly, mobility should be interpreted as a resource operating under specific functional conditions, in which both insufficient and excessive levels may negatively affect performance if they disrupt the balance between amplitude and control.

The importance of the results presented in this study lies primarily in their contribution to the limited body of knowledge concerning the functional characteristics of bocce athletes. While the sport is widely practiced in several countries, scientific investigations focusing on its biomechanical and physiological aspects remain relatively scarce. By providing preliminary data on joint mobility profiles in young athletes, this research contributes to filling an existing gap in the literature and offers an initial reference point for future investigations focusing on performance-related variables in this discipline. In particular, the integration of the different mobility parameters allows the definition of a preliminary functional profile, in which upper limb mobility, scapulo-humeral coordination, and trunk flexibility interact within a unified movement system. This integrative interpretation represents a first step toward the formulation of a functional explanatory model, in which joint mobility is conceptualized as a coordinated configuration of segmental contributions rather than as a set of independent variables.

From a practical perspective, the findings of this study may have implications for training methodologies in youth bocce programs. Coaches and trainers working with young athletes may benefit from incorporating regular assessments of joint mobility within their monitoring protocols. Such evaluations could help identify individual mobility limitations that might influence the execution of technical gestures and could support the development of targeted training interventions aimed at improving functional mobility. In particular, mobility exercises focused on the shoulder complex and trunk may represent useful components of warm-up routines or complementary conditioning programs designed to enhance movement efficiency and prevent potential musculoskeletal imbalances. Within this framework, mobility assessment may also support process control, allowing coaches to monitor functional adaptations and adjust training loads accordingly. In line with the proposed functional model, training interventions should aim not only at increasing mobility, but at optimizing the balance and coordination among different joint segments in order to enhance movement control and technical consistency. This implies that training should avoid a simplistic "more mobility is better" approach and instead focus on achieving optimal functional ranges compatible with the demands of precision performance.

Furthermore, the introduction of simple field-based mobility tests, such as those used in the present study, may represent a practical and accessible tool for monitoring the functional development of young athletes over time. These assessments require minimal equipment and can be easily implemented during training sessions or evaluation camps, providing coaches with valuable information about the physical readiness and functional status of their athletes. When interpreted within a functional framework, these measures may support the identification of imbalances between segmental contributions, offering actionable insights for individualized training adjustments.

Despite these potential applications, the present study also presents several limitations that should be acknowledged. First, the relatively small sample size limits the statistical power of the analyses and the generalizability of the findings. Second, the cross-sectional design does not allow the examination of causal relationships or the evolution of mobility characteristics over time. Third, the study did not include direct measures of technical performance (e.g., accuracy, consistency, or competition outcomes), which limits the possibility of establishing a direct link between joint mobility and performance effectiveness. Finally, the functional profiles and mobility balance configurations proposed in this study are exploratory in nature and should be interpreted as preliminary conceptual tools rather than definitive or normative thresholds. Future research could also explore the longitudinal development of mobility characteristics in young athletes practicing the Raffa specialty, examining how training exposure and technical experience influence functional adaptations over time. Moreover, comparative studies involving athletes from different levels of expertise or different bocce specialties or different disability and context (Di Palma et al., 2025; Latino et al., 2023) could provide further insights into the role of joint mobility within the broader performance model of this sport. Such investigations may contribute to refining the proposed functional framework and to identifying more precise criteria for the optimal organization of mobility within the movement system.

Therefore, the present study provides preliminary evidence regarding joint mobility characteristics in young athletes practicing bocce in the Raffa specialty. The findings highlight variability in shoulder and trunk mobility parameters and suggest potential gender-related differences in flexibility levels. More importantly, the results support an interpretation of joint mobility as a system of interrelated functional components, rather than isolated variables. In

particular, the study contributes to the conceptualization of joint mobility as a coordinated functional configuration that mediates the relationship between movement amplitude and control within the technical gesture of the Raffa specialty. Although exploratory in nature, the results contribute to the emerging scientific understanding of the functional aspects of bocce performance and underline the potential importance of mobility assessment within youth training contexts. Further research involving larger samples and more comprehensive performance analyses will be necessary to clarify the role of joint mobility within the technical and functional demands of this precision sport.

Conclusions

The present pilot study examined joint mobility characteristics in young athletes practicing bocce in the Raffa specialty. The results highlighted a certain variability in shoulder and spinal mobility within the analyzed sample and suggested some differences between male and female participants, particularly in trunk flexibility values. These findings contribute to outlining an initial functional profile of mobility parameters in youth bocce players. In particular, the results support the interpretation of joint mobility as a set of interrelated components within the movement system, rather than isolated variables. More specifically, the study supports the conceptualization of joint mobility as a coordinated functional configuration involving shoulder mobility, scapulo-humeral control, and spinal flexibility, whose interaction contributes to the regulation of movement amplitude, stability, and precision within the technical gesture of the Raffa specialty. Within this framework, joint mobility emerges as a non-linear factor, whose contribution to performance depends on its capacity to operate within functional ranges compatible with the demands of control and accuracy. These findings support a preliminary integrative rule according to which the functional value of joint mobility in the Raffa specialty depends on the balance and coherence among segmental components rather than on the maximal value of any single parameter. More broadly, the study suggests that the repeatability of the Raffa technical gesture is mediated by the capacity of the movement system to maintain a stable balance between movement amplitude and control through coordinated intersegmental contributions.

Although the study did not directly examine the relationship between joint mobility and technical performance, the results offer useful information about the functional characteristics of young athletes involved in this discipline. From a functional standpoint, joint mobility may be considered a regulatory factor influencing the balance between movement amplitude, coordination, and postural control during the execution of the technical gesture. Accordingly, joint mobility should be interpreted as a resource operating under specific functional conditions, in which both insufficient levels may limit movement amplitude and adaptability, and excessive levels may reduce segmental stability and fine motor control, ultimately affecting the consistency and precision of the gesture. In this perspective, the effectiveness of joint mobility depends on its integration within the movement system rather than on the isolated magnitude of individual parameters, highlighting the importance of coordinated segmental contributions. In this perspective, the assessment of joint mobility may represent a valuable component within the monitoring processes of youth training programs. This approach may also support process control, allowing practitioners to identify functional limits and adjust training interventions accordingly. Accordingly, training strategies should aim not only to improve mobility levels, but to optimize the balance and interaction among different joint segments in order to enhance movement control and technical consistency. This implies moving beyond a linear interpretation of mobility and focusing instead on the identification and maintenance of optimal functional ranges.

Given the exploratory nature of the research and the limited sample size, further studies involving larger samples and additional performance-related variables will be necessary in order to better understand the role of joint mobility within the technical and functional demands of the Raffa specialty. Future research should aim to integrate mobility assessment with biomechanical and performance indicators in order to refine the explanatory model and define more precise functional thresholds. In this sense, the present study provides a preliminary step toward the development of a functional explanatory model of joint mobility in bocce, in which mobility is interpreted as a system-level factor contributing to the organization and reproducibility of the technical gesture. Thus, the study contributes not only to describing joint mobility characteristics, but to proposing a functional interpretation of mobility as an intersegmental configuration that mediates the relationship between movement amplitude and execution control in precision performance. In particular, the study contributes to establishing the principle that the effectiveness of joint mobility lies not in its maximization, but in its functional calibration within the movement system.

Ethics Approval

The study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol was approved by the Institutional Review Board of the University of Naples "Parthenope" (DiSMMeB Prot. No. 88592/2024).

Informed Consent

Written informed consent was obtained from all participants prior to participation in the study. For participants under 18 years of age, written informed consent was additionally obtained from parents or legal guardians.

Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors did not use AI-assisted tools in the preparation of this manuscript.

Acknowledgements

Not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

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Функціональна рухливість суглобів у юних спортсменів, які займаються боччe Раффа: імплікації для моделі спортивної результативності

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Реферат. Стаття: 13 с., 5 табл., 6 рис., 23 джерела.

Мета дослідження. Боччe є видом спорту на точність, що потребує координації та технічного контролю. У дисципліні «Раффа» особливо важливими є координація верхніх кінцівок і постуральний контроль. Незважаючи на широке поширення цього виду спорту, дослідження функціональних характеристик юних спортсменів залишаються обмеженими. Це пошукове аналітичне пілотне дослідження мало на меті вивчити рухливість суглобів як функціональну конфігурацію в межах рухової системи, що лежить в основі технічного жесту Раффа.

Матеріали та методи. Двадцять п'ять спортсменів віком 14–18 років були обстежені під час регіональних тренувальних заходів, організованих Комітетом боччe Кампанії. Рухливість суглобів оцінювали за допомогою трьох польових тестів: тесту рухливості плечового суглоба, тесту скапуло-гумеральної рухливості з ротацією палиці та тесту нахилу тулуба вперед у положенні сидячи. Було розраховано описову статистику, t-критерій Стьюдента для незалежних вибірок і кореляції Пірсона. Для оцінювання інтегративної структури параметрів рухливості застосовували тест сферичності Бартлетта та дослідницький коефіцієнт альфа Кронбаха.

Результати. Виявлено статистично значущі відмінності у скапуло-гумеральній рухливості та гнучкості хребта, тоді як відмінностей у рухливості плечового суглоба не встановлено. Кореляційний аналіз показав слабкі та помірні взаємозв'язки між змінними. Тест Бартлетта ($\chi^2_{(3)}$=9.63, p=0.022) і коефіцієнт альфа Кронбаха 0.65 підтвердили наявність інтегрованої структури рухливості, що свідчить про взаємозалежність між сегментами.

Висновки. Рухливість суглобів виступає нелінійним, контекстно-залежним ресурсом, який може виконувати як функцію сприяння, так і функцію обмеження залежно від рівня інтеграції в рухову систему. Функціональна ефективність технічного жесту Раффа залежить від балансу між плечовими, скапуло-гумеральними та спінальними компонентами, а не від окремих максимальних показників. У дослідженні запропоновано попередню пояснювальну модель, у якій рухливість суглобів опосередковує взаємозв'язок між амплітудою руху та контролем.

Ключові слова: дисципліна Раффа, рухливість суглобів, юні спортсмени, гнучкість, спортивна результативність.

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High-Intensity Interval Training vs. Plyometric EMOM: A Comparison of Effects on Body Composition and Physical Fitness in 18-19-Year-Old Karate Athletes

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Abstract

Background. A scientific contradiction exists in kumite preparation: HIIT (metabolic-dominant via AMPK/PGC-1α) and plyometric training (neuromuscular-dominant via SSC) are theoretically predicted to produce distinct adaptation patterns, yet empirical literature reports only isolated effects without explanatory models of adaptation transfer to karate-specific fitness demands.

Objectives. This study aimed to compare the effects of conventional High-Intensity Interval Training (HIIT) and plyometric training using the Every Minute on the Minute (EMOM) format on physical fitness and body composition in male karate athletes aged 18-19 years.

Materials and Methods. Forty-four male karate athletes (aged 18-19 years) from the Polda DIY Karate Club were assigned to a quasi-experimental two-group pretest-posttest design, completing HIIT (n = 22) and plyometric-EMOM (n = 22) training over 8 weeks. Physical fitness was assessed using the Indonesian Physical Fitness Test (TKJI); body composition was measured using a Tanita BC-545N.

Results. Both groups improved substantially ($p < 0.001$). Significant Time×Group interactions were observed for TKJI, body fat, and body weight (all $p < 0.001$), with a moderate interaction for FFM ($p = 0.028$). The HIIT group demonstrated greater TKJI gains ($\Delta = +3.09$ vs. $+0.95$), while the plyometric-EMOM group produced greater fat loss ($\Delta = -5.36\%$ vs. -4.29%). Extremely large effect sizes (Cohen's d up to 6.80) reflect low variance within a homogeneous single-club sample rather than universal biological effects.

Conclusions. HIIT is superior for physical fitness via metabolic-cardiovascular pathways, whereas plyometric-EMOM excels in fat reduction via SSC-driven eccentric energetics, confirming the Dual-Pathway Specificity Model. These findings are context-specific to elite junior male karate athletes and require further validation for broader generalization.

Keywords: high-intensity interval training, plyometric EMOM, karate, physical fitness, body composition.

Introduction

Karate, as an intermittent combat sport, requires a combination of aerobic-anaerobic capacity, lower-limb muscle power, speed, agility, and high technical coordination; therefore, physical fitness and body composition are critical determinants of performance, particularly in young athletes aged 18-19 years who are entering the phase of competitive specialization (Martínez-de-Quel et al., 2020; Przybylski et al., 2021). The theory of training adaptation (specificity principle) predicts that HIIT will dominate metabolic-cardiovascular adaptations through stimulation of the AMPK/PGC-1α pathway and repeated lactate accumulation, producing body composition changes (↓fat, ↑VO_2peak) crucial for kumite endurance. Conversely, plyometric training via the stretch-shortening cycle (SSC) should excel in neuromuscular adaptations (↑rate of force development/RFD, tendon stiffness), essential for explosive movements

such as kicks and rapid defensive techniques (Kons et al., 2023; Laidi et al., 2025).

The demands of kumite competition are non-uniform (with fluctuating rhythm and intensity), characterized by a dominant aerobic contribution while still requiring anaerobic capacity for high-intensity offensive and defensive actions that determine match outcomes. A scientific contradiction arises in adolescent karate athletes who require a holistic balance of both adaptations for kumite performance. HIIT (metabolically-dominant) and plyometric-EMOM (neuromuscular-dominant) protocols are theoretically predicted to produce distinct adaptation patterns; yet empirical literature reports only isolated effects without explanatory models of why one protocol fails to transfer to karate-specific fitness demands. This leaves the transition from ‹unknown› to ‹knowledge-how› of training adaptations unresolved (Rezaei et al., 2024; Ojeda-Aravena et al., 2023). The specificity principle demands that training stimuli match kumite's metabolic demands (HIIT) versus neuromuscular demands (SSC); this mismatch in adaptation transfer challenges our understanding of combat sport-specific adaptations (Rezaei et al., 2024; Ojeda-Aravena et al., 2023).

This contradiction is further compounded by the role of body composition in kumite performance. Anthropometric characteristics such as relatively low body fat levels and adequate fat-free mass are associated with strength-to-weight ratio, movement efficiency, and the ability to execute explosive techniques, while fitness profiles (e.g., high VO_2peak, maximal strength, and muscular endurance) form an important baseline for designing effective individualized training programs (Da Costa Silva et al., 2020; Nema et al., 2024). It remains unclear whether metabolic-focused (HIIT) or neuromuscular-focused (plyometric-EMOM) interventions produce superior body composition outcomes in young karate athletes a dimension that directly connects to resolving the adaptation specificity contradiction. Although karate athletes generally exhibit fitness levels above those of their age-matched peers, appropriate training load management remains necessary to minimize the risk of overreaching and to maintain optimal body composition during phases of competitive intensification (Aziz et al., 2025).

Various sport-specific training interventions lasting 4-12 weeks (2-3 sessions/week), such as HIIT, plyometric training, circuit bodyweight training, and concurrent training, have been reported to improve key performance components (e.g., sprinting, vertical jumping, agility, and aerobic-anaerobic capacity) without excessively increasing training volume (Ojeda-Aravena et al., 2023; Xu & Wang, 2025; Fadhila et al., 2024). However, these studies report outcome differences without mechanistic explanations precisely the explanatory gap at the core of the present contradiction. Two approaches commonly used to support kumite performance are high-intensity interval training (HIIT) and plyometric training. HIIT stimulates aerobic-anaerobic adaptations through metabolic and cardiovascular stress, thereby enhancing VO_2max and tolerance to high-intensity work (Rezaei et al., 2024; Wiesinger et al., 2025). In contrast, plyometric training exploits the stretch-shortening cycle (SSC) to improve power, neuromuscular reactivity, and muscular coordination, which are directly relevant to the explosive movements required in combat sports (Kons et al., 2023; Ojeda-Aravena et al., 2023).

Along with the evolution of training practices, the every minute on the minute (EMOM) format has been increasingly adopted to "package" training sessions, as participants initiate a task at the beginning of each minute and use the remaining time within that minute as a rest period, allowing training density and inter-work intervals to be efficiently standardized (Laidi et al., 2025). Critically, the EMOM structure by standardizing training density and work-to-rest ratio provides a controlled experimental condition to isolate whether neuromuscular versus metabolic stimuli produce differential adaptation transfer to kumite-specific fitness, directly addressing the unresolved contradiction identified above. Conceptually, controlling training density and work-to-rest ratio is expected to help maximize specific physiological adaptations while reducing the risk of cumulative fatigue in young athletes.

Therefore, this study tests the mechanism-based hypothesis: (1) Plyometric-EMOM will be superior for neuromuscular adaptations (power, agility) via SSC-matching kumite demands; (2) HIIT will excel in body composition changes via metabolic pathways; (3) A predictive model of karate adaptation = f(metabolic vs neuromuscular + kumite specificity), generating 'knowledge-how' for karate training programs.

Materials and methods

Participants

A total of 44 male karate athletes (young police officers) from a single competitive club the Polda Special Region of Yogyakarta Karate Club, Indonesia, aged 18-19 years, were recruited using purposive sampling to ensure uniform training history and technical background, as required for controlled comparison of protocol-specific adaptations (M = 18.5 ± 0.5 years; height 172.1 ± 1.7 cm; body weight 70.6 ± 2.0 kg; BMI 23.8 ± 0.7). This single-club, narrow-age (18-19y) design deliberately ensured high homogeneity in training history, technical proficiency, and baseline fitness, minimizing between-subject variability to isolate protocol-specific effects (HIIT vs plyometric-EMOM) while acknowledging limited external validity beyond this specific population and training context. Inclusion criteria were: (1) a baseline TKJI score of 14-21, (2) BMI between 18.5 and 24.9 kg/m^2, and (3) free from musculoskeletal injury for at least 6 months prior to the study. Exclusion criteria included a history of cardiovascular or respiratory diseases limiting high-intensity exercise, use of medications affecting exercise responses, failure to complete either the pretest or posttest, and training attendance <80% of total sessions.

Consequently, the high within-group homogeneity of this sample is expected to produce artificially low variance, which directly inflates t-values and Cohen's d estimates reported in the Results; these should therefore be interpreted as sample-specific rather than universal biological effects.

Research design and organization

This study employed a quasi-experimental two-group pretest-posttest design with an active comparison group, comparing two training protocols (conventional HIIT

targeting metabolic adaptations vs. plyometric-EMOM targeting SSC-mediated neuromuscular adaptations) without a non-intervention control group. The overall study design and experimental flow are presented in Figure 1. The intervention was conducted over 8 weeks with a frequency of 2 sessions/week and a duration of 35-40 minutes/session. Training intensity was targeted at an RPE of 15-18 (hard to very hard) during the main training segment.

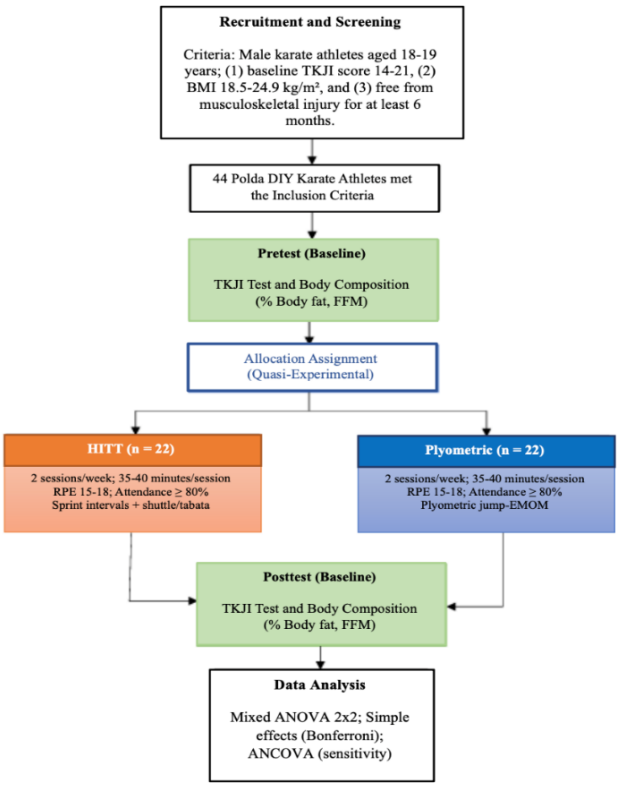

Fig. 1. Research Flows

Measurements were conducted at pretest and posttest for physical fitness and body composition. Physical fitness was assessed using the Indonesian Physical Fitness Test (Tes Kesegaran Jasmani Indonesia, TKJI), which includes a 60 m sprint, pull-ups, 30 s sit-ups, vertical jump, and a 1200 m run (total score range: 5-25). Body composition was measured using a Tanita BC-545N (bioelectrical impedance analysis/BIA) to obtain body fat percentage (% body fat), fat-free mass (FFM), and body weight (Son et al., 2024). Body composition measurements were performed at a consistent time (08:00 a.m. local time), barefoot, wearing light clothing, and supervised by the same trained assessor; the device was calibrated and verified according to laboratory procedures prior to data collection, and readings were repeated only in cases of device error or unstable electrode contact.

Controlled variables for both groups included an ad libitum diet (no specific dietary intervention), a minimum attendance requirement of 80%, and weekly RPE monitoring to maintain consistency of training stimulus across sessions and between groups. All pretest and posttest measurements were conducted using standardized test order and verbal instructions delivered by the facilitator, with rest intervals kept consistent across all testing sessions.

Intervention protocols

Conventional HIIT group (n = 22)

The HIIT protocol specifically targeted metabolic-cardiovascular adaptations (AMPK/PGC-1α activation via repeated lactate accumulation) to match kumite's prolonged aerobic-dominant energy demands. The HIIT group performed progressive sprint interval training (8-12 repetitions; 30-40 s sprint with 75-90 s recovery) and shuttle runs based on Tabata metabolic conditioning (10-16 repetitions; 20 s work with 30-40 s rest). Sessions lasted 35-40 minutes, 2x/week for 8 weeks. The detailed weekly structure and progression of the training program are presented in Table 1.

Plyometric EMOM group (n = 22)

The plyometric-EMOM protocol isolated neuromuscular adaptations via stretch-shortening cycle (SSC) mechanisms (↑RFD, tendon stiffness) to match karate's explosive offensive-defensive techniques. The plyometric-EMOM group performed high-intensity jump sequences using the every minute on the minute (EMOM) format for 10-15 minutes (depending on week/progression), including box jumps (30-50 cm), depth jumps, hurdle hops, and lateral bounds. Sessions lasted 30-35 minutes, 2x/week for 8 weeks. The weekly structure, progression of contact volume, and drill variations are presented in Table 2.

Table 1. Weekly Structure of Conventional HIIT (2 sessions/week, 8 weeks)

Week	Day 1 (Monday)	Day 2 (Thursday)	Intensity Progression	Main Effect
1-2	8x(30s sprint/90s walk) 4x(200m run/2min rest)	10x(20s shuttle/40s rest) 3x(4min tabata pushup-squat)	80-85% HRmax	↑ VO_2max
3-4	10x(30s sprint/90s walk) 4x(250m run/2min rest)	12x(20s shuttle/40s rest) 4x(4min tabata)	85-90% HRmax	↑ anaerobic power
5-6	12x(30s sprint/75s walk) 5x(250m/90s rest)	14x(20s shuttle/35s rest) 4x(5min tabata)	90% HRmax	↑ sprint endurance
7-8	12x(40s sprint/75s walk) 5x(300m/90s rest)	16x(20s shuttle/30s rest) 5x(5min tabata)	90-95% HRmax	Peak aerobic capacity

*Primary Method: Sprint intervals + metabolic conditioning | Duration: 35-40 minutes/session

Table 2. Weekly Structure of Plyometric EMOM (2 sessions/week, 8 weeks)

Week	Day 1 (Tuesday) EMOM 10-12 minutes	Day 2 (Friday) EMOM 12-15 minutes	Volume Progression	Main Effect
1-2	Minutes 1-10: 5 box jumps (30 cm) Minutes 11-12: 6 hurdle hops	Minutes 1-12: 4 depth jumps (30 cm) + 30 s rest/set	40-50 contacts	↑ reactive strength
3-4	Minutes 1-12: 6 box jump (40 cm) Minutes 13-15: 8 single leg hops	Minutes 1-15: 5 depth jump (40 cm) + lateral bounds	60 contacts	↑ explosive power
5-6	Minutes 1-12: 7 drop jumps (40 cm) Minutes 13-15: 6 hurdle + stick	Minutes 1-15: 6 depth jump (50 cm) + CoD drill	70-80 contacts	↑ CoD + power
7-8	Minutes 1-15: 8 reactive drop jumps Karate-specific test	Minutes 1-15: 7 plyometric + agility Performance test	90+ contacts	Peak SSC + agility

*Main method: EMOM jump-landing sequence | Duration: 30 minutes/session

Facilitators and training

The training intervention was delivered by two certified strength and conditioning practitioners and two karate coaches affiliated with the POLDA DIY karate club (total n = 4 facilitators). Prior to the intervention, all facilitators completed an 8-hour standardization workshop led by the research team to ensure consistent session delivery across groups.

The workshop covered: (1) safety procedures and injury prevention (warm-up/cool-down, sprint mechanics, jump-landing techniques, and load progression); (2) internal load monitoring using the Borg RPE Scale with a target of 15-18 for the core sets; and (3) session management (time regulation, enforcement of work-rest intervals, and criteria for stopping or modifying exercise in the presence of pain, dizziness, or excessive fatigue).

To standardize data collection, facilitators were trained in unified protocols for administering the TKJI test battery and assessing body composition using the Tanita BC-545N, including equipment calibration checks, standardized verbal instructions, consistent test order, and identical rest intervals. Attendance and weekly RPE were recorded using standardized logbooks, and participants were required to achieve ≥80% session attendance to be included in the analysis.

Monitoring instruments are provided in the Appendix/Supplement to support replication and transparent reporting of implementation fidelity.

Instrument

Body composition (Tanita BC-545N: %Body Fat, FFM)

Body composition was measured using the Tanita BC-545N (BIA) to obtain % body fat, fat-free mass (FFM), and body weight (Son et al, 2024). Measurements followed strict hydration controls: 08:00 a.m. (fasted >10h), barefoot, light clothing (<0.5kg), no exercise 24h prior, (urine specific gravity <1.020) , supervised by trained assessor. Test-retest reliability: ICC=0.95

Physical fitness (TKJI)

Physical fitness was assessed using the Indonesian Physical Fitness Test (Tes Kesegaran Jasmani Indonesia; TKJI) for adolescents aged 13-19 years. The TKJI battery comprises a 50-m sprint (speed), pull-ups (upper-body strength), sit-ups (abdominal strength and endurance), a vertical jump (explosive leg power), and a 1,000-m middle-distance run for males and an 800-m middle-distance run for females to assess cardiorespiratory endurance.

The validity and reliability of the TKJI have been reported to be high, with a validity coefficient of 0.720 and a reliability of 0.920 (Dulanlebit, 2020). Inter-rater reliability was acceptable to high (ICC = 0.88; two-way random-effects model, 20% subsample).

Statistical analysis

Data were analyzed using IBM SPSS version 26. Results are presented as mean ± SD, and statistical assumptions were examined using the Shapiro-Wilk normality test and Levene's variance homogeneity test (two-tailed $\alpha = 0.05$). Intervention effects were tested using a 2×2 mixed ANOVA (Time: pre, post × Group: HIIT, PLYO-EMOM) for each outcome, with emphasis on the Time × Group interaction and reporting $F(df=1,42)$, p values, and partial η^2.

Significant interactions were followed by planned simple-effects analyses (pre-post within each group) with Bonferroni adjustment ($\alpha = 0.025$) and Cohen's d effect sizes calculated as $d = |\text{mean difference}| / \text{pooled SD}$ ($\sqrt{[(SD\_pre^2 + SD\_post^2)/2]}$). ANCOVA on posttest values adjusted for baseline (pretest as covariate) was conducted as a sensitivity analysis with homogeneity of regression slopes verified (all $p > 0.05$). Sample size was determined a priori using G*Power (n = 22 per group; power = 0.90; f = 0.40; $\alpha = 0.05$ for medium-large interaction effects).

Results

Twenty-two karate athletes were assigned to each intervention group (HIIT, n=22; PLYO-EMOM, n=22).

Measurements of physical fitness (TKJI) and body composition (%Body Fat, FFM using Tanita BC-545N) were taken at pretest and posttest after 8 weeks. The results are presented as follows:

Table 3. Baseline Characteristics of Participants

Variable	HIIT (n = 22)	Plyometric EMOM (n = 22)
Age (years)	18.45 ± 0.510	18.45 ± 0.510
Body height (cm)	172.23 ± 1.817	172.23 ± 1.817
Body weight (kg)	70.50 ± 1.795	70.60 ± 1.795
BMI (kg/m2)	23.76 ± 0.167	23.79 ± 0.168
TKJI (Pre)	18.36 ± 2.083	19.23 ± 3.070
Lemak (Pre)	18.70 ± 0.807	18.67 ± 0.901
FFM (Pre)	57.36 ± 1.972	57.43 ± 2.008

Table 3 shows that the baseline characteristics of both groups were descriptively similar across demographic, anthropometric, physical fitness, and body composition variables. Given the quasi-experimental design, this similarity is not interpreted as evidence of "equivalence"; therefore, effect interpretation relies primarily on mixed ANOVA and is corroborated by ANCOVA.

Table 4. Normality Test (Shapiro-Wilk)

Variable (gain score)	Group	p (Shapiro-Wilk)
Body weight gain	HIIT	0.195
Body weight gain	Plyometric EMOM	0.619
Body fat gain	HIIT	0.159
Body fat gain	Plyometric EMOM	0.111
FFM gain	HIIT	0.290
FFM gain	Plyometric EMOM	0.294
TKJI gain	HIIT	0.184
TKJI gain	Plyometric EMOM	0.417

The distribution of all primary variables was examined using the Shapiro-Wilk normality test. All variables yielded p-values > 0.05, indicating normal data distributions. Accordingly, the use of parametric analyses was considered appropriate.

Table 5. Homogeneity of Variances (Levene's Test)

Variable	Levene's (Sig.)
Weight gain	0.284
Fat gain	0.068
FFM gain	0.205
TKJI gain	0.978

Levene's test indicated that all p values were > 0.05, suggesting homogeneous variances between groups and no evidence of heteroscedasticity affecting between-group comparisons.

Table 6 shows that both groups improved across all outcomes from pretest to posttest. HIIT demonstrated greater gains in physical fitness (TKJI: Δ = +3.09 vs. +0.95), whereas the plyometric-EMOM group showed greater reductions in body fat percentage (Δ = −5.36% vs. −4.29%) and body weight (Δ = −2.46 kg vs. −1.28 kg). Changes in FFM were comparable between groups (Δ = +1.84 kg vs. +1.65 kg), consistent with the moderate interaction effect observed in the mixed ANOVA

Based on Table 7, the main effect of Time was significant and very large for all outcomes, indicating that both groups changed from pretest to posttest. The extremely large F-values (e.g., F=3837.997 for body fat) reflect low between-subject variance characteristic of elite homogeneous samples from a single karate club, rather than generalizable training effects. Significant Time × Group interactions were observed for TKJI, body fat, and body weight (all $p < 0.001$), as well as for FFM ($p = 0.028$), indicating that the magnitude of pre-post change differed between groups and that training modality modulated adaptive responses. Practically, these findings support specificity of effects: HIIT was more favorable for improving TKJI, whereas plyometric EMOM was more favorable for reducing body fat and body weight (confirmed by simple-effects analyses).

Based on Table 8, all outcomes changed significantly from pretest to posttest in both groups (all $p < 0.001$; corrected $\alpha = 0.025$), indicating that both protocols were effective. However, extremely large t-values (e.g., t=113.376 for HIIT body weight; t=46.737 for HIIT body fat) and Cohen's d values (d=6.80, 5.96) are artifacts of extremely low baseline variance (SD < 1% for body fat) in this single-club homogeneous sample, rather than universal biological effect magnitudes. The magnitude of change differed: improvements in TKJI were greater in the HIIT group (d=1.47) than in the plyometric EMOM group (d=0.32), whereas reductions in body fat and body weight were greater in the plyometric EMOM group. Increases in FFM occurred in both groups with moderate between-group differences (d=0.98 vs 0.80). These context-specific effects align with metabolic (HIIT) vs neuromuscular (plyo-EMOM) adaptation pathways.

Prior to ANCOVA, the assumption of homogeneity of regression slopes was tested. No significant interaction between group and baseline values was detected ($p > 0.05$), indicating that the assumption was satisfied.

ANCOVA results controlling for baseline values demonstrated significant between-group differences across

Table 6. PRE-POST MEANS by group

Variable	HIIT Pre	HIIT Post	Δ HIIT	Plyo Pre	Plyo Post	Δ Plyo
TKJI	18.36 ± 2.083	21.47 ± 2.110	+3.09	19.23 ± 3.070	20.18 ± 2.986	+0.95
Body Fat (%)	18.70 ± 0.807	14.41 ± 0.413	−4.29	18.67 ± 0.901	13.31 ± 0.892	−5.36
FFM (kg)	57.36 ± 1.972	59.21 ± 1.769	+1.85	57.43 ± 2.008	59.08 ± 2.134	+1.65
Body Weight (kg)	70.50 ± 1.795	69.22 ± 1.780	−1.28	70.60 ± 1.795	68.14 ± 1.966	−2.46

Note: Δ = difference between posttest and pretest. Extremely low baseline SDs (e.g., body fat SD < 1%) reflect single-club homogeneity rather than population norms; interpret magnitude changes within this context. Negative values indicate a decrease; positive values indicate an increase.

Table 7. Mixed ANOVA (2×2) Results

Outcome	Source	F(1.42)	p	ηp^2	Interpretation
TKJI	Time	195.007	<0.001	0.823	Very large
TKJI	Group	0.070	0.792	0.002	No effect
TKJI	Time×Group	54.383	<0.001	0.564	Very large
Body Fat (%)	Time	3837.997	<0.001	0.989	Very large
Body Fat (%)	Group	6.455	0.015	0.133	Moderate
Body Fat (%)	Time×Group	47.472	<0.001	0.531	Very large
FFM (kg)	Time	1744.059	<0.001	0.976	Very large
FFM (kg)	Group	0.002	0.964	0.000	No effect
FFM (kg)	Time×Group	5.216	0.028	0.110	Moderate
Body Weight (kg)	Time	1098.418	<0.001	0.963	Very large
Body Weight (kg)	Group	0.795	0.378	0.019	Small
Body Weight (kg)	Time×Group	109.893	<0.001	0.723	Very large

Note: Extremely large F-values (>1000) and $\eta p^2 > 0.95$ primarily reflect artificially low variance (baseline SDs < 2) from highly homogeneous single-club sample, not universal biological effects. ηp^2 interpretation: 0.01-0.05 = small, 0.06-0.13 = moderate, ≥0.14 = large, ≥0.50 = very large effect.

Table 8. Planned Simple-Effects Comparisons (Bonferroni-adjusted $\alpha = 0.025$) with Cohen's d

Outcome	Comparison	Mean Diff	95% CI	t(df=21)	p	Cohen's d	Interpretation
TKJI	HIIT	+3.091	2.49, 3.68	10.803	<0.001	1.47	Very Large
TKJI	Plyo	+0.955	0.86, 1.04	21.000	<0.001	0.32	Small
Body fat (%)	HIIT	-4.286	-4.47, -4.09	46.737	<0.001	6.80	Very Large
Body fat (%)	Plyo	-5.359	-5.62, -5.09	42.595	<0.001	5.96	Very Large
FFM (kg)	HIIT	+1.840	1.73, 1.95	35.924	<0.001	0.98	Large
FFM (kg)	Plyo	+1.650	1.51, 1.78	24.984	<0.001	0.80	Large
Body weight (kg)	HIIT	-1.277	-1.30, -1.25	113.376	<0.001	0.71	Moderate
Body weight (kg)	Plyo	-2.459	-2.69, -2.23	21.922	<0.001	1.31	Very Large

Note: Cohen's d > 5.0 characteristic of highly homogeneous athletic cohorts (single club, narrow age range); interpret cautiously for external validity. 95% CI calculations available upon request.

Table 9. ANCOVA Results (Posttest Adjusted for Baseline)

Outcome	Adjusted Mean HIIT	Adjusted Mean Pliometrik EMOM	p	ηp^2
TKJI	21.85 ± 0.41	19.78 ± 0.41	< 0.001	0.553
Body fat (%)	14.40 ± 0.18	13.32 ± 0.19	< 0.001	0.635
FFM (kg)	59.23 ± 0.12	59.05 ± 0.11	0.028	0.112
Body weight (kg)	69.27 ± 0.16	68.09 ± 0.17	< 0.001	0.727

all variables. The HIIT group exhibited higher adjusted TKJI scores ($p < 0.001$, $\eta p^2 = 0.553$), indicating superior improvements in physical fitness. Conversely, the plyometric EMOM group showed lower adjusted body fat percentage and body weight ($p < 0.001$; $\eta p^2 = 0.635$-0.727), consistent with greater fat loss efficacy .Differences in fat-free mass were statistically significant but with small-to-moderate effect sizes ($p = 0.028$; $\eta p^2 = 0.112$), suggesting relatively comparable practical effects between groups. Large ηp^2 values primarily reflect low baseline variability rather than protocol superiority alone.Collectively, ANCOVA-adjusted results provide context-specific support for the mechanism-based hypotheses: HIIT superiority in physical fitness (TKJI) is consistent with metabolic-cardiovascular pathway activation, while plyometric-EMOM superiority in fat reduction aligns with SSC-driven neuromuscular and metabolic demands though generalization beyond this homogeneous cohort requires caution.

Discussion

This study examined whether HIIT (metabolic-dominant via AMPK/PGC-1α) and plyometric-EMOM (SSC-neuromuscular dominant) produce differential adaptation patterns in kumite-relevant fitness outcomes. Both protocols produced significant pre-post improvements; however, the direction and magnitude of adaptation differed systematically by modality. HIIT demonstrated superior improvements in physical fitness (TKJI: $\Delta = +3.09$ vs. $+0.95$; $d = 1.47$ vs. 0.32), while plyometric-EMOM yielded greater reductions in body fat ($\Delta = -5.36\%$ vs. -4.29%) and body weight ($\Delta = -2.46$ kg vs. -1.28 kg), with comparable FFM gains across groups. These findings align with prior research

showing HIIT's edge in aerobic-related fitness metrics, while plyometric protocols excel in fat loss due to higher SSC-driven metabolic demands (Sarfraz et al., 2022; Chen et al., 2025; Li et al., 2023).

Building on these modality-specific outcomes, a cautious interpretation is warranted for the extremely high t-value observed for body weight change in the HIIT group (t = 113.376), which corresponds to an unusually small standard deviation of gain scores (SD approximately 0.05 kg). These artifacts underscore the context-specific nature of findings, aligning with methodological limitations acknowledged in participant selection. This pattern likely reflects the combination of a highly homogeneous sample (male karate athletes aged 18-19 years from a single club with identical training frequency, intensity, and session structure), strict inclusion criteria (BMI 18.5-24.9), and the absence of dietary manipulation, conditions that may have naturally constrained inter-individual variability in body weight response. When all participants undergo the same standardized protocol under similar physiological and environmental conditions, convergence of individual responses is plausible, though the magnitude observed here is at the extreme end of what would typically be expected. Readers are therefore encouraged to interpret these values within the context of this specific sample rather than as generalizable population-level estimates.

The extremely large Cohen's d values observed for body fat percentage (HIIT: d = 6.80; plyometric-EMOM: d = 5.96) similarly reflect the very small pooled standard deviations of this outcome (SD approximately 0.60-0.70%), rather than indicating implausibly large biological effects. These small SDs are consistent with the homogeneous sample characteristics and tightly controlled measurement conditions described above. Mechanistically, HIIT's TKJI superiority reflects AMPK/PGC-1α-mediated mitochondrial biogenesis and upregulation of oxidative enzyme activity, which directly enhance aerobic energy turnover capacity matching kumite's 60-70% aerobic energy contribution during competitive bouts. Repeated lactate accumulation across HIIT intervals further stimulates cardiac output adaptations and buffer capacity, translating into sustained high-intensity work tolerance as measured by TKJI. Conversely, plyometric-EMOM's superior fat loss is explained by SSC-driven eccentric loading, which generates greater mechanical strain per repetition, elevating EPOC and post-exercise lipid oxidation beyond what is produced by HIIT's predominantly concentric work. Furthermore, SSC-specific neural adaptations including increased motor unit synchronization and enhanced tendon stiffness reduce the metabolic cost of explosive movements, indirectly improving energy efficiency during kumite-specific actions such as rapid kicks and defensive transitions (Kons et al., 2023; Ojeda-Aravena et al., 2023). These mechanistic interpretations are consistent with the observed outcome patterns and provide a plausible physiological basis for the differential effects, though direct measurement of these pathways (e.g., muscle biopsies, hormonal biomarkers) was beyond the scope of the present study.

It should be noted that Cohen's d is highly sensitive to sample variance, such that in highly homogeneous samples with standardized measurement protocols, even moderate absolute changes can produce very large d values. These effect sizes should therefore be interpreted as indicators of within-group consistency of response rather than as direct comparisons to effect sizes reported in more heterogeneous populations. Overall, the results support the principle of training specificity, as HIIT elicited stronger TKJI gains and plyometrics drove superior body composition shifts, consistent with González-Gálvez et al. (2024) and Domaradzki et al. (2025), challenging broader claims of HIIT's universal superiority for body composition and highlighting EMOM-structured plyometrics as a viable alternative in combat sports.

The present findings support the hypothesis that HIIT and plyometric-EMOM produce differential adaptation patterns, with HIIT favoring physical fitness gains and plyometric-EMOM favoring fat reduction in young male karate athletes. This modality-specific pattern is consistent with the mechanistic rationale underlying each protocol and with the broader principle of training specificity (Rezaei et al., 2024; Ojeda-Aravena et al., 2023).

The single-club, narrow-age (18-19y) design maximized internal validity but severely limits external validity to diverse populations. .Several limitations temper these promising findings. The quasi-experimental design without randomization limits causal claims, as baseline differences were adjusted via ANCOVA but unmeasured confounders persist (Suhandoko & Hsu, 2020). No passive control group precludes isolating effects from maturation or habitual training, ethically justified but weakening internal validity. The homogeneous sample (male karate athletes, 18-19 years, n=44 from one club) and ad libitum diet inflate effect sizes via low variance but restrict generalizability. The 8-week duration may undervalue plyometric neuromuscular gains, and lack of dietary control introduces energy balance confounds.

Despite these constraints, the results offer actionable insights for practitioners. Based on the empirical outcomes observed, HIIT appears more suitable during training phases prioritizing aerobic fitness and TKJI capacity development, while plyometric-EMOM appears more appropriate during phases requiring fat loss and body composition optimization. For karate coaches and athletes, HIIT suits TKJI enhancement during aerobic-focused phases, while plyometric-EMOM optimizes fat loss without compromising training volume. Implementation barriers include access to monitoring tools (e.g., Tanita BC-545N) and adherence in non-club settings; practitioners should standardize protocols and track RPE for fidelity (Taylor et al., 2015). These modality-specific recommendations are most actionable when applied to samples with characteristics analogous to the present study elite junior male athletes under standardized supervised conditions and should not be generalized to recreational or mixed-sex populations without further empirical validation.

In conclusion, the findings affirm modality-specific adaptations, aligning with literature on training specificity (Li et al., 2023) but contradicting HIIT's presumed body composition dominance (Sarfraz et al., 2022). New insights include EMOM plyometrics' superior fat/weight loss in homogeneous athletic samples, with extreme effect sizes reflecting protocol standardization rather than universal effects. These results contribute to the evidence base for EMOM-structured plyometric training in combat sports and provide preliminary empirical support for modality-

specific programming in karate, while acknowledging that further studies with larger, more diverse samples are needed to confirm and extend these findings.

Future studies should empirically test the mechanistic pathways suggested here using appropriate biomarkers and physiological measures with karate-specific metrics and biomarkers to validate pathways. Looking ahead, future studies should employ RCTs with passive controls, longer durations (≥12 weeks), dietary standardization, and diverse samples (e.g., females, other combat sports) to confirm generalizability (Nianogo et al., 2023). Incorporate karate metrics (e.g., kumite agility, biomarkers) and mechanistic probes (e.g., hormones) to explore adaptations, addressing gaps in external validity and plyometric timelines. This forward-looking agenda builds directly on the current study's contributions, ensuring progressive advancement in exercise science for combat athletes.

Conclusion

This study resolved the scientific contradiction between HIIT (AMPK/PGC-1α metabolic pathway) and plyometric-EMOM (SSC neuromuscular pathway), confirming the Dual-Pathway Specificity Model: Adaptation = f(metabolic + SSC + kumite specificity). HIIT produced greater improvements in physical fitness (TKJI) via aerobic-cardiovascular adaptations, while plyometric-EMOM yielded greater reductions in body fat percentage and body weight via SSC-driven eccentric energetics. Both protocols increased fat-free mass with comparable between-group differences. From an applied perspective, HIIT may be prioritized during fitness development phases, while plyometric-EMOM is recommended during body composition optimization or weight-category adjustment phases within karate periodization. These findings are context-specific to elite junior male karate athletes from a single club and should not be generalized to recreational, female, or mixed-combat-sport populations without further empirical validation.

Ethics Approval

This study received ethical approval from the Yogyakarta State University Ethics Committee (approval number: 0533/C3/DT.02.00/2025, dated July 08, 2025) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants (male police cadets/young police officers aged 18-19 years) prior to data collection. The consent form clearly explained the study objectives, procedures, intervention duration, potential minor physical risks (e.g., muscle soreness or fatigue), safety precautions, the voluntary nature of participation, and the right to withdraw at any time without penalties or consequences for training/education, employment status, or performance evaluation.

Informed Consent

Prior to participation, all athlete received detailed written and verbal information regarding the study objectives, procedures, potential risks and benefits, voluntary participation, and the right to withdraw at any time without consequences. Written informed consent was obtained from all participants. Participant confidentiality was ensured through data anonymization, with all personal information coded and stored in password-protected files accessible only to the research team. The study protocol ensured participant safety by: (1) conducting baseline health screening to exclude individuals with cardiovascular contraindications, (2) employing a certified massage therapist, (3) monitoring for adverse events throughout the intervention period, and (4) ensuring medical support was readily available if needed. No adverse events related to the massage intervention were reported during the study.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

AI Transparency Statement

In preparing this manuscript, the authors used Perplexity AI to support sentence structuring and language refinement. All content was carefully reviewed, edited, and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the manuscript.

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Conflict of Interest Statement

The author declares no conflict of interest.

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Високоінтенсивне інтервальне тренування проти пліометричного тренування у форматі EMOM: порівняння впливу на склад тіла та фізичну підготовленість каратистів віком 18–19 років

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 10 с., 9 табл., 1 рис., 22 джерела.

Обґрунтування. У підготовці куміте існує наукове протиріччя: теоретично передбачається, що ВІІТ (із домінуванням метаболічного фактора через сигнали AMPK/PGC-1α) та пліометричні тренування (із домінуванням нервово-м'язового фактора через цикл розтягування-скорочення — ЦРС) викликають відмінні моделі адаптації, проте в емпіричній літературі повідомляється лише про ізольовані ефекти без пояснювальних моделей перенесення адаптації на специфічні вимоги фізичної підготовленості в карате.

Мета дослідження. Дослідження мало на меті порівняти вплив традиційних високоінтенсивних інтервальних тренувань (ВІІТ) та пліометричних тренувань у форматі EMOM (виконання певної кількості вправ на початку кожної хвилини) на фізичну підготовленість і склад тіла каратистів чоловічої статі віком 18–19 років.

Матеріали та методи. Сорок чотири каратисти чоловічої статі (віком 18–19 років) із клубу "Polda DIY Karate Club" були залучені до квазіекспериментального дослідження за двогруповою схемою претест–посттест, виконуючи ВІІТ (n = 22) та пліометричні тренування у форматі EMOM (n = 22) протягом 8 тижнів. Оцінювання фізичної підготовленості проведено за допомогою Індонезійського тесту фізичної підготовленості (TKJI); склад тіла вимірювали за допомогою аналізатора Tanita BC-545N.

Результати. В обох групах спостерігалися суттєві покращення показників ($p < 0,001$). Значущу взаємодію чинників «Час × Група» виявлено для TKJI, жирової маси та маси тіла (усі значення $p < 0,001$), а також помірну взаємодію для безжирової маси тіла (БМТ, $p = 0,028$). Група ВІІТ продемонструвала більший приріст у тесті TKJI (Δ = +3,09 проти +0,95), тоді як група пліометричного тренування у форматі EMOM забезпечила вищу ефективність у зниженні жирової маси (Δ = −5,36% проти −4,29%). Надзвичайно великі розміри ефекту (d Коена до 6,80) відображають низьку дисперсію в межах однорідної вибірки з одного клубу, а не універсальні біологічні ефекти.

Висновки. ВІІТ має перевагу у покращенні фізичної підготовленості завдяки метаболічним серцево-судинним механізмам, тоді як пліометричне тренування у форматі EMOM відзначається вищою ефективністю у зниженні вмісту жиру завдяки ексцентричній енергетиці, зумовленій ЦРС, що підтверджує модель подвійного шляху специфічності. Отримані результати є специфічними для контексту підготовки елітних каратистів юніорського віку та потребують подальшої валідації для ширшого узагальнення.

Ключові слова: високоінтенсивне інтервальне тренування, пліометричне тренування у форматі EMOM, карате, фізична підготовленість, склад тіла.

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Original Scientific Articles. Training Effects and Experimental Design

Small-Sided Games Versus High-Intensity Interval Training: Effects on Aerobic Fitness, Agility, and Psychological Responses in Collegiate Female Field Hockey Players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Objectives. The study aimed to examine the impact of small-sided games (SSG) and high-intensity interval training (HIIT) on selected physical and psychological variables among collegiate female field hockey players.

Materials and Methods. Thirty collegiate female field hockey players (age: 20.20 ± 1.58 years) were randomly selected and divided into an SSG group (n = 15) and an HIIT group (n = 15). Both groups participated in a six-week training program (two sessions a week) alongside regular team practice. The SSG group played 4 vs 4 games on a 30 x 40 m field, while the HIIT group performed 15-s running bouts at 110% maximal aerobic speed (MAS) with 15-s passive recovery intervals. Pre- and post-intervention measurements were conducted for maximal aerobic speed, agility (Modified T-test), neuromuscular power (five-jump test), enjoyment (PACES), and mood state (total mood disturbance; TMD). Independent t-tests and ANCOVA ($p < 0.05$) were used for data analysis.

Results. No significant differences were observed at baseline ($p > 0.05$). Both groups enhanced MAS, but the SSG group demonstrated greater improvements in agility and psychological variables. ANCOVA revealed significant group effects for MAS ($p = 0.014$), agility ($p = 0.002$), PACES ($p = 0.001$), and TMD ($p = 0.001$), favoring SSG. Neuromuscular power did not show any significant differences between the groups.

Conclusions. SSG yielded superior results in agility and psychological responses while being equally effective in improving aerobic fitness. These findings confirm the application of SSG as an ecologically valid and effective conditioning strategy for collegiate field hockey players.

Keywords: small-sided games, high-intensity interval training, field hockey, aerobic fitness, agility, PACES.

Introduction

Field hockey is characterized by intermittent high-intensity activity patterns involving frequent accelerations, decelerations, and rapid directional changes performed in a dynamic competitive environment. Players perform a range of activities during match play, including walking, jogging, sprinting, and executing technical actions such as passing, dribbling, and tackling. These demands place considerable stress on both aerobic and anaerobic energy systems (Spencer et al., 2004; Macutkiewicz and Sunderland, 2011). This therefore makes well-developed neuromuscular performance, agility, and aerobic capacity crucial in sustaining performance during competition. Besides physical preparedness, psychological variables like pleasure, motivation, and mood have been reported to be essential determinants of training compliance and progress in performance (Scanlan et al., 2014). Traditional conditioning approaches in team sports have primarily relied on structured running-based methods, especially high-intensity interval training (HIIT), to enhance aerobic fitness. HIIT is typically performed in repeated bursts of high- intensity running separated by short intervals of rest, typically performed at or close to anaerobic exhaustion rate. Previous research has consistently demonstrated that HIIT has beneficial effects on cardiovascular function, maximal oxygen uptake and repeated sprint ability (Buchheit & Laursen, 2013; Iaia & Bangsbo, 2010). Consequently, HIIT is now a common means of creating physiological stress-inducing effects in

training numerous team-based sports, such as soccer, rugby and field hockey (Helgerud et al., 2001; Dupont et al., 2004). As a result, HIIT has become a widely adopted method for inducing physiological stress efficiently across various team sports, including soccer, rugby, and field hockey (Helgerud et al., 2001; Dupont et al., 2004).

Despite its physiological effectiveness, HIIT presents several limitations when used in skill-based, open-field sports. The majority of HIIT protocols rely on linear and repetitive running patterns that do not entirely simulate the multidirectional movement, the perceptual tasks and decision-making processes of the competitive settings. Consequently, gains in the physical capacity do not always prove effective when it comes to sport-related performance (Impellizzeri et al., 2006). Furthermore, interval running may be perceived as monotonous, which can decrease pleasure and enthusiasm especially in a long-term training program, and this can influence the participation and compliance of the athlete (Halson, 2014).

As a reaction to such constraints, small-sided games (SSG) have been developed as an alternative means of training, that incorporates physical, technical, and tactical aspects along with sport-specific context. Small-sided games are a subset of the game that is played with a reduced number of players and/or a smaller playing field, which coaches can adjust the training intensity by varying the number of players, size of the playing field, and the rules of the game (Hill-Haas et al., 2011). Past studies, especially on soccer, have demonstrated that SSG has the potential to induce physiological responses just as intense as those that high-intensity interval training can, such as increased heart rate and duration of time spent in aerobic areas of training (Dellal et al., 2012; Owen et al., 2012; Hill-Haas et al., 2009).

In addition to the physiological responses, small-sided games offer a dynamic training environment which involves constant interaction with team-mates and opponents, quick reaction to decision-making, and frequent practice of sport-specific skills. These features align with the ecological theories of learning skills, in which perception and action are intimately bound together in representative task-like conditions (Davids et al., 2013). Subsequently, SSG could lead to higher rates of transfer of training adaptations to competition. Moreover, interactive and competitive features of training in game form have been linked to increased pleasure and intrinsic motivation than traditional methods of conditioning (Selmi et al., 2020).

An upper hand in the reciprocation of similar results, earlier studies in soccer and the other invasion sports have shown where SSG-based training interventions have led to aerobic fitness, agility and movement efficiency improvements (Rampinini et al., 2007; Hill-Haas et al., 2009). These are usually explained by the synergistic outcomes of high-intensity motion patterns, repeated changes of direction, and sport-specific motor requirements of the game-based activities. Conversely, the traditional HIIT is based more on the provision of physiological changes via planned running, and little focused on motor variability and the involvement of perceptions (Buchheit & Laursen, 2013).

However, as much as the scientific evidence surrounding the effectiveness of small-sided games continues to increase, there are some conceptual weaknesses in literature on the topic. Comparisons of training methods have mainly concerned outcome-based comparisons with little consideration to the underlying mechanisms that create these adaptations. Specifically, the role of physiological load, neuromuscular coordination and cognitive-perceptual demands in sport-specific training situations has not been adequately addressed. Also, the studies exploring the correlations between them in female field hockey athletes are limited, even though the unique technical and tactical features of this sport (Macutkiewicz and Sunderland, 2011).

From a mechanistic perspective, small-sided games can be considered a combined training stimulus that stops at the same time to interact with several systems of adaptation. In contrast to HIIT that mainly causes cardiovascular and metabolic loads by using predetermined patterns of running, SSG presents uninterrupted perception action coupling, reactive decision-making, and bidirectional movement. All these factors could lead to better neuromuscular coordination, higher adaptability in movements, and elevated psychological involvement. Thus, variations in training responses between SSG and HIIT may not be solely attributed to training intensity but also the interplay between physiological, motor and cognitive demands.

Here, the choice of outcome variables can be considered to be a system of adaptation in itself. Maximal aerobic speed (a measure of cardiovascular performance), agility (neuromuscular coordination and change-of-direction ability), and neuromuscular power (capacity to produce explosive force) are all indicators of neuromuscular fitness. Variables of an affective nature like enjoyment and mood state can give us a glimpse into the psychological factors that affect training adherence and performance maintenance. A combination of these variables will make it possible to evaluate the training effectiveness in a multidimensional manner, including physiological, motor, and psychological aspects. Although there has been an increased literature of research on the comparison of small-sided game and high-intensity interval training, the scientific problem is not well described. The available literature has mainly centred on the comparison of outcomes, whereas the mechanistic premise of adapting physiological, neuromuscular and psychological systems in female field hockey players has been dissatisfactory.

Therefore, the aim of the current study was to compare the differences in six weeks of mini-games and high-intensity running on the chosen physical and psychological indicators among the female athletes of field hockey in collegiate institutions. In detail, the maximal aerobic speed, agility, neuromuscular power, enjoyment, and mood state were measured before and after the intervention. The hypothesis was that both training approaches would enhance aerobic fitness, and the small-sided games would yield more during agility and psychological reactions as they are sport-specific and interactive.

Materials and Methods

Study Design

In the current research, one applied experimental design was the randomised pre-test and post-test that was used to study the functioning of two conditioning stimuli, including small-sided games (SSG) and high-intensity interval training (HIIT), on a chosen set of physical and

psychological variables of the impact of these programmes on the chosen group of participants in the case of the study of collegiate women in the field hockey team. The respondents were chosen randomly to be put in an experimental group that exercised SSG or a control group that exercised HIIT. The two groups went through a coordinated six weeks conditioning programme besides their normal field hockey practice. The pre-intervention experiments were done a week prior to the commencement of the training programme whereas the post-intervention tests were taken right after the six weeks of the intervention. The study design enabled the comparison to be made on effectiveness of the sport-specific conditioning intervention utilising small-sided games in comparison to the traditional interval-based conditioning.

Sample Size Estimation

G * Power software (version 3.1) was used to conduct an a priori power analysis to establish the necessary number of samples required to achieve significant differences between groups. Taking a moderate effect size (f = 0.25), an 0.05 level of alpha, and 0.80 level of statistical power in analysing covariance (ANCOVA), the estimated minimum of 28 participants were necessary. Consequently, the recruiting of athletes involved was 30, which is sufficient to achieve a robust statistical power of the study (Faul et al., 2007).

Participants

This study was done on thirty female field hockey players of colleges (age 18 to 23 years) who came forward to volunteer in this research. All the athletes were intercollegiate players with an experience of three years of playing and were themselves regularly subjected to institutional training and competition. The participants were randomly divided into the experimental small-sided games group (SSG; n = 15) or the control group of high-intensity interval training (HIIT; n = 15) based on a randomization selection by computer. All participants gave written informed consent and were briefed on the procedures that will be followed during the study beforehand. The players who have sustained injuries, musculoskeletal disorders, or other medical conditions that could restrict the exercise to high intensity were excluded. The participants were also advised to stick to their normal diet and not to participate in many other conditioning programmes in the course of intervention. Figure 1 demonstrates the participant recruitment, allocation, follow-up and analysis processes. The study was conducted in accordance with the Declaration of Helsinki, and ethical approval was obtained from the institutional research ethics committee prior to commencement.

Training Intervention

The duration of the intervention was six weeks (Table 1), with the participants undergoing two sessions of the conditioning along with their routine training in field hockey. The duration of every session was around 30 to 35 minutes. The experimental and control group adhered to various conditioning regimens, but had similar training frequency and training duration. The experimental group engaged in small-sided games (SSG) player-to-player and setting-to-setting variations of match situations consisting of small playing areas and a smaller number of players. These games were meant to simulate match-specific

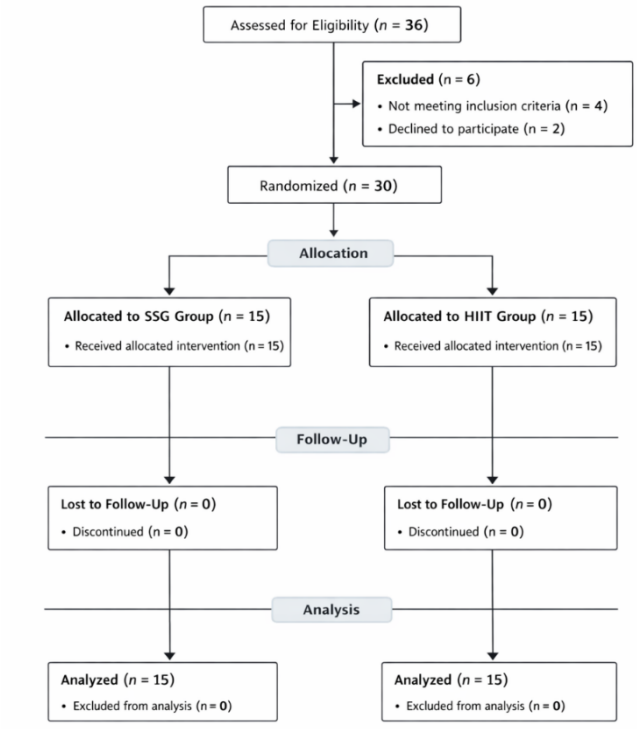

Fig. 1. CONSORT Flow Diagram

requirements in the sense that they included ball involvement on a continuous basis, direction changes as well as timely tactical decision making. The control group performed high-intensity interval training (HIIT) consisting of structured intermittent running bouts at intensities exceeding maximal aerobic speed (MAS). The protocol contained short-duration running intervals repeated and separated with short periods of passivity. The intensity and volume of training was gradually enhanced in the course of the six-week period through manipulation of the duration of gameplay, the number of participants, field area, and the length of running periods.

Training Load Control

Training load was monitored throughout the intervention period to ensure consistency between groups. After every training session, the participants provided the rating of perceived exertion (sRPE) that was measured on the Borg CR-10 scale. The internal training load was determined by multiplying the sRPE score and session duration. Also, an assessment of the heart rate was done during chosen sessions to ensure that the participants worked in a range of target intensity which was about 85-95 of the maximum heart rates. Such procedures made sure that the two training programmes placed similar physiological stress although training format was different (Foster et al., 2001).

Testing Procedures

Every participant was physically and psychologically evaluated before and after the training intervention. All of the tests were done on the same field and similar environmental conditions, to maintain the consistency. All the participants underwent a standardised 10-minute warm-up which included light jogging, dynamic stretching and

Table 1. Six-Week Training Intervention Schedule for the Experimental (SSG) and Control (HIIT) Groups

Week	Experimental Group – Small-Sided Games (SSG)	Control Group – High-Intensity Interval Training (HIIT)
Week 1	4 vs 4 games on 30 × 40 m field; 4 bouts × 4 min; 2 min passive recovery between bouts. Emphasis on ball possession and continuous play.	Intermittent running: 15 s at 110% MAS + 15 s passive recovery; 4 sets × 4 min; 2 min passive recovery between sets.
Week 2	4 vs 4 games; 4 bouts × 4 min; field size unchanged. Players encouraged to increase tempo and maintain high pressing intensity.	Same protocol as Week 1; athletes instructed to maintain running speed above MAS target; 4 sets × 4 min intervals.
Week 3	4 vs 4 games; 5 bouts × 4 min; 2 min recovery; additional tactical rule introduced (maximum 3 touches per player) to increase movement intensity.	Intermittent running: 15 s at 110% MAS + 15 s passive recovery; 5 sets × 4 min intervals; 2 min recovery between sets.
Week 4	5 vs 5 games on 35 × 45 m field; 4 bouts × 5 min; 2 min recovery; emphasis on quick ball circulation and attacking play.	Intermittent running: 20 s at 110% MAS + 20 s recovery; 4 sets × 5 min; 2 min passive recovery between sets.
Week 5	4 vs 4 games; reduced field size (28 × 38 m) to increase intensity; 5 bouts × 5 min; 2 min recovery; rule: immediate transition after ball loss.	Intermittent running: 20 s at 110% MAS + 20 s recovery; 5 sets × 5 min; 2 min recovery between sets.
Week 6	Mixed SSG formats (3 vs 3 and 4 vs 4); field size 25 × 35 m; 5 bouts × 5 min; 2 min recovery; maximum competitive intensity encouraged.	Intermittent running: 20 s at 115% MAS + 20 s recovery; 5 sets × 5 min; 2 min recovery between sets.

mobility exercises followed by testing. This was to achieve reduced risk on injury and enhance reliability of testing through standardised warm up procedures (Bishop, 2003).

Maximal Aerobic Speed (MAS)

The aerobic fitness was evaluated by a progressive running test which is aimed to identify the maximal aerobic speed. Participants were required to run at progressively increasing speeds until volitional exhaustion. Maximal aerobic speed was the highest running speed that was attained during the test. The assessment of maximal aerobic speed that has been extensively applied among team sport athletes is progressive field tests, which have high validity and reliability (Buchheit, 2008).

Agility Test

Agility performance was determined by the use of Modified Agility T-test used to assess the capacity to speed up, slow down and change direction quickly. The participants were made to run at full speed, jog along and reverse in a fixed route. Digital stopwatch was used in determining the total time of completion. The T-Test has been found to be very reliable and valid in the measure of agility among athletics (Pauole et al., 2000).

Five-Jump Test

Neuromuscular power of lower body was measured in the form of the five-jump test (5JT). The participants were required to take 5 successive horizontal jumps using alternate legs after standing position. A measuring tape was used to determine the total distance between the starting point to the ultimate landing location. The five-jump test has been found to be a good field test in the assessment of explosive power of lower-body among athletes (Chamari et al., 2004).

Psychological Measures

The effects of the training interventions were assessed based on validated questionnaires psychological reactions to the examination.

Physical Activity Enjoyment Scale (PACES)

The Physical activity enjoyment scale (PACES) was used to measure enjoyment related to the training. The scale of the questionnaire includes various questions where the higher the score the more enjoyable it is to take part in physical activity (Kendzierski and DeCarlo, 1991).

Total Mood Disturbance (TMD):

The profile of mood states (POMS) questionnaire was used to measure mood states. The individual mood component scores were added to obtain the total mood disturbance scores using the scoring procedures (McNair et al., 1971).

Reliability of Tests

The performance tests utilised in the current study have shown that they are highly reliable in their test in the past studies. Most of the tests high test-retest reliability experiments displaying high test-retest reliability coefficients of more than 0.85 have demonstrated high test-retest reliability (Table 2), consistent measurements in populations involving athletes (Pauole et al., 2000; Chamari et al., 2004).

Table 2. Reliability of Selected Performance Tests

Test	Variable	Reliability (ICC)
Progressive Running Test	Maximal Aerobic Speed	0.91
Modified T-Test	Agility	0.89
Five Jump Test	Lower-body Power	0.92

All tests demonstrated high reliability (ICC > 0.85), indicating good measurement consistency.

Statistical Analysis

Statistical analyses were conducted using SPSS version 25.0. All variables were determined by the calculus of

descriptive statistics in the form of the mean standard deviation. Before inferential analyses, the assumptions of normality and homogeneity of variance were tested in Shapiro/wilk test and Levene test respectively. Independent samples t-tests were used to assess the differences in the baselines across the groups. Analysis of covariance (ANCOVA) was used to determine the effects of the intervention by putting in the pretest scores as covariates to correct the baseline differences. The magnitude of training effect was computed by using Cohen d. All analyses were set at $p < 0.05$ which is the statistical significance (Cohen, 1988).

Results

The descriptive characteristics of the participants at baseline are presented (Table 3).

Table 3. Baseline Descriptive Characteristics of the Participants

Variable	Experimental Group (SSG) (n = 15) Mean ± SD	Control Group (HIIT) (n = 15) Mean ± SD
Age (years)	20.13 ± 1.62	20.27 ± 1.54
Height (cm)	163.45 ± 5.11	162.98 ± 4.87
Body Mass (kg)	57.82 ± 4.76	58.34 ± 4.58
Playing Experience (years)	5.27 ± 1.41	5.13 ± 1.36
Maximal Aerobic Speed (km·h^{-1})	13.48 ± 0.79	13.42 ± 0.83
Agility (Modified T-Test, s)	10.61 ± 0.46	10.65 ± 0.49
5-Jump Test Distance (m)	10.31 ± 0.58	10.27 ± 0.62
PACES Score (Enjoyment)	93.74 ± 6.18	92.96 ± 6.41
Total Mood Disturbance (TMD)	96.21 ± 8.35	97.08 ± 8.11
Hooper Index Score	9.12 ± 1.73	9.27 ± 1.65

Note. Values are presented as Mean ± Standard Deviation (SD). No significant differences were observed between groups at baseline ($p > 0.05$), indicating comparable initial characteristics.

The experimental and control groups (SSG and HIIT, respectively) were similar regarding age, anthropometric issues, and performance indicators during the baseline. There are no significant variations between groups before the intervention, meaning that the participants were not that heterogeneous before the intervention.

The pre- and post-intervention changes in the selected physical and psychological variables are presented (Table 4). Following the six-week training program, both groups demonstrated improvements in maximal aerobic speed (MAS). The SSG group increased from 13.48 ± 0.79 km·h^{-1} to 14.72 ± 0 .68 km·h^{-1}, while the HIIT group improved from 13 .42 ± 0.83 km·h^{-1} to 14 .41 ± 0 .74 km·h^{-1}. For agility performance, the SSG group showed a greater reduction in agility time compared with the HIIT group. Agility time decreased from 10.61 ± 0 .46 s to 9.94 ± 0.41 s in the SSG group, whereas the HIIT group improved only slightly from 10.65 ± 0 .49 s to 10 .47 ± 0.46 s. Changes in neuromuscular power were low in both groups and did not reach statistical significance. With respect to mental responses, the PACES scores showed a strong increase in the SSG group, improving from 93.74 ± 6.18 to 104.62 ± 5.83, whereas the HIIT group demonstrated only a minor increase. In contrast, total mood disturbance (TMD) decreased in the SSG group but increased slightly in the HIIT group.

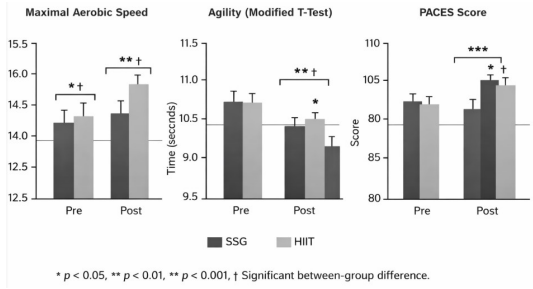

Fig. 2. Pre–Post Changes in MAS, Agility, and PACES

To determine the true intervention effect after adjusting for baseline differences, an analysis of covariance (ANCOVA) was performed. The results of this analysis are presented (Table 5). The ANCOVA analysis revealed an significant group effect for outside aerobic speed ($F = 6 .84$, $p = 0.014$), indicating that the improvement in aerobic fitness was greater in the SSG group compared with the HIIT group. Similarly, an significant group effect was observed for agility performance ($F = 11 .72$, $p = 0.002$), demonstrating that the SSG training program produced significantly greater improvements in agility. In contrast, no significant group difference was found for neuromuscular power (five-jump

Table 4. Pre- and Post-Intervention Changes in Physical and Psychological Variables

Variable	Group	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Change	Effect Size (d)	p-value
Maximal Aerobic Speed (km·h^{-1})	SSG	13.48 ± 0.79	14.72 ± 0.68	+1.24	1.69	0.001*
	HIIT	13.42 ± 0.83	14.41 ± 0.74	+0.99	1.25	0.003*
Agility (Modified T-Test, s)	SSG	10.61 ± 0.46	9.94 ± 0.41	−0.67	1.54	0.001*
	HIIT	10.65 ± 0.49	10.47 ± 0.46	−0.18	0.38	0.089
Five-Jump Test (m)	SSG	10.31 ± 0.58	10.49 ± 0.57	+0.18	0.31	0.122
	HIIT	10.27 ± 0.62	10.43 ± 0.61	+0.16	0.26	0.148
PACES Score	SSG	93.74 ± 6.18	104.62 ± 5.83	+10.88	1.82	0.001*
	HIIT	92.96 ± 6.41	95.31 ± 6.07	+2.35	0.37	0.094
Total Mood Disturbance	SSG	96.21 ± 8.35	88.42 ± 7.12	−7.79	0.98	0.004*
	HIIT	97.08 ± 8.11	101.36 ± 8.45	+4.28	0.52	0.071

*Significant at $p < 0.05$

Table 5. Analysis of Covariance (ANCOVA) Results for Post-Test Scores

Variable	Source	Sum of Squares	df	Mean Square	F-value	p-value	Partial Eta Squared (η^2)
Maximal Aerobic Speed	BG	1.36	1	1.36	6.84	0.014*	0.20
	WG	5.37	27	0.20			
Agility (Modified T-Test)	BG	2.14	1	2.14	11.72	0.002*	0.30
	WG	4.94	27	0.18			
Five-Jump Test	BG	0.18	1	0.18	1.02	0.321	0.04
	WG	4.75	27	0.18			
PACES Score	BG	689.31	1	689.31	19.63	0.001*	0.42
	WG	947.22	27	35.08			
Total Mood Disturbance	BG	1265.48	1	1265.48	16.94	0.001*	0.39
	WG	2015.73	27	74.65			

* Statistically significant at $p < 0.05$

test). For the mental variables, the analysis showed significant group effects for PACES (F = 19 .63, p = 0.001) and total mood disturbance (F = 16 .94, p = 0.001), indicating that the SSG intervention resulted in greater improvements in enjoyment and mood state compared with HIIT.

Figure 2 illustrates the variables demonstrating significant post-intervention effects between groups. Significant improvements were observed for maximal aerobic speed, agility performance, and enjoyment (PACES), with greater adaptations in the small-sided games group. In contrast, no significant between-group effect was found for neuromuscular power, as assessed by the five-jump test.

Discussion

The findings indicate that six weeks of small-sided games (SSG) and high-intensity interval training (HIIT) positively influenced selected physical and psychological variables in collegiate female field hockey players. While both training modalities significantly improved maximal aerobic speed, SSG resulted in greater improvements in agility and psychological responses. No significant changes were observed in neuromuscular power. These findings extend previous research by providing a more integrated understanding of how different conditioning strategies influence multiple systems of adaptation in team-sport athletes (Buchheit and Laursen, 2013; Hill-Haas et al., 2011).

The improvements in maximal aerobic speed in both groups may be attributed to different, yet complementary, physiological processes. High-intensity interval training has been proven to be an effective stimulus of central cardiovascular adaptations, such as augmented stroke volume, augmented cardiac output, and augmented oxygen transport capacity (Helgerud et al., 2001; Buchheit & Laursen, 2013). Such adaptations are mainly instigated by recurrent exposure to near-maximal intensities in a controlled format. Conversely, small-sided games probably cause similar aerobic adaptations with intermittent high-intensity exercise interspersed with game-based exercise. The repeated alternations between offensive and defensive movements, the frequent accelerations and decelerations can cause significant metabolic loads, which can in turn trigger central and peripheral adaptations (Hill-Haas et al., 2009). The marginally higher increase in the SSG group may be explained by the fact that effort is variable and self-regulated during the game play, and thus can facilitate long-term engagement at high intensities.

One of the main findings was the significantly greater improvement in agility performance following SSG compared with HIIT. This distinction may be explained by the principle of specificity and the system of ecological processes. Small-sided games naturally involve athletes reacting to ever-evolving environmental factors, such as the position of opponents, ball control, and space. These conditions facilitate perception-action coupling, wherein decision-making and motor execution are closely coupled (Davids et al., 2013). Consequently, athletes will be exposed to repetitive, sport-specific stimuli that can improve neuromotor coordination, reactive strength and movement efficiency. Conversely, HIIT protocols are usually predetermined, linear running patterns with little variation and limited mental activity. Although useful in enhancing metabolic capacity, these conditions might be inadequate to activate neuromotor processes involved in quick change-of-direction performance. As such, the higher agility improvements in the SSG group might be attributed to the combination of cognitive and motor tasks and not physical load per se (Rampinini et al., 2007; Davids et al., 2013).

In contrast, neither training modality resulted in significant changes in neuromuscular power, as assessed by the five-jump test. This observation indicates that the main focus of both SSG and HIIT is on metabolic and coordinative modifications, as opposed to the maximal production of force. Though small-sided games require numerous accelerations and explosive motions, the magnitude and mechanical loading might be insufficient to cause significant neuromuscular adjustments related to the stretch shortening cycle. Likewise, HIIT training programs focus on the development of energy systems, as opposed to maximal output. Past studies have always shown that the enhancement in explosive power is better through resistance training or plyometric training that is specifically geared towards neuromuscular activation and force production (Markovic & Mikulic, 2010). Thus, the lack of meaningful differences in neuromuscular power in the findings can probably be explained by the specificity of the training stimuli.

The observed psychological responses provide further insight into the differences in the effects of the two training modalities. Participants in the SSG group demonstrated greater improvements in enjoyment and decrease in mood disturbance than the HIIT group. These findings may be explained in terms of self-determination theory, which lays stress on autonomy, competence, and relatedness in the process of developing intrinsic motivation. These elements are inherent in small-sided games as they offer a chance to make decisions, socialize, and express their skills in a competitive setting. These conditions will probably increase intrinsic motivation and positive affective reactions (Selmi et al., 2020). HIIT, on the contrary, is repetitive, externally regulated activity with a small range of variability, which can potentially decrease engagement and perceived monotony. Since psychological aspects are significant in the training of adherence and long-term development of athletes, these findings indicate the value-added of game-based training methods (Scanlan et al., 2014).

In a more general sense, These findings support the concept that training adaptations in team sports are the outcome of the interactions between physiological, neuromuscular, and cognitive systems, but not the reaction to the physical load independently. Small-sided games seem to be a multidimensional training stimulus, which concurrently activates these areas, which improves performance and engagement. Although conventional forms of conditioning like HIIT are still effective in enhancing aerobic capacity, they may not be as effective in transferring to sport-specific performance when not supplemented with context-specific training. These findings support the role of incorporating representative learning settings in conditioning programs to achieve the fullest training benefits (Hill-Haas et al., 2011).

These findings imply that conditioning in team sports must not be thought of as a single physiological loading, but as a combination of metabolic stress, neuromotor coordination, and perceptual-cognitive demands. In this regard, training strategies like small-sided games might have better ecological validity in promoting transfer of adaptations to competitive performance.

Although the study has its strengths, a number of limitations must be noted. The intervention period was not very long (six weeks), and this might not have been enough to produce any meaningful neuromuscular changes. Also, the sample was restricted to a certain population of collegiate female field hockey players, which can influence the extrapolation of the findings. In addition, the research lacked direct physiological observation like oxygen uptake, blood lactate level, or GPS-tracked movement data, which would have helped to gain a more in-depth understanding of the processes behind the identified adaptations. Further studies are advised to include longer intervention periods, larger samples, and objective physiological and match-related performance outcomes to gain a better understanding of the processes of adaptation.

Conclusions

This study examined the effects of six weeks of small-sided games (SSG) and high-intensity interval training (HIIT) on selected physical and psychological variables in collegiate female field hockey players. Both training modalities significantly improved maximal aerobic speed, indicating their effectiveness in enhancing aerobic fitness. However, SSG produced greater improvements in agility and psychological responses, likely due to its sport-specific, multidirectional, and interactive nature. Neither intervention resulted in significant changes in neuromuscular power, suggesting that additional strength or plyometric training may be required to enhance explosive performance. Overall, these findings support the use of small-sided games as an effective and practical conditioning strategy that simultaneously develops physical performance and psychological engagement in team-sport athletes.

Conflict of Interest

The authors declare no conflict of interest.

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Ethical Approval

The study was conducted in accordance with the ethical guidelines of the Institutional Research Ethics Committee of Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India (HITS/CRC/004/24SR923002) in carrying out the study. All the participants were informed by signing a written informed consent prior to the participation. The paper had been in adherence to the principles of the Declaration of Helsinki (2013 update).

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Data Availability Statement

The data supporting the findings of this study are derived from the author's ongoing PhD research and are not publicly available due to institutional and ethical constraints. However, data may be made available from the corresponding author upon reasonable request, subject to institutional approval.

AI Transparency Statement

The authors confirm that no artificial intelligence tools were used to generate the scientific content of this manuscript. Language editing assistance was used to improve clarity and readability, and all content was critically reviewed and approved by the authors.

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Ігри неповними складами проти високоінтенсивних інтервальних тренувань: вплив на аеробну підготовленість, спритність та психологічні реакції студенток-хокеїсток на траві

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 5 табл., 2 рис., 26 джерел.

Мета дослідження. Мета дослідження полягала у вивченні впливу ігор неповними складами (ІНС) та високоінтенсивних інтервальних тренувань (ВІІТ) на обрані фізичні та психологічні показники студенток-хокеїсток на траві.

Матеріали і методи. Тридцять студенток-хокеїсток на траві (вік: 20,20 ± 1,58 року) були відібрані за методом рандомізації та розділені на групу ІНС (n = 15) та групу ВІІТ (n = 15). Обидві групи брали участь у шеститижневій програмі тренувань (два заняття на тиждень) паралельно з регулярною практикою командних тренувань. Група ІНС грала у форматі 4 проти 4 на майданчику розміром 30 × 40 м, тоді як група ВІІТ виконувала 15-секундні бігові серії на рівні 110% від максимальної аеробної швидкості (МАШ) з 15-секундними інтервалами пасивного відновлення. На перед- та постінтервенційному етапах проводилися вимірювання показників максимальної аеробної швидкості, спритності (модифікований Т-критерій Стьюдента), нервово-м'язової потужності (тест на 5 стрибків), рівня задоволення від занять фізичною активністю (шкала PACES) та психоемоційного стану (загальне порушення настрою; ЗПН). Для аналізу даних використовувалися t-критерії для незалежних вибірок та коваріаційний аналіз ($p < 0,05$).

Результати. На початковому етапі дослідження значущих відмінностей не спостерігалося ($p > 0,05$). В обох групах покращився показник МАШ, проте група ІНС продемонструвала суттєвіші зрушення у показниках спритності та психологічних змінних. Коваріаційний аналіз виявив значущі групові ефекти щодо показників МАШ ($p = 0,014$), спритності ($p = 0,002$), PACES ($p = 0,001$) та ЗПН ($p = 0,001$) на користь тренувань за методикою ІНС. Показники нервово-м'язової потужності не продемонстрували статистично значущих відмінностей між групами.

Висновки. Ігри неповними складами забезпечили кращі результати у розвитку спритності та психологічних реакцій, продемонструвавши рівноцінну ефективність щодо покращення аеробної підготовленості. Ці результати підтверджують доцільність застосування методики ІНС як екологічно валідної та ефективної кондиційної стратегії підготовки студенток-хокеїсток на траві.

Ключові слова: ігри неповними складами, високоінтенсивне інтервальне тренування, хокей на траві, аеробна підготовленість, спритність, PACES.

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Original Scientific Articles. Training Effects and Experimental Design

The Effect of Plyometric Training Versus Combined Plyometric and Core Training on Autonomic Regulation and Muscle Oxygenation During Incremental Resistance Exercise in Collegiate Athletes

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Abstract

Objectives. This study aimed to compare the effects of plyometric training (PT) and combined plyometric plus core training (PT+CT) on autonomic nervous system regulation and local muscle oxygenation during resistance exercise in collegiate athletes. Specifically, changes in heart rate variability (HRV), muscle oxygen saturation (SmO_2), and performance parameters were examined following a 10-week intervention.

Materials and Methods. A three-arm, parallel-group, assessor-blinded randomized controlled trial was conducted with 45 collegiate athletes (aged 19–24 years) from volleyball, soccer, and basketball backgrounds. Participants were randomly assigned to PT (n = 15), PT+CT (n = 15), or a control group (CON; n = 15). The PT group performed progressive plyometric exercises, while the PT+CT group completed identical plyometric training supplemented with structured core exercises, three sessions per week for 10 weeks. The CON group continued sport-specific training only. Primary outcomes included resting and post-exercise HRV indices (RMSSD, SDNN, HF power, LF/HF ratio) and SmO_2 measured via near-infrared spectroscopy during incremental back squat at 60%, 70%, and 80% of 1-RM. Secondary outcomes included maximal strength, jump performance, blood lactate, and perceived exertion.

Results. Forty-two participants completed the study. Both PT and PT+CT groups showed significantly greater improvements in 1-RM back squat compared with CON ($P < .001$). The PT+CT group demonstrated superior increases in resting RMSSD compared with PT ($P = .008$) and CON ($P < .001$). During high-intensity exercise (80% 1-RM), SmO_2 was significantly higher in PT+CT than in both PT and CON ($P \leq .01$). Post-exercise HF power was better preserved in PT+CT than CON ($P = .003$). Additionally, countermovement jump performance improved more in PT+CT than PT ($P = .04$) and CON ($P < .001$), with no significant differences observed in blood lactate or RPE.

Conclusions. The findings confirm that combined plyometric and core training elicits superior improvements in autonomic regulation and muscle oxygenation compared to plyometric training alone, supporting its integration into resistance-based conditioning programs for enhanced physiological and performance adaptations.

Keywords: plyometric training, core stability, heart rate variability, muscle oxygenation, near-infrared spectroscopy, resistance exercise, autonomic regulation.

Introduction

Plyometric training, which exploits the stretch-shortening cycle to generate maximal force in brief time intervals, has become a standard conditioning tool across team sports (Zhang et al., 2026). Numerous randomized trials and meta-analyses confirm that structured plyometric programs improve jump height, sprint speed, change-of-direction ability, and lower-limb power in young athletes (Markovic & Mikulic, 2010; Moran et al., 2024; Ramirez-Campillo et al., 2018; Sun et al., 2025). These neuromuscular benefits are driven by enhanced motor unit recruitment, increased rate of force development, and improvements in tendon stiffness and fascicle behavior that collectively raise the ceiling for explosive movement (Cormie et al., 2011; Suchomel et al., 2016).

Core musculature, encompassing the deep stabilizers of the lumbo-pelvic-hip complex and the superficial global movers of the trunk, functions as the kinetic link between lower and upper extremities during athletic tasks (Kibler et al., 2006). Deficits in core stability reduce force transfer across the kinetic chain, impair balance under dynamic loading, and may elevate injury risk (Hibbs et al., 2008; Reed et al., 2012). A 2025 comprehensive meta-analysis of 29 randomized controlled trials involving 956 athletes aged 15 to 25 years reported that core training produced large improvements in general athletic performance (standardized mean difference, 1.38; 95% CI, 0.85-1.82; $P < .001$), with particularly strong effects on core endurance and balance (Yu et al., 2025). Several investigators have therefore proposed combining plyometric and core exercises into integrated programs, reasoning that the postural control and trunk rigidity developed through core work should amplify the force-transfer benefits of plyometric loading (Cabrejas et al., 2023; Prieske et al., 2016).

Despite abundant data on performance outcomes, relatively little is known about how these training modalities influence autonomic nervous system regulation and local muscle oxygenation during subsequent resistance exercise (Benjamim et al., 2021; Leng et al., 2024; Ruiz-Moreno et al., 2022). Heart rate variability, a noninvasive index of cardiac autonomic modulation, reflects the dynamic interplay between sympathetic and parasympathetic activity and is widely used to monitor training adaptation and recovery in athletic populations (Addleman et al., 2024; Buchheit, 2014). A 2025 systematic meta-analysis examining long-term exercise effects on HRV reported that high-intensity interventions can improve both time-domain indices (SDNN, RMSSD) and frequency-domain parameters (HF power), with the magnitude of change depending on training modality and baseline fitness (W. Zhang et al., 2025). Whether plyometric or combined training produces distinctive autonomic adaptations remains unclear (Yang et al., 2024).

Muscle oxygen saturation, measured by near-infrared spectroscopy (NIRS), provides real-time insight into the local balance between oxygen delivery and utilization within working muscle (Boushel & Piantadosi, 2000; Tuesta et al., 2022). An updated 2024 systematic review identified muscle oximetry as a particularly promising wearable biosensor for monitoring skeletal muscle oxidative performance and training adaptation in sports (Perrey et al., 2024). During resistance exercise, SmO_2 declines as metabolic demand outstrips capillary oxygen supply; the rate and magnitude of this desaturation relate to exercise tolerance, fatigue onset, and local vascular capacity (Baker et al., 2010). Training-induced improvements in capillary density, mitochondrial function, and endothelial vasodilatory capacity can shift these dynamics favorably, yet few studies have tracked SmO_2 responses to incremental loading before and after structured plyometric or combined training programs (Pelka et al., 2024).

To address these gaps, we designed a 10-week, three-arm randomized controlled trial comparing plyometric training alone, combined plyometric and core training, and sport-specific training only (control) in collegiate team-sport athletes. We hypothesized that both training groups would improve strength, jump performance, and autonomic recovery relative to control, and that the combined group would demonstrate additional advantages in HRV indices and SmO_2 preservation during high-intensity resistance exercise, reflecting enhanced cardiovascular efficiency and local oxidative capacity.

Materials and Methods

Study Design

A three-arm, parallel-group, assessor-blinded randomized controlled trial was conducted at the Saveetha School of Physical Education, Saveetha Institute of Medical and Technical Sciences (SIMATS University), Tamil Nadu, India, between August 2024 and January 2025. The study protocol was reviewed and approved by the Institutional Ethics Committee of SIMATS University, and all procedures were carried out in accordance with established ethical standards for human research. All procedures conformed to the Declaration of Helsinki ("World Medical Association Declaration of Helsinki," 2013). Written informed consent was obtained from every participant prior to baseline testing.

Participants

Forty-five collegiate athletes (30 men, 15 women; age 19-24 years) were recruited from the university volleyball, soccer, and basketball teams between August and September 2024. Eligibility required a minimum of 2 years of structured resistance and sport-specific training (at least 3 sessions per week), familiarity with back squat and bench press exercises, and clearance on a pre participation physical examination. Exclusion criteria were current musculoskeletal injury, use of ergogenic supplements or anabolic agents within the preceding 3 months, diagnosed cardiovascular or metabolic disease, and any condition that could preclude maximal effort testing. A priori sample size estimation (G*Power 3.1.9.7) indicated that 12 participants per group were needed to detect a medium-to-large effect (Cohen $f = 0.40$) with 80% power at alpha = .05 for a 3 x 2 repeated-measures design, assuming a correlation among repeated measures of 0.50. We enrolled 15 per group to account for potential attrition. Figure 1 illustrates the overall experimental design and study timeline.

Randomization and Blinding

After baseline testing, participants were stratified by sex and sport and then randomly allocated in a 1:1:1

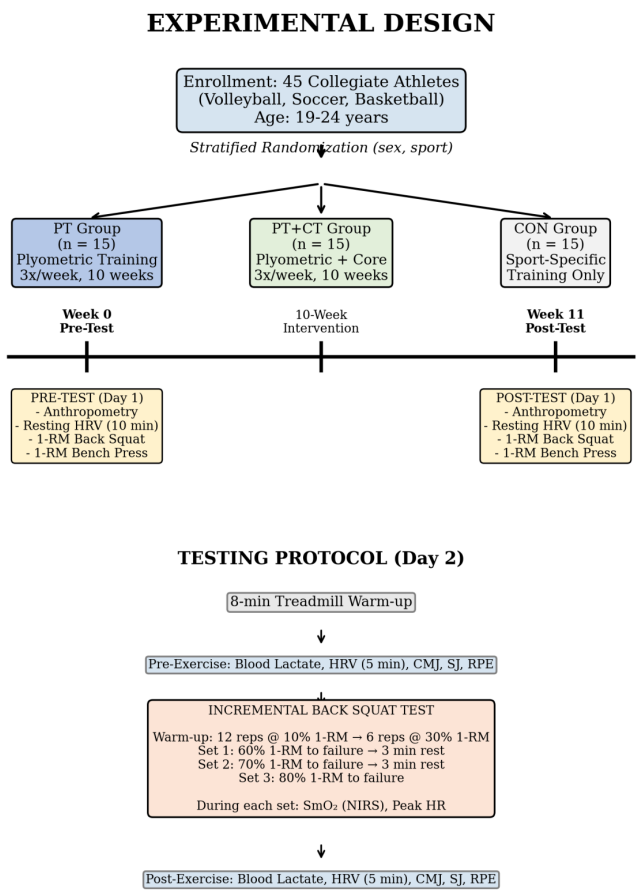

Fig. 1. Experimental Design and Study Timeline.
Note: PT indicates plyometric training; PT+CT, plyometric plus core training; CON, control; 1-RM, 1-repetition maximum; HRV, heart rate variability; SmO_2, muscle oxygen saturation; CMJ, countermovement jump; SJ, squat jump; RPE, rating of perceived exertion.

ratio to the PT, PT+CT, or CON group using a computer-generated random sequence (Research Randomizer, version 4.0) prepared by an investigator not involved in training or testing. Allocation was concealed in sequentially numbered, opaque, sealed envelopes. Outcome assessors were blinded to group assignment; participants and trainers could not be blinded to the intervention.

Interventions

All sessions were supervised by certified strength and conditioning specialists and took place at the same indoor facility between 15:00 and 17:00 hours to minimize circadian confounding. Training was conducted 3 days per week (Monday, Wednesday, Friday) for 10 weeks, yielding 30 total sessions. The PT group performed a progressive plyometric program that included squat jumps, countermovement jumps, depth jumps (box heights 30-50 cm), single-leg hops, lateral bounds, and tuck jumps. Volume increased from 80 ground contacts per session in weeks 1 to 3, to 100 in weeks 4 to 6, and 120 in weeks 7 to 10. Rest intervals were 60 to 90 seconds between sets and 2 to 3 minutes between exercises. The PT+CT group performed the identical plyometric program followed immediately by a structured core training block lasting approximately 20 minutes. Core exercises included front plank, side plank, dead bug, bird dog, pallof press, cable woodchop, hanging leg raise, and stability ball rollout. Volume progressed from 2 sets of 30 seconds (isometric holds) or 10 repetitions (dynamic exercises) in weeks 1 to 3, to 3 sets of 45 seconds or 15 repetitions by weeks 7 to 10. Resistance was added through weighted vests or cable loads as competency was established. The CON group maintained their regular sport-specific training schedule, which comprised technical skill work and tactical sessions but did not include structured plyometric, core, or resistance training beyond normal practice. The complete training program progression for both groups is summarised in Table 1. All groups were instructed to continue their habitual dietary intake and avoid initiating any new supplementation during the study period. A 24-hour dietary recall was completed before each testing session to monitor compliance.

Table 1. Training Program Progression for PT and PT+CT Groups

Phase	Weeks	Plyometric Vol	Core Sets	Core Hold/ Reps	Rest (s)	Sessions/wk
Introductory	1-3	80 contacts	2	30 s/10 reps	60-90	3
Development	4-6	100 contacts	2-3	35 s/12 reps	60-90	3
Intensification	7-10	120 contacts	3	45 s/15 reps	60-90	3

Note: PT group performed plyometric exercises only. PT+CT group performed identical plyometric volume plus core training block (~20 min). Core exercises: front plank, side plank, dead bug, bird dog, pallof press, cable woodchop, hanging leg raise, stability ball rollout. Plyometric exercises: squat jumps, countermovement jumps, depth jumps (30-50 cm), single-leg hops, lateral bounds, tuck jumps. Vol indicates ground contacts per session for plyometric exercises. Core hold refers to isometric exercises; reps refers to dynamic exercises. Rest interval is between plyometric sets.

Testing Procedures

Outcome assessments were performed at baseline (week 0) and post-intervention (week 11). All testing was conducted over 2 consecutive days at the same time of day, in a temperature-controlled environment (24 +/- 1 degrees C).

Day 1 began with anthropometric assessment (bioelectrical impedance; InBody 770, InBody Co., Seoul, South Korea), followed by resting HRV recording and maximal strength testing. Resting HRV was recorded with participants in the supine position for 10 minutes in a quiet, temperature-controlled room. Beat-to-beat R–R intervals were captured using a validated Polar H10 chest strap (Polar Electro, Finland) interfaced with the EliteHRV application (version 4.0). Participants were instructed to breathe spontaneously, avoid speaking, and remain motionless throughout the recording. The first 5 minutes served as a stabilisation period; HRV indices were computed from the final 5 minutes. Following the HRV recording, participants performed a standardised warm-up (5 minutes of light cycling at 50 W followed by two sets of 10 repetitions of

bodyweight squats) before the 1-RM back squat test. The 1-RM protocol followed American Society of Exercise Physiologists guidelines. Participants began with a set of 8 repetitions at 50% of their estimated 1-RM, then 3 repetitions at 70%, and 1 repetition at 90%, with 3-minute rest intervals between warm-up sets. Thereafter, the load was increased by 2.5 to 5.0 kg per attempt until a 1-RM was established within five maximal attempts, each separated by 3 to 5 minutes. Bar velocity was monitored throughout with an accelerometer-based sensor (Vmaxpro, Blaumann and Meyer Sports Technology, Germany) to confirm maximal effort. The highest load successfully lifted through full range of motion with acceptable technique was recorded as the 1-RM. The same protocol was applied for 1-RM bench press after a 15-minute rest.

Day 2 included jump performance testing followed by the incremental back squat protocol. Before the incremental test, countermovement jump (CMJ) height and squat jump (SJ) height were assessed on a calibrated force plate (Kistler 9260AA, Kistler Instrumente AG, Winterthur, Switzerland) sampling at 1,000 Hz. For the CMJ, participants stood with feet shoulder-width apart on the force plate and, on a verbal signal, performed a rapid downward countermovement to a self-selected depth before jumping vertically as high as possible with hands maintained on the hips throughout. Knee flexion and arm swings during the flight phase were not permitted; trials where these occurred were repeated. Three maximal-effort trials were conducted with a 60-second inter-trial recovery period, and the best trial was selected for analysis. For the SJ, participants descended to a static squat position of approximately 90° knee flexion, held that position for 3 seconds, and then jumped vertically with maximal effort without any prior countermovement. Any visible downward displacement before take-off disqualified the trial. Three trials were performed with 60-second inter-trial recovery, and the highest jump was recorded. Jump height was calculated from flight time using the impulse-momentum method from force-plate data. Following jump testing, pre-exercise HRV was recorded for 5 minutes in the supine position using the same Polar H10 and EliteHRV protocol described above. Muscle oxygen saturation (SmO_2) and total haemoglobin (tHb) were monitored continuously via a Moxy near-infrared spectroscopy sensor (Fortiori Design LLC, Hutchinson, MN) placed on the belly of the vastus lateralis of the dominant leg, secured with an opaque neoprene sleeve to exclude ambient light. The sensor was repositioned at the same anatomical landmark at pre- and post-intervention testing using skin-surface markings. After an NIRS stabilisation period of 3 minutes at rest, participants completed the standardised warm-up (12 repetitions at 10% 1-RM, 6 repetitions at 30% 1-RM) before performing 3 sets to failure at 60%, 70%, and 80% of their current 1-RM back squat, with 3-minute rest intervals between sets. SmO_2 data were sampled at 0.5 Hz throughout each set; the mean value of the final 30 seconds of each set was used for analysis. Peak heart rate was recorded during each set using the Polar H10 chest strap. Post-exercise HRV was assessed in the supine position for 5 minutes beginning 2 minutes after completion of the final set. Blood lactate was sampled from the hyperaemised earlobe (Lactate Pro 2, Arkray, Kyoto, Japan) at rest before warm-up, immediately after the 80% 1-RM set, and 3 minutes after completion of the protocol; a minimum of 5 µL of capillary blood was collected onto the test strip following standard preparation of the sampling site. Rating of perceived exertion (RPE) was collected immediately after the incremental protocol using the Borg CR10 scale (range 0–10); participants received standardised verbal anchoring instructions before testing. Post-exercise CMJ and SJ were assessed in the same manner as described above within 5 minutes of completing the incremental test.

HRV Analysis

HRV data were processed following current Task Force guidelines. From each 5-minute recording, the following indices were computed: mean RR interval (ms), RMSSD (ms), SDNN (ms), low-frequency power (LF; 0.04-0.15 Hz), high-frequency power (HF; 0.15-0.40 Hz), and the LF/HF ratio. Ectopic beats and artifacts were corrected using automatic algorithms in the EliteHRV software, with manual verification by a trained investigator.

Statistical Analysis

All data are presented as mean (SD) unless otherwise indicated. Normality was assessed with the Shapiro-Wilk test (Shapiro & Wilk, 1965). For primary outcomes, a 3 (group) x 2 (time: pre vs post) mixed-model analysis of variance (ANOVA) was used (Field, 2013). When significant interactions were found, post hoc pairwise comparisons were conducted with Bonferroni correction (Armstrong, 2014). For within-session SmO_2 and peak HR data across intensities, a 3 (group) x 3 (intensity) repeated-measures ANOVA was applied at the post-intervention time point (Girden, 1992). Delta change from pre- to post-intervention was compared across groups using one-way ANOVA or the Kruskal-Wallis test as appropriate (Kruskal & Wallis, 1952). Effect sizes were computed as partial eta squared (small, 0.01; moderate, 0.06; large, 0.14) and Cohen d (trivial, 0.20 or less; small, 0.21-0.60; moderate, 0.61-1.20; large, 1.21-2.0) (Cohen, 2013). All analyses were conducted in R (version 4.3.2) using the afex and rstatix packages (Kassambara, 2023). Significance was set at $P < .05$ (2-sided).

Analytical Framework and Decision Rule

The primary outcome of this trial was resting RMSSD, selected because it is the most reproducible and practically relevant vagal index for athlete monitoring (Addleman et al., 2024; Buchheit, 2014). Two confirmatory secondary outcomes were designated a priori: SmO_2 at 80% of 1-RM (local oxidative capacity) and CMJ height (functional power transfer). The decision rule for evaluating the added value of core training was as follows: the core training component would be considered effective if and only if PT+CT showed a statistically and practically meaningful advantage over PT alone on the primary outcome, with at least one confirmatory secondary outcome moving in the same direction. If the primary outcome showed no between-group difference, or if secondary outcomes contradicted the primary finding, the core component would be classified as non-contributory for that domain. Remaining variables (1-RM, bench press, peak power, lactate, RPE) were treated as descriptive indicators to map the boundary conditions under which the core training effect operates.

Results

Participant Flow and Baseline Characteristics

Of the 45 enrolled participants, 42 completed the trial (14 in PT, 14 in PT+CT, 14 in CON). Three participants withdrew due to reasons unrelated to the intervention (1 ankle sprain during recreational activity, 1 personal scheduling conflict, 1 lost to follow-up). Baseline characteristics were similar across groups (Table 2). Session attendance was 93.2% in PT and 91.8% in PT+CT, with no adverse events attributable to the training programs.

Table 2. Baseline Characteristics of Study Participants

Characteristic	PT (n=15)	PT+CT (n=15)	CON (n=15)	p
Age, mean (SD), y	21.4 (1.7)	21.0 (1.5)	21.3 (1.8)	0.78
Sex, No. (%) male	10 (67)	10 (67)	10 (67)	1.0
BMI, mean (SD), kg/m²	22.6 (1.9)	22.1 (1.7)	22.5 (2.0)	0.71
Training experience, y	3.8 (1.2)	3.6 (1.1)	3.9 (1.3)	0.82
1-RM back squat, kg	92.4 (14.6)	90.8 (13.9)	91.1 (15.2)	0.94
CMJ height, cm	35.1 (4.5)	34.6 (4.8)	34.8 (5.0)	0.96
SJ height, cm	31.2 (4.1)	30.8 (4.3)	31.0 (4.5)	0.97
Resting RMSSD, ms	41.8 (10.7)	42.3 (11.2)	43.1 (11.5)	0.94
Resting SDNN, ms	53.4 (12.8)	54.1 (13.6)	54.8 (13.2)	0.95
Resting HF power, ms²	408 (102)	412 (98)	415 (95)	0.98

Abbreviations: BMI, body mass index; CMJ, countermovement jump; CON, control; HF, high frequency; PT, plyometric training; PT+CT, plyometric plus core training; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal intervals; SJ, squat jump; 1-RM, 1-repetition maximum.

Both training groups demonstrated improvements in 1-RM back squat that were greater than CON (group x time interaction: $F_{(2,39)} = 18.72$; $P < .001$; $\eta p^2 = 0.49$). The PT group improved from a mean (SD) of 92.4 (14.6) kg to 104.2 (15.1) kg (mean change, +12.8%; 95% CI, 9.4%-16.2%), and the PT+CT group from 90.8 (13.9) kg to 103.6 (14.8) kg (mean change, +14.1%; 95% CI, 10.9%-17.3%). The CON group changed from 91.1 (15.2) kg to 93.2 (15.0) kg (+2.3%; p = .31). Pairwise comparisons showed no difference between PT and PT+CT (p = .58).

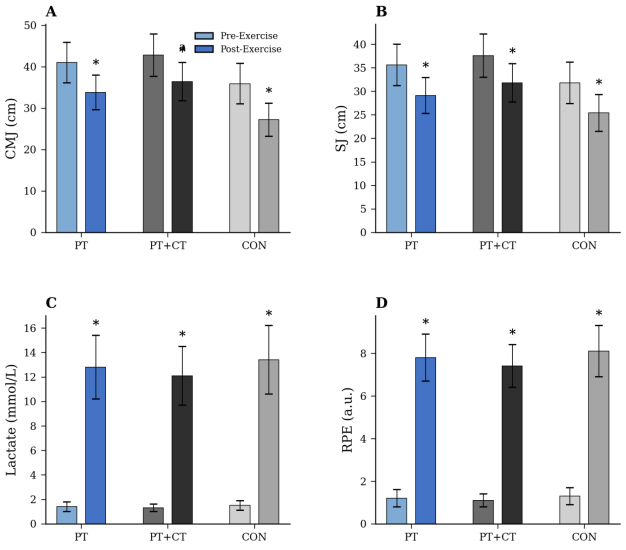

Fig. 2. CMJ, SJ, Blood Lactate, and RPE Recorded Pre- and Post-Exercise at the Post-Intervention Assessment. [Four-panel bar chart. Panels: (A) CMJ height, (B) SJ height, (C) Blood lactate, (D) RPE. Each panel shows pre-exercise (light bars) and post-exercise (dark bars) values for PT, PT+CT, and CON. Significance markers: * compared to pre-exercise; a compared to CON.]

CMJ height increased in both training groups relative to CON (group x time interaction: $F_{(2,39)} = 14.36$; $p < .001$; $\eta p^2 = 0.42$). The PT+CT group gained a mean of 8.2 cm (from 34.6 [4.8] cm to 42.8 [5.1] cm), compared with 5.9 cm in PT (from 35.1 [4.5] cm to 41.0 [4.9] cm) and 1.1 cm in CON (from 34.8 [5.0] cm to 35.9 [4.9] cm). Post hoc analysis indicated that PT+CT outperformed PT (p = .04; d = 0.72) and CON (p < .001; d = 1.89), while PT exceeded CON (p < .001; d = 1.48). SJ height followed a similar pattern, with the PT+CT group gaining 6.8 cm, PT gaining 4.4 cm, and CON gaining 0.8 cm (group x time interaction: $F_{(2,39)} = 11.09$; $P < .001$). Pre- and post-intervention values for all performance outcomes are presented in Table 3, and the corresponding bar charts including blood lactate and RPE are illustrated in Figure 2.

Heart Rate Variability

For resting RMSSD, a significant group x time interaction was observed ($F[2,39] = 9.47$; $P < .001$; $\eta p^2 = 0.33$). The

Table 3. ANOVA Results for Performance Outcomes Pre- and Post-Intervention (Mean±SD)

Variable	PT		PT+CT		CON		ANOVA
	Pre	Post	Pre	Post	Pre	Post	Group x Time
1-RM BS (kg)	92.4±14.6	104.2±15.1*	90.8±13.9	103.6±14.8*	91.1±15.2	93.2±15.0	F=18.72, P<.001, ηp^2=0.49
CMJ (cm)	35.1±4.5	41.0±4.9*	34.6±4.8	42.8±5.1*ab	34.8±5.0	35.9±4.9	F=14.36, P<.001, ηp^2=0.42
SJ (cm)	31.2±4.1	35.6±4.4*	30.8±4.3	37.6±4.6*a	31.0±4.5	31.8±4.4	F=11.09, P<.001, ηp^2=0.30
1-RM BP (kg)	68.2±11.4	74.6±12.0*	67.5±11.1	75.1±12.2*	68.0±11.8	69.3±11.5	F=9.84, P<.001, ηp^2=0.34
Peak Power (W)	876±108	962±115*	869±102	981±118*	878±112	891±109	F=7.21, P=.002, ηp^2=0.27
Peak Velocity (m/s)	0.54±0.08	0.62±0.09*	0.53±0.07	0.64±0.08*	0.55±0.09	0.56±0.08	F=8.47, P=.001, ηp^2=0.30

Abbreviations: 1-RM BS, 1-repetition maximum back squat; 1-RM BP, 1-repetition maximum bench press; CMJ, countermovement jump; CON, control; PT, plyometric training; PT+CT, plyometric plus core training; SJ, squat jump. * P < .05 compared to Pre within group; [a] P < .05 compared to CON; [b] P < .05 compared to PT

Table 4. Resting Heart Rate Variability Indices Pre- and Post-Intervention (Mean±SD)

HRV Index	PT		PT+CT		CON		ANOVA
	Pre	Post	Pre	Post	Pre	Post	Group x Time
MeanRR (ms)	812±74	846±78*	808±71	872±82*a	815±76	821±75	F=5.23, P=.009
RMSSD (ms)	41.8±10.7	49.7±11.4*	42.3±11.2	58.6±12.8*ab	43.1±11.5	44.7±11.8	F=9.47, P<.001
SDNN (ms)	53.4±12.8	61.2±13.1*	54.1±13.6	68.9±14.2*ab	54.8±13.2	56.2±13.4	F=7.83, P=.001
LF (ms²)	524±118	486±112	518±122	462±108*	530±115	522±119	F=3.14, P=.054
HF (ms²)	408±102	496±108*	412±98	587±112*ab	415±95	428±101	F=8.21, P=.001
LF/HF	1.31±0.28	1.02±0.24*	1.28±0.30	0.82±0.22*a	1.30±0.26	1.25±0.27	F=4.18, P=.02

Abbreviations: CON, control; HF, high frequency; LF, low frequency; PT, plyometric training; PT+CT, plyometric plus core training; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal intervals. * p < .05 compared to Pre within group; [a] p < .05 compared to CON; [b] p < .05 compared to PT. ηp² values: RMSSD = 0.33; SDNN = 0.29; HF = 0.30; LF/HF = 0.18.

PT+CT group showed the largest increase (pre: 42.3 [11.2] ms; post: 58.6 [12.8] ms; change, +16.3 ms; d = 1.35), followed by PT (pre: 41.8 [10.7] ms; post: 49.7 [11.4] ms; change, +7.9 ms; d = 0.71), and CON (pre: 43.1 [11.5] ms; post: 44.7 [11.8] ms; change, +1.6 ms; d = 0.14). Post hoc comparisons confirmed that PT+CT exceeded both PT (mean difference, 8.4 ms; 95% CI, 2.3-14.5 ms; P = .008) and CON (mean difference, 14.7 ms; 95% CI, 8.6-20.8 ms; P < .001). The PT group also exceeded CON (mean difference, 6.3 ms; 95% CI, 0.2-12.4 ms; P = .04).

Resting SDNN increased in PT+CT (pre: 54.1 [13.6] ms; post: 68.9 [14.2] ms; change, +14.8 ms; d = 1.06) and PT (pre: 53.4 [12.8] ms; post: 61.2 [13.1] ms; change, +7.8 ms; d = 0.60), with minimal change in CON (+1.4 ms; d = 0.10). The group x time interaction was significant ($F_{(2,39)}$ = 7.83; p = .001; ηp² = 0.29). Post hoc testing showed PT+CT greater than CON (p < .001) and greater than PT (p = .02), while the PT versus CON comparison reached significance (p = .04).

Resting HF power increased in PT+CT (pre: 412 [98] ms-squared; post: 587 [112] ms-squared; d = 1.66) and PT (pre: 408 [102] ms-squared; post: 496 [108] ms-squared; d = 0.84), with CON showing negligible change (pre: 415 [95] ms-squared; post: 428 [101] ms-squared; d = 0.13). The interaction was significant ($F_{(2,39)}$ = 8.21; p = .001). The LF/HF ratio did not differ significantly among groups at either time point (p = .14).

Post-exercise HRV data revealed that all groups experienced reductions in RMSSD, SDNN, and HF power following the incremental test at both time points (all p < .001). At the post-intervention assessment, the magnitude of post-exercise decline in RMSSD was smaller in PT+CT (delta, -31.4%) compared with PT (delta, -38.7%) and CON (delta, -46.2%), and the one-way ANOVA on these delta values was significant ($F_{(2,39)}$ = 4.92; p = .01; ηp² = 0.20). Resting HRV indices at both time points are presented in Table 4, and pre- versus post-exercise HRV values at the post-intervention assessment are illustrated in Figure 3. Percent changes in all HRV indices, performance variables, and metabolic markers are depicted in Figure 4.

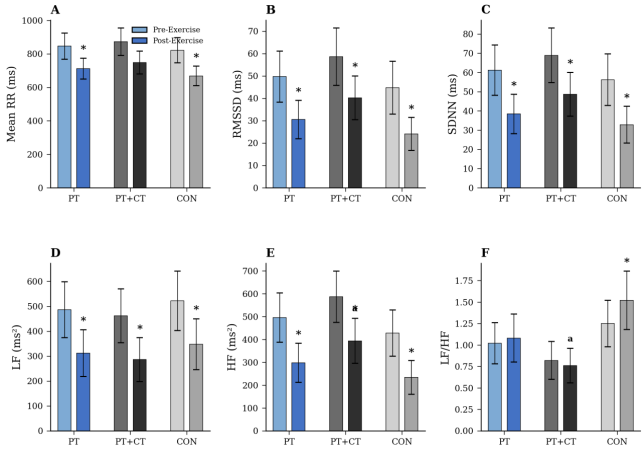

Fig. 3. Heart Rate Variability Indices Recorded Pre- and Post-Exercise at the Post-Intervention Assessment. [Six-panel bar chart (grouped bars with error bars). Panels: (A) MeanRR, (B) RMSSD, (C) SDNN, (D) LF, (E) HF, (F) LF/HF ratio. Each panel shows pre-exercise (light bars) and post-exercise (dark bars) values for PT, PT+CT, and CON. Significance markers: * compared to pre-exercise; a compared to CON.]

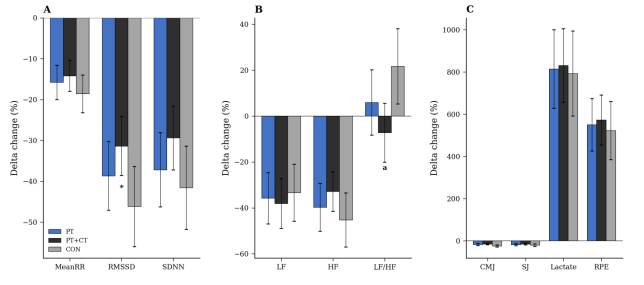

Fig. 4. Delta Pre-Post (%) Change in HRV Indices, CMJ, SJ, Blood Lactate, and RPE From Pre- to Post-Exercise at the Post-Intervention Assessment. [Three-panel grouped bar chart showing percent change (delta) values. Panel 1: HRV time-domain indices (MeanRR, RMSSD, SDNN). Panel 2: HRV frequency-domain indices (LF, HF, LF/HF). Panel 3: Performance and metabolic variables (CMJ, SJ, Lactate, RPE). Each variable shows 3 bars (PT, PT+CT, CON) with error bars. Significance markers: a compared to CON; b compared to PT.]

Muscle Oxygen Saturation

At the post-intervention incremental test, SmO_2 during back squat was analyzed using a 3 (group) x 3 (intensity) mixed ANOVA. A significant main effect of group was

Table 5. SmO_2, Total Hemoglobin, and Peak Heart Rate During Post-Intervention Incremental Back Squat at 60% and 80% of 1-RM (Mean±SD)

	PT		PT+CT		CON		
SmO2 (%)	**60%**	**80%**	**60%**	**80%**	**60%**	**80%**	**Group Effect**
	80.1±2.2	76.9±2.6	82.4±1.9[a]	79.8±2.4[ab]	78.5±2.4	75.2±2.8	F=12.84, p<.001
tHb (g/dL)	**60%**	**80%**	**60%**	**80%**	**60%**	**80%**	
	12.51±0.22	12.58±0.24	12.48±0.20	12.55±0.21	12.53±0.23	12.61±0.26	F=0.74, p=.48
Peak HR (bpm)	**60%**	**80%**	**60%**	**80%**	**60%**	**80%**	
	138.2±5.8	168.4±4.2[*¤]	135.6±6.1	164.8±4.8[*¤a]	140.1±5.4	171.0±3.9[*¤]	F=4.87, p=.01

Abbreviations: CON, control; PT, plyometric training; PT+CT, plyometric plus core training; SmO_2, muscle oxygen saturation; tHb, total hemoglobin. [*] $p < .05$ compared to 60%; [¤] $p < .05$ compared to 70%; [a] $p < .05$ compared to CON; [b] $p < .05$ compared to PT. Group Effect column reports main effect of supplementation condition from 3 (group) x 3 (intensity) mixed ANOVA.

found ($F_{(2,39)} = 12.84$; $P < .001$; $\eta p^2 = 0.40$), along with a main effect of intensity ($F_{(2,78)} = 8.91$; $p < .001$; $\eta p^2 = 0.19$), but the interaction did not reach significance ($F_{(4,78)} = 1.87$; $p = .12$).

At 60% of 1-RM, SmO_2 values were 82.4% (1.9%) in PT+CT, 80.1% (2.2%) in PT, and 78.5% (2.4%) in CON. At 70%, values were 81.2% (2.1%) in PT+CT, 79.0% (2.3%) in PT, and 77.3% (2.5%) in CON. At 80%, values were 79.8% (2.4%) in PT+CT, 76.9% (2.6%) in PT, and 75.2% (2.8%) in CON. Pairwise comparisons showed PT+CT had higher SmO_2 than CON at all intensities ($p < .01$ for each) and higher than PT at 80% of 1-RM (mean difference, 2.9%; 95% CI, 0.7%-5.1%; $p = .01$). Total hemoglobin showed no significant differences among groups at any intensity ($p > .10$ for all comparisons). SmO_2, total hemoglobin, and peak heart rate values at both intensities are presented in Table 5.

Peak heart rate during the incremental test was lower in PT+CT than in CON at 70% of 1-RM (mean difference, 4.8 bpm; $p = .02$) and 80% of 1-RM (mean difference, 6.2 bpm; $p = .006$). The PT group showed lower peak HR than CON at 80% only (mean difference, 4.1 bpm; $p = .03$). No differences between PT and PT+CT reached significance for peak HR.

Blood Lactate and RPE

Blood lactate concentrations increased from pre- to post-exercise in all groups at both time points ($p < .001$), with no significant between-group differences in the magnitude of lactate accumulation at either assessment (group x time interaction: $p = .22$). RPE similarly increased post-exercise in all groups at both assessments, with no between-group differences ($p = .38$). Pre-to-post intervention change scores for lactate and RPE did not differ among groups ($p > .20$ for all).

Discussion

Mechanism of the Combined Training Advantage

This trial compared plyometric training alone with combined plyometric-core training and sport-specific training on autonomic regulation, muscle oxygenation, and performance in collegiate athletes. Applying the a priori decision rule, the primary outcome (resting RMSSD) showed a clear advantage for PT+CT over PT (mean difference, 8.4 ms; $p = .008$; $d = 1.35$ vs. 0.71), and both confirmatory secondary outcomes confirmed this direction: SmO_2 at 80% 1-RM was 2.9 percentage points higher in PT+CT than PT ($p = .01$), and CMJ height gained an additional 2.3 cm ($p = .04$; $d = 0.72$). Because all three indicators converged, the core training component meets the pre-specified criterion for effectiveness in the autonomic-oxygenation domain.

The autonomic mechanism most consistent with these data involves improved baroreflex sensitivity. Chronic exercise training increases arterial baroreflex gain, which speeds vagal re-engagement after sympathetic perturbation (Nobrega et al., 2014). The core exercises in our protocol required sustained isometric contractions with controlled breathing patterns, and this combination may have functioned as a form of low-grade respiratory training that further sensitized baroreflex pathways (Shaffer & Ginsberg, 2017). The 16.3-ms RMSSD increase in PT+CT exceeds the 7.9-ms gain in PT alone, and this magnitude aligns with the upper range reported in a 2025 meta-analysis of long-term exercise effects on HRV (W. Zhang et al., 2025). The smaller post-exercise RMSSD decline in PT+CT (31.4% vs. 38.7% in PT and 46.2% in CON) further indicates that the combined intervention built greater autonomic resilience under high-intensity loading.

The SmO_2 advantage in the PT+CT group, present at all three loading intensities but widest at 80% 1-RM, points to improved local oxidative capacity rather than increased blood volume, because total hemoglobin did not differ between groups. Training-induced gains in capillary-to-fiber ratio, mitochondrial density, and endothelial nitric oxide production collectively increase the tissue oxygen reserve, delaying the point at which oxygen supply fails to match demand (Jones et al., 2018). Core exercises that load trunk stabilizers isometrically while the athlete breathes against postural resistance may have improved respiratory mechanics and trunk muscle perfusion efficiency, sustaining cardiac output during heavy lower-limb loading. Salem et al. (2025) observed a comparable SmO_2 preservation without total hemoglobin change following acute beetroot juice ingestion, attributing the effect to optimized perfusion of underutilized capillary beds; our data suggest that chronic combined training produces an analogous adaptation through vascular remodeling rather than pharmacological vasodilation.

Boundary of Effect Analysis

The data reveal a clear boundary separating outcomes where core training adds value from those where it does

not. The PT+CT advantage was strongest for autonomic regulation: resting RMSSD (d = 1.35), SDNN (d = 1.06), and HF power (d = 1.66) all showed large effects favoring the combined group over PT alone. The oxygenation advantage was moderate and intensity-dependent: the SmO_2 difference between PT+CT and PT was 2.3 percentage points at 60% 1-RM (non-significant), 2.2 points at 70% (non-significant), and 2.9 points at 80% (p = .01). This pattern suggests that the core training benefit for muscle oxygenation emerges primarily under high metabolic stress, where trunk stability and respiratory mechanics are most challenged.

By contrast, the core training component produced no additional effect on maximal strength. The 1-RM back squat improved by 12.8% in PT and 14.1% in PT+CT, with no between-group difference (p = .58). Bench press, peak power, and peak velocity followed the same pattern. These gains fall within the range reported for plyometric-resistance protocols of comparable duration (Sun et al., 2025). This plateau indicates that maximal force production in compound lifts is driven by neuromuscular adaptations to the plyometric stimulus itself, and core training does not augment this pathway within the tested intensity range. Blood lactate and RPE also showed no group differences at either time point, confirming that the metabolic cost of the incremental protocol was equivalent across conditions.

Functional Role of the Core Training Component

Synthesizing the boundary analysis, the core training component functioned as follows within this 10-week protocol. It enhanced outcomes in three areas: parasympathetic recovery at rest (RMSSD, SDNN, HF power), muscle oxygenation at high intensity (SmO_2 at 80% 1-RM), and functional power transfer (CMJ height, where trunk stiffness likely improved kinetic chain coordination as documented by Cabrejas et al., 2023, and consistent with the kinetic-link model described by Kibler et al., 2006). It did not affect maximal strength (1-RM BS, 1-RM BP, peak power), blood lactate accumulation, or perceived exertion. The data provide no evidence that core training inhibited or reduced any measured outcome. However, the absence of loading intensities above 80% 1-RM in our protocol means that the upper boundary of the core training effect remains undefined. At near-maximal or supramaximal loads, the additional training volume from core exercises could introduce competing fatigue that offsets any cardiovascular benefit.

Lower peak heart rate in PT+CT at 70% and 80% 1-RM (mean differences of 4.8 and 6.2 bpm compared with CON) suggests improved stroke volume or peripheral vascular conductance, allowing equivalent cardiac output at a lower rate (Michael et al., 2017). PT alone produced a smaller but directionally consistent trend, consistent with the known cardiovascular demands of repeated maximal-effort jumping (Staniszewski et al., 2024). The convergence of lower peak HR, higher SmO_2, and better-preserved post-exercise RMSSD in the PT+CT group supports the interpretation that the core component enhanced cardiovascular efficiency rather than simply adding training volume.

Applied Training Model and Practical Implications

Based on the convergent evidence from the decision rule analysis, we propose the following applied model for practitioners working with collegiate team-sport athletes. When the training goal is to improve cardiovascular efficiency and autonomic recovery alongside strength and power development, appending 20 minutes of progressive core exercises (isometric holds progressing from 2 sets of 30 seconds to 3 sets of 45 seconds; dynamic exercises from 2 x 10 to 3 x 15 repetitions) to each plyometric session, three times per week for at least 10 weeks, can be expected to produce meaningful gains in parasympathetic tone and local muscle oxygenation without compromising maximal strength adaptation. This model applies to loads up to 80% 1-RM in trained athletes aged 19 to 24 years with at least 2 years of resistance training experience. The model does not extend to outcomes governed primarily by glycolytic metabolism (lactate, RPE), which appear insensitive to the core training stimulus at the tested volume and duration.

Limitations

Several constraints should be noted. First, the sample (n = 42 completers) was drawn from a single university, limiting generalizability. Second, we did not measure plasma biomarkers of vascular function (nitrite/nitrate) or perform echocardiographic assessment, which would have strengthened mechanistic interpretations. Third, the control group did not perform a time-matched sham intervention, so a Hawthorne effect cannot be excluded. Fourth, NIRS measurements were limited to a single site on the vastus lateralis. Fifth, loading intensities above 80% 1-RM were not tested, leaving the upper boundary of the core training effect unknown. Sixth, the 10-week duration may not capture the full trajectory of autonomic and vascular remodeling. Finally, blinding of trainers and participants was not feasible, although outcome assessors were blinded. Future studies should incorporate longer interventions (16 to 20 weeks), direct vascular assessments (flow-mediated dilation, pulse wave velocity), multi-site NIRS recordings, and loading protocols extending to 90% or 95% 1-RM to map the complete dose-response relationship.

Conclusions

In collegiate team-sport athletes (19–24 years), 10 weeks of training (3 sessions/week, up to 80% 1-RM) demonstrated that combined plyometric and core training elicited greater improvements in cardiac autonomic regulation and local muscle oxygenation than plyometric training alone. The combined approach increased resting RMSSD (+16.3 ms vs +7.9 ms), enhanced SmO_2 during submaximal loading, and produced modest additional gains in CMJ height (+2.3 cm). These adaptations may be explained by improved baroreflex function and enhanced local oxidative capacity associated with sustained isometric contractions and controlled breathing during core exercises. In contrast, maximal strength, blood lactate, and perceived exertion were unaffected, indicating domain-specific adaptations. Practically, integrating ~20 minutes of progressive core training into plyometric sessions may enhance parasympathetic recovery and cardiovascular efficiency in trained athletes, although effects at near-maximal intensities require further investigation.

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AI Transparency

In the preparation of this manuscript, we utilized paperpal AI, as an assistive tool for editing, paraphrasing and improving the language. All AI-generated contents were thoroughly reviewed, verified, and edited by the authors.

Conflict of Interest

The authors declare no conflicts of interest

Data Availability Statement

The datasets generated and/or analyzed during the current study are not publicly available due to ethical and privacy restrictions, as they contain identifiable physiological data from student-athletes. Data access is restricted by the SIMATS University Ethics Committee. De-identified data may be made available from the corresponding author upon reasonable request, subject to institutional ethical approval and completion of a data-sharing agreement in accordance with applicable data protection regulations.

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Вплив пліометричного тренування та його поєднання з тренуванням м'язів кору на вегетативну регуляцію та оксигенацію м'язів під час виконання силових вправ із інкрементальним навантаженням у студентів-спортсменів

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Реферат. Стаття: 12 с., 5 табл., 4 рис., 39 джерел.

Мета дослідження. Це дослідження мало на меті порівняти вплив пліометричного тренування (ПТ) та його поєднання з тренуванням м'язів кору (ПТ+КТ) на регуляцію вегетативної нервової системи та локальну оксигенацію м'язів під час виконання силових вправ у студентів-спортсменів. Зокрема, було вивчено зміни варіабельності серцевого ритму (ВСР), сатурації кисню в м'язах (SmO_2) та показників результативності після 10-тижневої інтервенції.

Матеріали і методи. Проведено тригрупове рандомізоване контрольоване дослідження в паралельних групах із засліпленням оцінювача, у якому взяли участь 45 студентів-спортсменів (вік: 19–24 роки), які займаються волейболом, футболом та баскетболом. Учасників розподілили за методом рандомізації до групи ПТ (n = 15), групи ПТ+КТ (n = 15) або контрольної групи (КОН; n = 15). Група ПТ виконувала прогресивні пліометричні вправи, тоді як група ПТ+КТ виконувала ідентичне пліометричне тренування, доповнене структурованими вправами для м'язів кору, із частотою три заняття на тиждень протягом 10 тижнів. Група КОН продовжувала лише специфічне для конкретного виду спорту тренування. Первинні показники включали індекси ВСР у стані спокою та після фізичного навантаження (RMSSD, SDNN, потужність у діапазоні високих частот, співвідношення LF/HF), а також SmO_2, виміряну за допомогою ближньої інфрачервоної спектроскопії під час присідань зі штангою на плечах із інкрементальним навантаженням на рівні 60%, 70% та 80% від 1-ПМ. Вторинні показники включали максимальну силу, результативність стрибків, рівень лактату в крові та суб'єктивне сприйняте навантаження.

Результати. Сорок два учасники повністю завершили дослідження. У групах ПТ та ПТ+КТ спостерігалося значніше покращення показників 1-ПМ у присіданнях зі штангою на плечах порівняно з групою КОН ($P < .001$). Група ПТ+КТ продемонструвала вищі темпи зростання індексу RMSSD у стані спокою порівняно з групою ПТ ($P = .008$) та групою КОН ($P < .001$). Під час високоінтенсивних вправ (80% від 1-ПМ) рівень SmO_2 був значно вищим у групі ПТ+КТ, ніж в обох групах ПТ та КОН ($P \leq .01$). Потужність високих частот (HF) після виконання вправ краще зберігалася в групі ПТ+КТ, ніж у КОН ($P = .003$). Крім того, показники стрибка з контррухом продемонстрували суттєвіший приріст у групі ПТ+КТ, ніж у ПТ ($P = .04$) та КОН ($P < .001$), при цьому статистично значущих відмінностей у рівнях лактату в крові або показниках рейтингу сприйнятого навантаження (RPE) виявлено не було.

Висновки. Отримані результати підтверджують, що поєднання пліометричного тренування з методикою тренувань м'язів кору забезпечує значніше поліпшення показників вегетативної регуляції та оксигенації м'язів порівняно з виключним застосуванням пліометрики, що обґрунтовує інтеграцію зазначеного методу у програми кондиційного тренування на основі силових вправ з метою покращення фізіологічної адаптації та підвищення результативності.

Ключові слова: пліометричне тренування, стабільність кору, варіабельність серцевого ритму, оксигенація м'язів, ближня інфрачервона спектроскопія, силові вправи, вегетативна регуляція.

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Original Scientific Articles. Training Effects and Experimental Design

The Effect of Virtual Reality-Based Multimodal Training Programs on the Balance and Agility Skills of Young Soccer Players

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Young soccer athletes often demonstrate insufficient development of balance and agility, which may limit their overall performance. The integration of structured training programs with virtual reality (VR) technology offers a promising approach to enhancing these physical components.

Objectives. The study aimed to examine the effect of a VR-based multimodal training program integrating the FIFA 11+ protocol on balance and agility in young soccer players.

Materials and Methods. A randomized controlled trial with a pretest–posttest design was conducted involving 20 male soccer players aged 11–13 years. Participants were randomly assigned to an experimental group (VR-based training, n = 10) and a control group (conventional training, n = 10). The intervention lasted 8 weeks (3 sessions per week). Balance was assessed using the Stork Static Balance Test, and agility using the T-Test. Data were analyzed using mixed ANOVA with repeated measures, including evaluation of the Time × Group interaction, and effect sizes (Cohen's d).

Results. A significant Time × Group interaction was observed for balance ($F = 124.35$, $p < 0.001$) and agility ($F = 26.21$, $p < 0.001$). The experimental group demonstrated greater improvements in balance ($\Delta = 4.87$ s; $d = 1.07$) and agility ($\Delta = 0.83$ s; $d = 2.70$) compared to the control group ($\Delta = 1.37$ s; $d = 0.54$ and $\Delta = 0.31$ s; $d = 1.05$, respectively).

Conclusions. The findings indicate that VR-based multimodal training significantly improves balance and agility in young soccer players and can be considered an effective and innovative approach in youth soccer training programs.

Keywords: virtual reality, multimodal training, balance, agility, soccer.

Introduction

An athlete in a multifactorial sport, such as soccer, requires physical fitness, high technical skills, and well-developed tactical competencies. Many studies show that physical fitness has the greatest influence on overall physical performance of soccer players (Luo et al., 2023). Accordingly, athletic performance is largely determined by an athlete's physical, technical, and tactical capacities (Koopmann et al., 2020). In addition, integrating sport-specific exercises, particularly in youth soccer, into this routines can benefit physical performance and long-term physiological adaptation. Athletes who compete regularly require well-developed physical components particularly adolescents aged between 10 and 14 years and boys involved in sports activities that demand repeated jumping and agility movements (such as soccer, basketball, volleyball, and tennis)(Almousa et al., 2024; Chamera et al., 2023). Some studies define agility as rapid whole-body movement

involving changes in speed or direction in response to external stimuli such as ball movement, opponent movement, and teammate movement (Z. Zhao et al., 2026). Soccer players often perform complex maneuvers, such as rapid changes of direction, high-intensity sprints, and precise ball control, which require synchronized effort from both legs (Haddad, 2024). During actions such as kicking, passing, and jumping, players tend to rely predominantly on one leg, which demands well-developed balance capacity (DeLang et al., 2021). Therefore, young soccer players must develop good balance and agility skills to support the systematic development of movement quality.

Observations conducted with coaches at the Soccer School (SSB) in November 2025 revealed that the athletes' physical capacity was not yet optimal. The mean agility ability score measured using the T-Test agility showed 12.5 seconds categorised as low and below the normative profile of competitive young athletes. The mean balance score measured using the Stork Static Balance Test was 27 seconds, below the normative average for most people. Without targeted intervention, young soccer players will continue to experience deficits in physical performance, particularly in balance and agility. Targeted physical performance training is a highly effective intervention in sports training programs. . An increasing number of athletes and teams have adopted physical training programs as an important component of warm-up or exercise routines The goal is to improve the physical performance of young athletes through balance and agility components. FIFA11+ is one of the most eefective training programs to improving athletes' balance and agility (Aouadi et al., 2025). FIFA 11+ is a multimodal exercise programs derived from neuromuscular training principles (Belamjahad et al., 2025). Literature review, it is shown that there is positive evidence regarding the effect of the FIFA 11+ program on physical performance outcomes in young female athletes aged 9 years (Kambitta Valappil et al., 2025). Initially developed as an injury prevention protocol, the FIFA 11+ programs has also been shown to be effective in improving athletes' physical fitness more broadly (Nuhu et al., 2021). The integration of the FIFA 11+ programs with emerging sports technologies such as virtual reality (VR) can provide valuable insights into the true potential of technology-enhanced training compared to traditional methods (K. Zhao & Guo, 2022). VR can be utilized to enhance the performance of individual athletes and serve as a valuable tool for coaches and teams in designing more effective physical and tactical strategies. VR can transform training sessions into engaging and immersive experiences, making practice more enjoyable and motivating for athletes (Richlan et al., 2023). According to Shousha et al., (2021), VR training can improve static and dynamic balance in soccer athletes aged 12-16 years. Virtual reality training has also been shown to be an enjoyable medium that increases agility in adults (Wang, 2023). The benefits of VR in complementing conventional training include the creation of an immersive multisensory environment and the facilitation of faster and more effective motor pattern development.

To date, virtual reality research has largely focused on physical fitness, injury rehabilitation, and education. However, physical performance training programs targeting the balance and agility components of young soccer athletes through FIFA 11+-integrated VR multimodal training have not been studied. This study therefore presents an opportunity to investigate the effects of VR-based multimodal training on young soccer athletes. By targeting the physical components of balance and agility, training interventions can prevent young soccer athletes from failing to reach their developmental potential. This study uses the FIFA 11+ protocol with VR-based multimodal training to improve balance and agility. The VR simulation is interactive, enabling the enhancement of balance and agility in young soccer players. The insights gained will inform the development of balance and agility training strategies through VR-based multimodal exercises for young soccer players.

Materials and Methods

Participants

The participants in this study were young male soccer athletes aged 11 to 13 years. This study was carried out from January to March 2026 at a soccer training center in Indonesia. The sample comprised 20 athletes recruited using random sampling and subsequently allocated at random to one of two groups. The experimental group (n = 10) received VR-based multimodal training, while the control group (n = 10) underwent conventional training without virtual reality. The sample must meet certain inclusion criteria, including having been a registered soccer club athlete for at least one year, being male, and being physically active with a training frequency of three sessions per week. Exclusion criteria included any current illness that could affect physical activity or physical condition at the commencement of the study. Participants were also excluded if they had a history of medical conditions. All participants were first given an explanation of the objectives of the study as well as the initial conditions required to participate in the activity. Written informed consent was obtained from all participants prior to commencing the study. In addition, the testing procedure was explained thoroughly and in detail, with special emphasis on important aspects to minimize the risk of injury during the study.

Study Design

This study uses a quantitative approach with a randomized controlled trial design pretest and posttest. The research was conducted for 8 weeks from January to March 2026. This design is to determine the effect of virtual reality-based multimodal training programs compared to conventional training methods in improving the balance and agility of young soccer athletes (fig. 1).

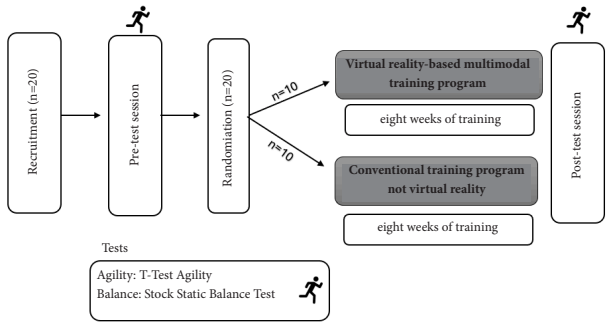

Fig. 1. Experimental Design of the Study

Procedures and Instruments

The procedural sequence consisted of three stages: pre-test, program intervention, and post-test.

Pretest

The measurement test was initiated to measure balance using the Stork Static Balance Test and to measure agility using the T-Test Agility. Measurements were carried out with the same procedure on all subjects to ensure data consistency.

Program Intervention

The training program was carried out 3 times per week for 8 weeks. Virtual Reality ExperimentalGroup: Research subjects performed a VR-based multimodal training programme using the Meta Quest 2 device, integrating the FIFA 11+ protocol for 20 minutes per session, incorporating balance training, core stability, plyometric exercises, and agility drills.

This exercise using virtual reality tools has interactive aspects, security, and affordability of use. In the context of soccer, virtual reality-based multimodal training was developed to replicate the game conditions of the sport of soccer through controlled simulations, including response to visual stimuli, the ability to change direction dynamically, and the integration of movement coordination. This approach allows athletes to adapt to the situational demands of the game in a more specific and measurable way. The control group conventionally had a training program consisting of agility exercises: shuttle run, ladder drill; balance exercises: ladder drill + balance, plyometric exercises: box jump and lateral jump for 30 minutes per session. Conventional training was conducted without virtual reality and was designed for general youth soccer training.

Table 1. FIFA 11+ Virtual Reality-based integrated multimodal training program

Training Unit Components	Movement Name	Description
Part 1 - Running Exercises (6 Movements for 8 minutes)	Running Straight Ahead	Run straight for about 40 m, then run back
	Running Hip Out	Walk/run while rotating the hips outward
	Running Hip In	Walk/run while rotating inward
	Running Circling Partner	Running around a partner (about 2 m)
	Running Shoulder Contact	Run side by side shoulder contact
	Running Quick Forwards & Backwards	Run forward and backward quickly
Part 2 – Strength, Balance & Plyometrics (15 Movements for 10 Minutes)	Level 1 (Beginner)	
	The Bench (Static)	Static plank push-up position
	Sideways Bench (Static)	Static side plank
	Hamstrings (Beginner)	Two-legged bridge, heels on the floor
	Single-Leg Stance	Stand on one foot
	Squats (With Toe Raise)	Squat + lift heels
	Jumping – Vertical Jumps	Vertical jump, soft landing
	Level 2 (Intermediate)	
	The Bench (Alternate Legs)	Plank + alternate leg raises
	Sideways Bench (Raise Lower Hip)	Side plank hip lift
	Hamstrings (Intermediate)	One-legged bridge
	Single-Leg Stance (Throwing Ball)	One foot + throw and catch the ball
	Squat (Walking Lunges)	Forward lunge step
	Jumping – Lateral Jumps	Side jump on one foot
	Level 3 (Advanced)	
	The Bench (One Leg Lift & Hold)	Single-leg plank hold
	Sideways Bench (With Leg Lift)	Side plank + leg lift
	Hamstrings (Advanced)	Nordic hamstring exercise
	Single-Leg Stance (Partner Push)	One foot + partner's push
	Squats (One-Leg Squats)	Single-leg squat
	Jumping-Box Jumps	Jump to the box + controlled landing
Part 3 – Running Exercises (3 Moves for 2 Minutes)	Running Across the Pitch	Sprint across the field
	Running Bounding	Run with explosive long strides
	Running Plant & Cut	Run, stop, change direction sharply

Fig. 2. Virtual reality-based multimodal training

Instruments

Agility: T-Test Agility

Time counting begins when participants cross the start/finish line of the start time counter and stops when they return to the finish line. Three attempts were conducted with a rest interval of 2–3 minutes between each attempt, and the best time was recorded. The T-Test agility test is conducted using the standard version as reported in the literature i.e. forming a distance of 10 × 10 m.

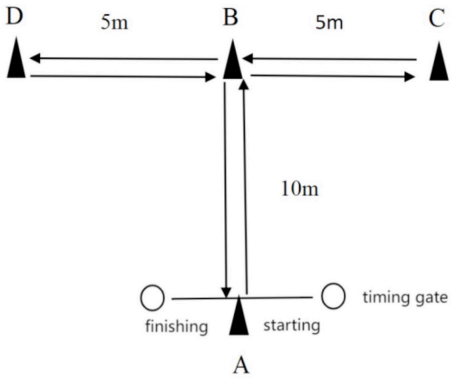

Fig. 3. T-Test Agility

Balance: Stork Static Balance Test

Balance was measured using the Stork Static Balance Test. 'Participants stood upright with both hands on the hips and placed the non-dominant foot against the inner knee of the stance leg, then lifted the heel of the stance foot off the ground on the signal "go". Participants are asked to maintain this position as long as possible. The test ends when the raised heel touches the ground or when the supporting foot moves away from the knee. Tested over 3 trials, the best score is used. The test–retest reliability is 0.86

Post-test

After the intervention was completed over 8 weeks, participants were reassessed using the same instruments as in the pre-test stage. The post-test results were then compared with the initial measurements to determine the level of improvement in balance and agility.

Statistical Analysis

Data were analysed using SPSS version 23, the normality of data distribution was tested using the Shapiro–Wilk test and Levene's test was used to confirm homogeneity of variance. Descriptive statistics were used to determine the basic parameters of the test results in each group (experiment and control) at the initial and final test stages (mean; standard deviation). To test the hypotheses and analyse differences between initial and final test scores within and between groups, a mixed ANOVA with repeated measures was employed to evaluate changes over time and compare subjects' scores from both groups. In all tests, the confidence level used was 0.05. In addition, Cohen's d coefficient was included as an indicator of effect size. The criteria for effect size were set as follows: negligible (<0.20), small (0.20–0.50), medium (0.50–0.80), and large (>0.80).

Results

Description of Research Data

The description of the data shows the average values of balance and agility before and after the intervention in the virtual reality (experimental) group compared with the conventional (control) group.

Based on Table 2 the experimental group (virtual reality) showed significant descriptive results. The mean balance value increased from 35.82 to 40.69 seconds, while agility increased from 12.16 to 11.33. The experimental group recorded significant differences in balance and agility between the pre-test and post-test compared to the control group, which showed small variations as shown in the table above.

Preliminary Assumption Tests

Normality Test

The data normality test used the Shapiro-Wilk method with a significance level of 0.05.

Table 2. Descriptive Statistics of the Experimental Group vs Control Group

Variable	Experimental					Control			
	N	Min	Max	Mean	SD	Min	Max	Mean	SD
PreTest Balance	10	27.86	42.75	35.82	4.80	28.96	36.41	32.40	2.52
PostTest Balance	10	33.82	48.73	40.69	4.82	30.77	38.13	33.77	2.55
PreTest Agility	10	11.68	12.70	12.16	0.34	12.10	13.01	12.60	0.31
PostTest Agility	10	10.97	11.78	11.33	0.27	11.95	12.69	12.30	0.26

Table 3. Normality Test Results

Variable	Sig. Experimental	Sig. Control	Description
Pre-test Balance	0.945	0.787	Normal
Post-test Balance	0.867	0.346	Normal
Pre-test Agility	0.847	0.705	Normal
Post-test Agility	0.676	0.280	Normal

The results of the normality test showed that all pre-test, post-test, balance and agility variables as well as experimental and control had a significance of $p > 0.05$ so that it could be concluded that the data were distributed normally and met the assumptions of parametric analysis.

Homogeneity Test

Table 4. Homogeneity Test Results

Variable	Sig.	Description
Pre-test Balance	0.62	Homogeneous
Post-test Balance	0.85	Homogeneous
Pre-test Agility	0.736	Homogeneous
Post-test Agility	0.872	Homogeneous

The results of the homogeneity test showed that the variance across all groups was homogeneous ($p > 0.05$).

Hypothesis Test

Mixed Anova Test

Hypothesis Test of Virtual Reality-Based Exercise on Balance

Table 5. Summary of Hypothesis Testing of Virtual Reality on Balance

Source	Type III Sum of Square	Df	Mean Square	F	Sig.	ηp^2
Time	97.188	1	97.188	393.044	0.000	0.956
Time*Group	30.748	1	30.748	124.348	0.000	0.874
Error (Time)	4.451	18	0.247			

Based on the results of table 5 on the Time x Group row, the value of $F = 124.348$ ($p<0.05$) means that there is a Time x Group interaction.

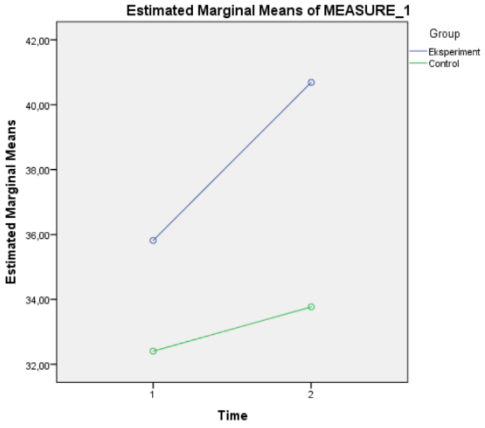

Fig. 3. Plot of the Experimental Group and the Control Group

Figure 3 Shows that there is an interaction between the experimental group and the control group across the pre-test and post-test measurement points.

Hypothesis Test of Virtual Reality-Based Exercise on Agility

Table 6. Summary of Hypothesis Test of Virtual Reality on Agility

Source	Type III Sum of Square	df	Mean Square	F	Sig.	ηp^2
Time	3.336	1	3.226	123.186	0.000	0.873
Time*Group	0.686	1	0.686	26.210	0.000	0.593
Error (Time)	0.471	18	0.026			

Based on the results of Table 6 in the Time x Group row, it shows an F value = 26.210 ($p<0.05$) which means there is a Time x Group interaction.

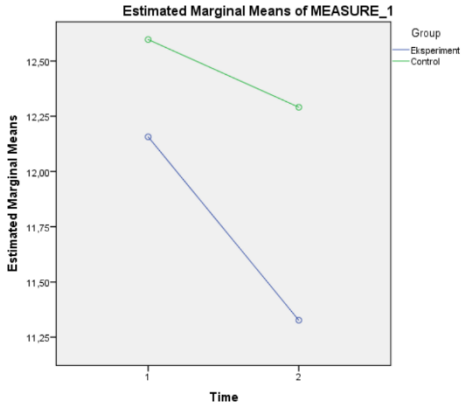

Fig. 4. Plot of the Experimental Group and the Control Group

Figure 4 shows that there is an interaction between the experimental group and the control group during the pre-test and post-test.

Table 7. Effect Size (Cohen' d)

Variable	Group	Δ (Change)	Effect Size (d)	Category
Balance	Experimental	+4.87 seconds	1.07	Large
	Control	+1.37 seconds	0.54	Medium
Agility	Experimental	+0.83 seconds	2.70	Very Large
	Control	+0.31 seconds	1.05	Large

Effect size analysis showed that virtual reality-based interventions had a large impact on balance and a very large impact on agility. The effect size value was very large ($d > 0.80$) in the experimental group (virtual reality) compared to the control group.

Discussion

This study provides evidence that FIFA 11+-integrated VR-based multimodal training has a significant impact on the balance and agility abilities of young soccer athletes. The significant Time × Group interaction indicates meaningful difference in pre-test and post-test scores between the experimental and control groups, as illustrated in Figures

3 and 4. Another study highlights the significant positive impact of the integration of virtual reality technology in improving the physical components of young female soccer players (Makhadmeh & Fayad, 2025). Consistent with these findings, the VR-based experimental intervention produced markedly greater improvements in balance and agility than the conventional control condition. In conventional sports training, motivation and comfort tend to decline as training intensity increases; however, the present study found that intensity and comfort of sports training in the higher intensity phase through VR (Giakoni-Ramírez et al., 2023). These findings should be interpreted with consideration of the specific characteristics of the participants, who are young soccer athletes aged 11 to 13 years. The literature reveals that high-achieving young athletes who start playing earlier in sports involving more specific training demonstrate faster progress than those who begin later (Güllich et al., 2022). This idea supports the theoretical suggestion about the developmental phases of young athletes' talent, one of which is the early enhancement of physical capacity before the secondary specialization period in the form of specialized training. Specialised warm-up training in the form of FIFA 11+ with VR technology improves proprioception and neuromuscular control by providing visual stimulation to users as they perform athletic movements carried out in a safe environment (Pangestuputra & Changestu, 2024). Given that soccer demands a high level of physical conditioning, incorporating training elements such as balance and agility into warm-up routines is particularly important (Barbour et al., 2024). Bukowska et al., (2021) found that body balance improves with an increase in the duration and intensity of exercise. The present study's multimodal training programme incorporates movement components specifically targeting balance and agility. a menu of multimodal training programs contains movements that resemble components for balance and agility.

The multimodal integrative training derived from FIFA 11+ encompasses balance training, core stability work, plyometrics, and agility drills which may be a concern due to potential cumulative effects. However, systematic reviews report that concurrent training is more effective than single-mode plyometric or balance training in improving agility and balance in children and adolescents (Blavt et al., 2023; Sun et al., 2025). Multimodal training has a component of virtual reality-based agility training that can affect athletes' agility. In line with Li et al. (2025) the effectiveness of virtual reality training in improving athletes' physical abilities includes speed, flexibility, and agility. The improvement of balance and agility based on virtual reality is greater than conventional. Similarly, Cariati et al., (2025) revealed that virtual reality training was better than conventional training control groups with regard to the balance of young soccer athletes aged 15 to 16 years.

The present study demonstrates that a training program of three sessions per week over 8 weeks significantly improves agility. Arede et al., (2022) demonstrated that a similar multimodal protocol based on the FIFA 11+ framework, conducted twice weekly over six weeks, improved agility in 11-year-old athletes. Meanwhile, FIFA 11+ using virtual reality shows success in simultaneously improving balance and agility in athletes who trained for 8 weeks (Davidovica et al., 2025; Panchal et al., 2025). Research findings by Demeco et al., (2024) show that VR is superior to other forms of training because it provides more immersive and engaging information, and effectively improves cognitive perceptual skills. This study provides an additional improvement in the performance of young soccer players through a multimodal training program. These findings suggest that VR-based training represents a technologically advanced alternative to conventional training approaches. Although the findings are promising, several limitations should be acknowledged. Future studies are recommended to adopt longitudinal designs with larger and more diverse samples, accounting for gender and age range, over extended study durations..

Conclusions

Based on the findings of this study, it can be concluded that virtual reality-based multimodal training can improve the balance and agility of young soccer athletes. In addition, from the data, the increase statistically has more impact than conventional training. Virtual reality-based training enhances physical performance through an immersive, engaging, and effective training experience. This positions VR-based multimodal training as an innovative method in the field of training technology for modern soccer. Thus, further research is recommended for a longer research time and a wider sample to obtain more detailed data.

Ethics Approval

The research was conducted in accordance with the principles of the code of ethics. The research protocol was reviewed and approved by the Ethics Committee of Universitas Negeri Yogyakarta (No. T/1423.1/UN34.9/PT.01.04/2025).

Data Availability Statement

Open access.

AI Transparency Statement

No AI tools were used in this study.

Acknowledgements

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Conflicts of Interest

All authors must declare any potential conflicts of interest.

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Вплив мультимодальних програм тренувань на основі віртуальної реальності на показники рівноваги та спритності юних футболістів

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Реферат. Стаття: 12 с., 5 табл., 4 рис., 39 джерел.

Обґрунтування. Юні футболісти часто демонструють недостатній рівень розвитку рівноваги та спритності, що може обмежувати їхню загальну результативність у грі. Інтеграція структурованих тренувальних програм із технологіями віртуальної реальності (VR) є перспективним підходом до вдосконалення цих фізичних складових.

Мета дослідження. Метою дослідження було вивчити вплив мультимодальної програми тренувань на основі VR, що інтегрує протокол FIFA 11+, на показники рівноваги та спритності юних футболістів.

Матеріали і методи. Проведено рандомізоване контрольоване дослідження за схемою претест–посттест із залученням 20 футболістів чоловічої статі віком 11–13 років. Учасників було розподілено за методом рандомізації на експериментальну групу (тренування на основі VR, n = 10) та контрольну групу (традиційні тренування, n = 10). Інтервенційна програма тривала 8 тижнів (3 заняття на тиждень). Для оцінювання рівноваги використовували тест статичної рівноваги «Лелека», а спритність вимірювали за допомогою t-критерію Стьюдента. Аналіз даних проведено із застосуванням змішаного двофакторного дисперсійного аналізу з повторними вимірюваннями, включаючи оцінку взаємодії чинників «Час × Група» та розміри ефекту (d Коена).

Результати. Виявлено значущу взаємодію чинників «Час × Група» для показників рівноваги ($F = 124,35$, $p < 0,001$) та спритності ($F = 26,21$, $p < 0,001$). В експериментальній групі зафіксовано суттєвіше покращення рівноваги ($\Delta = 4,87$ с; $d = 1,07$) та спритності ($\Delta = 0,83$ с; $d = 2,70$) порівняно з контрольною групою ($\Delta = 1,37$ с; $d = 0,54$ та $\Delta = 0,31$ с; $d = 1,05$ відповідно).

Висновки. Отримані результати свідчать, що мультимодальні тренування на основі технології VR достовірно покращують рівновагу та спритність юних футболістів, і їх можна розглядати як ефективний та інноваційний підхід у програмах підготовки юнацького футболу.

Ключові слова: віртуальна реальність, мультимодальне тренування, рівновага, спритність, футбол.

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Trust as a Mechanism of Role-Dependent Regulation in Acrobatic Pairs

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Abstract

Objectives. This study aimed to examine how cognitive and affective trust are organized within acrobatic pairs depending on compatibility type and partner role. It was hypothesized that trust organization varies across compatibility configurations and partner roles, and that the balance between cognitive and affective trust reflects distinct mechanisms of interaction regulation associated with responsibility distribution and regulatory tension within the dyadic system.

Materials and Methods. The study involved 25 acrobatic pairs (N = 50 athletes) aged 11–16 years competing in acrobatic gymnastics at the stage of preliminary basic training. Compatibility types were determined according to a typology of acrobatic pair compatibility previously developed by the authors. The typology integrates indicators of technical execution reliability, postural and phase coordination, and emotional–expressive coherence. Interpersonal trust was assessed using an adapted version of Daniel J. McAllister's Affect- and Cognition-Based Trust Scale. Nonparametric statistical procedures were applied, including Kruskal–Wallis tests, Mann–Whitney U tests, and Dwass–Steel–Critchlow–Fligner post-hoc comparisons.

Results. The findings revealed generally high levels of interpersonal trust between partners. No statistically significant differences between partner roles were identified. However, the structure of trust organization differed across compatibility types. Functionally oriented pairs demonstrated relatively higher cognitive trust, whereas expressively oriented pairs exhibited relatively higher affective trust. Complex synergy pairs showed consistently high levels of both trust components and demonstrated the highest values on the trust balance index, indicating a more integrated mechanism of interaction regulation.

Conclusions. Trust in acrobatic pairs functions not only as an individual psychological characteristic but also as a mechanism regulating interaction within a functionally asymmetric partnership. Variations in the balance between cognitive and affective trust reflect different coordination mechanisms associated with the distribution of responsibility, emotional synchronization, and interaction stability in acrobatic pairs.

Keywords: interpersonal trust, partner compatibility, dyadic interaction, interpersonal coordination, functional role asymmetry, acrobatic gymnastics.

Introduction

In sports that require close coordination between two athletes, such as sports acrobatics, pair figure skating, and other synchronized disciplines, competitive success largely depends on the quality of interaction between partners. The execution of complex elements requires precise temporal and spatial coordination, continuous prediction of a partner's actions, and the ability to maintain stability within the pair (Eccles & Tenenbaum, 2004).

In acrobatic gymnastics, such coordination unfolds during the execution of competitive routines, where partners must continuously adjust their movements within a shared performance structure.

Sports acrobatics provides a particularly clear example of such interdependence. Acrobatic elements require constant

coordination between partners performing different functional roles within the pair. Typically, the base partner maintains the stability of the support system, whereas the top partner performs complex dynamic and balance elements that depend on the base's reliability. This structure creates pronounced role asymmetry and a high level of mutual dependence during performance (Denysenko, 2020).

Interaction between partners in technical-aesthetic sports, including sports acrobatics and pair figure skating, may involve at least two complementary dimensions of joint performance. The first concerns functional coordination and the distribution of motor roles within the pair, particularly in tasks requiring asymmetric contributions from partners. Research within ecological dynamics and joint action frameworks shows that such coordination emerges through continuous perceptual-motor coupling between performers, allowing them to stabilize joint actions within a shared action space under changing task constraints (Araújo et al., 2006; Passos et al., 2012; Vicaria & Dickens, 2016). In this perspective, stable performance emerges through interpersonal coupling that links partners into a coordinated system. In sports acrobatics, this functional dimension of interaction has been described through the concept of technical coordination reliability between partners (Maksymov & Denysenko, 2025).

The second dimension concerns expressive and interpersonal synchronization reflecting emotional and communicative aspects of interaction (Hoehl et al., 2021). In technical-aesthetic sports, competitive routines combine technical execution with artistic and expressive components contributing to performance evaluation (FIG, 2024; Odynets et al., 2023). In sports acrobatics, expressive coordination between partners has also been identified as an important component of partner compatibility and performance interaction (Maksymov et al., 2026). Within this discipline, partners must maintain functional coordination of movement while simultaneously creating expressive unity of performance.

Effective interaction in highly interdependent tasks depends not only on technical coordination but also on psychological mechanisms supporting joint action (Marsh et al., 2009; Sebanz & Knoblich, 2021). Studies on interpersonal coordination show that successful cooperative performance requires partners to anticipate each other's actions and continuously adjust their movements (Hoehl et al., 2021; Marschner et al., 2024; Dockendorff et al., 2025). More broadly, coordinated behavior emerges through dynamic coupling and mutual adjustment between interacting individuals (Schmidt & Richardson, 2008; Richardson et al., 2007), while similarity in movement dynamics may facilitate coordination and stabilize cooperative performance (Słowiński et al., 2016). Research on joint action also suggests that efficient coordination depends on how interacting individuals distribute effort and responsibility within the shared action system (Török et al., 2019).

Within sport contexts, trust is considered an important psychological factor facilitating cooperation, decision-making, and interaction stability in both team and dyadic activities (McAllister, 1995; Mayer et al., 1995; Carron et al., 2012; Filho, 2020; McGuire et al., 2025). In social psychology, trust is conceptualized as a mechanism enabling individuals to accept vulnerability under conditions of uncertainty and interdependence (Simpson, 2007; Rotenberg et al., 2025). Trust increases the predictability of a partner's behavior and supports the willingness to rely on another person in situations involving uncertainty and shared responsibility.

In acrobatic pairs, complex elements often place one partner in a physically vulnerable position, requiring strong mutual reliance between athletes. Trust is commonly defined as a willingness to accept vulnerability based on positive expectations regarding another person's actions (Mayer et al., 1995). In highly interdependent motor tasks such as acrobatic pair performance, this willingness may involve relying on a partner for control and responsibility during complex elements. Under conditions of role asymmetry between the top and the base partner, such delegation becomes a necessary component of coordinated performance. Trust may therefore function as a psychological mechanism regulating the tension between maintaining individual control and delegating part of this control to a partner during joint performance.

From the perspective of joint action research, successful cooperation emerges through dynamic regulation of shared action and continuous mutual adjustment (Marsh et al., 2009; Sebanz & Knoblich, 2021; Boukarras et al., 2025). In this context, trust may facilitate interpersonal coordination during joint performance. The interaction between individual motor control and the need to coordinate actions with a partner may create a state of regulatory tension reflecting the balance between individual and shared control of movement. Similar dynamics between synchrony and individual action have been discussed in broader frameworks of social interaction (Mayo & Gordon, 2025). In dyadic performance contexts, the quality of partnership interaction has also been linked to athlete engagement and competitive outcomes (Liu et al., 2023). Neuroscientific studies further suggest that successful interpersonal interaction may be accompanied by neural synchronization between partners, supporting a multi-level understanding of coordination in dyadic performance (Zhao et al., 2024).

Despite the recognized importance of trust in cooperative activities, its role in regulating dyadic interaction in sports acrobatics remains insufficiently understood. Most studies have examined trust primarily as an individual psychological characteristic. However, in highly interdependent motor tasks such as acrobatic pair performance, trust may function as a property of dyadic interaction itself. Little attention has been given to the balance between cognitive and affective components of trust and their potential role in stabilizing coordinated performance between partners. Such regulatory dynamics may vary depending on how interaction is organized within the pair, suggesting that different compatibility configurations may be associated with distinct patterns of trust organization. Previous research in sports acrobatics indicates that pair interaction may be organized through different compatibility configurations integrating technical coordination reliability and emotional–expressive coherence (Maksymov & Maksymova, 2025). Biomechanical research also emphasizes the importance of precise inter-partner coordination and interaction dynamics in partner-assisted acrobatic elements (Leite, 2025; Leite et al., 2023).

In highly interdependent sports such as Acrobatic Gymnastics, the stability of joint routine execution may therefore depend on how psychological mechanisms

support interpersonal coupling between partners. Within this framework, trust may represent one of the psychological mechanisms through which different compatibility configurations regulate interaction between partners during joint performance. The aim of this study was to determine how cognitive and affective trust are distributed within acrobatic pairs depending on compatibility type and partner role. It was hypothesized that trust organization differs across compatibility types and partner roles, and that the balance between cognitive and affective trust reflects distinct patterns of dyadic regulation during joint performance.

Materials and Methods

Study Design

The study employed a cross-sectional descriptive–comparative design focusing on structural configurations rather than solely on mean-level differences. The analytical framework emphasized the role-based organization of cognitive and affective trust within asymmetric dyadic interaction.

Participants

The initial sample consisted of 30 acrobatic pairs (N = 60 athletes) aged 11–16 years competing in sports acrobatics at the stage of preliminary basic training. Inclusion criteria required at least three years of shared training experience and the absence of acute injuries at the time of data collection.

Following compatibility profiling procedures (see Sample and Analytical Strategy), 25 pairs (N = 50 athletes) representing stable regulatory configurations were included in inferential analyses.

The mean age of top partners was 15.48 years (SD = .58), whereas base partners had a mean age of 12.12 years (SD = 1.08). Data collection was conducted during the regular training period.

Ethical Considerations

The study was conducted in collaboration with sports clubs specializing in acrobatic gymnastics. Participation was voluntary, and written informed consent was obtained from all athletes and their legal guardians. The procedures involved performance assessment and psychometric evaluation and were conducted in accordance with the ethical standards for research involving human participants and the principles of the Declaration of Helsinki.

Sample and Analytical Strategy

All 30 pairs were initially profiled within a two-dimensional compatibility matrix integrating technical coordination reliability and emotional–expressive coherence, based on a previously developed typology of acrobatic pair compatibility (Maksymov & Maksymova, 2025).

Within this framework, pair interaction is evaluated through two complementary dimensions: technical coordination reliability and emotional–expressive coherence.

Technical coordination reliability was operationalized through a combination of postural stability and temporal coordination indicators. Postural stability was assessed using stabilography (stabilometric platform "Stabilan") during a handstand position of the top partner supported by the base partner, with statokinesiogram length as the primary parameter. Temporal coordination was analyzed during the execution of a dynamic element ("tempo from hands to hands") using an optoelectronic 3D motion capture system (Qualisys). The temporal difference between movement initiation phases was calculated, and anticipatory actions of the base partner were treated as synchronization errors and incorporated as a penalty component. These parameters were combined into a composite index of technical coordination reliability.

Emotional–expressive coherence was assessed through expert evaluation of partner interaction during routine performance, including emotional synchrony, coherence of movement character, stylistic unity, correspondence of expressive behavior to the routine content, and coordination of tempo and rhythm in expressive movements. A composite index was calculated based on expert ratings.

The indicators of technical coordination reliability demonstrated high test–retest reliability (r = 0.82–0.88) and significant correlations with technical performance scores in competition routines (r = 0.41–0.47, $p < .05$) (Maksymov & Denysenko, 2025). The emotional–expressive coordination scale demonstrated satisfactory internal consistency (Cronbach's $\alpha = 0.82$), high inter-rater reliability (Kendall's W = 0.91), and significant associations with indicators of performance coherence and artistic evaluation in competition (r = 0.38–0.45; $p < .05$) (Maksymov et al., 2026).

To ensure comparability, both indices were standardized using z-transformation. Standardized values reflected the relative position of each pair within the sample distribution. Based on these standardized indicators, a rule-based compatibility classifier was applied, in which each pair was assigned to a compatibility type according to the sign combination of the two dimensions. This procedure allowed formalized classification of dyadic interaction patterns and ensured consistency of group assignment across the sample.

Compatibility types were assigned according to the sign combination of the standardized indices. Pairs with positive values on both dimensions ($z > 0$; $z > 0$) were classified as complex synergy (CS). Pairs with positive technical coordination reliability and negative emotional–expressive coherence ($z > 0$; $z < 0$) were classified as functionally oriented (FO). Pairs with negative technical coordination reliability and positive emotional–expressive coherence ($z < 0$; $z > 0$) were classified as expressively oriented (EO). Pairs with negative values on both dimensions ($z < 0$; $z < 0$) were classified as were classified as low integration.

Thus, classification was based on the relative positioning of pairs within the sample rather than fixed normative cut-offs, ensuring reproducibility while avoiding arbitrary thresholds.

Pairs classified as low integration (n = 5) were excluded from inferential analyses, as the study focused on stable regulatory configurations. Accordingly, comparative analyses were conducted on 25 pairs representing three compatibility configurations: complex synergy (CS; n = 7), functionally oriented (FO; n = 10), and expressively oriented (EO; n = 8).

The proposed typological framework provides a structured tool for identifying distinct configurations of

partner interaction and may support the optimization of training processes in acrobatic pairs.

Trust variables were not used for classification but were analyzed as outcome indicators reflecting role-dependent regulation within the identified compatibility types.

Trust Measures

Interpersonal trust was assessed at the individual level. Each athlete evaluated their partner using an adapted version of McAllister's (1995) Affect- and Cognition-Based Trust Scale.

The instrument conceptualizes trust as a two-component construct comprising cognitive trust (belief in a partner's competence and reliability) and affective trust (emotional bond and mutual care). The scale consisted of 11 items: six measuring cognitive trust and five assessing affective trust. Responses were recorded on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree).

Item wording was adapted to reflect the context of acrobatic pair training and competition while preserving the original construct structure.

Composite scores were calculated for each participant (N = 50) as mean subscale scores. Higher scores indicated stronger perceived trust toward the partner.

These measures served as the primary variables for examining trust distribution across compatibility types.

Statistical Analysis

All statistical analyses were conducted using nonparametric procedures due to the sample size and non-normal distribution of variables.

Descriptive statistics are presented as medians (Me) and interquartile ranges (IQR). Group differences across compatibility configurations (CS, FO, EO) were examined using the Kruskal–Wallis test. When significant effects were identified, post hoc pairwise comparisons were performed using the Mann–Whitney U test with adjusted significance levels.

Given the dyadic structure of the data, trust ratings were analyzed at the individual level (N = 50 athletes), with compatibility configuration treated as a between-group factor. This approach reflects the conceptual structure of the construct, as trust represents an individual perception directed toward a partner while being embedded within a dyadic interaction system.

Role-specific differences in trust were examined using the Mann–Whitney U test.

Statistical significance was set at $p < .05$.

The study corresponds to a cross-sectional observational design and is reported in accordance with the STROBE guidelines. Given its exploratory nature, the analyses focused on structural patterns of interaction within asymmetric dyadic performance systems.

Results

Descriptive statistics of trust indicators

Descriptive statistics of trust variables are presented in Table 1.

Table 1. Descriptive statistics of trust variables in acrobatic pairs

Variable	Median	IQR	Min	Max
Cognitive trust	4.64	0.43	3.86	5.00
Affective trust	4.57	0.57	4.00	5.00
Balance (Cog – Aff)	0.00	0.57	−0.71	0.86

A trust balance index was calculated to reflect the proportional relationship between cognitive and affective trust within the dyad.

Both cognitive and affective trust showed high median values (Me = 4.64 and Me = 4.57), indicating generally high levels of trust between partners. The trust balance index showed moderate variability (IQR = 0.57), suggesting individual differences in the proportional relationship between cognitive and affective components of trust.

The balance between cognitive and affective trust represents an additional dimension of interaction organization within acrobatic pairs.

Differences in trust indicators between partner roles

The comparison between partner roles (top vs. base) did not reveal statistically significant differences in any of the trust indicators (Table 2). Although top partners demonstrated slightly higher cognitive trust and base partners slightly higher affective trust, these differences did not reach statistical significance ($p > .05$).

Table 2. Role differences in trust variables (Mann–Whitney test)

Variable	Top partner (Me)	Base partner (Me)	U	p
Cognitive trust	4.86	4.57	228	.092
Affective trust	4.43	4.57	273	.438
Balance	0.14	0.00	221	.072

These findings suggest that trust operates as a dyadic characteristic, without pronounced overall role differences.

Trust indicators across compatibility types

The trust indicators across compatibility types are presented in Table 3.

Table 3. Median values of cognitive trust, affective trust, and trust balance across compatibility types and partner roles

Compatibility type	Partner role	Cog_trust (Me)	Aff_trust (Me)	Balance (Me)
FO	Top	5.00	4.86	0.14
	Base	4.14	4.14	0.00
EO	Top	4.07	4.21	0.00
	Base	4.57	4.86	−0.21
CS	Top	5.00	4.43	0.57
	Base	4.86	4.43	0.43

Note. Medians (Me) are presented separately for Top and Base partners within each compatibility type. Balance represents the difference between cognitive and affective trust scores.

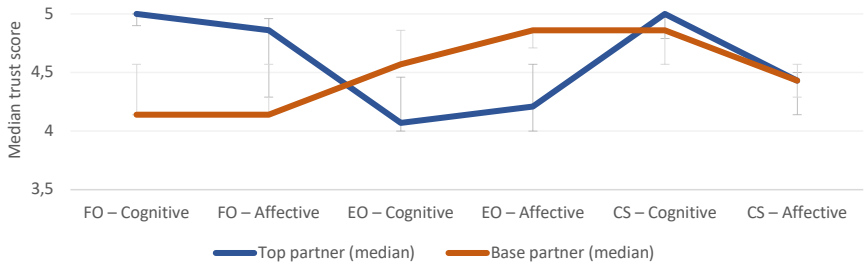

Fig. 1. Median profiles of cognitive and affective trust in top and base partners across compatibility types. Error bars represent interquartile ranges.

As shown in Table 3, compatibility types demonstrate distinct trust configurations. Figure 1 illustrates the corresponding trust profiles. Figure 1 illustrates the characteristic trust profiles associated with each compatibility configuration.

Functionally oriented (FO) pairs demonstrate relatively higher cognitive trust, particularly among top partners, whereas expressively oriented (EO) pairs show relatively higher affective trust, especially among base partners. Complex synergy (CS) pairs demonstrate consistently high levels of both trust components together with the highest balance values of the trust balance index, indicating a more integrated configuration of dyadic trust within the pair.

Kruskal–Wallis tests revealed significant differences between compatibility types for cognitive trust ($\chi^2_{(2)} = 9.95$, $p = .007$) and the trust balance index ($\chi^2_{(2)} = 11.73$, $p = .003$), whereas affective trust did not differ significantly ($\chi^2_{(2)} = 2.43$, $p = .297$).

Pairwise comparisons between compatibility types

Post-hoc pairwise comparisons using the Dwass–Steel–Critchlow–Fligner test revealed significant differences between expressively oriented (EO) and complex synergy (CS) pairs for cognitive trust ($p = .006$). No significant differences were observed between FO and EO pairs ($p = .089$) or between FO and CS pairs ($p = .449$).

For the trust balance index, significant differences were also observed between EO and CS pairs ($p = .001$), whereas differences between EO and FO ($p = .209$) and between FO and CS pairs ($p = .171$) were not statistically significant.

Role-specific patterns of trust organization

Pairwise comparisons of compatibility types within partner roles are presented in Table 4.

Role-specific analyses revealed differentiated patterns of trust organization. Among top partners, significant differences were observed for cognitive trust, with expressively oriented pairs demonstrating lower values than both functionally oriented and complex synergy pairs. In contrast, among base partners significant differences were observed mainly for affective trust, with expressively oriented pairs demonstrating higher affective trust compared with the other configurations. These findings suggest that trust regulation in acrobatic pairs may be role-dependent.

Overall, the results indicate that trust in acrobatic pairs is regulated through different interaction mechanisms depending on compatibility type, with complex synergy pairs demonstrating the most integrated trust configuration.

These patterns provide an empirical basis for understanding the role of trust in regulating dyadic interaction in acrobatic pairs.

Discussion

The present results indicate that trust in acrobatic pairs is organized not only at the level of individual attitudes but also at the level of dyadic regulation. These findings demonstrate that trust operates as a regulatory mechanism of interaction within acrobatic pairs, with different compatibility types characterized by distinct balances between cognitive and affective trust. This perspective suggests that trust represents a component of a broader system regulating interpersonal coordination in acrobatic pairs. Overall trust levels were relatively high, which is consistent with the strong interpersonal dependence and physical risk inherent in acrobatic pair performance. At the same time, the organization of trust varied by compatibility type and partner role. Significant differences were found for cognitive trust and the trust balance index, whereas affective trust did not differ significantly across compatibility types. Functionally

Table 4. Pairwise comparisons of compatibility types within partner roles (DSCF test)

Role	Variable	EO–CS	EO–FO	CS–FO
Top partners	Cognitive trust	4.198 (.008)	5.201 (<.001)	0.430 (.950)
	Affective trust	0.840 (.824)	2.813 (.115)	2.233 (.255)
	Balance	3.810 (.019)	2.440 (.196)	−1.530 (.524)
Base partners	Cognitive trust	1.310 (.623)	−2.870 (.105)	−3.170 (.065)
	Affective trust	−4.667 (.003)	−4.992 (.001)	−0.822 (.830)
	Balance	3.400 (.043)	1.170 (.687)	−2.240 (.251)

Note. Values represent W statistics with corresponding p-values in parentheses.

oriented pairs showed relatively higher cognitive trust, especially in top partners, whereas expressively oriented pairs showed relatively higher affective trust, particularly in base partners. In contrast, complex synergy pairs demonstrated consistently high trust indicators together with the highest values of the trust balance index, suggesting a more integrated organization of trust within the dyad.

Trust in acrobatic pairs should not be viewed merely as a stable interpersonal attitude. Rather, it functions as a regulatory mechanism involved in the organization of joint performance under conditions of strong interdependence. Differences between compatibility types indicate that trust participates in structuring how partners coordinate responsibility, stabilize interaction, and maintain role-dependent cooperation during the execution of complex elements. It is therefore not simply an individual characteristic but part of the regulatory architecture of dyadic action.

An important methodological contribution of the present study is the proposed trust balance index, which reflects the proportional relationship between cognitive and affective trust within the pair. Unlike approaches that examine these components separately, this index allows trust to be interpreted as a systemic characteristic of dyadic interaction. This approach opens the possibility of examining trust as a structural element within multi-level models of dyadic performance regulation. The index was not intended as a diagnostic classification criterion but as an analytical indicator of how trust is functionally organized within the pair. Higher relative cognitive trust may reflect a stronger orientation toward predictability and competence in the partner, whereas higher affective trust may indicate greater reliance on emotional security and interpersonal support. In asymmetric sports dyads such as acrobatic pairs, the balance between these components provides an additional perspective for understanding how coordination is stabilized during performance.

The general comparison between top and base partners did not reveal statistically significant role-related differences in trust indicators. This suggests that trust in acrobatic pairs is not simply tied to one role being "more trusting" than the other, but operates primarily as a dyadic characteristic shared by the interaction system as a whole. However, analyses within compatibility types revealed role-specific patterns. Role asymmetry in trust therefore does not emerge uniformly across all pairs, but depends on how coordination is organized within a particular compatibility configuration.

These role-specific differences are theoretically meaningful in sports acrobatics, where partners perform clearly asymmetric functional roles. During the execution of pair elements, the top partner is placed in a position of physical vulnerability and must partially relinquish control over body stability and safety, whereas the base partner assumes primary responsibility for maintaining the stability of the shared motor system. Trust is therefore directly linked to the sharing control. In functionally oriented pairs, the higher cognitive trust observed in top partners may reflect a greater readiness to rely on the base partner's competence during technically demanding elements. In expressively oriented pairs, by contrast, the higher affective trust in base partners may indicate that the stabilizing role of the base is supported not only through technical reliability but also through emotional involvement and interpersonal attunement.

Interaction in acrobatic pairs may thus be interpreted as a regulatory system arising from the dynamic balance between maintaining individual motor control and sharing part of this control with the partner. This state may be described as regulatory tension. During performance, the top partner must preserve body organization while simultaneously entrusting a substantial part of stability and safety to the base partner. The base partner, in turn, must maintain control over the support system while adapting to the top partner's movements and timing. Coordinated performance depends on the ability of both athletes to balance individual control with delegated responsibility.

Trust patterns should also be interpreted in relation to structural differences between compatibility types. According to the typology of acrobatic pair compatibility proposed by Maksymov and Maksymova (2025), interaction within pairs may be organized through different configurations combining technical coordination reliability and emotional–expressive coherence. Functionally oriented pairs are organized primarily around technical coordination reliability and rigid role distribution. In such pairs, shared control may emerge more readily because the interaction system is stabilized through functional predictability and acceptance of role distribution. Expressively oriented pairs rely more strongly on emotional–expressive interaction, which may shift the regulatory center toward the base partner and increase the importance of affective trust as a stabilizing resource. Complex synergy pairs combine high technical coordination with strong emotional–expressive integration, which may explain the more symmetrical and integrated trust organization observed in these dyads.

These findings can also be interpreted within the broader framework of joint action and interpersonal coordination. Research in this field shows that successful cooperation in highly interdependent tasks requires continuous prediction of a partner's actions, dynamic adjustment of one's own behavior, and the formation of shared action spaces in which movements are regulated relative to one another (Marsh et al., 2009; Sebanz & Knoblich, 2021; Vicaria & Dickens, 2016). Coordinated behavior emerges through dynamic coupling between interacting individuals rather than through isolated motor control (Schmidt & Richardson, 2008). In acrobatic pairs, such coupling must remain stable throughout routine execution despite role asymmetry and rapidly changing movement dynamics. Interpersonal coordination arises through continuous mutual adjustment of movement patterns (Richardson et al., 2007). Similarity in movement dynamics may further facilitate coordination and stabilize cooperative performance (Słowiński et al., 2016).

Within this framework, trust may function as a psychological condition that stabilizes joint action in asymmetric dyads. Studies of synchronous joint action indicate that cooperative performance involves continuous negotiation between self-related and shared control of action (Marschner et al., 2024). Research on communicative adaptation in joint action further shows that partners actively modify their behavior to make their goals more predictable to one another (Dockendorff et al., 2025). Efficient cooperation also depends on how interacting individuals distribute effort and responsibility within the joint system (Török et al., 2019). In social psychology, trust is conceptualized as a mechanism that allows individuals to accept vulnerability under conditions of uncertainty and interdependence

(Simpson, 2007). In cooperative contexts, it reduces the perceived risk associated with relying on another person and thereby facilitates coordinated action. In this sense, trust may contribute to stabilizing interpersonal coupling during joint routine execution. Recent integrative perspectives further emphasize its role in regulating interpersonal behavior within complex social systems (Rotenberg et al., 2025).

Recent research also highlights the importance of synchrony and engagement in cooperative performance contexts. Studies of DanceSport couples demonstrate that the quality of partnership interaction influences competitive performance through increased athlete engagement (Liu et al., 2023). More broadly, contemporary theoretical models suggest that synchrony and segregation between interacting individuals depend on contextual constraints and task demands (Mayo & Gordon, 2025). Neuroscientific evidence further indicates that successful interpersonal interaction is associated with increased neural synchronization between partners (Zhao et al., 2024). Although such neural processes were not directly examined in the present study, these findings support the idea that coordination in pair sports involves multi-level mechanisms integrating motor, psychological, and interpersonal processes.

In sports acrobatics, these findings suggest that trust functions as a regulatory mechanism of dyadic coordination, whereby the balance between cognitive and affective trust stabilizes joint action and reflects distinct patterns of interaction across compatibility types.

Conclusions

The results indicate that trust in acrobatic pairs is organized not only as an individual characteristic but also as a property of dyadic interaction. Different compatibility types demonstrate distinct configurations of cognitive and affective trust, reflecting different patterns of interaction regulation within the pair. Functionally oriented pairs are characterized by relatively higher cognitive trust, whereas expressively oriented pairs demonstrate relatively higher affective trust. Complex synergy pairs show the most integrated configuration of trust indicators. These findings suggest that the balance between cognitive and affective trust may represent one of the mechanisms supporting the stability of coordinated routine execution in acrobatic pairs under conditions of role asymmetry and physical interdependence.

Future Research

Future studies may further examine the dynamic role of trust in regulating interaction processes within acrobatic pairs using longitudinal and experimental designs. In particular, investigating the relationship between trust organization, interpersonal interaction styles, and psychophysiological regulation may provide deeper insight into the multi-level mechanisms underlying compatibility in dyadic sports. The analysis of interpersonal positioning based on Leary's interpersonal circumplex may further clarify how role distribution and interaction patterns are organized within acrobatic pairs.

Ethical Approval

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki. The research protocol involved non-invasive psychometric assessment and observation during regular training sessions and did not include any experimental intervention. According to institutional regulations, formal ethical committee approval was not required for this type of study.

Informed Consent

Written informed consent was obtained from the parents or legal guardians of all participants prior to data collection. The athletes were informed about the purpose and procedures of the study and voluntarily agreed to participate.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

AI Use Statement

The authors used artificial intelligence tools for language editing and text refinement. The authors take full responsibility for the content of the manuscript.

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Conflict of Interest

The authors declare no conflict of interest.

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Довіра як механізм рольової регуляції взаємодії в акробатичних парах

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 4 табл., 4 рис., 39 джерел.

Мета дослідження. Метою дослідження було вивчити організацію когнітивної та афективної довіри в акробатичних парах залежно від типу сумісності та партнерської ролі. Передбачалося, що організація довіри відрізняється залежно від конфігурації сумісності та партнерських ролей, а баланс між когнітивною та афективною довірою відображає різні механізми регуляції взаємодії, пов'язані з розподілом відповідальності та регуляторною напруженістю в діадичній системі.

Матеріали і методи. У дослідженні взяли участь 25 акробатичних пар (N = 50 спортсменів) віком 11–16 років, які займалися спортивною акробатикою на етапі попередньої базової підготовки. Типи сумісності визначалися відповідно до типології сумісності акробатичних пар, раніше розробленої авторами. Типологія інтегрує показники надійності технічного виконання, постуральної та фазової координації, а також емоційно-експресивної узгодженості. Міжособистісну довіру оцінювали за допомогою адаптованої версії шкали афективної та когнітивної довіри Daniel J. McAllister. Для статистичного аналізу застосовували непараметричні методи, зокрема критерій Краскела–Уолліса, U-критерій Манна–Уїтні та post-hoc порівняння Dwass–Steel–Critchlow–Fligner.

Результати. Результати дослідження виявили загалом високий рівень міжособистісної довіри між партнерами. Відмінності між партнерськими ролями були обмеженими та не досягли статистичної значущості. Водночас структура організації довіри відрізнялася залежно від типу сумісності. Функціонально орієнтовані пари демонстрували відносно вищий рівень когнітивної довіри, тоді як експресивно орієнтовані пари характеризувалися відносно вищим рівнем афективної довіри. Пари зі складною синергією показали стабільно високі значення обох компонентів довіри та найвищі показники індексу балансу довіри, що свідчить про більш інтегрований механізм регуляції взаємодії.

Висновки. Довіра в акробатичних парах функціонує не лише як індивідуальна психологічна характеристика, але й як механізм регуляції взаємодії у функціонально асиметричному партнерстві. Відмінності у балансі між когнітивною та афективною довірою відображають різні механізми координації, пов'язані з розподілом відповідальності, емоційною синхронізацією та стабільністю взаємодії в акробатичних парах.

Ключові слова: міжособистісна довіра, партнерська сумісність, діадична взаємодія, міжособистісна координація, функціональна асиметрія ролей, спортивна акробатика.

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Original Scientific Articles. Training Effects and Experimental Design

Phase-Dependent Interaction Between Oxidative Stress and Muscle Damage During Acute Recovery Following Eccentric Exercise

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Abstract

Background. Eccentric exercise induces oxidative stress, muscle damage, and decreased neuromuscular performance. However, the temporal relationship between these responses is not fully understood, particularly in recreationally active individuals.

Objectives. This study aimed to investigate the time-course changes and phase-dependent relationships between oxidative stress, muscle damage, and neuromuscular performance following an athletics-based eccentric exercise protocol.

Materials and Methods. A single-group repeated-measures design was employed involving 46 recreationally active male students (age: 19.15 ± 0.76 years). Participants performed an eccentric exercise protocol consisting of jump-landing, bounding, sprint deceleration, and slow-tempo squats. Malondialdehyde (MDA), Creatine Kinase (CK), and Countermovement Jump (CMJ) performance were measured at baseline and at 24, 48, and 72 hours post-exercise. Data were analyzed using repeated-measures ANOVA with Bonferroni post hoc tests and Pearson correlation analysis.

Results. Significant time effects were observed for all variables ($p < 0.001$). MDA and CK levels increased at 24 h, subsequently declining at 48 h and 72 h, yet remaining elevated compared to baseline. CMJ performance decreased at 24 h and showed partial recovery, but did not return to baseline at 72 h. No significant correlation was found between MDA and CK at 24 h; however, moderate positive correlations were observed at 48 h ($r = 0.557$, $p < 0.001$) and 72 h ($r = 0.496$, $p < 0.001$). No significant relationships were found between biochemical markers and CMJ.

Conclusions. Eccentric exercise induces oxidative stress and muscle damage alongside decreased neuromuscular performance. Biochemical markers peak at 24 h and decline thereafter, while neuromuscular recovery remains incomplete at 72 h. The relationship between oxidative stress and muscle damage is time-dependent, emerging during the recovery phase rather than the acute phase. These findings indicate distinct temporal patterns, suggesting that neuromuscular performance is not fully explained by biochemical markers.

Keywords: eccentric exercise, oxidative stress, creatine kinase, malondialdehyde, neuromuscular performance, recovery.

Introduction

Exercise-induced muscle damage (EIMD) is commonly observed following eccentric exercise and is typically characterized by muscle soreness, reduced strength, and decreased neuromuscular performance (Leite et al., 2023; Li et al., 2024). Eccentric training is widely implemented in sport and physical education settings to enhance muscle strength, functional performance, and rehabilitation outcomes (Burgos-Jara et al., 2023; Cvečka et al., 2023; Maia et al., 2026). Eccentric muscle actions involve active muscle lengthening under tension, commonly occurring during deceleration phases of movement such as jumping and sprinting, and are integral to most sport-specific and

resistance training activities (Tecchio et al., 2024; Tomalka, 2023). Notably, eccentric contractions can generate greater force than concentric actions (approximately 20–50% higher) (Schoenfeld et al., 2017; Tecchio et al., 2024), making them effective stimuli for physiological responses associated with training.

However, this superior force-generating capacity is also associated with increased mechanical stress on muscle tissue, leading to exercise-induced muscle damage, characterized by structural disruption of muscle fibers, elevated oxidative stress, and temporary reductions in performance (Bontemps et al., 2020; Lepley et al., 2023; J. Peake et al., 2005). A conceptual contradiction can be identified within eccentric exercise: the same physiological processes that are associated with muscle damage and oxidative stress are also discussed in relation to recovery-related processes. This creates a challenge in determining whether attenuating these responses improves or limits functional outcomes.

In practice, attempts to maximize the benefits of eccentric training often involve increasing mechanical load, which may further exacerbate muscle damage and prolong recovery time (Chen et al., 2023; Rosvoglou et al., 2023; Zhang et al., 2026). Therefore, achieving an appropriate balance between induced muscle damage and recovery remains an important consideration in training design. A clearer understanding of acute physiological and functional responses to eccentric loading may help inform this balance.

This issue is particularly relevant in physical education contexts, where recreationally active students are frequently exposed to eccentric loading during practical sessions (Križaj et al., 2022; Maroto-Izquierdo et al., 2023), often without individualized recovery strategies (Lewis et al., 2012; Rosvoglou et al., 2023). One of the primary physiological responses to eccentric exercise is increased production of reactive oxygen species (ROS), contributing to oxidative stress, commonly assessed using biomarkers such as malondialdehyde (MDA) (Canals-Garzón et al., 2022; Wadley et al., 2019). Concurrently, muscle fiber disruption results in the release of intracellular enzymes into circulation, with creatine kinase (CK) widely recognized as a marker of muscle damage (Stožer et al., 2020). These physiological changes are often accompanied by reductions in neuromuscular performance, as assessed by countermovement jump (CMJ), a practical indicator reflecting muscle function and movement efficiency (Bishop et al., 2023; Yoshida et al., 2024). Collectively, these variables provide complementary indicators for evaluating responses to eccentric loading.

Previous literature suggests that oxidative stress and muscle damage are not solely negative responses. Moderate changes have been associated with physiological processes related to muscle repair (Di Meo et al., 2019; Wadley et al., 2019). However, excessive responses may delay recovery and impair subsequent performance (Şenışık et al., 2021). Thus, understanding the balance between these responses remains an important issue.

Despite this, these variables are often examined separately rather than in relation to each other. As a result, the temporal relationship between oxidative stress, muscle damage, and functional performance remains unclear, particularly following a single bout of eccentric exercise.

Therefore, this study aimed to investigate the temporal relationship between oxidative stress and muscle damage, in relation to changes in neuromuscular performance following eccentric exercise, using MDA, CK, and CMJ as respective indicators. It was hypothesized that increases in oxidative stress and muscle damage would be associated with reductions in performance, while their relationships may vary across the recovery period.

Materials and Methods

Study Design

This study employed a single-group experimental repeated-measures design to examine the temporal relationship between oxidative stress, muscle damage, and neuromuscular performance following an athletics-based eccentric exercise protocol. Measurements were conducted at baseline (pre-exercise), and at 24, 48, and 72 hours post-exercise to capture the temporal dynamics of physiological and neuromuscular performance.

The design was structured to examine changes in oxidative stress, muscle damage, and neuromuscular performance across time. This approach allows for the description of temporal patterns in physiological and performance responses following eccentric exercise.

By integrating biochemical (malondialdehyde and creatine kinase) and neuromuscular performance (countermovement jump) indicators across multiple time points, the study aimed to describe the temporal relationship between biochemical responses and neuromuscular performance following eccentric exercise in recreationally active individuals.

Participants

Participants were recruited from male undergraduate students (n = 128) enrolled in an athletics course at the Department of Sports Science, Universitas Negeri Surabaya. This group represented the accessible population, consisting of recreationally active individuals regularly exposed to athletics-related activities as part of their academic curriculum.

A total of 46 participants were selected using purposive sampling based on predefined inclusion and exclusion criteria. An a priori power analysis conducted using G*Power (version 3.1) indicated that a minimum sample size of 30–35 participants was required to detect a moderate effect size ($f = 0.25$) with a significance level of $\alpha = 0.05$ and statistical power $(1 - \beta) = 0.80$. Therefore, the final sample size was considered sufficient to detect statistically significant changes across time points within the repeated-measures design.

The inclusion criteria were as follows: (1) male students aged 18–22 years; (2) engagement in regular physical activity at least three times per week for the previous two months; (3) enrollment in an athletics course; and (4) no history of musculoskeletal injury within the past six months.

Exclusion criteria included: (1) failure to complete the exercise protocol; (2) absence from any follow-up measurement session; (3) use of medications or supplements that could influence oxidative stress or muscle damage

responses; and (4) any medical condition that could interfere with study procedures or compromise participant safety.

All participants provided written informed consent prior to participation. Recruitment was conducted during scheduled course sessions. All participants completed the study, and no dropouts were recorded.

Ethical approval was obtained from the Health Research Ethics Committee of Airlangga University (No. 104/EA/KEPK/2023) in accordance with the Declaration of Helsinki.

Anthropometric Measurements

Anthropometric measurements were obtained prior to the experimental protocol. Body height was measured using a stadiometer to the nearest 0.1 cm, and body mass was recorded using a digital scale to the nearest 0.1 kg. Body mass index (BMI) was subsequently calculated as body mass divided by the square of height (kg/m^2).

Eccentric Exercise Protocol

Participants performed an athletics-based eccentric exercise protocol consisting of jump-landing drills, bounding, sprint deceleration tasks, and slow-tempo squats. Prior to the protocol, participants completed a standardized warm-up consisting of 5 minutes of light jogging followed by dynamic stretching exercises targeting the lower limbs. All exercises were performed at a self-selected maximal effort while maintaining proper technique.

The protocol was specifically designed to be applicable to recreationally active university students enrolled in an athletics course, emphasizing movements commonly practiced in physical education settings. The exercises were structured to induce substantial eccentric loading on the lower limb musculature, particularly during phases of landing, ground contact, and rapid deceleration.

The exercises were performed in the following sequence: jump-landing, bounding, sprint deceleration, and eccentric squats. The jump-landing component consisted of 5 sets of 10 repetitions, where participants were instructed to achieve maximal jump height and perform controlled landings by flexing the hips, knees, and ankles over approximately 2–3 seconds to absorb impact forces safely.

Bounding was performed over a distance of 20 meters for 4 sets, emphasizing horizontal propulsion followed by controlled single-leg landings to increase eccentric demand during each ground contact.

Sprint deceleration tasks consisted of 6 repetitions of 20-meter sprints followed by an abrupt stop within a 3-meter deceleration zone, requiring rapid reduction of forward momentum and generating high eccentric loading in the quadriceps and hamstring muscle groups.

To further enhance eccentric stimulus, participants performed slow-tempo bodyweight squats for 4 sets of 12 repetitions, with a controlled eccentric phase lasting approximately 4 seconds per repetition.

A fixed rest interval of 90 seconds was provided between sets to maintain high mechanical stress while minimizing full recovery. The total duration of the protocol was approximately 45–50 minutes. The protocol was specifically designed to induce exercise-induced muscle damage and oxidative stress responses for subsequent analysis. A summary of the exercise protocol is presented in Table 1.

The progression of participants throughout the study, covering recruitment, group allocation, follow-up, and data analysis, is illustrated in Figure 1.

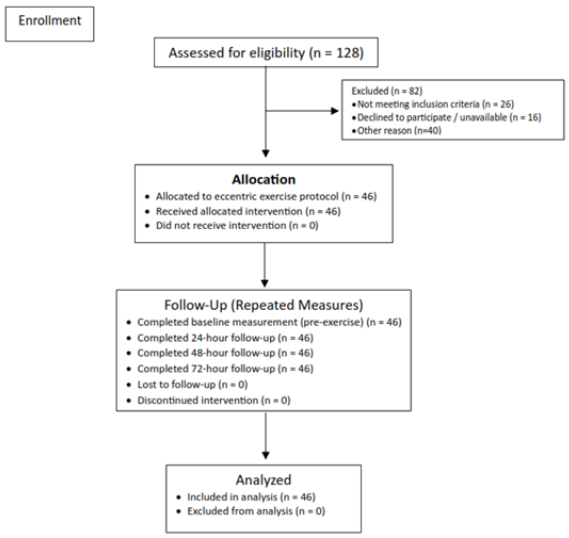

Fig. 1. CONSORT Flow Diagram

Table 1. Summary of the Eccentric Exercise Protocol

Component	Exercise Structure	Intensity / Execution	Volume	Rest Interval	Key Characteristics
Warm-up	Light jogging + dynamic stretching (lower limbs)	Low to moderate intensity	5 minutes	—	Prepare muscles and reduce injury risk
Jump-Landing	Repeated vertical jumps with controlled landing	Maximal effort; 2–3 s eccentric landing phase	5 sets × 10 reps	90 s	Emphasizes impact absorption and eccentric control
Bounding	Horizontal bounding over 20 m	Maximal horizontal propulsion with controlled single-leg landing	4 sets	90 s	Increases eccentric load during ground contact
Sprint Deceleration	20 m sprint + sudden stop within 3 m	Maximal sprint followed by rapid braking	6 reps	90 s	High eccentric demand on quadriceps and hamstrings
Eccentric Squat	Bodyweight squat	Controlled 4 s eccentric phase	4 sets × 12 reps	90 s	Prolonged time under tension for eccentric loading

Outcome Measures

The primary outcome measures included oxidative stress, muscle damage, and neuromuscular performance, assessed using Malondialdehyde (MDA), Creatine Kinase (CK), Countermovement Jump (CMJ), respectively. All measurements were conducted at baseline (pre-exercise), and at 24, 48, and 72 hours following the eccentric exercise protocol to describe changes in biochemical and neuromuscular performance variables over time.

Oxidative stress was assessed by measuring plasma Malondialdehyde (MDA) levels as an indicator of lipid peroxidation. Venous blood samples were collected under standardized conditions at each time point. Blood samples were centrifuged to obtain plasma, which was subsequently analyzed using a commercially available enzyme-linked immunosorbent assay (ELISA) kit according to the manufacturer's instructions. MDA concentrations were expressed in nmol/mL.

Muscle damage was evaluated by measuring serum Creatine Kinase (CK) activity. Blood samples were analyzed using an automated enzymatic colorimetric method, and CK activity was expressed in U/L.

Neuromuscular performance was evaluated using the Countermovement Jump (CMJ) test. Participants performed the test with their hands placed on the hips to minimize arm swing, starting from an upright standing position followed by a rapid downward movement and an immediate maximal vertical jump. Jump height was recorded using a Jump MD device. Each participant performed three trials at each time point, and the highest value was used for analysis. A standardized rest interval of 60 seconds was provided between trials to minimize fatigue.

Statistical analysis

All data were analyzed using appropriate statistical software. Descriptive statistics are presented as mean ± standard deviation (SD). The normality of data distribution was assessed using the Shapiro–Wilk test.

To examine changes in oxidative stress (MDA), muscle damage (CK), and neuromuscular performance (CMJ) across time (baseline, 24, 48, and 72 hours post-exercise), a one-way repeated-measures analysis of variance (ANOVA) was performed. When a significant main effect of time was detected, pairwise comparisons were conducted using Bonferroni post hoc tests.

In addition, Pearson correlation analysis was performed to evaluate the relationships between MDA, CK, and CMJ at each time point, to assess the relationships between physiological responses and neuromuscular performance.

Effect sizes for ANOVA were calculated using partial eta squared (η^2p) and interpreted as small (0.01), medium (0.06), and large (0.14). Statistical significance was set at $p < 0.05$.

Results

Participant Characteristics

A total of 46 participants met all eligibility criteria and completed all measurement sessions (baseline, 24 h, 48 h, and 72 h post-exercise), with no loss to follow-up. Therefore, all analyses were conducted using a complete-case approach.

Participant characteristics are presented in Table 2. The participants were recreationally active male university students with a mean age of 19.15 ± 0.76 years, height of 167.97 ± 5.20 cm, and body mass of 59.10 ± 6.00 kg. The mean body mass index (BMI) was 20.91 ± 1.40 kg/m², indicating a normal weight range.

Table 2. Participant Characteristics

Variable	Mean (± SD)
Age (years)	19.15 ± 0.76
Height (cm)	167.97 ± 5.20
Weight (kg)	59.10 ± 6.00
BMI (kg/m²)	20.91 ± 1.40

Descriptive and Time-Course Changes

Descriptive statistics for MDA, CK, and CMJ across all time points are presented in Table 3.

MDA levels increased from baseline to 24 h post-exercise, followed by a gradual decline at 48 h and 72 h, although values remained elevated relative to baseline. A similar pattern was observed for CK, which peaked at 24 h and progressively decreased thereafter, but did not fully return to baseline levels.

In contrast, CMJ performance showed a different pattern, with a reduction at 24 h, followed by a gradual recovery at 48 h and 72 h. However, CMJ values remained slightly lower than baseline even at 72 h.

These temporal patterns are illustrated in Figure 2.

These results show different temporal patterns between biochemical markers and neuromuscular performance, with peak MDA and CK values observed at 24 h alongside the lowest CMJ performance.

Repeated-Measures ANOVA

A repeated measures ANOVA revealed a significant main effect of time for all variables.

MDA levels were significantly affected by time ($F(1.203, 54.137) = 1166.676$, $p < 0.001$, $\eta^2p = 0.963$), with a large effect size.

Table 3. Changes in MDA, CK, and CMJ from baseline to 72 h post-exercise

Variable	Baseline	24 h	48 h	72 h
MDA (nmol/mL)	3.36 ± 0.26[a]	5.29 ± 0.15[b]	4.87 ± 0.29[c]	4.36 ± 0.20[d]
CK (U/L)	110.37 ± 18.03[a]	259.36 ± 19.36[b]	181.54 ± 34.73[c]	158.55 ± 25.63[d]
CMJ (cm)	40.48 ± 2.96[a]	35.34 ± 2.59[b]	36.85 ± 2.47[c]	39.32 ± 2.68[d]

Notes: Values are presented as mean ± SD. Different superscripts (a–d) indicate significant differences between time points ($p < 0.05$, Bonferroni-adjusted).

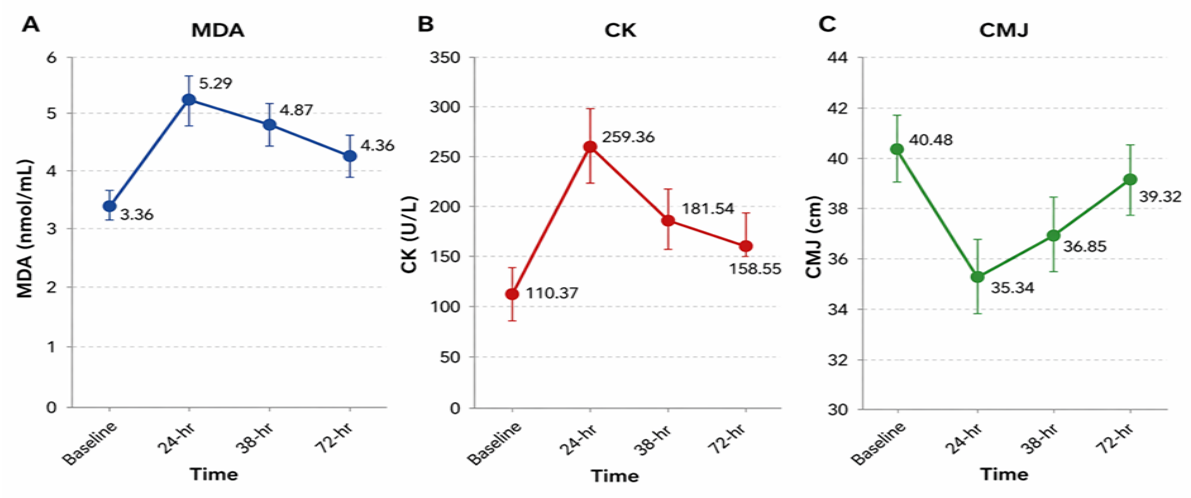

Fig. 2. Time-course changes in oxidative stress (MDA), muscle damage (CK), and neuromuscular performance (CMJ) following exercise. Notes: A: Malondialdehyde (MDA); B: Creatine Kinase (CK); C: Countermovement Jump (CMJ). Values are presented as mean ± SD. Values are presented as mean ± standard deviation

Table 4. Pairwise comparisons of MDA, CK, and CMJ across time points (Bonferroni-adjusted)

Variable	Comparison	Mean Difference (I–J)	95% CI	p-value
MDA (nmol/mL)	Baseline vs 24 h	-1.928	-2.025 to -1.831	p < 0.001
	Baseline vs 48 h	-1.505	-1.652 to -1.359	p < 0.001
	Baseline vs 72 h	-0.995	-1.118 to -0.871	p < 0.001
	24 h vs 48 h	0.423	0.353 to 0.492	p < 0.001
	24 h vs 72 h	0.933	0.892 to 0.974	p < 0.001
	48 h vs 72 h	0.510	0.472 to 0.549	p < 0.001
CK (U/L)	Baseline vs 24 h	-148.994	-157.912 to -140.076	p < 0.001
	Baseline vs 48 h	-71.173	-86.761 to -55.584	p < 0.001
	Baseline vs 72 h	-48.184	-60.271 to -36.097	p < 0.001
	24 h vs 48 h	77.821	63.967 to 91.675	p < 0.001
	24 h vs 72 h	100.810	90.106 to 111.513	p < 0.001
	48 h vs 72 h	22.989	19.167 to 26.811	p < 0.001
CMJ (cm)	Baseline vs 24 h	5.137	3.648 to 6.627	p < 0.001
	Baseline vs 48 h	3.627	2.600 to 4.653	p < 0.001
	Baseline vs 72 h	1.155	0.294 to 2.016	p = 0.003
	24 h vs 48 h	-1.511	-2.746 to -0.276	p = 0.009
	24 h vs 72 h	-3.982	-5.029 to -2.936	p < 0.001
	48 h vs 72 h	-2.472	-3.357 to -1.586	p < 0.001

Notes: Values represent mean differences (I–J). Confidence intervals (CI) are presented at 95%. P-values were adjusted using the Bonferroni correction for multiple comparisons. Statistical significance was set at $p < 0.05$.

Similarly, CK levels showed a significant effect of time ($F_{(1.465, 65.904)} = 446.903$, $p < 0.001$, $\eta^2_p = 0.909$), with a large effect size.

CMJ performance also demonstrated a significant effect of time ($F_{(2.165, 97.431)} = 66.879$, $p < 0.001$, $\eta^2_p = 0.598$), with a moderate to large effect size.

Post Hoc Analysis

Bonferroni-adjusted pairwise comparisons are presented in Table 4.

MDA levels were significantly higher at 24 h, 48 h, and 72 h compared to baseline ($p < 0.001$ for all comparisons). Significant differences were also observed between all post-exercise time points (24 h vs 48 h, 24 h vs 72 h, and 48 h vs 72 h; $p < 0.001$).

CK levels were significantly higher at 24 h, 48 h, and 72 h compared to baseline ($p < 0.001$ for all comparisons). Significant differences were also observed between all post-exercise time points ($p < 0.001$).

CMJ performance was significantly lower at 24 h, 48 h, and 72 h compared to baseline ($p < 0.01$ for all comparisons).

Significant differences were also found between 24 h and 48 h ($p = 0.009$), 24 h and 72 h ($p < 0.001$), and 48 h and 72 h ($p < 0.001$).

Correlation Analysis

Pearson correlation coefficients are presented in Table 5.

No significant correlations were observed between variables at 24 h post-exercise, suggesting that the association between oxidative stress and muscle damage has not yet fully developed during the acute phase.

However, significant positive correlations between MDA and CK emerged at 48 h ($r = 0.557$, $p < 0.001$) and 72 h ($r = 0.496$, $p < 0.001$), indicating a stronger association between oxidative stress and muscle damage during the recovery phase.

No significant relationships were observed between CMJ and either MDA or CK at any time point.

Table 5. Pearson correlation coefficients between MDA, CK, and CMJ at 24 h, 48 h, and 72 h post-exercise

Time	Variable	MDA	CK	CMJ
24 h post-exercise	MDA	1	0.199	-0.131
	CK	0.199	1	0.111
	CMJ	-0.131	0.111	1
48 h post-exercise	MDA	1	0.557**	0.131
	CK	0.557**	1	-0.036
	CMJ	0.131	-0.036	1
72 h post-exercise	MDA	1	0.496**	-0.061
	CK	0.496**	1	0.024
	CMJ	-0.061	0.024	1

Notes: Values represent Pearson correlation coefficients (r). Statistical significance was set at $p < 0.05$ (2-tailed). **$p < 0.01$ (2-tailed). MDA = Malondialdehyde; CK = Creatine Kinase; CMJ = Countermovement Jump.

Scatter Plot Analysis

The relationships between MDA and CK at 48 h and 72 h are illustrated in Figure 3.

At 48 h, a moderate positive linear relationship was observed ($R^2 = 0.31$), indicating a moderate shared variance between MDA and CK. A similar, though slightly weaker, relationship was observed at 72 h.

These findings visually reinforce the correlation analysis, highlighting that the association between oxidative stress and muscle damage becomes more pronounced during the recovery phase rather than the acute phase, suggesting a delayed temporal association between oxidative stress and muscle damage.

Discussion

Principal Findings

The present study shows that eccentric exercise is associated with increases in oxidative stress (MDA) and muscle damage (CK), along with a reduction in neuromuscular performance (CMJ). MDA and CK peaked at 24 h post-exercise and remained elevated up to 72 h, whereas CMJ showed a gradual recovery pattern but had not fully returned to baseline at 72 h.

Correlation analysis showed no significant association between MDA and CK at 24 h. Moderate positive correlations were observed at 48 h and 72 h. No significant relationships were found between biochemical markers (MDA and CK) and CMJ performance at any time point.

These results indicate that biochemical and neuromuscular responses may follow different temporal patterns during recovery. These findings reflect acute recovery responses following a single bout of eccentric exercise.

Time-Course of Oxidative Stress and Muscle Damage

The increase in MDA at 24 h reflects elevated lipid peroxidation, which is commonly used as an indirect marker of oxidative stress following eccentric exercise.

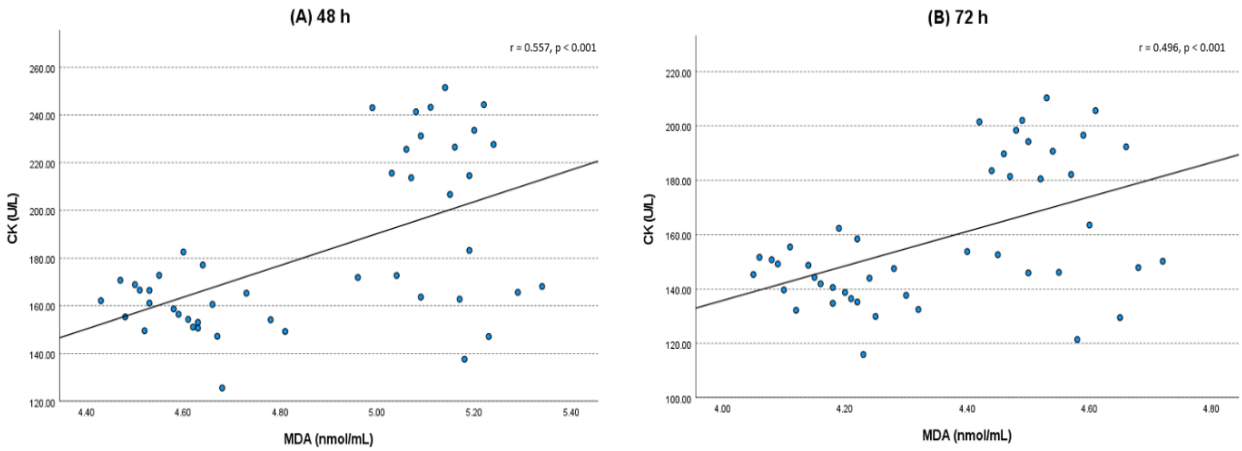

Fig. 3. Relationship between malondialdehyde (MDA) and creatine kinase (CK) at 48 h (A) and 72 h (B) post-exercise. Significant positive correlations were observed at both time points (48 h: $r = 0.557$, $p < 0.001$; 72 h: $r = 0.496$, $p < 0.001$)

Previous studies have suggested that eccentric loading may increase reactive oxygen species (ROS) production, which is associated with oxidative stress responses (Blazevich et al., 2025; Xu & Guo, 2025).

Eccentric exercise has been reported to induce mechanical strain at the muscle fiber level, which may contribute to structural disturbances such as Z-disk disruption and altered calcium regulation (Dowling et al., 2022; Tomalka, 2023). These processes are often discussed in the literature as part of muscle damage-related responses following unaccustomed eccentric loading.

Similarly, CK increased significantly at 24 h, which is widely considered an indicator of muscle membrane disruption and leakage of intracellular enzymes into circulation (Blank et al., 2022; Ying et al., 2024).

Although both MDA and CK peaked at 24 h, the absence of a significant correlation at this time point suggests that these markers may reflect partially independent physiological responses during the early recovery phase. This interpretation aligns with previous literature suggesting that early post-exercise responses are influenced by multiple overlapping mechanisms (J. M. Peake et al., 2017; Proske & Morgan, 2001)intense exercise causes an "open window" of immunodepression during recovery after exercise is well accepted. Repeated exercise bouts or intensified training without sufficient recovery may increase the risk of illness. However, except for salivary IgA, clear and consistent markers of this immunodepression remain elusive. Exercise increases circulating neutrophil and monocyte counts and reduces circulating lymphocyte count during recovery. This lymphopenia results from preferential egress of lymphocyte subtypes with potent effector functions [e.g., natural killer (NK.

At later time points (48–72 h), a moderate association between MDA and CK was observed, suggesting a closer temporal alignment between oxidative stress and muscle damage during recovery. Nevertheless, this relationship remains correlational and does not imply causality or a direct mechanistic link. Accordingly, this interpretation should be approached with caution, particularly given the inherent limitations of biochemical markers in reflecting underlying physiological processes.

Neuromuscular Performance and Recovery Pattern

CMJ performance decreased at 24 h following eccentric exercise, indicating a temporary reduction in neuromuscular performance. This finding is consistent with previous reports showing reduced jump performance in the early recovery phase after eccentric loading (Hemmatinafar et al., 2023).

The decline in performance may be associated with multiple factors described in the literature, including altered excitation–contraction coupling, changes in calcium handling, and transient reductions in neural drive (Tabuchi et al., 2022). In addition, delayed onset muscle soreness (DOMS) and protective neural inhibition may also contribute to reduced performance capacity (Boyd et al., 2023; Sozlu et al., 2025).

Although CMJ showed gradual improvement at 48 h and 72 h, it had not fully returned to baseline within the observation period, suggesting that neuromuscular recovery may not be fully complete within 72 h under the present conditions.

Importantly, no significant correlations were found between CMJ and either MDA or CK. This suggests that neuromuscular performance recovery is likely influenced by multiple factors beyond biochemical markers alone.

Phase-Dependent Relationship Between Oxidative Stress and Muscle Damage

The present findings indicate that the relationship between MDA and CK may vary across time. No significant association was observed at 24 h, whereas moderate positive correlations appeared at 48 h and 72 h.

During the early phase (24 h), CK elevation likely reflects structural muscle perturbation, while oxidative stress markers may represent a parallel response that is not directly linked at this stage. This interpretation aligns with previous studies indicating that early responses to eccentric exercise involve multiple independent physiological processes (Qian et al., 2023).

In the later phase (48–72 h), previous studies have reported increased involvement of inflammatory and immune-related processes, including ROS production and tissue remodeling activity (J. M. Peake et al., 2017; Tidball & Villalta, 2010)intense exercise causes an "open window" of immunodepression during recovery after exercise is well accepted. Repeated exercise bouts or intensified training without sufficient recovery may increase the risk of illness. However, except for salivary IgA, clear and consistent markers of this immunodepression remain elusive. Exercise increases circulating neutrophil and monocyte counts and reduces circulating lymphocyte count during recovery. This lymphopenia results from preferential egress of lymphocyte subtypes with potent effector functions [e.g., natural killer (NK. These processes may contribute to the observed association between oxidative stress and muscle damage markers during recovery.

Overall, the time-dependent pattern observed in this study suggests a changing relationship between these variables across the recovery period. However, due to the observational nature of the data, causal interpretation should be made cautiously. This pattern may reflect differences between early and later phases of recovery, with changes in the relationship between variables over time.

Lack of Association Between Biochemical Markers and Performance

The absence of significant correlations between CMJ and biochemical markers suggests that neuromuscular performance is not directly explained by MDA or CK levels in this study.

This finding aligns with previous studies suggesting that recovery of jump performance is influenced by a combination of peripheral and central factors, including neuromuscular control, pain perception, and psychological responses. Therefore, biochemical markers alone may not fully represent neuromuscular recovery.

Practical Implications

The results indicate that eccentric exercise induces time-dependent changes in biochemical and neuromuscular

variables, with the highest levels of oxidative stress and muscle damage observed at 24 h, and gradual recovery observed thereafter.

These findings may be useful for informing general recovery considerations in recreationally active individuals exposed to eccentric loading, particularly in understanding the temporal pattern of recovery responses.

However, practical applications should be interpreted cautiously, as this study did not directly test training interventions or recovery strategies.

Final Synthesis

In summary, eccentric exercise induces distinct temporal responses in oxidative stress, muscle damage, and neuromuscular performance. The relationship between biochemical markers appears to vary across time, while neuromuscular recovery seems to involve additional factors beyond biochemical changes alone.

These findings contribute to a descriptive understanding of the time-course response following eccentric exercise. However, further studies with controlled designs and additional physiological measurements are required to clarify the underlying mechanisms.

Conclusion

Eccentric exercise is associated with increased oxidative stress and muscle damage, accompanied by a reduction in neuromuscular performance. Biochemical markers peaked at 24 h post-exercise and gradually declined, whereas neuromuscular recovery remained incomplete at 72 h.

The relationship between oxidative stress and muscle damage appeared to be time-dependent, with associations emerging during the recovery phase rather than the acute phase.

These findings indicate that biochemical and neuromuscular responses may follow different temporal patterns following eccentric exercise. Neuromuscular recovery does not appear to be fully explained by biochemical markers alone, suggesting the involvement of additional physiological and neuromuscular factors.

Overall, the present results provide a descriptive account of acute recovery dynamics following eccentric loading. Further research using controlled designs and additional physiological measures is required to better understand the underlying processes.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the sample consisted exclusively of young male participants, which limits the generalizability of the results to other populations, including females, older individuals, or different training backgrounds.

Second, only indirect biochemical markers of oxidative stress and muscle damage were assessed. The absence of direct measurements of inflammatory and cellular processes (e.g., cytokines or immune responses) restricts the ability to comprehensively characterize the underlying physiological responses.

Third, neuromuscular performance was evaluated using a single test (CMJ), which may not fully capture the multidimensional nature of neuromuscular recovery.

Fourth, the single-group design without a control or comparator group limits the ability to attribute the observed changes exclusively to the eccentric exercise protocol and does not account for potential influences such as repeated testing effects or natural variability over time.

Finally, dietary intake and physical activity outside the experimental protocol were not strictly controlled, which may have influenced individual recovery responses.

Taken together, these limitations indicate that the present findings should be interpreted as descriptive of acute responses under the specific study conditions, rather than as evidence of causal mechanisms or generalizable recovery patterns. Additionally, the observational nature of the study and the use of correlational analyses preclude any causal inference regarding the relationship between oxidative stress, muscle damage, and neuromuscular responses.

Ethics Approval

This study was approved by the Health Research Ethics Committee of Airlangga University (No. 104/EA/KEPK/2023) and conducted in accordance with the Declaration of Helsinki.

Informed Consent

Written informed consent was obtained from all participants prior to participation in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors did not use AI-assisted tools in the preparation of this manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Фазово-залежна взаємодія між оксидативним стресом і пошкодженням м'язів під час гострого відновлення після ексцентричних вправ

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Реферат. Стаття: 11 с., 5 табл., 3 рис., 37 джерел.

Обґрунтування. Ексцентричні вправи спричиняють оксидативний стрес, пошкодження м'язів та зниження нервово-м'язової працездатності. Проте часовий взаємозв'язок між цими реакціями залишається недостатньо зрозумілим, зокрема у фізично активних осіб, які займаються рекреаційним спортом.

Мета дослідження. Це дослідження мало на меті вивчити часову динаміку змін та фазово-залежні взаємозв'язки між оксидативним стресом, пошкодженням м'язів і нервово-м'язовою працездатністю після виконання протоколу ексцентричних вправ на основі легкоатлетичних елементів.

Матеріали і методи. Застосовано одногруповий дизайн дослідження з повторними вимірюваннями, до якого залучили 46 фізично активних студентів чоловічої статі, які займаються рекреаційним спортом (вік: 19,15 ± 0,76 року). Учасники виконували протокол ексцентричних вправ, що включав стрибки з приземленням, багатоскоки, уповільнення під час спринту та присідання в повільному темпі. Рівні малонового діальдегіду (МДА), креатинкінази (КК) та показники стрибка з контррухом (СКР) вимірювали на вихідному рівні, а також через 24, 48 та 72 години після фізичного навантаження. Аналіз даних проведено за допомогою дисперсійного аналізу з повторними вимірюваннями із застосуванням post-hoc критерію Бонферроні та кореляційного аналізу Пірсона.

Результати. Для всіх змінних виявлено значущі часові ефекти ($p < 0,001$). Рівні МДА та КК зросли через 24 години, після чого знизилися через 48 і 72 години, проте залишалися підвищеними порівняно з вихідним рівнем. Показники СКР знизилися через 24 години й продемонстрували часткове відновлення, але не повернулися до вихідного рівня через 72 години. Не було виявлено значущої кореляції між МДА та КК через 24 години; однак помірні позитивні кореляції спостерігалися через 48 годин ($r = 0,557$, $p < 0,001$) та 72 години ($r = 0,496$, $p < 0,001$). Значущих взаємозв'язків між біохімічними маркерами та показниками СКР не виявлено.

Висновки. Ексцентричні вправи індукують оксидативний стрес і пошкодження м'язів на тлі зниження нервово-м'язової працездатності. Біохімічні маркери досягають пікових значень через 24 години з подальшою тенденцією до зниження, тоді як нервово-м'язове відновлення залишається незавершеним навіть через 72 години. Взаємозв'язок між оксидативним стресом і пошкодженням м'язів є часозалежним, проявляючись під час фази відновлення, а не в гострій фазі. Отримані результати вказують на відмінності в часових закономірностях і свідчать про те, що оцінювати нервово-м'язову працездатність виключно за біохімічними маркерами є недостатнім.

Ключові слова: ексцентричні вправи, оксидативний стрес, креатинкіназа, малоновий діальдегід, нервово-м'язова працездатність, відновлення.

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Original Scientific Articles. Health-Related Physical Activity and Inclusion

Promoting School Inclusion Through Structured Physical Activity: Physiological, Cognitive, and Social Outcomes in Migrant Students

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Abstract

Background. In multicultural educational contexts, schools are increasingly required to promote inclusive practices that support the social integration and well-being of students with a migrant background. Physical activity has been identified as a potentially effective tool for fostering relational and intercultural skills; however, empirical evidence based on structured interventions remains limited.

Objectives. This study aimed to evaluate the effectiveness of a structured, inclusion-oriented physical activity programme in improving social inclusion, self-esteem, and classroom climate among lower secondary school students, with particular attention to those with a migrant background.

Materials and Methods. A mixed-method quasi-experimental design with pre-test and post-test measures was adopted. The sample consisted of 72 students aged 11–13 years, divided into an experimental group (n = 36) and a control group (n = 36). The 12-week intervention included cooperative learning, peer tutoring, non-verbal communication activities, and culturally relevant games. Quantitative data were collected using validated instruments (SISCA, Rosenberg Self-Esteem Scale, Classroom Climate Scale) and analysed using t-tests and repeated measures ANOVA. Qualitative data were gathered through focus groups, teacher logbooks, and systematic observation.

Results. The experimental group showed statistically significant improvements compared to the control group. Social inclusion scores increased from M = 2.91 (SD = 0.43) to M = 3.47 (SD = 0.38) ($F_{(1,70)} = 14.62$; $p = 0.001$). Self-esteem improved from M = 21.8 (SD = 3.6) to M = 25.1 (SD = 3.2) ($t = 4.07$; $p = 0.002$). Classroom climate scores increased from M = 3.02 (SD = 0.40) to M = 3.55 (SD = 0.36) ($F_{(1,70)} = 11.89$; $p = 0.003$). No statistically significant changes were observed in the control group ($p > 0.05$). Qualitative findings corroborated these results, indicating improvements in peer relationships, non-verbal communication, and sense of belonging.

Conclusions. Under structured and theory-driven conditions, physical activity programmes based on inclusive pedagogical strategies can significantly enhance social inclusion, self-esteem, and classroom climate in multicultural lower secondary school settings. These findings support the implementation of targeted physical activity interventions as an effective approach to promoting social integration and psychological well-being among students, particularly those with a migrant background.

Keywords: physical activity, school inclusion, migrant students, physical education, mixed approach.

Introduction

In the new millennium, education systems are called upon to deal with increasing social, cultural, and linguistic complexity, largely determined by migration processes and the progressive heterogeneity of school populations. In this context, schools play a strategic role not only in the transmission of knowledge, but also in the construction of inclusive, equitable educational environments geared towards the overall development of the individual (Ainscow, Booth & Dyson, 2006). Inclusion, therefore, cannot be considered exclusively as a response to special needs or situations of disadvantage, but rather as a founding principle of contemporary education systems and

an essential prerequisite for sustainable social development (UNESCO, 2017).

In the field of education, numerous studies emphasize that school inclusion involves moving beyond compensatory or welfare-based models in favor of approaches that value diversity as an educational and cultural resource (Slee, 2011; Fiorucci, 2014). In particular, students with a migrant background may encounter difficulties related to language barriers, a sense of belonging, and the construction of social identity, especially in the pre-adolescent phase, which is characteristic of lower secondary school (Benadusi, 2018). In this scenario, physical and sporting activities take on an educational function of primary importance. Thanks to their physical, relational, and experiential nature, they promote forms of nonverbal communication and situated learning processes, capable of reducing inequalities and facilitating the encounter between cultural, linguistic, and social differences (Bailey, 2006; Kirk, 2010). Physical education, in particular, is a privileged context for the development of transversal skills such as cooperation, respect for rules, responsibility, autonomy, and self-awareness, in line with European guidelines on key competences for lifelong learning (European Commission, 2018). From a psycho-pedagogical point of view, several studies show that participation in structured physical activities can have a positive impact on self-esteem, perceived self-efficacy, and sense of belonging to the group, which are crucial elements for well-being at school and the prevention of adolescent distress (Fox, 2000; Weiss & Ferrer-Caja, 2002). In particular, for foreign students, physical activity represents an educational space in which the body becomes a cultural mediator, allowing them to overcome language barriers and build meaningful relationships based on collaboration and shared play (Dagkas, Benn & Jawad, 2011). International literature indicates that students with a migrant background are more exposed to the risk of social isolation, low participation in school activities, and reduced levels of self-esteem, especially in educational contexts lacking intentional inclusive strategies (OECD, 2019; Suarez-Orozco et al., 2018). From this perspective, inclusive physical education can be a powerful tool for promoting educational equity, provided that it is designed according to active, cooperative, and culturally sensitive methodologies (Haegele, Hodge & Rizzo, 2018). Despite widespread theoretical recognition of the inclusive value of physical activity, there are still few experimental studies that systematically analyze the effectiveness of motor programs aimed at school inclusion, especially through mixed research designs capable of integrating quantitative and qualitative data (Bailey et al., 2013). Furthermore, the Italian context, and in particular that of lower secondary school, still appears to be under-explored by empirical research linking pedagogical, psychological, and physiological dimensions. However, a clear gap persists between the intended educational outcomes of inclusive school systems—namely, the effective social integration, active participation, and psychological well-being of students with a migrant background—and the existing pedagogical approaches implemented in physical education. While the literature widely acknowledges the inclusive potential of physical activity, most existing interventions remain either descriptive, non-experimental, or insufficiently structured to systematically target intercultural inclusion. Moreover, there is a lack of studies adopting mixed-method designs capable of simultaneously capturing measurable psychosocial outcomes and the underlying relational processes. Therefore, the research problem addressed in this study lies in bridging the gap between the theoretical recognition of physical activity as an inclusive tool and the limited availability of empirically validated, structured, and pedagogically grounded intervention models within lower secondary school contexts. In light of these considerations, this study aims to contribute to the scientific debate in the field of motor and sports sciences by offering an experimental analysis of the impact of an inclusive physical activity program aimed at Italian and foreign students in lower secondary schools.

To address this gap, the present study proposes and empirically tests a structured physical activity intervention explicitly designed according to inclusive pedagogical principles, including cooperative learning, peer tutoring, nonverbal communication strategies, and the valorization of students' cultural backgrounds through traditional games. Unlike previous approaches, the intervention is systematically implemented and evaluated through a mixed-method quasi-experimental design, allowing for the integration of quantitative measures (social inclusion, self-esteem, classroom climate) with qualitative insights into students' experiences and interaction dynamics.

By doing so, this study aims to provide robust empirical evidence on both the effectiveness and the mechanisms of inclusive physical activity, contributing to the development of replicable and evidence-based educational practices in multicultural school settings.

Materials and Methods

This study adopts an experimental design with a mixed-methods approach, integrating quantitative and qualitative analyses in order to obtain an in-depth and multidimensional understanding of the phenomenon under study. This approach is particularly appropriate in the field of motor sciences and inclusive education, as it allows for the combination of objective measurement of the effects of the intervention with the analysis of the subjective experiences of the participants (Creswell & Plano Clark, 2018). The research is structured according to a pre-test/post-test model with an experimental group and a control group, which allows the effectiveness of the inclusive physical activity program to be evaluated by comparing the changes observed in the two groups over time. Quantitative measurements were taken before the start of the intervention (T0) and at the end of the program (T1), while qualitative data were collected longitudinally during and at the end of the experience. The experimental group participated in a structured physical activity program with specific inclusive strategies, while the control group followed the regular physical education curriculum required by ministerial guidelines. Participants were assigned to groups on a natural basis (pre-existing classes), making the study quasi-experimental, in line with research practices in real school contexts (Shadish, Cook & Campbell, 2002).

Sample

The overall sample consists of 72 students (aged between 11 and 13) attending the first and second years of three lower

secondary schools in the province of Milan, selected for their significant presence of students with a migrant background and their willingness to participate in the research project.

The sample distribution is as follows:

Experimental group (EG): 36 students

- 18 Italian students
- 18 foreign students

Control group (CG): 36 students

- 19 Italian students
- 17 foreign students

The foreign students mainly come from first- and second-generation migrant backgrounds, with different cultural and linguistic backgrounds. This heterogeneity was considered a relevant factor for the analysis of the inclusive effectiveness of the intervention. The sample size is consistent with similar experimental studies conducted in schools, in which groups of between 30 and 40 subjects allow statistically significant effects to be detected in relation to psychosocial and educational variables (Bailey et al., 2013).

Although an a priori power analysis was not conducted, the sample size is consistent with previous quasi-experimental studies in school-based physical education contexts, which have demonstrated sufficient statistical power to detect medium-sized effects in psychosocial variables. Moreover, the balanced distribution between experimental and control groups contributes to the internal validity of the study and supports the reliability of the observed effects.

Inclusion criteria

Students who met the following criteria were included in the study:

- regular enrollment in a lower secondary school at the time of the survey;
- age between 11 and 13 years;
- for the subsample of foreign students, at least one parent born abroad, regardless of the student's citizenship;
- possession of a medical certificate of fitness for non-competitive physical activity;
- regular participation in physical education classes;
- acquisition of written informed consent from parents or legal guardians, in accordance with current ethical regulations and EU Regulation 2016/679 (GDPR).

Exclusion criteria

- Students who had one or more of the following conditions were excluded from the study:
- certified diagnosis of severe motor or cognitive disabilities that prevented participation in the proposed physical activities;
- presence of chronic diseases or clinical conditions incompatible with structured physical activity;
- absences exceeding 25% of the total activities planned during the intervention period, considered insufficient to guarantee exposure to the experimental treatment;
- simultaneous participation in high-intensity structured extracurricular sports programs (more than three sessions per week), in order to reduce the risk of confounding variables related to external training.

Activities

The experimental intervention was designed according to an educational, inclusive, and interdisciplinary approach, integrating pedagogical, psychological, and motor principles, with the aim of promoting school inclusion and the psychological and physical well-being of students, particularly those with a migrant background. The program lasted a total of 12 weeks, with two 60-minute sessions per week, for a total of 24 teaching units, and was fully integrated into the physical education curriculum.The time frame of the intervention is consistent with the literature, which shows that programs lasting between 8 and 16 weeks are sufficient to produce significant changes in psychosocial and relational variables in childhood (Bailey et al., 2013; Lubans et al., 2016). Each session was divided into three main phases:

1. Initial phase (10–15 minutes): motor activation and playful, cooperative warm-up games.
2. Central phase (35–40 minutes): structured activities oriented towards inclusive goals.
3. Final phase (5–10 minutes): cool-down, guided reflection, and sharing of the experience.

Cooperative games and adapted team sports

A central component of the program was the use of cooperative games and adapted team sports, designed to reduce excessive competitiveness and encourage peer collaboration. According to Johnson and Johnson (2009), cooperative learning in motor contexts promotes positive interdependence, individual responsibility, and the development of social skills. Team sports (e.g., basketball, volleyball, soccer) were adapted through:

- rule changes;
- systematic role rotation;
- group rather than individual goals;
- valuing the contribution of each participant.

These adaptations are consistent with models of inclusive physical education, which aim to ensure equal opportunities for participation and motor success for all students, regardless of skill level or cultural background (Kirk, 2010; Haegele & Sutherland, 2015).

Activities based on nonverbal communication

Particular attention was paid to motor activities based on nonverbal communication, such as mimicry games, cooperative motor courses, relay races without the use of words, and rhythmic activities. The body was conceived as a privileged tool for expression and cultural mediation. The literature highlights how nonverbal communication plays a key role in the inclusion of foreign students, especially in the early stages of school integration, when language skills may be limited (Garcia & Wei, 2014). In the motor field, body language allows for the construction of shared meanings and authentic relationships, reducing the risk of exclusion (Shilling, 2012).

Peer tutoring and cooperative learning strategies

The program systematically integrated peer tutoring and cooperative learning strategies, assigning specific roles

to students (tutor, observer, facilitator) and promoting mutual support among peers. In particular, Italian and foreign students were frequently placed in pairs or small heterogeneous groups, encouraging intercultural interaction. Numerous studies show that peer tutoring in physical education improves not only motor skills but also the self-esteem, sense of self-efficacy, and social skills of the students involved (Ward & Lee, 2005; Dyson & Casey, 2012). Furthermore, cooperative learning promotes a positive and inclusive classroom climate, reducing isolation and marginalization (Casey & Goodyear, 2015).

Promoting cultural differences through traditional games

A distinctive feature of the intervention was the inclusion of traditional games and physical activities from the countries of origin of the foreign students, selected and adapted with the active involvement of the participants themselves. This methodological choice is based on the principles of intercultural pedagogy, which recognizes the educational value of cultural diversity and promotes dialogue between different identities (Portera, 2013). Through the sharing of traditional games, foreign students took on the role of 'cultural experts', promoting social recognition and strengthening personal identity. The literature emphasises how this approach contributes to improving the sense of belonging and counteracting stereotypes and prejudices in schools (Dagkas et al., 2011; Benn, Pfister & Jawad, 2011).

Role of the teacher and monitoring of the intervention

The physical education teacher acted as a facilitator of the educational process, adopting a democratic and reflective teaching style in line with student-centered teaching models (Mosston & Ashworth, 2008). During the intervention, systematic observation grids were used to monitor participation, social interactions, and inclusive behaviors.

Control group

The control group followed the normal physical education curriculum set out in the National Guidelines, without the introduction of teaching strategies specifically geared towards intercultural inclusion. This made it possible to attribute any changes observed in the experimental group to the proposed intervention with greater reliability.

Tools

In order to systematically and comprehensively evaluate the effectiveness of the experimental intervention, the research involved the use of quantitative and qualitative assessment tools, selected on the basis of their scientific validation, reliability, and suitability for the school context. The integration of different tools made it possible to capture both the measurable outcomes of the intervention and the experiential and relational dimensions perceived by the subjects involved, in line with the principles of mixed-method educational research (Creswell & Plano Clark, 2018). Quantitative measurements were taken at two distinct moments: before the start of the program (pre-test, T0) and at the end of the twelve weeks of intervention (post-test, T1). Qualitative tools, on the other hand, were used longitudinally and conclusively in order to explore the educational processes that had been activated.

Quantitative Tools

For the quantitative analysis, standardized questionnaires that have been widely validated in international scientific literature were used. These were administered in paper form during school hours, under the supervision of researchers and teachers.

The Social Inclusion Scale for Children and Adolescents (SISCA; Pijl & Frostad, 2010) was used to assess the level of social inclusion perceived by students within the school context. The scale measures dimensions such as sense of belonging to the group, quality of peer relationships, and participation in school activities. Previous studies have shown good internal reliability of the instrument ($\alpha > 0.80$) and solid construct validity, making it particularly suitable for multicultural educational contexts.

The Rosenberg Self-Esteem Scale (RSES; Rosenberg, 1965), adapted for adolescents, was used to assess self-esteem. The scale, consisting of ten items on a Likert scale, measures overall self-assessment and is one of the most widely used tools in psychology and education. Numerous studies confirm its reliability and sensitivity to changes resulting from educational and sports interventions (Fox, 2000; Marsh et al., 2014).

The classroom climate was investigated using the Classroom Climate Scale (CCS; Moos & Trickett, 1987), a tool that analyzes students' perceptions of interpersonal relationships, mutual support, involvement, and the level of cooperation within the class group. The classroom climate is a key variable in the processes of school inclusion and psychosocial well-being, especially in contexts characterized by high cultural heterogeneity (Thapa et al., 2013).

Qualitative Tools

Alongside quantitative tools, qualitative tools were used for exploratory and interpretative purposes, with the aim of deepening the meaning attributed by students and teachers to the inclusive motor experience.

Semi-structured focus groups were conducted with foreign students belonging to the experimental group at the end of the intervention. The focus groups allowed us to collect narratives, perceptions, and experiences related to relational dynamics, sense of belonging, and the experience of physical activity as an inclusive space. This methodology is particularly effective for investigating social and identity processes in adolescence (Morgan, 1997).

The logbooks kept by physical education teachers provided a tool for systematic reflection on the progress of the intervention. Teachers noted observations regarding student participation, peer interactions, difficulties encountered, and teaching strategies adopted. The use of logbooks is widely recognized as a useful tool for documenting educational processes and promoting informed professional reflection (Zabalza, 2004).

Finally, systematic observation of motor activities was conducted using structured grids based on the model

proposed by Anguera (2003). The grids made it possible to detect observable behaviors related to cooperation, active participation, peer support, and the inclusion of foreign students. Direct observation made it possible to integrate self-reported data with behavioral evidence, increasing the overall validity of the study.

Data analysis

The quantitative data were analyzed using descriptive and inferential statistical procedures, using dedicated statistical software. In the first phase, the mean, standard deviation, and frequency distribution were calculated for all the variables considered. Subsequently, to verify the differences between the experimental group and the control group and the variations over time, t-tests for independent samples and analysis of variance (ANOVA) with repeated measures were applied, with a significance level set at $p < 0.05$. These analyses are appropriate for quasi-experimental studies with pre- and post-intervention measurements (Field, 2018). Qualitative data were analyzed using thematic analysis according to the model proposed by Braun and Clarke (2006). The analysis process involved a phase of familiarization with the data, followed by inductive coding, identification of emerging themes, and their interpretation. To ensure the reliability of the analysis, the coding was carried out by two independent researchers, with subsequent comparison and consensus on the final themes. The integration of quantitative and qualitative results allowed for a more complete reading of the effects of the intervention, making it possible to link measurable changes to the experiences of the participants, in line with the principles of methodological triangulation.

In addition to significance testing, effect sizes were calculated to assess the magnitude of the observed differences. Cohen's d was computed for paired and independent comparisons, while partial eta squared (η^2) was reported for ANOVA models. Furthermore, interaction effects between group (experimental vs. control) and time (T0 vs. T1) were examined using repeated measures ANOVA, in order to verify whether the changes over time differed significantly between the two groups. This approach allows for a more robust interpretation of the intervention effects beyond statistical significance.

Results

The quantitative analysis made it possible to evaluate the effectiveness of the experimental intervention by comparing the scores obtained by the experimental group and the control group in the three variables considered: perceived social inclusion, self-esteem, and classroom climate. In the pre-test phase (T0), no statistically significant differences emerged between the two groups for any of the variables analyzed, confirming the initial homogeneity of the sample.

Table 1. Pre-test (T0) Comparison Between Groups

Variable	Experimental Group (M ± SD)	Control Group (M ± SD)	Significant Difference
Social Inclusion (SISCA)	2.91 ± 0.43	2.94 ± 0.45	p > 0.05
Self-Esteem (Rosenberg)	21.80 ± 3.6	21.90 ± 3.9	p > 0.05
Classroom Climate	3.02 ± 0.40	3.04 ± 0.41	p > 0.05

With regard to the Social Inclusion Scale for Children and Adolescents (SISCA), the experimental group showed a significant increase in average scores from the pre-test to the post-test. In particular, the average score went from M = 2.91 (SD = 0.43) at T0 to M = 3.47 (SD = 0.38) at T1, with a statistically significant difference detected by repeated measures ANOVA ($F(1,70) = 14.62$; $p = 0.001$). The control group, on the other hand, did not show any significant changes (T0: M = 2.94; SD = 0.45; T1: M = 2.99; SD = 0.44; $p > 0.05$). Analysis of the subscales showed particularly significant improvements in the dimensions relating to sense of belonging and participation in group activities.

Table 2. Social Inclusion (SISCA) Results

Group	T0 (M ± SD)	T1 (M ± SD)	Significance
Experimental Group	2.91 ± 0.43	3.47 ± 0.38	p = 0.001
Control Group	2.94 ± 0.45	2.99 ± 0.44	p > 0.05

With regard to self-esteem, measured using the Rosenberg Self-Esteem Scale, the experimental group showed a significant increase in the overall average score, which rose from M = 21.8 (SD = 3.6) at T0 to M = 25.1 (SD = 3.2) at T1. The paired samples t-test showed a statistically significant difference ($t = 4.07$; $p = 0.002$). Again, the control group showed no significant changes during the period considered ($p > 0.05$). The increase in self-esteem was particularly marked in the subgroup of foreign students in the experimental group.

These quantitative improvements are supported by qualitative findings, which provide insight into the underlying relational processes. In particular, students reported a strengthened sense of belonging to the class group, frequently describing cooperative activities as opportunities to "feel part of the group" and "be accepted without differences". Observational data and teacher logbooks confirmed an increase in peer interaction and active participation, especially among students with a migrant background. These findings suggest that the increase in social inclusion scores was mediated by enhanced peer relationships and shared group experiences.

Table 3. Self-Esteem (Rosenberg Scale)

Group	T0 (M ± SD)	T1 (M ± SD)	Significance
Experimental Group	21.8 ± 3.6	25.1 ± 3.2	p = 0.002
Control Group	21.9 ± 3.9	22.0 ± 3.8	p > 0.05

With regard to classroom climate, assessed using the Classroom Climate Scale, the results indicate a significant improvement in the experimental group in terms of cooperation, peer support, and involvement. The overall average score increased from M = 3.02 (SD = 0.40) at T0 to M = 3.55 (SD = 0.36) at T1, with a statistically significant difference ($F_{(1,70)} = 11.89$; $p = 0.003$). In the control group, scores remained essentially stable over time.

The quantitative increase in self-esteem in the experimental group is further explained by qualitative evidence. Teachers' logbooks and student narratives highlighted a progressive increase in self-confidence and initiative, particularly among initially marginalised students. Many participants began to take on active roles during

activities, especially in contexts where cultural competencies were valued (e.g., traditional games). This suggests that the observed improvement in self-esteem was linked to processes of social recognition, role-taking, and perceived competence within the group.

Table 4. Classroom Climate Results

Group	T0 (M ± SD)	T1 (M ± SD)	Significance
Experimental Group	3.02 ± 0.40	3.55 ± 0.36	p = 0.003
Control Group	3.04 ± 0.41	3.04± 0.41	p > 0.05

Qualitative findings also help explain the observed improvement in classroom climate. Systematic observations and teacher reports indicated a reduction in exclusion behaviours and an increase in prosocial interactions, such as cooperation, mutual support, and encouragement. Students described the learning environment as more collaborative and inclusive over time. These findings suggest that the improvement in classroom climate scores was driven by the implementation of cooperative learning strategies and peer tutoring, which fostered a more supportive and cohesive group dynamic.

The quantitative results indicate that participation in the inclusive physical activity program had significant and positive effects on the psychosocial variables analyzed, confirming the effectiveness of the intervention compared to the normal physical education curriculum.

Overall, the integration of quantitative and qualitative data provides a coherent explanatory framework for interpreting the effects of the intervention. While statistical analyses demonstrate significant improvements in key psychosocial variables, qualitative findings clarify the mechanisms underlying these changes, highlighting the role of cooperative learning, nonverbal communication, and cultural recognition in promoting inclusion, self-esteem, and a positive classroom climate.

To ensure a coherent interpretation of the results across multiple outcome variables, a rule of decision was defined. Specifically, the intervention was considered effective when statistically significant improvements ($p < 0.05$) were observed in at least two of the three primary outcomes (social inclusion, self-esteem, and classroom climate), accompanied by convergent qualitative evidence supporting the underlying mechanisms of change.

In the present study, all three variables showed significant improvements in the experimental group compared to the control group, while no significant changes were observed in the control group. Therefore, according to the predefined decision rule, the intervention can be considered effective in promoting psychosocial inclusion outcomes in the target population.

Discussion

The results of this study confirm the central role of physical activity as an educational and inclusive tool, capable of significantly influencing social integration processes, psychological well-being, and the relational climate within middle schools. This evidence is consistent with pedagogical models centered on the person and the body in motion, which recognize the global educational value of motor experience, rather than merely its performance value (Kirk, 2010; Mosston & Ashworth, 2008). From a quantitative point of view, the improvements observed in the experimental group in terms of perceived social inclusion, self-esteem, and classroom climate are consistent with international literature, which highlights the effectiveness of structured physical activity programs intentionally geared toward inclusion (Bailey et al., 2013; Lubans et al., 2016). In particular, the significant increase in scores relating to sense of belonging and participation in group activities confirms that physical activity can be a powerful mediator of positive social relationships, especially for students with a migrant background, who are often exposed to marginalization (OECD, 2019). The increase in self-esteem levels found in the experimental group, especially among foreign students, is reflected in studies that highlight a positive relationship between participation in inclusive physical activities and the development of self-efficacy and self-image in childhood (Fox, 2000; Weiss & Ferrer-Caja, 2002). The adoption of strategies such as peer tutoring, role rotation, and the enhancement of cultural skills has probably contributed to creating contexts of widespread motor success, reducing the risk of exclusion and promoting the perception of personal competence. The improvement in the classroom climate, highlighted by both quantitative data and systematic observation, appears particularly relevant in relation to the cooperative dimension of the intervention. The literature emphasizes that a positive relational climate is an essential condition for learning and well-being at school, especially in contexts characterized by high cultural heterogeneity (Thapa et al., 2013; Dyson & Casey, 2012). In this sense, inclusive physical education is a privileged space for building relationships based on trust, mutual respect, and collaboration. The qualitative results allow us to explore the mechanisms through which the intervention produced the observed effects. The thematic analysis highlighted the role of the body as a universal language and as a tool for intercultural mediation, confirming what has been argued by several authors regarding the communicative and symbolic function of movement (Shilling, 2012; Garcia & Wei, 2014). To strengthen the causal interpretation of the intervention effects, it is important to clarify the underlying mechanisms through which the proposed strategies produced the observed outcomes. Specifically, cooperative learning structures fostered positive interdependence and shared goal orientation, which in turn increased peer support and reduced social isolation. Peer tutoring activated processes of role-taking, mutual responsibility, and social recognition, contributing to the development of self-efficacy and self-esteem, particularly among migrant students. Activities based on nonverbal communication enabled participation beyond linguistic barriers, facilitating immediate engagement and the construction of shared meanings through embodied interaction. Finally, the inclusion of culturally relevant games promoted identity validation and social recognition, enhancing students' sense of belonging. These mechanisms jointly operated as mediating processes linking the pedagogical design of the intervention to improvements in social inclusion, classroom climate, and psychological well-being.The reduction of language barriers through nonverbal communication encouraged the active participation of foreign students, strengthening their sense of belonging and involvement in group dynamics. Particularly significant is the theme of valuing cultural differences through the introduction of traditional games from the

students' countries of origin. This approach, in line with the principles of intercultural pedagogy, has made it possible to recognize and legitimize the cultural identities of foreign students, transforming them into an educational resource for the entire class (Portera, 2013; Benn, Pfister & Jawad, 2011). This recognition seems to have had a positive impact on self-confidence and active participation, as evidenced by both teachers' logbooks and students' narratives. The mixed methodological approach adopted in the study proved particularly effective in capturing the complexity of the phenomenon under investigation. The integration of quantitative and qualitative data made it possible not only to measure the outcomes of the intervention but also to understand the underlying educational processes, strengthening the interpretative validity of the results (Creswell & Plano Clark, 2018). In this sense, the study contributes to filling a gap in the literature by providing empirical evidence on the effectiveness of inclusive physical education programs in the context of lower secondary school. Overall, the results suggest that physical activity, if designed according to inclusive pedagogical and methodological criteria, can be a strategic tool for responding to the educational challenges posed by cultural and social diversity. This implies the need for specific training for physical education teachers, geared towards the development of intercultural, reflective, and methodological skills, capable of integrating pedagogical and physiological dimensions in a perspective of global psychophysical development. While aware of the limitations of the study, mainly related to the sample size and the specific territorial context, the results obtained offer relevant indications for the design of future educational interventions and the implementation of school policies oriented towards inclusion and well-being.

The interpretation of these findings should be considered in light of specific boundary conditions that may influence the generalisability of the results. First, the effectiveness of the intervention appears to be contingent upon the structured and theory-driven nature of the programme, including the systematic use of cooperative learning, peer tutoring, and culturally responsive activities. It is therefore unlikely that similar outcomes would be achieved in unstructured or traditional physical education contexts lacking these pedagogical components.

Second, the observed effects are specific to the age group considered (11–13 years), a developmental stage characterised by heightened sensitivity to peer relationships and identity construction. The impact of the intervention may differ in younger children or older adolescents.

Third, the positive outcomes appear to be particularly pronounced among students with a migrant background, suggesting that the intervention may have differential effects depending on initial levels of social integration and vulnerability.

Finally, the intervention was implemented within a relatively controlled school context and over a defined period (12 weeks); therefore, the stability and long-term persistence of these effects remain to be further investigated.

Conclusions

The results of this study indicate that structured physical activity intentionally geared toward inclusion is an effective educational strategy for promoting psychological and physical well-being, social integration, and the development of transferable skills in middle school students with a migrant background. The proposed intervention has been shown to have a positive impact on key variables such as sense of belonging, self-esteem, and relational climate, confirming the potential of physical education as a privileged context for building inclusive school environments. The integration of pedagogical and physiological approaches proved particularly significant, highlighting how physical movement can act as an educational mediator capable of overcoming linguistic and cultural barriers. In this sense, physical activity is not only a tool for promoting health, but also a global educational experience capable of fostering personal growth, autonomy, and active participation in school life. The use of a mixed methodological approach made it possible to grasp the complexity of the phenomenon studied, offering an integrated reading of the measurable outcomes and the experiential dimensions experienced by the participants. The qualitative results, in particular, helped to clarify the mechanisms through which the teaching strategies adopted fostered inclusive dynamics, reinforcing the interpretative validity of the quantitative data. In light of this evidence, there is a clear need to promote the conscious planning of physical education in schools, geared towards the development of intercultural, relational, and cooperative skills. This implies investment in the initial and in-service training of teachers, so that they can acquire the methodological tools needed to manage the complexity of contemporary educational contexts. Finally, although the study has some limitations related to the sample size and the limited geographical context, it offers relevant insights for future research, suggesting the opportunity to extend the investigation to different contexts and to explore the long-term effects of inclusive physical activity programs. In conclusion, physical activity and sport, if properly designed, can contribute significantly to the creation of a more equitable and inclusive school system geared towards the sustainable development of individuals and society.

Ethics Approval

The study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol was reviewed and approved by the Ethics Committee of the University of Naples "Parthenope".

Informed Consent

All participants provided written informed consent prior to participation in the study. Participants were informed about the study procedures, potential risks, and their right to withdraw from the study at any time without consequences.

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Transparency Statement

The authors declare that artificial intelligence tools were used solely for language editing and text refinement. All scientific content, analysis, and interpretations were developed and verified by the authors.

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Сприяння шкільній інклюзії засобами структурованої фізичної активності: фізіологічні, когнітивні та соціальні результати учнів-мігрантів

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 4 табл., 38 джерел.

Обґрунтування. В контексті мультикультурного освітнього простору перед закладами освіти дедалі частіше виникає потреба впроваджувати інклюзивні практики, що сприяють соціальній інтеграції та благополуччю учнів, які мають міграційне походження. Фізична активність визначається як потенційно ефективний інструмент розвитку комунікативних та інтеркультурних навичок, проте кількість емпіричних даних, що ґрунтуються на структурованих інтервенціях, залишається обмеженою.

Мета дослідження. Метою дослідження було оцінити ефективність структурованої, інклюзивно орієнтованої програми фізичної активності у підвищенні рівня соціальної інклюзії, самооцінки та покращенні психологічного клімату в класі серед учнів базової середньої школи, з особливим акцентом на здобувачах освіти з міграційним походженням.

Матеріали і методи. У роботі застосовано квазіекспериментальний дизайн із використанням змішаних методів та вимірюванням показників на претест- посттестовому етапах дослідження. Вибірку склали 72 учні віком 11–13 років, яких було розподілено на експериментальну (n = 36) та контрольну (n = 36) групи. Інтервенція тривалістю 12 тижнів передбачала кооперативне навчання, взаємонавчання, вправи на невербальну комунікацію та культурологічно релевантні ігри. Збирання кількісних даних проведено за допомогою валідизованих інструментів (SISCA, Шкала самооцінки Розенберга, Шкала психологічного клімату в класі) та проаналізовано за допомогою t-критеріїв та дисперсійного аналізу з повторними вимірюваннями. Якісні дані були отримані шляхом проведення фокус-груп, аналізу вчительських щоденників та систематичного спостереження.

Результати. В експериментальній групі виявлено статистично значущі покращення порівняно з контрольною групою. Показники соціальної інклюзії зросли з M = 2,91 (SD = 0,43) до M = 3,47 (SD = 0,38) ($F_{(1, 70)}$ = 14,62; p = 0,001). Рівень самооцінки підвищився з M = 21,8 (SD = 3,6) до M = 25,1 (SD = 3,2) (t = 4,07; p = 0,002). Показники психологічного клімату в класі зросли з M = 3,02 (SD = 0,40) до M = 3,55 (SD = 0,36) ($F_{(1, 70)}$ = 11,89; p = 0,003). У контрольній групі статистично значущих змін не зафіксовано (p > 0,05). Якісні результати підтвердили ці дані, вказуючи на покращення взаємин між однолітками, розвиток невербальної комунікації та посилення почуття приналежності до колективу.

Висновки. За умов структурованого та теоретично обґрунтованого підходу програми фізичної активності, побудовані на інклюзивних педагогічних стратегіях, можуть суттєво підвищити рівень соціальної інклюзії, самооцінки та покращити психологічний клімат у класі в мультикультурному середовищі базової середньої школи. Отримані результати свідчать на користь упровадження цільових інтервенцій фізичної активності як ефективного підходу до сприяння соціальній інтеграції та психологічному благополуччю учнів, зокрема тих, які мають міграційне походження.

Ключові слова: фізична активність, шкільна інклюзія, учні-мігранти, фізичне виховання, змішаний метод.

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Emotional Synchronisation and Motor Coordination in Artistic Swimming: The Role of Team Cohesion in Synchronised Performance

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Background. Motor synchronisation is a key determinant of performance in artistic swimming; however, it is primarily analysed from a technical perspective, with limited consideration of emotional and relational processes within the team. A more comprehensive understanding of synchronised performance requires analysis of the interaction between emotional attunement, team cohesion, and collective motor coordination.

Objectives. This study aimed to analyse the relationship between emotional attunement, team cohesion, and motor synchronisation in artistic swimming, with particular attention to the effects of an educational intervention focused on relational and emotional skills.

Materials and Methods. A mixed-methods quasi-experimental design was employed. The sample consisted of 150 competitive artistic swimmers aged 17–28 years, divided into an experimental group and a control group. Participants were additionally stratified into three age subgroups (17–19, 20–23, and 24–28 years). The experimental group underwent an educational programme designed to enhance team cohesion and emotional awareness. Quantitative data were collected using the Group Environment Questionnaire (GEQ) and structured video analysis of routines, whereas qualitative data were obtained through focus groups. Independent samples t-tests and subgroup analyses were conducted. A two-way ANOVA (Group × Age group) was performed to examine the interaction between intervention and age.

Results. The experimental group demonstrated significantly higher levels of group cohesion across all GEQ dimensions compared to the control group (e.g., Group Integration–Task: $M = 7.8$ vs. 6.5; $t = 4.21$; $p < .01$; $d = 0.78$). Similar differences were identified for Group Integration–Social ($M = 7.6$ vs. 6.3; $p < .01$) and Individual Attraction dimensions ($p < .05$). The experimental group also achieved significantly higher motor synchronisation scores across all indicators, including temporal precision (87% vs. 74%), body position uniformity (85% vs. 72%), synchronisation with music (88% vs. 76%), and execution timing consistency (86% vs. 73%) ($p < .05$). These differences remained stable across all age subgroups. ANOVA revealed a significant main effect of group ($p < .01$), whereas the main effect of age and the interaction effect (Group × Age group) were non-significant ($p > .05$). Qualitative findings additionally highlighted the importance of trust, non-verbal communication, and shared emotional states in facilitating coordination.

Conclusions. Motor synchronisation in artistic swimming should be considered not only a technical skill but also a multidimensional process influenced by emotional attunement and team cohesion. Educational interventions targeting relational and emotional dynamics may substantially improve collective coordination and performance quality in team sports, independently of age-related differences.

Keywords: artistic swimming, team cohesion, motor synchronisation, emotional attunement, sports psychology, team performance.

Introduction

Artistic swimming, formerly known as synchronised swimming, is an aquatic sport that combines elements of swimming technique, dance, gymnastics and artistic expression. This sport demands a high level of motor coordination, body control, strength, flexibility and timing from the athletes. Routines are performed in the water following a structured choreography set to music, during which the athletes must execute complex technical movements whilst maintaining aesthetic harmony and

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perfect synchronisation with their teammates (Mountjoy, 2009; Vathagavorakul et al., 2020). The origins of artistic swimming date back to the early decades of the 20th century, when aquatic shows combining choreographed movements and swimming techniques began to spread across Europe and North America. Initially, the discipline had a strong demonstrative and spectacular component, often presented in theatrical settings or aquatic exhibitions. Over time, however, synchronised swimming has gradually evolved into a structured competitive sport, characterised by technical regulations and specific judging criteria (Vathagavorakul et al., 2020). Official recognition by international sports federations has contributed to its spread and the progressive definition of technical and artistic standards. Synchronised swimming became part of the Olympic programme in 1984, consolidating its status as a top-level sporting discipline. In 2017, the International Swimming Federation (now World Aquatics) officially adopted the name 'artistic swimming' to emphasise the expressive and choreographic elements that characterise this discipline (Mountjoy, 2009). Artistic swimming differs from many other sports due to its highly interdisciplinary nature, which integrates technical, artistic and performative components. The athletes must perform sequences of complex movements that include technical figures, lifts, rotations and choreographic transitions, whilst maintaining a high level of breath control and physical endurance. Furthermore, the performance requires constant temporal alignment between the athletes' movements and the musical rhythm, an element that helps to create an effect of harmony and fluidity in the choreography (Vathagavorakul et al., 2020; Mountjoy, 2009). Within this context, synchronisation is one of the fundamental elements of performance assessment. Judges evaluate not only the technical precision of the movements, but also the degree of coordination between the athletes, the harmony of the routine and the quality of artistic expression. The ability to perform simultaneous and perfectly coordinated movements is therefore a core skill in artistic swimming, particularly in team routines (Mountjoy, 2009). Traditionally, the synchronisation of movements has been analysed primarily from a technical and biomechanical perspective, focusing on aspects such as the temporal precision of movements, the alignment of body positions and the quality of technical execution. However, in recent years, the literature in the field of sport psychology has highlighted how coordination in team sports is influenced not only by motor skills, but also by psychological and relational factors (Eys et al., 2015). In particular, recent studies have emphasised the role of team cohesion, empathy between teammates and the ability to share emotional states during performance (Carron et al., 2002; Eys et al., 2015). In artistic swimming, the team dimension takes on particular significance. Athletes must develop a form of collective coordination that goes beyond the simple simultaneous execution of movements. The performance requires, in fact, a strong capacity for mutual anticipation, deep trust between teammates and constant attention to the physical and rhythmic cues coming from the group. This form of coordination implies a high level of harmony among the athletes, which is built up over time through shared training sessions, competitive experiences and relational dynamics within the team (Eccles et al., 2004; Eys et al., 2015). In this sense, synchronisation in artistic swimming can be interpreted not only as a motor phenomenon, but also as the result of a process of interpersonal coordination involving cognitive, emotional and relational dimensions. The athletes' ability to perceive the group's rhythm, anticipate their teammates' movements and adapt to variations in performance is a fundamental skill for the success of the routine (Eccles & Tenenbaum, 2004). The emotional dimension also plays a central role in the practice of this discipline. During competition, athletes must manage high levels of emotional arousal, competitive pressure and concentration, whilst maintaining a strong sense of connection with their teammates. Sharing emotions, mutual support and trust within the group can help strengthen team cohesion and facilitate the coordination of movements during the performance (Carron et al., 2002).

The main objective of this study was to analyse the relationship between emotional attunement among athletes and the precision of motor synchronisation in artistic swimming performances. In particular, the study aimed to examine how relational dynamics and emotional processes within the group may influence the quality of coordination and collective performance during the execution of routines. Previous research in sport psychology suggests that coordination in team sports depends not only on technical and motor skills but also on interpersonal, cognitive, and emotional processes that facilitate mutual anticipation and synchronisation of actions among team members (Eccles & Tenenbaum, 2004; Eys et al., 2015).

Within this framework, the present study focused on the role of group cohesion, mutual trust, empathy among athletes, and emotional harmony as potential mechanisms underlying effective collective coordination in artistic swimming. Several studies have demonstrated that high levels of cohesion and trust within sports teams are associated with improved communication, cooperation, and collective performance effectiveness (Carron et al., 2002; Eys et al., 2015).

Accordingly, the objectives of the study were:

- to assess the level of group cohesion in artistic swimming teams;
- to analyse the precision of motor synchronisation through video analysis of routines;
- to explore emotional management strategies adopted by athletes during performance;
- to examine the role of mutual trust and relational harmony in the process of team coordination.

Based on the literature on group cohesion and coordination in sports teams, the following hypotheses were formulated:

H1. A higher level of group cohesion is associated with greater precision in motor synchronisation during the execution of routines (Carron et al., 2002; Eys et al., 2015).

H2. Teams characterised by greater emotional harmony among athletes demonstrate higher levels of coordination and fluidity of movement (Eccles & Tenenbaum, 2004; Cooke et al., 2000).

H3. Mutual trust and the perception of support among teammates promote better emotional regulation during performance (Carron et al., 2002).

H4. Athletes who perceive a high degree of emotional connection with the group report a greater ability to anticipate teammates' movements and maintain synchronisation

during the routine (Eccles & Tenenbaum, 2004; Eys et al., 2015).

Materials and Methods

Study Design

The study employed a mixed-methods quasi-experimental design combining quantitative and qualitative approaches. The research involved an experimental group and a control group and aimed to examine the effects of an educational intervention focused on emotional attunement and team cohesion in artistic swimming. Quantitative methods were used to assess group cohesion and motor synchronisation, whereas qualitative methods explored athletes' perceptions of emotional and relational dynamics within the team context.

Participants

The sample was selected using a non-probability convenience sampling procedure due to the accessibility of the sporting environment and the possibility of continuous observation during training activities. The study was conducted at a swimming school located in the Naples metropolitan area with a competitive artistic swimming section.

The sample consisted of 150 competitive artistic swimmers aged 17–28 years who regularly participated in training sessions and official competitions. Participants were additionally stratified into three age subgroups:

- 17–19 years (late adolescence);
- 20–23 years (emerging adulthood);
- 24–28 years (young adulthood).

Participants were included according to the following criteria:

- regular participation in official artistic swimming competitions;
- a minimum of two years of experience in the discipline;
- participation in team routines;
- provision of written informed consent prior to participation.

Educational intervention

The educational intervention was implemented only in the experimental group during the competitive season, whereas the control group continued the standard technical and physical training programme provided by the swimming school.

The intervention aimed to develop emotional awareness, mutual trust, relational harmony, and team cohesion through integrated educational activities conducted alongside regular training sessions. The programme included:

- team-building activities;
- cooperative coordination exercises;
- group trust-building exercises;
- guided emotional reflection sessions;
- non-verbal communication and synchronisation exercises;
- competition simulations followed by group discussions.

Specific activities involved synchronised movements without verbal communication, pair coordination exercises, rhythm adaptation tasks, and guided reflection on emotional states experienced during performance and competition.

The control group continued routine technical training focused on:

- swimming technique and body control;
- technical figures and choreographic transitions;
- synchronisation exercises through routine repetition;
- coordination with music;
- physical conditioning for strength, endurance, and flexibility.

Instruments

Group cohesion assessment

Group cohesion was assessed using the Group Environment Questionnaire (GEQ) developed by Carron et al. (1985). The questionnaire includes 18 items organised into four dimensions:

- Group Integration – Task;
- Group Integration – Social;
- Individual Attractions to the Group – Task;
- Individual Attractions to the Group – Social.

Responses were provided using a 9-point Likert scale ranging from 1 (strongly disagree) to 9 (strongly agree). The questionnaire was administered individually under conditions ensuring anonymity and confidentiality.

Motor synchronisation assessment

Motor synchronisation was assessed through structured video analysis of routines recorded during training sessions and competition simulations using high-definition cameras positioned at poolside.

The analysis included the following indicators:

- temporal precision of movements;
- body position uniformity;
- synchronisation with musical rhythm;
- execution timing consistency.

Each indicator was evaluated using a structured observational scoring system to obtain a composite synchronisation index.

Qualitative data Collection

Qualitative data were collected through semi-structured focus groups conducted with the athletes. Focus groups explored:

- emotional experiences during performance;
- perception of group harmony;
- non-verbal communication;
- mutual trust within the team;
- emotional regulation strategies during competition.

Each session lasted approximately 45–60 minutes and was audio-recorded and transcribed for analysis.

Statistical Analysis

Descriptive statistics were calculated for all study variables and are presented as means and standard deviations

(M ± SD). Independent samples t-tests were used to compare the experimental and control groups across all dimensions of group cohesion and motor synchronisation.

To examine the potential influence of age, subgroup analyses were conducted across the predefined age categories (17–19, 20–23, and 24–28 years). In addition, a two-way analysis of variance (ANOVA) (Group × Age group) was performed to assess:

- the main effect of the intervention;
- the main effect of age;
- the interaction effect between intervention and age.

Effect sizes were calculated using Cohen's d. Statistical significance was set at $p < .05$.

Qualitative data obtained from focus groups were analysed using thematic analysis according to Braun and Clarke (2006).

Results

Quantitative results

The analysis of the quantitative data was conducted with the aim of comparing the results obtained by the experimental group and the control group in relation to levels of group cohesion and the precision of motor synchronisation during the performance of artistic swimming routines. In an initial phase, descriptive statistics were calculated for the variables under study, including the mean (M), standard deviation (SD) and distribution of scores obtained in the Group Environment Questionnaire (GEQ) and in the scores derived from video analysis of the performances. This preliminary phase provided a general overview of the characteristics of the two groups and identified any differences in levels of team cohesion and motor coordination. Subsequently, a comparison was made between the experimental group and the control group to verify the presence of statistically significant differences between the two groups. In particular, the analysis took into account the mean scores for the four dimensions of the Group Environment Questionnaire — task-oriented group integration, socially oriented group integration, individual attraction to the group in relation to the task, and individual attraction to the group in relation to the social dimension — as well as the scores relating to the precision of motor synchronisation obtained through the observation grid used for the video analysis of the routines. To assess the differences between the two groups, an independent samples t-test was used, a statistical procedure frequently employed in quasi-experimental studies in sports science to compare the means of different groups and verify the possible effect of an educational or training intervention.

Descriptive and inferential statistics for group cohesion variables are presented in Table 1, allowing a structured and reproducible comparison between the experimental and control groups across all GEQ dimensions.

As shown in Table 1, the experimental group reported significantly higher levels of group cohesion across all GEQ dimensions compared to the control group. The differences were statistically significant and associated with medium-to-large effect sizes, indicating a consistent and substantial impact of the educational intervention on both task-related and social aspects of cohesion. Significant differences between the two groups also emerged regarding the precision of motor synchronisation, assessed through the analysis of routines recorded during training sessions and competition simulations. Descriptive and inferential statistics for motor synchronisation variables are presented in Table 2, allowing a clear and reproducible comparison between the experimental and control groups across all performance indicators.

As shown in Table 2, the experimental group achieved higher levels of motor synchronisation across all indicators analysed, including temporal precision, uniformity of body positions, synchronisation with the musical rhythm and execution timing consistency. These differences were statistically significant and supported by consistent effect sizes, confirming the positive impact of the intervention on collective coordination performance.

To further examine the internal validity of the findings, additional analyses were conducted across the predefined age subgroups (17–19, 20–23, 24–28 years). Across all age categories, the experimental group consistently reported higher levels of group cohesion compared to the control group on all GEQ dimensions. The pattern of results was stable across subgroups, with mean differences comparable to those observed in the overall sample.

Similarly, for motor synchronisation indicators, the experimental group outperformed the control group within each age subgroup. Improvements were observed in temporal precision, body position uniformity, synchronisation with music, and execution timing consistency across all age ranges.

However, some minor variations emerged. Athletes in the younger subgroup (17–19 years) showed slightly larger differences in social cohesion dimensions, suggesting a stronger impact of the intervention on relational dynamics at earlier developmental stages. In contrast, athletes in the

Table 1. Comparison between experimental and control group on GEQ dimensions

Variable	Group	Mean (M)	SD	t-value	p-value	Effect size (Cohen's d)
Group Integration – Task	Experimental	7.8	0.9	4.21	< .01	0.78
	Control	6.5	1.1			
Group Integration – Social	Experimental	7.6	1.0	3.87	< .01	0.72
	Control	6.3	1.2			
Individual Attraction – Task	Experimental	7.9	0.8	3.95	< .01	0.75
	Control	6.7	1.0			
Individual Attraction – Social	Experimental	7.4	1.1	3.52	< .05	0.65
	Control	6.2	1.3			

Table 2. Comparison between experimental and control group on motor synchronisation indicators

Variable	Group	Mean (%)	SD	p-value	Effect size (Cohen's d)
Temporal precision	Experimental	87	5	< .05	0.80
	Control	74	6		
Body position uniformity	Experimental	85	6	< .05	0.78
	Control	72	7		
Synchronisation with music	Experimental	88	5	< .05	0.82
	Control	76	6		
Execution timing consistency	Experimental	86	6	< .05	0.79
	Control	73	7		

Table 3. Comparison between experimental and control group across age subgroups

Variable	Age group	Experimental (M ± SD)	Control (M ± SD)	p-value
Group Integration – Task	17–19	7.9 ± 0.8	6.4 ± 1.1	< .01
	20–23	7.8 ± 0.9	6.5 ± 1.0	< .01
	24–28	7.7 ± 1.0	6.6 ± 1.1	< .05
Group Integration – Social	17–19	7.7 ± 0.9	6.2 ± 1.2	< .01
	20–23	7.6 ± 1.0	6.3 ± 1.1	< .01
	24–28	7.5 ± 1.1	6.4 ± 1.2	< .05
Temporal precision (%)	17–19	86 ± 6	73 ± 7	< .05
	20–23	87 ± 5	74 ± 6	< .05
	24–28	88 ± 4	75 ± 5	< .05
Synchronisation with music (%)	17–19	87 ± 6	75 ± 7	< .05
	20–23	88 ± 5	76 ± 6	< .05
	24–28	89 ± 4	77 ± 5	< .05

older subgroup (24–28 years) demonstrated more stable performance in motor synchronisation indicators, with lower variability in execution timing.

The two-way ANOVA (Group × Age group) revealed a significant main effect of group ($p < .01$), confirming the overall effectiveness of the educational intervention. The main effect of age was not statistically significant ($p > .05$), indicating that age alone did not account for the observed differences. Importantly, the interaction effect between group and age was not statistically significant ($p > .05$), suggesting that the impact of the intervention was consistent across age groups and not dependent on the age structure of the sample.

As shown in Table 3, the differences between the experimental and control groups remained consistent across all age subgroups, confirming the stability of the intervention effect across different age ranges.

Overall, the results show a consistent pattern across all variables and age groups, with the experimental group outperforming the control group in both cohesion and motor synchronisation, indicating a structured and robust effect of the educational intervention rather than isolated or age-dependent differences.

Qualitative results

The analysis of the qualitative data was carried out through a thematic analysis of the focus group transcripts, with the aim of exploring the athletes' perceptions of the emotional, relational and communicative dynamics that characterise team performance in artistic swimming. The analysis identified several recurring themes in the participants' narratives, particularly regarding the harmony between athletes, the management of emotions during performance, non-verbal communication and the role of mutual trust in team coordination. During the focus groups, a number of guiding questions were used to stimulate reflection and discussion among the participants. Among the main questions posed to the athletes were:

- "How would you describe the level of harmony with your teammates whilst performing the routines?"
- "What emotions do you experience whilst performing a routine in competition or during a performance simulation?"
- "How do you communicate with your teammates during the routine, even without speaking?"
- "How important do you consider mutual trust to be for maintaining synchronisation during the performance?"

With regard to the perception of harmony among the athletes, significant differences emerged between the experimental group and the control group. The athletes in the experimental group, who had taken part in the educational programme aimed at developing group cohesion, described a strong sense of connection and mutual coordination whilst

performing the routines. Several participants emphasised how the collaboration and mutual understanding developed during the intervention had fostered greater fluidity in their movements and a better perception of the collective rhythm. One of the athletes stated: "During the routine, I almost automatically feel my teammates' movements, as if we were all moving to the same rhythm." Another participant noted: "When we're in the water, we don't need to keep looking at each other, because we already know what the other will do." In contrast, the athletes in the control group described coordination based primarily on technical training and the repetition of choreographic sequences. Some participants emphasised that synchronisation depends above all on individual attention and memory of the choreography. One of the athletes stated: "I try to focus a lot on the beat of the music and on what I have to do, trying to stay in sync with the others." Another observed: "If someone makes a mistake or moves too early, it becomes difficult to regain synchronisation." Another theme that emerged from the focus groups concerns the management of emotions during the performance of routines, particularly in competitive contexts. The athletes in the experimental group demonstrated greater awareness of their own emotions and of the strategies used to manage anxiety and the pressure of competition. Some participants highlighted how comparing themselves with their teammates and the reflective activities carried out during the educational intervention helped to develop greater confidence. One of the athletes said: "Before the competition I always feel a bit tense, but knowing that my teammates are as focused as I am helps me stay calm." Another participant said: "When we're in the water I try to focus on the group, not just on myself. This helps me not to get overwhelmed by anxiety." In the control group, however, the athletes described a more individual approach to managing their emotions. Some participants highlighted how the pressure of the competition can affect concentration and the precision of movements.

One of the athletes said: "During the competition, I'm sometimes afraid of making a mistake and this makes me lose my rhythm a bit." Another added: "When I'm very nervous, I find it harder to stay in sync with the others." A further theme that emerged from the analysis concerns the role of non-verbal communication in coordination between the athletes. Participants in the experimental group highlighted the importance of body signals, eye contact and the perception of their teammates' movements in maintaining synchronisation during the routine. One of the athletes explained: "Even without speaking, we can tell when to speed up or slow down just by looking at each other." Another participant said: "During some moves, I can really feel the others' movements and I adapt automatically." In the control group, however, the athletes relied more on the music and counting the beats as their main reference for maintaining coordination. One participant stated: "I try to follow the rhythm of the music above all to stay in time." Finally, a recurring theme that emerged from the discussions concerns the role of mutual trust within the team. The athletes in the experimental group emphasised how trust in their teammates is a fundamental element in approaching the performance with greater confidence. One participant said: "When I know my teammates are as focused and alert as I am, I feel more at ease during the routine." Another stated: "Trust within the group is essential, especially during the most difficult parts of the choreography." In the control group, however, trust within the group was mentioned less frequently and was often linked primarily to the technical competence of teammates.

Discussion

The aim of this study was to analyse the relationship between emotional attunement among female athletes and the precision of motor synchronisation in artistic swimming performances, taking into account the role of relational dynamics and team cohesion in collective coordination processes. In this perspective, sport has increasingly been recognised as a complex educational environment in which motor, cognitive and relational dimensions interact, contributing to both performance and personal development (Di Palma et al., 2025; Mazzeo et al., 2016).

The findings from the quantitative and qualitative analyses provide valuable insights into how psychological and relational factors can influence performance quality in team sports contexts. The quantitative data showed that the experimental group, which took part in an educational programme aimed at developing emotional attunement and group cohesion, reported significantly higher levels of cohesion across the various dimensions measured by the Group Environment Questionnaire compared to the control group. In particular, the athletes in the experimental group showed higher mean scores both in the dimensions relating to task-oriented group integration and in those linked to the social dimension. This result suggests that educational activities aimed at strengthening collaboration, mutual trust and a sense of belonging to the team may contribute to improving the perception of unity and cohesion among group members. Moreover, a growing body of literature has also highlighted how structured and guided motor programmes can significantly enhance social skills, group cohesion and cooperative behaviours in both educational and sport contexts (Tafuri et al., 2026; Raiola et al., 2015). These findings are also consistent with the literature on sports psychology, which suggests that high levels of group cohesion are associated with greater collective performance effectiveness and better coordination among team members (Carron et al., 2002; Eys et al., 2015; Carron et al., 2000).

Similarly, analysis of the data on motor synchronisation revealed that the experimental group achieved higher average scores than the control group across all indicators analysed, including the temporal precision of movements, the uniformity of body positions, synchronisation with the musical rhythm, and the consistency of execution times among the athletes. These results suggest that the development of relational and emotional skills within the team may foster greater interpersonal coordination during the execution of routines. In other words, the athletes' ability to perceive themselves as part of a cohesive group and to share goals and emotional states appears to help facilitate the alignment of movements and the fluidity of collective performance.

Importantly, the stratified analysis by age groups further strengthens the interpretation of these findings. The results showed that the positive effects of the educational intervention on both group cohesion and

motor synchronisation remained consistent across all age subgroups. Although some age-related variability emerged—particularly in relation to social cohesion among younger athletes and greater stability in motor performance among older participants—these differences did not alter the overall pattern of results. From a statistical perspective, the absence of a significant interaction between group and age indicates that the effectiveness of the intervention does not depend on the age structure of the sample. This finding is particularly relevant in addressing potential concerns related to internal validity, as it supports the interpretation that the observed improvements are primarily attributable to the educational programme rather than to developmental differences among participants. In this sense, the results reinforce the idea that emotional attunement and team cohesion act as key mechanisms in facilitating motor synchronisation, independently of age-related factors, confirming the robustness and generalisability of the intervention within the analysed age range.

The qualitative findings further indicated that athletes perceive synchronisation not solely as a technical process but as a form of collective adaptation based on non-verbal communication, emotional connection, and the anticipation of teammates' movements. Emotion regulation also emerged as an important component of performance, as perceived group support and shared emotional states appeared to facilitate concentration and emotional stability during competition. These findings are consistent with previous sport psychology research highlighting the role of emotional regulation processes and psychological coping strategies in maintaining performance under competitive pressure (Lane et al., 2012; Weinberg & Gould, 2019).

The findings of the present study suggest that the relationship between team cohesion and motor synchronisation in artistic swimming should be interpreted as a dynamic and process-based phenomenon rather than a simple associative effect. From an analytical perspective, coordination can be understood as an emergent process resulting from continuous interactions among athletes, in which cognitive, perceptual and emotional components are tightly interconnected. In this framework, group cohesion does not act directly on performance, but operates as a facilitating condition that enhances the efficiency of interpersonal coordination mechanisms.

Conclusion

This study examined the relationship between emotional attunement, group cohesion, and motor synchronisation in artistic swimming performances using a mixed-methods approach that combined questionnaires, video analysis of routines, and focus groups with athletes.

The findings demonstrated that athletes involved in an educational programme focused on emotional and relational skills achieved higher levels of team cohesion and greater precision of motor synchronisation compared to the control group. The results suggest that mutual trust, emotional harmony, and relational quality within the team represent important mechanisms facilitating collective coordination processes.

The qualitative findings additionally indicated that athletes perceive synchronisation not solely as a technical process but as a form of collective adaptation based on non-verbal communication, emotional connection, and the anticipation of teammates' movements. Emotion regulation also emerged as an important component of performance, as perceived group support and shared emotional states appeared to facilitate concentration and emotional stability during competition.

Several limitations should nevertheless be acknowledged. The study was based on convenience sampling and included athletes from a single sporting organisation, which may limit the generalisability of the findings. In addition, the quasi-experimental design relied on pre-existing teams rather than random assignment.

An additional limitation concerns the heterogeneity of the sample in terms of age. Participants ranged from late adolescence to young adulthood (17–28 years), potentially introducing variability in emotional regulation, interpersonal interaction, and coordination abilities. However, subgroup analyses demonstrated that the positive effects of the educational intervention remained consistent across all age categories, supporting the interpretation that the observed improvements were primarily associated with the intervention rather than developmental differences among participants.

Finally, the relatively short duration of the intervention limits conclusions regarding the long-term stability of the observed effects. Future studies should include larger and more diverse samples, longitudinal designs, and more advanced motion-analysis technologies to further investigate the mechanisms underlying collective synchronisation in team sports.

Overall, the findings suggest that motor synchronisation in artistic swimming should be understood not only as a technical skill but also as a multidimensional process shaped by emotional attunement, interpersonal trust, and team cohesion. These results support the integration of socio-emotional and relational training strategies into preparation programmes for highly coordinated team sports.

Ethics Approval

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. Ethical approval for the study protocol was obtained from the institutional ethics committee of the participating university prior to data collection. All procedures involving participants were reviewed and approved in accordance with national and institutional ethical standards.

Informed Consent

All participants provided written informed consent prior to participation in the study. Participants were informed about the objectives, procedures, voluntary nature of participation, and confidentiality of the collected data. For participants under the age of 18 years, written informed consent was additionally obtained from a parent or legal guardian.

Data Availability Statement

The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

AI Transparency Statement

The authors used AI-assisted tools for language editing and text refinement only and take full responsibility for the content of the manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Емоційна синхронізація та моторна координація в артистичному плаванні: роль згуртованості команди в синхронному виступі

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 3 табл., 16 джерел.

Обґрунтування. Моторна синхронізація є ключовим визначальним фактором успішності виступу в артистичному плаванні; однак вона аналізується переважно з технічної точки зору, при цьому емоційним та реляційним процесам у команді приділяється обмежена увага. Більш цілісне розуміння синхронного виступу потребує аналізу взаємодії між емоційним налаштуванням, згуртованістю команди та колективною моторною координацією.

Мета дослідження. Це дослідження мало на меті проаналізувати взаємозв'язок між емоційним налаштуванням, згуртованістю команди та моторною синхронізацією в артистичному плаванні, акцентуючи увагу на вплив навчальної інтервенції, спрямованої на розвиток реляційних та емоційних навичок.

Матеріали і методи. У дослідженні застосовано квазіекспериментальний дизайн із використанням змішаних методів. Вибірку склали 150 спортсменок змагального рівня з артистичного плавання віком 17–28 років, яких було розподілено на експериментальну та контрольну групи. Учасниць додатково стратифікували за трьома віковими підгрупами (17–19, 20–23 та 24–28 років). Експериментальна група пройшла навчальну програму, спрямовану на підвищення згуртованості команди та емоційної усвідомленості. Збір кількісних даних проведено за допомогою опитувальника групового середовища (GEQ) та структурованого відеоаналізу програм, тоді як якісні дані були отримані через фокус-групи. Було застосовано t-критерій для незалежних вибірок та проведено аналіз у підгрупах. Для вивчення взаємодії між інтервенцією та віком виконано двофакторний дисперсійний аналіз (Група × Вікова група).

Результати. Експериментальна група продемонструвала статистично значуще вищі рівні групової згуртованості за всіма вимірами опитувальника GEQ порівняно з контрольною групою (наприклад, інтеграція групи — завдання: M = 7,8 проти 6,5; t = 4,21; p < .01; d = 0,78). Подібні відмінності були виявлені за вимірами «інтеграція групи — соціальна» (M = 7,6 проти 6,3; p < .01) та «індивідуальна привабливість» (p < .05). Експериментальна група також досягла статистично значуще вищих показників моторної синхронізації за всіма індикаторами, включаючи часову точність (87% проти 74%), одноманітність положення тіла (85% проти 72%), синхронність із музикою (88% проти 76%) та стабільність часу виконання (86% проти 73%) (p < .05). Зазначені відмінності залишалися стабільними в усіх вікових підгрупах. Дисперсійний аналіз виявив значущий головний ефект чинника групи (p < .01), тоді як головний ефект віку та ефект взаємодії (Група × Вікова група) були статистично незначущими (p > .05). Результати якісного аналізу додатково підкреслили важливість довіри, невербальної комунікації та спільних емоційних станів для полегшення координації.

Висновки. Моторну синхронізацію в артистичному плаванні слід розглядати не лише як технічну навичку, але й як багатовимірний процес, на який впливають емоційне налаштування та згуртованість команди. Навчальні інтервенції, спрямовані на реляційну та емоційну динаміку, можуть суттєво покращити колективну координацію та якість виступу в командних видах спорту незалежно від вікових відмінностей.

Ключові слова: артистичне плавання, згуртованість команди, моторна синхронізація, емоційне налаштування, спортивна психологія, командна результативність.

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Running as a Psychoeducational Intervention for Reducing Anxiety in Adolescents

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Abstract

Background. Adolescence is a developmental stage characterised by increased vulnerability to anxiety and emotional dysregulation. Physical activity, particularly aerobic exercise such as running, has been identified as a potentially effective and accessible strategy for promoting mental health; however, evidence from structured and inclusive school-based interventions remains limited, especially for adolescents with Special Educational Needs (SEN) and Specific Learning Disorders (SLD).

Objectives. This study aimed to evaluate the effectiveness of a structured running programme in reducing state and trait anxiety among adolescents, and to examine its impact on self-efficacy and emotional well-being, including in students with SEN/SLD.

Materials and Methods. A mixed-methods experimental design with pre-test (T0) and post-test (T1) measures was adopted. The sample consisted of 60 adolescents (aged 13–17 years), divided into an experimental group (n = 30) and a control group (n = 30). The experimental group participated in an 8-week running programme (three sessions per week, 30–40 minutes per session, moderate intensity), while the control group followed regular school activities. Quantitative data were collected using the STAI-C for state and trait anxiety, a self-efficacy scale, and measures of emotional well-being, and were analysed using paired t-tests and repeated-measures ANOVA. Qualitative data were collected through journals, interviews, and guided reflections, and analysed using thematic analysis.

Results. The experimental group showed significant reductions in state anxiety (T0: M = 42.6, SD = 6.1; T1: M = 35.2, SD = 5.4; $t_{(29)} = 6.84$, $p < .001$, $d = 1.25$) and trait anxiety (T0: M = 44.1, SD = 5.8; T1: M = 38.7, SD = 5.2; $t_{(29)} = 5.12$, $p < .001$, $d = 0.94$), while no marked changes were observed in the control group ($p > .05$). Repeated-measures ANOVA revealed significant group × time interactions for state anxiety ($F_{(1,58)} = 21.47$, $p < .001$, $\eta^2_p = .27$) and trait anxiety ($F_{(1,58)} = 16.83$, $p < .001$, $\eta^2_p = .22$). Self-efficacy increased notably in the experimental group (T0: M = 27.4, SD = 4.3; T1: M = 32.1, SD = 4.0; $t_{(29)} = -5.76$, $p < .001$, $d = 1.05$), with no significant change in the control group. Emotional well-being also improved substantially ($F_{(1,58)} = 14.62$, $p < .001$, $\eta^2_p = .20$). Comparable effects were observed in adolescents with and without SEN/SLD. Qualitative findings supported these results, highlighting improvements in emotional regulation, body awareness, self-efficacy, and social connectedness.

Conclusions. Under structured conditions involving moderate intensity, regular frequency, and psychoeducational support (e.g., mindful running and goal setting), running programmes can significantly reduce anxiety and enhance psychological well-being in adolescents. The intervention appears particularly effective for individuals with higher baseline anxiety and is adaptable to inclusive educational contexts, including students with SEN/SLD. These findings support the use of structured running as a scalable and evidence-based strategy for promoting adolescent mental health in school settings.

Keywords: social science education, inclusion, SEN/SLD, blended approach, innovative teaching.

Introduction

Adolescence is a particularly sensitive developmental stage from a neuropsychological perspective, characterized by profound cognitive, emotional, and social changes. The asynchronous development between cognitive control systems and limbic systems involved in emotional and motivational responses contributes to increased reactivity to stress and heightened vulnerability to internalizing disorders, including anxiety (Steinberg, 2014). During this period, environmental demands—particularly those

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related to the school setting, family expectations, and peer relationship dynamics—can represent powerful risk factors for psychological well-being, especially in the absence of adequate coping resources (Compas et al., 2017).

Within this framework, the health promotion approach emphasizes the importance of preventive and universal interventions capable of addressing risk factors early on and strengthening individual and contextual resources. According to the bio-psycho-social model, mental health cannot be understood as merely the absence of symptoms, but as a dynamic state of well-being involving emotional, cognitive, behavioral, and relational dimensions (Engel, 1977). From this perspective, physical activity is not merely a healthy behavior from a physical standpoint, but a powerful educational and psychological tool capable of fostering processes of self-regulation, mind-body integration, and the development of transferable skills (WHO, 2018).

Recent literature highlights that physical activity-based interventions are particularly effective when designed in an intentional and theoretically grounded manner, integrating motivational, relational, and reflective components (Lubans et al., 2016). In the field of sports psychology, various theoretical models—including Self-Determination Theory (Deci & Ryan, 2000) and Social Cognitive Theory (Bandura, 1997) —highlight the central role of motor experience in fostering a sense of competence, autonomy, and self-efficacy, factors closely associated with reduced anxiety levels and improved psychological well-being. In particular, the experience of gradual success, the sense of control over one's own body, and the ability to set realistic and personalized goals are key elements in countering the feelings of helplessness and worry typical of adolescent anxiety.

Compared to other forms of physical activity, running has unique characteristics that make it particularly well-suited for preventive and inclusive interventions. It requires minimal equipment, can be practiced in various settings (school, extracurricular, natural environments), allows for a wide range of intensity levels, and fosters an experiential dimension that is easily adaptable to individual differences. Empirical studies indicate that rhythmic and cyclical aerobic activities, such as running, facilitate emotional regulation and reduce physiological arousal, contributing to a subjective perception of calm and control (Ekkekakis et al., 2011). Furthermore, the repetitiveness of the motor movement and the focus on bodily experience can promote processes of mindful attention, with positive effects on the management of anxious and ruminative thoughts.

From a neuropsychological perspective, numerous findings support the hypothesis that regular aerobic exercise induces functional and structural changes in the brain circuits involved in the regulation of stress and emotions. In particular, it has been observed that physical activity can contribute to a reduction in the amygdala's reactivity to stressful stimuli and to an enhancement of the control functions exerted by the prefrontal cortex, with beneficial effects on emotional regulation (Erickson et al., 2019). These mechanisms are particularly relevant during adolescence, a period when these circuits are still maturing and are therefore more plastic and sensitive to environmental stimuli.

Another point of interest concerns the psychosocial dimension of running when practiced in structured and guided settings. Participation in physical activity programs can foster a sense of belonging, peer support, and the quality of relationships—elements that play a protective role against anxiety and emotional distress (Bailey et al., 2013). Even when practiced primarily as an individual activity, running can take on relational and symbolic significance, becoming a space for self-exploration, emotional expression, and identity formation—aspects central to the adolescent development process.

The focus on the inclusion of adolescents with Special Educational Needs and Specific Learning Disorders addresses a growing need for equity in health promotion initiatives. The literature highlights how students with SLDs may experience higher levels of academic and social anxiety, often related to repeated experiences of failure, stigmatization, or a perception of inadequacy (Nelson & Harwood, 2011). In this sense, interventions centered on physical activity and the body can offer an alternative channel for self-expression and skill development, reducing the burden of cognitive and linguistic demands and fostering experiences of success not mediated by academic performance.

Despite the extensive literature supporting the benefits of physical activity on mental health, some critical issues still emerge. First, many studies employ observational designs or short-term interventions, limiting the ability to draw robust causal conclusions. Second, the number of studies adopting a mixed-methods approach—capable of integrating standardized quantitative data with qualitative analysis of adolescents' subjective experiences—remains limited. Finally, few studies explicitly include educationally heterogeneous samples, systematically considering the presence of SEN/SLD as a relevant variable.

In light of these gaps, it appears necessary to develop experimental studies that evaluate the effectiveness of structured running interventions not only in terms of reducing anxiety symptoms but also with respect to the underlying psychological processes and the participants' lived experiences. The adoption of a qualitative-quantitative approach allows for capturing the complexity of the phenomenon, integrating the objective measurement of changes with an understanding of the meaning attributed to the motor experience by the adolescents themselves.

This study fits within this theoretical and applied framework, aiming to contribute to the literature on sports psychology and health promotion through the experimental evaluation of a structured, inclusive, and well-being-oriented running program targeting a sample of adolescents with and without SEN/SLD. The objective is to provide empirical evidence to support the implementation of physical activity-based interventions in school and preventive settings, promoting running as an educational and emotional regulation tool.The study aims to:

1. Evaluate the effectiveness of a structured running program in reducing anxiety levels among adolescents.
2. Analyze the differences between the experimental group and the control group.
3. Explore, using qualitative methods, adolescents' subjective perceptions regarding emotional well-being, self-efficacy, and anxiety management.
4. Verify the feasibility and effectiveness of the intervention, including among adolescents with special educational needs (SEN) or specific learning disabilities (SLD).

Materials and methods

Study Design

This study employs a controlled experimental design with pre-test and post-test measures, integrating quantitative and qualitative approaches using a mixed-methods methodology. This methodological choice addresses the need to capture not only measurable changes in anxiety levels and related psychological variables, but also to explore in depth the subjective experiences of adolescents during the intervention, in line with the latest findings in sports psychology and health promotion research. The design includes:

- an experimental group, which underwent a structured running program;
- a control group, which did not participate in the intervention and followed normal school activities.

Participants were assigned to groups based on balance by age, gender, and presence of SEN/SLD, in order to reduce potential selection biases and ensure comparability between groups. Both groups were assessed at the same time points (T0 = pre-test; T1 = post-test), allowing for an analysis of intra-group and inter-group variations. The integration of quantitative and qualitative data follows a parallel convergent model, in which the two datasets are collected over the same time period, analyzed separately, and subsequently integrated to provide a comprehensive interpretation of the results.

Participants

The sample consists of 60 adolescents (aged 13 to 17; M = 15.1; SD = 1.2), recruited from middle and high schools located in urban and suburban areas. Participants were selected in collaboration with the participating schools through a project presentation aimed at students, families, and teachers. The sample was divided into two equivalent groups:

- Experimental group (n = 30)
  - 20 students without Special Educational Needs or Specific Learning Disorders.
  - 10 students with certified SEN/SLD (specifically, specific learning disorders and non-intellectual special educational needs).
- Control group (n = 30)
  - 20 students without SEN/SLD.
  - 10 students with certified SEN/SLD.

The intentional inclusion of students with SEN/SLD in both groups meets a criterion of inclusivity and representativeness, allowing for the evaluation of the intervention's effectiveness even within a population that is potentially more vulnerable from an emotional and academic standpoint.

Inclusion criteria

The study included adolescents who met the following criteria:

- aged between 13 and 17 years at the start of the study;
- regular school attendance at their school;
- written informed consent from parents or legal guardians and informed consent from the minor;
- medical fitness to engage in non-competitive aerobic physical activity;
- willingness to participate throughout the entire intervention period and in the pre- and post-intervention assessment phases.

Exclusion criteria:

The following adolescents were excluded from the study:

- severe psychiatric disorders in the acute phase (e.g., psychotic disorders, severe mood disorders that had not stabilized);
- ongoing pharmacological treatments that could significantly influence mood or the response to stress;
- participation in intense competitive sports, defined as more than 5 hours per week, in order to avoid a confounding effect related to high levels of prior training;
- medical conditions incompatible with running.

Educational intervention

After the project was approved by school authorities and informed consent was obtained, participants completed the pre-test phase (T0), during which quantitative assessments were administered and sociodemographic data were collected. Subsequently, the experimental group participated in an 8-week structured running program, while the control group continued with their usual school activities without receiving any additional interventions. At the end of the intervention, both groups completed the post-test phase (T1), using the same quantitative instruments administered during the pre-test phase. Concurrently, qualitative data were collected exclusively from the experimental group. The experimental group participated in a structured running program lasting a total of 8 weeks, designed with preventive and psychoeducational goals, in line with the evidence in the literature indicating that short- to medium-term physical activity interventions (6–12 weeks) can produce significant effects on reducing anxiety symptoms in adolescents (Biddle et al., 2019; Lubans et al., 2016). The choice of an eight-week timeframe addresses the need to ensure sufficient exposure to physical activity while maintaining high adherence and sustainability of the intervention within the school setting. The program included three weekly sessions, in accordance with international recommendations on physical activity for children and adolescents, which indicate a minimum frequency of regular aerobic activity for the maintenance and promotion of mental health (World Health Organization [WHO], 2020). Each session lasted between 30 and 40 minutes, consistent with studies showing that moderate-intensity aerobic exercise sessions lasting longer than 20 minutes are associated with acute and chronic improvements in mood and a reduction in state anxiety levels (Ekkekakis et al., 2011). The intensity of the activity was maintained at a moderate level, defined as a subjective perception of exertion ranging from "light" to "somewhat strenuous," in order to avoid excessive stress responses that could counteract the anxiolytic effects of exercise, particularly in untrained adolescents (Dishman et al., 2006). The intensity was tailored to the participants' individual characteristics, with particular attention given to

students with special educational needs (SEN) and learning disabilities (LD), with a focus on personalization and inclusion. Each running session was structured into three main phases. The initial warm-up phase (approximately 10 minutes) included joint mobility exercises and body activation, with the goal of preparing the musculoskeletal system for exertion and facilitating a gradual transition to aerobic activity. The central phase consisted of continuous or interval running exercises, tailored to the group's level and individual abilities. The final cool-down phase included light stretching and controlled breathing exercises, designed to facilitate a gradual return to a state of physiological calm. Innovative strategies derived from sports psychology and emotional regulation practices were integrated into the intervention's structure, with the aim of enhancing the impact of physical activity on psychological well-being. In particular, mindful running was introduced, encouraging participants to focus their attention on their breathing, stride rhythm, and bodily sensations. This approach is based on evidence linking body awareness and mindfulness to a reduction in ruminative thoughts and anxiety levels (Mehling et al., 2011), and is particularly suitable during adolescence to promote mind-body integration. Another central element of the intervention was personalized goal setting, through which each participant was supported in defining realistic and individualized goals (e.g., maintaining a run for a specific duration or improving the perception of comfort during the activity). The use of goal setting is widely supported by the sports psychology literature, which highlights its effectiveness in promoting motivation, self-efficacy, and persistence in physical activity (Locke & Latham, 2002). In particular, the progressive achievement of personal goals was considered a key factor in counteracting feelings of insecurity and worry, which are common among adolescents with high levels of anxiety. At the end of each session, a brief guided reflection was held, during which participants were invited to share, either verbally or in writing, the emotional and physical sensations they had experienced during the activity. This practice is consistent with reflective approaches in education and sports, which emphasize that verbalizing experiences fosters emotional awareness and the processing of lived experiences, thereby reinforcing the effect of mental health promotion interventions (Schon, 1983; Bailey et al., 2013). The control group did not participate in any structured intervention during the study period and continued with normal school activities. This methodological choice allows any observed changes in the experimental group to be attributed to the effect of the running intervention, reducing the influence of external or developmental factors. Overall, the procedure was designed to ensure theoretical consistency, replicability, and sustainability, with particular attention to inclusivity and the psychological well-being of participants. The integration of physical activity, body awareness, and guided reflection addresses the need to move beyond an exclusively performance-oriented approach to sport, highlighting running as an educational tool and a means of emotional regulation during adolescence.

Data Analysis

The data analysis was conducted using an integrated approach, in line with the study's mixed-methods design, involving statistical analysis of the quantitative data and a systematic qualitative analysis of the narrative materials collected from the experimental group.

Quantitative data were analyzed using specialized statistical software. In the first phase, descriptive statistics (mean, standard deviation, range) were calculated for all variables under study in order to describe the characteristics of the sample and verify the distribution of scores across the different experimental conditions. To assess changes in anxiety levels and related psychological variables within each group, paired t-tests were used, comparing scores obtained at the pre-test (T0) and post-test (T1). This analysis allowed for the identification of any significant changes over time within the experimental group and the control group. Subsequently, to analyze the effect of the intervention and compare the trends of the variables between the two groups, a repeated-measures analysis of variance (ANOVA) was conducted with two factors: a within-subjects factor represented by time (pre-test vs. post-test) and a between-subjects factor represented by group (experimental vs. control). The group × time interaction was considered the primary indicator of the intervention's effectiveness, allowing us to verify whether the changes observed in the experimental group differed significantly from those observed in the control group. Where appropriate, effect size indices (e.g., Cohen's d and partial r-squared) were also calculated to estimate the practical relevance of the results, in line with recommendations from the methodological literature. Additional exploratory analyses were conducted to examine potential differences related to the presence of SEN/SLD, treating these conditions as descriptive variables and assessing the trend of scores across subgroups, with the aim of exploring the consistency of the intervention's effect from an inclusive perspective.

The qualitative data, collected through reflective journals, semi-structured interviews, and guided reflection sessions, were analyzed using thematic analysis, following a systematic and inductive procedure. In the initial phase, the textual materials were read repeatedly to foster a thorough familiarity with the content. Subsequently, relevant units of meaning were identified and open-coded. The initial codes were progressively grouped into thematic categories based on conceptual similarities and semantic recurrences. The analysis led to the identification of main themes related to emotional experiences associated with running, the perception of the body and physical sensations, subjective strategies for managing anxiety, and changes in self-perception and social relationships. To increase the reliability of the analysis, the categorization process underwent iterative review, comparing emerging categories with the theoretical framework, thereby avoiding forced or predefined interpretations. Qualitative analysis was used not only for descriptive purposes but also for interpretive ones, in order to enrich and contextualize the quantitative results.

The quantitative and qualitative results were integrated during the interpretive phase using a data triangulation approach. This integration made it possible to compare the changes measured using standardized instruments with the subjective experiences reported by the participants, thereby strengthening the overall validity of the study and providing a comprehensive understanding of the effectiveness of the running program in managing anxiety among adolescents.

Results

Quantitative results

Analysis of the quantitative data revealed significant differences between the experimental group and the control group with regard to the psychological variables examined (Table 1).

Table 1. Socio-demographic characteristics of the sample

Variable	Experimental Group (n = 30)	Control Group (n = 30)	Tot (N = 60)
Average Age (DS)	15.2 (1.1)	15.0 (1.3)	15.1 (1.2)
Male	14 (46.7%)	15 (50.0%)	29 (48.3%)
Female	16 (53.3%)	15 (50.0%)	31 (51.7%)
Students without SEND	20 (66.7%)	20 (66.7%)	40 (66.7%)
Students with SEND	10 (33.3%)	10 (33.3%)	20 (33.3%)
Secondary School	13 (43.3%)	12 (40.0%)	25 (41.7%)
High School	17 (56.7%)	18 (60.0%)	35 (58.3%)

With regard to state anxiety, the experimental group showed a statistically significant reduction in scores between the pre-test and post-test. Specifically, the mean pre-test score was M = 42.6 (SD = 6.1), while the post-test score decreased to M = 35.2 (SD = 5.4). The paired t-test revealed a significant difference, $t_{(29)} = 6.84$, $p < .001$, with a large effect size (Cohen's d = 1.25)(Table 2).

Table 2. Average (DS) pre-test post-test STAI-C

Group	Pre-test M (DS)	Post-test M (DS)	Δ M
Experimental	42.6 (6.1)	35.2 (5.4)	-7.4
Control	41.9 (6.3)	41.2 (6.5)	-0.7

Nota. Δ M = average difference post-test and pre-test.

A similar trend was observed for trait anxiety. In the experimental group, the mean score decreased from M = 44.1 (SD = 5.8) at the pre-test to M = 38.7 (SD = 5.2) at the post-test. Again, the reduction was statistically significant, $t_{(29)} = 5.12$, $p < .001$, with a medium-to-large effect size (Cohen's d = 0.94)(Table 3).

Table 3. Average (DS) pre-test and post-test STAI-C

Group	Pre-test M (DS)	Post-test M (DS)	Δ M
Experimental	44.1 (5.8)	38.7 (5.2)	-5.4
Control	43.7 (5.9)	43.1 (6.0)	-0.6

In the control group, by contrast, no statistically significant changes were observed for either state anxiety or trait anxiety. Mean scores remained essentially stable between the pre-test and post-test (state anxiety: M = 41.9, SD = 6.3 vs. M = 41.2, SD = 6.5; trait anxiety: M = 43.7, SD = 5.9 vs. M = 43.1, SD = 6.0), with non-significant p-values.

Repeated-measures analysis of variance confirmed these results, revealing a significant group × time interaction for both state anxiety, $F_{(1,58)} = 21.47$, $p < .001$, $\eta^2_p = .27$, and for trait anxiety, $F_{(1,58)} = 16.83$, $p < .001$, $\eta^2_p = .22$, indicating that the reduction in anxiety levels over time is attributable to the running intervention (Table 4).

Table 4. ANOVA results repeated measurements (group × time)

Variabile	$F_{(1,58)}$	p	η^2_p
State Anxiety	21.47	< .001	.27
Trait Anxiety	16.83	< .001	.22
Perceived self-efficacy	18.06	< .001	.24
Emotional Well-being (SDQ)	14.62	< .001	.20

Nota. η^2_p = partial sum of squares.

With regard to perceived self-efficacy, the experimental group showed a significant increase in scores from the pre-test (M = 27.4; SD = 4.3) to the post-test (M = 32.1; SD = 4.0), $t_{(29)} = -5.76$, $p < .001$, Cohen's d = 1.05. In the control group, the increase in scores did not reach statistical significance (M = 27.9; SD = 4.1 vs M = 28.4; SD = 4.2)(Table 5).

Table 5. Average (DS) pre-test and post-test perceived self-efficacy

Group	Pre-test M (DS)	Post-test M (DS)	Δ M
Experimental	27.4 (4.3)	32.1 (4.0)	+4.7
Control	27.9 (4.1)	28.4 (4.2)	+0.5

Measures of general emotional well-being also showed a significant improvement in the experimental group, with a reduction in emotional distress scores and an increase in adaptive resources. The group × time interaction was significant, $F_{(1,58)} = 14.62$, $p < .001$, $\eta^2_p = .20$, suggesting an overall positive effect of the intervention on emotional functioning.

An exploratory subgroup analysis also showed that adolescents with SEN/SLD in the experimental group benefited from the intervention to a comparable extent to their peers without SEN/SLD. In both subgroups, reductions in anxiety levels and increases in self-efficacy were significant, with no statistically significant differences in effect size. This finding suggests that the structured running programme proved to be effective and inclusive, regardless of the presence of special educational needs or specific learning difficulties (Table 6).

Table 6. SEND vs non SEND

Variable	BES/DSA Δ M	Non BES/DSA Δ M	p
State Anxiety	-7.1	-7.6	p > 0.05
Trait Anxiety	-5.2	-5.5	p > 0.05
Percived Self-Efficacy	+4.5	+4.8	p > 0.05

No statistically significant differences were observed between adolescents with and without SEN/SLD across all variables. The magnitude of change was comparable between groups, with p-values consistently exceeding the significance threshold (p > 0.05), indicating a similar response to the intervention regardless of educational needs.

Overall, the quantitative results indicate that participation in the running programme led to significant and clinically relevant improvements in anxiety levels, perceived self-efficacy and general emotional well-being among adolescents, whereas no such changes were observed in the control group.

Qualitative results

The qualitative analysis of the data collected from the experimental group enabled an in-depth exploration of the subjective experiences of the adolescents involved in the running programme, providing a detailed understanding of the psychological processes underlying the changes observed in the quantitative data. The thematic analysis revealed four main broad themes, which cut across gender, age and the presence of SEN/SLD, albeit with some individual variations. The first thematic area concerns the perception of emotions and emotional regulation. Numerous participants described a gradual reduction in feelings of tension, agitation and worry over the course of the intervention weeks. Running was frequently associated with experiences of 'mental relief' and temporary detachment from sources of daily stress, particularly those linked to school and social relationships. Some adolescents reported that, compared to the initial phase, by the end of the programme it was easier to recognise and manage states of anxiety without feeling overwhelmed by negative emotions. This finding appears consistent with the reduction in state and trait anxiety scores observed in the quantitative analyses. A second thematic area concerns the perception of the body and physical sensations. In the early stages, several participants reported focusing predominantly on fatigue, a racing heartbeat and laboured breathing. As the intervention progressed, these sensations were gradually reinterpreted as signs of the body functioning rather than as indicators of distress or loss of control. In particular, the practice of mindful running fostered greater familiarity with bodily sensations and a reduction in catastrophic interpretations associated with physiological signals, an aspect particularly relevant for adolescents with high somatic anxiety. The third thematic area emerging from the qualitative analysis concerns the sense of self-efficacy and personal competence. Many participants emphasised the importance of achieving small personal goals, such as being able to run for longer or feeling less tired than in the first sessions. These experiences were frequently described as a source of personal satisfaction and increased confidence in their own abilities. This aspect was particularly evident among adolescents with SEN/SLD, who reported that running provided a space where they could feel competent and valued, regardless of the difficulties they experienced at school. The accounts gathered suggest that the programme helped to change their self-perception, fostering a more positive and functional self-image. A fourth thematic area concerns the relational and social dimension of the experience. Although running was structured as a predominantly individual activity, many participants highlighted the value of the group setting as a source of emotional and motivational support. Sharing the experience, the absence of competitive judgement and the atmosphere perceived as welcoming fostered a sense of belonging and helped normalise emotional difficulties. Some adolescents reported an improvement in the quality of their peer relationships, both within the intervention group and in the wider school context, attributing these changes to greater self-confidence and a reduction in social anxiety. Overall, the qualitative findings suggest that the running programme did not act solely on a symptomatic level, but triggered deeper processes of change, involving emotional awareness, body image, perceived competence and social relationships. The integration of physical activity, guided reflection and personalised goals appears to have fostered a meaningful and transformative experience, capable of supporting adolescents' psychological well-being in an inclusive manner. The qualitative analysis reinforces and enriches the quantitative findings, suggesting that the reduction in anxiety levels observed in the experimental group is mediated not only by physiological factors, but also by cognitive and emotional changes linked to the way in which adolescents interpret their own feelings, cope with difficulties and attribute meaning to the running experience.

Discussion

The aim of this study was to evaluate the effectiveness of a structured running programme in reducing anxiety levels in a sample of adolescents, using a mixed-methods approach and intentionally including students with Special Educational Needs and Specific Learning Disorders. The results provide converging evidence supporting the hypothesis that running, when offered as part of a deliberate, guided and non-competitive intervention, can be an effective tool for promoting mental health in childhood and adolescence.

From a quantitative perspective, the significant reduction in state and trait anxiety levels observed in the experimental group appears consistent with findings in the international literature on the anxiolytic effect of aerobic physical activity. Meta-analyses and systematic reviews have indeed shown that structured physical exercise programmes are associated with a reduction in anxiety symptoms in children and adolescents, with moderate to high effect sizes, particularly in interventions involving regular frequency and moderate intensity (Biddle et al., 2019; Rodriguez-Ayllon et al., 2019). The results of the present study are consistent with this evidence, reinforcing the hypothesis that physical activity may act as a protective factor against emotional distress in adolescence.

The absence of significant changes in the control group further supports the causal interpretation of the results, suggesting that the changes observed in the experimental group are attributable to the running intervention rather than to maturational or contextual factors. This aspect is particularly relevant in studies conducted in school settings, where numerous environmental variables can influence adolescents' psychological well-being in the short term.

A further significant finding concerns the significant increase in perceived self-efficacy in the experimental group. According to Social Cognitive Theory, self-efficacy represents a key variable in the regulation of behaviour and emotions, influencing the way in which individuals cope with stressful situations and interpret their own coping abilities (Bandura, 1997). The increase in self-efficacy observed in the present study suggests that the running programme fostered experiences of mastery and control, helping to reduce the perception of vulnerability typical of adolescent anxiety. These findings are consistent with previous studies that have highlighted a positive relationship between physical activity, perceived competence and psychological well-being in childhood and adolescence (Lubans et al., 2016).

Qualitative analysis allows us to explore the mechanisms underlying these quantitative changes, offering a more nuanced understanding of the participants' lived experience. The adolescents' accounts highlight how running has been

progressively reinterpreted not only as a physical activity, but as a space for emotional regulation, self-exploration and stress management. In particular, the reduction in feelings of agitation and the increased ability to recognise and tolerate anxious sensations suggest a change in the cognitive processes of emotional interpretation, in line with models of emotional regulation that emphasise the importance of awareness and acceptance of internal experiences (Gross, 2015).

The bodily dimension emerges as a central element in the experience of change. In an initial phase, many participants describe a problematic relationship with the physiological sensations associated with exertion, often interpreted as signals of loss of control or danger. As the intervention progresses, these sensations are gradually normalised and integrated, leading to a reduction in somatic anxiety. This finding appears particularly significant in light of evidence linking adolescent anxiety to hypersensitivity to bodily signals and catastrophic interpretations of physiological sensations (Domschke et al., 2010). The practice of mindful running appears to have played a facilitating role in this process, supporting greater mind-body integration.

A significant contribution of the present study concerns the inclusion of adolescents with SEN/SLD and the observation of benefits comparable to those of peers without special educational needs. The literature highlights that students with SLD present an increased risk of internalising emotional difficulties, often linked to school experiences characterised by frustration, performance anxiety and reduced self-esteem (Nelson & Harwood, 2011; Mugnaini et al., 2009). In this context, running emerges as an activity with low cognitive barriers, in which performance is not mediated by linguistic or academic skills, offering alternative opportunities for success and reinforcing a more positive self-image. The results of this study suggest that interventions of this kind may help to reduce emotional inequalities and promote well-being from a truly inclusive perspective.

The relational dimension, which emerged strongly from the qualitative analysis, represents a further aspect of interest. Although running is often considered an individual activity, the group context and non-competitive atmosphere appear to have fostered a sense of belonging and mutual support. This finding is consistent with the literature highlighting the role of peer relationships as a protective factor for mental health in adolescence (Bailey et al., 2013). The opportunity to share the experience without judgement and without performance comparison appears particularly relevant for adolescents with high levels of social anxiety.

Overall, the results suggest that the effectiveness of the intervention cannot be attributed solely to the physiological mechanisms of aerobic exercise, such as the modulation of the hypothalamic-pituitary-adrenal axis or the release of endorphins and endocannabinoids (Dishman et al., 2006; Matta Mello Portugal et al., 2013), but must be interpreted in the light of an integrated model that includes psychological, cognitive and social dimensions.

In order to further clarify the scope and applicability of the findings, it is important to define the boundaries of effectiveness of the intervention. The results of the present study suggest that the anxiolytic effects of the running programme are not uniform across all conditions, but are influenced by specific parameters related to intensity, duration, and baseline psychological characteristics.

First, the effectiveness of the intervention appears to be strongest under conditions of moderate exercise intensity. The programme was intentionally designed to maintain a moderate level of perceived exertion, avoiding excessive physiological activation that could potentially increase anxiety, particularly in untrained or vulnerable adolescents. This finding is consistent with the literature indicating that moderate-intensity aerobic activity is optimal for emotional regulation, whereas very high intensity may produce counterproductive stress responses.

Second, the duration and regularity of the intervention represent critical factors. The observed improvements emerged within an 8-week programme with a frequency of three sessions per week, suggesting that a minimum threshold of exposure is necessary to activate both physiological and psychological mechanisms of change. Shorter or less frequent interventions may not produce comparable effects, while longer programmes may be required to ensure the stability and consolidation of outcomes over time.

Third, baseline levels of anxiety appear to play a moderating role in the effectiveness of the intervention. Although improvements were observed across the entire experimental group, qualitative and quantitative trends suggest that adolescents with higher initial levels of anxiety experienced more pronounced benefits, particularly in terms of emotional regulation and perceived self-efficacy. This indicates that the intervention may be especially effective as a targeted preventive or early intervention strategy for individuals at greater psychological risk.

Finally, the effectiveness of the programme appears to depend on its structured and guided nature, including the integration of mindful running, personalised goal setting, and reflective practices. These elements likely enhance the psychological impact of physical activity, suggesting that running in itself may not be sufficient unless embedded within a coherent psychoeducational framework.

In addition to defining the conditions of effectiveness, it is important to consider the functional dynamics through which the observed changes developed over time. The results of the present study suggest that the response to the intervention followed a progressive and multi-phase trajectory, rather than an immediate or uniform effect.

In an initial phase, participants appeared to experience a period of physiological and psychological adjustment, often characterised by heightened awareness of bodily sensations (e.g., fatigue, increased heart rate) and, in some cases, mild discomfort or resistance. Qualitative data indicate that, during this stage, some adolescents tended to interpret these sensations as signs of difficulty or inefficiency, particularly those with higher baseline anxiety levels.

This was followed by an adaptive phase, during which participants progressively reinterpreted bodily signals as functional and non-threatening. The repeated exposure to running, combined with mindful attention and guided reflection, appeared to facilitate a shift in cognitive appraisal, leading to improved emotional regulation and a reduction in catastrophic interpretations of physiological activation. This adaptive process is consistent with theoretical models of interoceptive exposure and emotion regulation.

In the later phase of the intervention, participants demonstrated consolidation of both psychological and behavioural changes. This phase was characterised by

increased self-efficacy, greater autonomy in managing effort, and a more stable perception of emotional control. The ability to set and achieve personalised goals further reinforced these changes, contributing to a positive feedback loop between perceived competence and emotional well-being.

Importantly, the data also suggest the presence of individual variability in response to the intervention. While most participants showed progressive improvements, the rate and magnitude of change differed depending on factors such as initial anxiety levels, prior experience with physical activity, and personal coping styles. In particular, adolescents with higher baseline anxiety appeared to exhibit slower initial adaptation but greater overall gains over time.

These findings highlight that the effectiveness of running as a psychoeducational intervention is not static, but unfolds through dynamic and adaptive processes that vary across individuals and over time. Understanding these functional dynamics is essential for optimising intervention design and tailoring programmes to the specific needs of different adolescent populations.

From a practical perspective, the findings of this study provide clear indications for the implementation of running-based psychoeducational interventions in school and youth settings. To ensure effectiveness, the intervention should be applied as a structured and guided programme rather than as a generic physical activity. Specifically, it should include a predefined duration (at least 8 weeks), a regular frequency (approximately three sessions per week), and sessions lasting between 30 and 40 minutes, in line with the parameters adopted in the present study. The intensity of the activity should be maintained at a moderate level, allowing participants to remain engaged without triggering excessive physiological stress.

In addition, the integration of key psychoeducational components is essential. These include mindful attention to bodily sensations during running, personalised goal setting tailored to individual abilities, and guided reflection at the end of each session. These elements appear to play a crucial role in enhancing emotional regulation, self-efficacy, and adherence to the programme, and should therefore be considered core components rather than optional additions.

The intervention can be effectively adapted to heterogeneous groups, including adolescents with Special Educational Needs and Specific Learning Disorders. In these cases, particular attention should be given to flexibility and personalisation. For example, running intensity and duration may be adjusted based on individual capacities, and alternative forms of participation (e.g., walking–running intervals) can be introduced. The use of clear, simple instructions, visual supports, and consistent routines can facilitate engagement for students with learning difficulties. Moreover, the non-competitive and inclusive nature of the programme should be preserved to ensure that all participants experience a sense of competence and psychological safety.

Key parameters for successful implementation include the presence of trained facilitators (e.g., physical education teachers or educators with basic training in sports psychology), a supportive and non-judgmental environment, and the integration of the programme within the school schedule to ensure continuity and accessibility. Monitoring tools, such as brief self-report measures or reflective journals, may also be useful to track progress and adapt the intervention over time.

Overall, these findings suggest that running-based interventions can be feasibly implemented in educational contexts as low-cost, scalable, and inclusive strategies for promoting adolescent mental health, provided that they are designed and delivered according to structured, theory-informed principles.

The combination of physical activity, body awareness, personalised goal-setting and guided reflection appears to have triggered a multi-level process of change, in line with the principles of health promotion.

From a practical perspective, the findings of this study offer valuable insights for the design of preventive interventions in schools. The inclusion of structured running programmes within the curriculum or as extracurricular activities could represent a sustainable and cost-effective strategy for supporting adolescents' mental health. However, the data suggest that the effectiveness of such interventions depends largely on the quality of the design and the presence of competent guidance, capable of integrating physical activity with educational and reflective dimensions.

Despite the encouraging results, the study has certain limitations that must be considered. Firstly, the sample size, whilst adequate for a pilot experimental study, limits the generalisability of the results. Secondly, the duration of the intervention does not allow for an assessment of the stability of the effects in the long term. Future studies could include longitudinal follow-ups to verify the persistence of benefits and the role of adherence over time. Furthermore, the use of self-report measures, although widely validated, could be supplemented with physiological or observational indicators for a more comprehensive assessment of changes.

Looking ahead, it would be desirable to explore the comparative effectiveness of different types of physical activity, as well as the specific role of the innovative components introduced in this intervention, such as mindful running and goal setting. Further research could also investigate individual differences in response to the intervention, considering variables such as baseline anxiety levels, gender and socio-cultural context.

In conclusion, this study contributes to the literature on sports psychology and health promotion by providing evidence supporting the effectiveness of running as a psycho-educational intervention for reducing anxiety in adolescence. The integration of quantitative and qualitative approaches has enabled us to capture the complexity of change processes, highlighting how physical activity, if properly structured, can represent not only a means of prevention but also a space for personal growth, inclusion and psychological well-being.

Conclusions

This study analysed the effectiveness of a structured running programme as an intervention to promote mental health in adolescence, adopting a mixed-methods experimental approach and intentionally including students with Special Educational Needs and Specific Learning Disorders. Overall, the results provide consistent and converging evidence supporting the hypothesis that running, when designed and conducted in a purposeful, guided and non-competitive manner, can be an effective tool for reducing anxiety levels and improving psychological well-being in childhood and adolescence.

The quantitative data revealed a significant reduction in state and trait anxiety, an increase in perceived self-efficacy and an improvement in general emotional well-being in the experimental group, compared with the absence of significant changes in the control group. These results suggest that the intervention produced changes not attributable to maturational or contextual factors, but specifically linked to participation in the running programme. The presence of comparable benefits in adolescents with and without SEN/SLD further reinforces the inclusive value of the intervention, indicating that running can provide a space for positive and accessible experiences even for students with greater emotional and academic vulnerabilities.

The qualitative analysis allowed for an in-depth exploration of the processes underlying these changes, highlighting how the experience of running was perceived by the adolescents not only as physical activity, but as an opportunity for emotional regulation, for re-evaluating their relationship with their bodies, and for strengthening their sense of personal competence. The narratives collected suggest that the integration of mindful running, personalised goal setting and guided reflection sessions fostered greater emotional awareness and a transformation in the way adolescents interpret and manage feelings of anxiety. In this sense, the intervention appears to have operated on multiple levels, combining physiological, psychological and relational effects.

From a practical perspective, the study's findings highlight the potential of running as a tool for promoting mental health in school and educational settings. The relative simplicity of the activity, the possibility of adapting it to different ability levels, and its cost- and resource-effectiveness make running particularly suitable for preventive programmes targeting large groups of adolescents. However, the data suggest that the effectiveness of the intervention does not depend solely on the physical activity itself, but on the quality of the design and the ability to integrate educational, motivational and reflective dimensions into the programme.

Overall, this study contributes to expanding the literature on sports psychology and health promotion, highlighting how physical activity can take on an educational and transformative role when delivered in a mindful and inclusive manner. Running emerges not only as a means of reducing anxiety symptoms, but as an experience capable of supporting the development of fundamental personal resources in adolescence, such as self-efficacy, self-awareness and the ability to cope with emotional difficulties.

In light of these considerations, it is hoped that future interventions and research will continue to explore and refine the use of running and other physical activities from a preventive perspective, integrating them permanently into school and community settings, with the aim of promoting a conception of mental health that values movement, the body and experience as central resources for adolescents' well-being.

Ethics Approval

The study was conducted in accordance with the principles of the Declaration of Helsinki. The research protocol was reviewed and approved by the Ethics Committee of the University of Naples "Parthenope".

Informed Consent

All participants provided written informed consent prior to participation in the study. Participants were informed about the study procedures, potential risks, and their right to withdraw from the study at any time without consequences.

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

AI Transparency Statement

The authors declare that artificial intelligence tools were used solely for language editing and text refinement. All scientific content, analysis, and interpretations were developed and verified by the authors.

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Біг як психоосвітня інтервенція для зниження рівня тривожності в підлітків

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 11 с., 6 табл., 22 джерела.

Обґрунтування. Підлітковий вік є етапом розвитку, що характеризується підвищеною вразливістю до тривожності та емоційної дисрегуляції. Фізична активність, зокрема аеробні вправи, як-от біг, визначається як потенційно ефективна та доступна стратегія зміцнення психічного здоров'я; утім, кількість наукових даних щодо структурованих та інклюзивних інтервенцій на базі шкіл залишається обмеженою, особливо стосовно підлітків з особливими освітніми потребами (ООП) та специфічними розладами навчання (СРН).

Мета дослідження. Це дослідження мало на меті оцінити ефективність структурованої програми з бігу у зниженні ситуативної та особистісної тривожності серед підлітків, а також вивчити її вплив на самоефективність та емоційне благополуччя, зокрема в учнів з ООП/СРН.

Матеріали і методи. У роботі застосовано експериментальний дизайн із використанням змішаних методів та вимірюванням показників на претест (T0) та постестовому етапах дослідження (T1). Вибірку склали 60 підлітків (віком 13–17 років), яких було розподілено на експериментальну (n = 30) та контрольну (n = 30) групи. Експериментальна група брала участь у 8-тижневій програмі з бігу (три заняття на тиждень, по 30–40 хвилин кожне, помірна інтенсивність), тоді як контрольна група займалася стандартною шкільною активністю. Збирання кількісних даних проведено за допомогою опитувальника STAI-C (шкала тривоги Спілбергера-Ханіна) для оцінки ситуативної та особистісної тривожності, шкали самоефективності та методик вимірювання емоційного благополуччя. Аналіз здійснювали за допомогою t-критеріїв для

парних вибірок та дисперсійного аналізу з повторними вимірюваннями. Якісні дані збирали за допомогою щоденників, інтерв'ю та керованої рефлексії, а аналізували методом тематичного аналізу.

Результати. В експериментальній групі зафіксовано статистично значуще зниження ситуативної тривожності (T0: M = 42, 6, SD = 6,1; T1: M = 35,2, SD = 5,4; t(29) = 6,84, p < .001, d = 1,25) та особистісної тривожності (T0: M = 44,1, SD = 5,8; T1: M = 38,7, SD = 5,2; $t_{(29)}$ = 5,12, p < .001, d = 0,94), тоді як у контрольній групі суттєвих змін не виявлено (p > .05). Дисперсійний аналіз з повторними вимірюваннями показав значущу взаємодію факторів «група х час» для ситуативної тривожності ($F_{(1,58)}$ = 21.47, p < .001, η^2_p = .27) та особистісної тривожності ($F_{(1,58)}$ = 16,83, p < .001, η^2_p = .22). Показники самоефективності суттєво зросли в експериментальній групі (T0: M = 27,4, SD = 4,3; T1: M = 32,1, SD = 4,0; $t_{(29)}$ = −5,76, p < .001, d = 1,05) за відсутності значущих змін у контрольній групі. Емоційне благополуччя також статистично значуще покращилося ($F_{(1,58)}$ = 14,62, p < .001, η^2_p = .20). Подібні ефекти спостерігалися як у підлітків з ООП/СРН, так і без них. Якісні результати підтвердили ці дані, вказуючи на покращення емоційної регуляції, усвідомлення власного тіла, підвищення самоефективності та зміцнення соціальних зв'язків.

Висновки. За умов структурованого підходу, що передбачає помірну інтенсивність, регулярність занять та психоосвітній супровід (наприклад, усвідомлений біг та постановку цілей), програми з бігу здатні суттєво знизити рівень тривожності та покращити психологічне благополуччя підлітків. Ця інтервенція є особливо ефективною для осіб із вищим базовим рівнем тривожності та легко адаптується до інклюзивного освітнього середовища, зокрема для учнів з ООП/СРН. Отримані результати свідчать на користь використання структурованого бігу як доступної та науково обґрунтованої стратегії зміцнення психічного здоров'я підлітків в умовах закладу освіти.

Ключові слова: суспільствознавча освіта, інклюзія, ООП/СРН, змішаний метод, інноваційне навчання.

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Original Scientific Articles. Health-Related Physical Activity and Inclusion

The Association Between Physical Activity and Loneliness Among International Students in Java

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Abstract

Background. Perceived loneliness and social isolation are significant challenges for international students adapting to different cultural and academic environments. Physical activity has been suggested as a key factor that may be associated with mental health, social interactions, and emotional well-being.

Objectives. The study aimed to examine the association between physical activity and loneliness among international students residing in Java, Indonesia.

Materials and Methods. A cross-sectional survey was conducted with 164 international students from universities in Java, selected using random sampling. Physical activity levels were assessed using the International Physical Activity Questionnaire (IPAQ), and loneliness was measured via the Revised UCLA Loneliness Scale. Descriptive statistics and multiple linear regression analyses were performed using SPSS v.2025.

Results. The majority of participants were highly educated, and 56.1% reported high physical activity. Loneliness was prevalent, with 68.9% of students experiencing moderate to high levels. Multiple regression analysis indicated a significant negative association between physical activity and loneliness ($\beta = -0.42$, $p = 0.001$), explaining 23% of the variance.

Conclusions. These findings suggest that higher levels of physical activity are associated with lower loneliness among international students, highlighting the potential role of physical activity in supporting social inclusion and well-being. Universities may consider promoting structured physical activity opportunities to facilitate student engagement and adjustment.

Keywords: international students, physical activity, loneliness.

Introduction

Educational globalisation studies primarily focus on the growing trend of international student mobility, with millions of students seeking higher education outside their home countries each year. According to Project Atlas, about 5.3 million students study abroad worldwide. In the United States alone, there are more than one million international students. International students are increasingly choosing Southeast Asian countries such as Indonesia as their study destinations due to improvements in their educational infrastructure (Suryadi et al., 2023). Java has become a popular place for students from both Indonesia and other countries to study, given its higher concentration of schools and relatively better infrastructure compared to other parts of Indonesia. The Indonesian Central Bureau of Statistics said that in the 2021/2022 school year, there were 2,181,900 students on the island of Java, which is home to 5,273 high schools. This distribution contributes to the role as an educational centre (Lenge & Huwae, 2023).

Even though there are many benefits to being an international student, there are also many health problems associated with it, such as loneliness, difficulty adjusting to a new culture, and homesickness (Suryadi et al., 2023). Researchers have found that loneliness is a common problem among international students, and it is associated with serious effects on their mental health, academic performance, and quality of life (Cahyadi, 2019; Koo & Jiang, 2022; Wachyunni et al., 2023). The COVID-19 pandemic has made these problems even worse. Research

shows that mental health problems, such as self-harm and suicidal thoughts, have risen sharply among young adults and students living away from home, especially in Java (Liem et al., 2021). Given the significance of loneliness, there is a growing interest in examining how exercise may relate to mental health among international students (Suryadi et al., 2023). Java is the most populous island in Indonesia, and it is home to many of the nation's universities and colleges. As a result, it has become a popular place for students from both Indonesia and other countries to study (Lenge & Huwae, 2023). These students frequently encounter difficulties associated with cultural adaptation, linguistic obstacles, and social integration (Wachyunni et al., 2023).

Loneliness, in a psychological perspective, is the feeling that one's social relationships are not adequate in some way, both in terms of the number of people they know and how well they know them (Faisal & Turnip, 2019). It is different from mere physical isolation; it reflects a deeper sense of emotional and social disconnection. International students often feel incredibly alone because they are far away from their families, come from different cultures, and don't speak the same language (Koo & Jiang, 2022). Researchers established emotional loneliness, social loneliness, and cultural loneliness as distinct dimensions of this phenomenon (Akoth & Enoksen, 2022).

Physical activity encompasses a movement that utilises energy, including organised exercise and routine activities such as walking or leisure excursions. Research indicates that participation in physical activity is associated with improvements in psychological well-being, such as lower levels of stress, higher self-esteem, and increased opportunities for social interactions, especially in communal environments (Lenge & Huwae, 2023). Ryff's multidimensional model of psychological well-being refers to self-acceptance, positive relationships, autonomy, environmental mastery, a sense of purpose in life, and personal growth. Research indicates a substantial inverse association between loneliness and factors such as environmental mastery and positive relationships among international students (Cahyadi, 2019).

Studies consistently show that international students report higher levels of loneliness than domestic students, potentially related to differences in social media usage and cultural contexts (Koo & Jiang, 2022). Research conducted in Indonesia, notably by Cahyadi (2019), identified a negative correlation between loneliness and psychological well-being, with heightened loneliness associated with cultural and identity differences (Wachyunni et al., 2023). Moreover, physical activity has been demonstrated to markedly improve psychological well-being by elevating mood, alleviating loneliness, and promoting social connections (Lenge & Huwae, 2023).

Several key findings are well established: International students often experience elevated loneliness compared to domestic students, primarily related to cultural and social challenges (Akoth & Enoksen, 2022; Koo & Jiang, 2022). Loneliness adversely affects psychological well-being, significantly influencing environmental mastery and interpersonal relationships (Cahyadi, 2019). Physical activity, especially in group contexts, significantly mitigates loneliness by promoting social interaction and fostering community development (Lenge & Huwae, 2023). Previous research has examined the role of physical activity in improving well-being; however, it has not specifically investigated its capacity to mitigate loneliness among international students in Java (Lenge & Huwae, 2023). Moreover, although the impact of culture shock is identified as a factor related to increased loneliness, research on structured physical activity programs as a potential intervention for loneliness remains limited (Suryadi et al., 2023; Wachyunni et al., 2023).

While there has been extensive research on the well-being of international students, no one has examined the link between physical activity and lower loneliness among international students in Java (Lenge & Huwae, 2023). This indicates a significant gap in the literature, particularly given the elevated levels of loneliness reported among these students (Liem et al., 2021). This research investigates whether participation in physical activity can mitigate feelings of loneliness among international students in Java. It seeks to: (1) examine the prevalence and characteristics of loneliness; (2) investigate patterns of physical activity engagement; and (3) explore the correlation between physical activity and loneliness levels. The study aims to contribute to understanding factors related to mental health among international students in Java.

Materials and Methods

Study Design and Participants

The study employed a cross-sectional survey design. The target population consisted of international students enrolled in academic programs at universities located in the Indonesian province of Java. Data collection was conducted using a non-probability convenience sampling approach, which is widely applied in studies involving specific and difficult-to-access populations, including international student communities.

Participants were eligible for inclusion if they had resided in Indonesia, specifically on the island of Java, for at least six months and were officially enrolled as international students at universities in the region. Students who were not enrolled in universities in Java or had not yet obtained international student status were excluded from participation.

A voluntary self-administered questionnaire was distributed via WhatsApp. Initially, 220 responses were collected. To reduce potential bias associated with the overrepresentation of certain nationalities, simple random sampling was subsequently applied to obtain a more balanced nationality distribution, resulting in a final analysed sample of 164 participants.

The questionnaire was prepared using clear and simple language, avoiding unnecessarily complex sentence structures. Participants required approximately 15–35 minutes to complete the survey. All collected data were treated as strictly confidential to ensure respondents' privacy and anonymity.

Instruments

Physical Activity Assessment

Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003), a validated instrument extensively used in international

research due to its reliability, practicality, and cost-effectiveness. The IPAQ evaluates physical activity performed during the previous seven days across three domains: walking, moderate-intensity activity, and vigorous-intensity activity.

Physical activity volume was expressed in metabolic equivalent task minutes per week (MET-min/week). According to IPAQ scoring procedures, walking activity was assigned 3.3 METs, moderate activity 4.0 METs, and vigorous activity 8.0 METs. Total weekly physical activity was calculated using the formula:

MET-min/week=MET×days×minutes

Based on IPAQ scoring guidelines, participants were classified into low, moderate, or high physical activity categories.

Loneliness Assessment

Loneliness was measured using the 20-item Revised UCLA Loneliness Scale (Russell et al., 1980), a validated self-report instrument designed to assess perceived emotional and social isolation. Responses were scored on a four-point Likert scale ranging from 1 ("Never") to 4 ("Often"). Total scores ranged from 20 to 80, with higher scores indicating greater levels of loneliness.

For analytical purposes, participants were classified into the following categories: low loneliness (20–29), medium-low loneliness (30–40), medium-high loneliness (41–50), and very high loneliness (51–80), according to normative data reported for college student populations.

Statistical Analysis

Data were analysed using SPSS version 2025. Descriptive statistics were calculated for all study variables. Data normality was assessed prior to inferential analysis. Multiple regression analysis was performed to examine the relationship between physical activity and loneliness while controlling for potential confounding variables.

Statistical significance was established at: $p<0.05$.

All results are presented in the tables below.

Results

Participants: 164 foreign students aged 18–52 years from different nations currently studying at distinct universities across Java, Indonesia (male n = 90, female n = 74, SD = 5.97) took part in this study. Ethical approval by the respective institutional review board, which supervised compliance with ethical standards in this investigation, was obtained. Written consent for all participants was obtained, and their anonymity and confidentiality were warranted.

Table 1. Participant Level of Study

Variable	Frequency	Percent
Associate Degree	1	.6
Bachelor's Degree	61	37.2
Doctoral Degree	21	12.8
Master's Degree	81	49.4
Total	164	100.0

Table 1 presents educational attainment among the 164 respondents: the largest group held a master's degree (n = 81, 49.4%), followed by a bachelor's degree (n = 61, 37.2%). The sample includes 12.8% (n = 21) of respondents with a doctoral degree and only 0.6% (n = 1) with an associate degree. Together, more than half of the respondents (50.6%) have a graduate-level degree, resulting in a mostly well-educated sample.

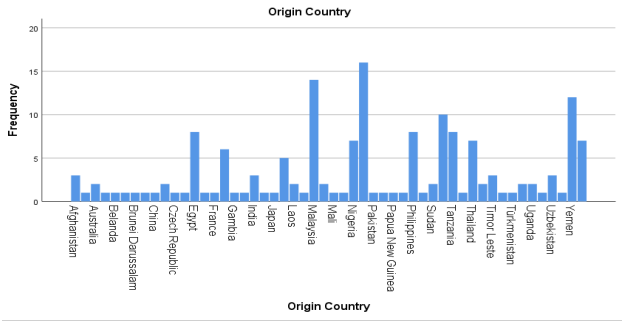

Fig. 1. Participant Country Origin

Figure 1 illustrates the frequency of respondents from each represented country. The highest numbers were observed for Pakistan (n = 16), Malaysia (n = 14), and Yemen (n = 12). There is moderate representation for Sudan (n = 10), Egypt and the Philippines (n = 8), and France (n = 6). Other nations have few respondents at all, with Afghanistan, China, Brunei, the Czech Republic, Japan, Laos, Papua New Guinea, Timor Leste, and Turkmenistan each contributing only one or two. In general, the chart reveals that the sample is diverse geographically but has high density in a few countries, suggesting possible spatial clustering in the data.

Table 2. Descriptive Statistics: Frequency Table for Physical Activity

Characteristics		N	Percentage
Physical Activity	High	92	56.1
	Low	16	9.8
	Moderate	56	34.1
	Total	164	100.0

The distribution of physical activity levels among the 164 respondents is presented in Table 2, with most participants reporting high levels of physical activity (n = 92, 56.1%), followed by moderate physical activity (n = 56, 34.1%). Fewer respondents self-reported low physical activity (n = 16, 9.8%). Overall, the data indicate that most respondents exhibit moderate to high physical activity, while a small proportion report low activity levels.

Table 3. Descriptive Statistics: Frequency Table for Loneliness

Variable	Frequency	Percent
High loneliness	113	68.9
Low loneliness	4	2.4
Moderate loneliness	11	6.7
Moderately high loneliness	36	22.0
Total	164	100.0

Table 3 summarises the pattern of loneliness levels among the 164 respondents, with a majority reporting high loneliness (n = 113, 68.9%) and others reporting moderate or low loneliness (n = 36, 22.0%). Some experienced moderate loneliness (n=11, 6.7%); a few experienced low loneliness (n=4, 2.4%). Overall, the data indicate that a substantial portion of the sample exhibits moderate to high loneliness, with 91% of respondents falling into these categories.

Table 4. Multiple Regression Results

Predictor Variable	B	SE B	β	t	p
Physical Activity	-0.37	0.08	-0.42	4.88	0.001
Age	0.05	0.03	0.08	1.67	0.097
Gender (Male=1, Female=0)	-0.11	0.10	-0.06	1.10	0.273
Country Origin	-0.08	0.05	-0.07	1.60	0.112
Level of Study	-0.06	0.04	-0.06	1.50	0.136
Language Proficiency	-0.05	0.04	-0.05	1.40	0.165

Model Summary: $R^2 = 0.23$, $F(3, 160) = 15.8$, $p < 0.001$, B – Unstandardized, β – Standardized

The multiple linear regression model significantly projected levels of loneliness, accounting for 23% of the variation ($R^2 = 0.23$, $F(3, 160) = 15.8$, $p < 0.001$). Physical activity was identified as the only significant predictor ($\beta = -0.42$, $p = 0.001$), indicating a negative correlation with loneliness, such that greater physical activity was associated with lower loneliness scores. Conversely, Age, gender, country of origin, level of education, and language competence exhibited negligible, non-significant correlations with loneliness ($p > 0.05$), indicating a modest impact on perceived social isolation in this setting. These results indicate that higher reported physical activity levels were statistically associated with lower loneliness scores, while demographic factors showed no significant associations in this sample.

Discussion

This study examined the association between physical activity and loneliness among international students in Java. The multiple linear regression analysis indicated that higher reported physical activity levels were statistically associated with lower loneliness scores, while demographic factors such as age, gender, country of origin, level of study, and language proficiency showed no significant associations. The observed association aligns with previous research indicating a negative correlation between physical activity and loneliness in university populations across diverse cultural contexts. These findings suggest that students who report higher engagement in physical activity tend to report lower levels of loneliness, consistent with patterns identified in both international and local student samples. The data also highlight that a considerable portion of participants experienced moderate to high loneliness, indicating that social isolation remains prevalent among international students in Java. This underscores the relevance of facilitating opportunities for participation in physical activity as part of broader student support initiatives.

The current findings indicate an association between higher levels of physical activity and lower levels of loneliness among international students acclimating to life in Java. This pattern corresponds with extensive literature indicating a negative correlation between physical exercise and loneliness among university populations, encompassing both international and local students across many cultural contexts. Reduced physical activity was independently associated with increased loneliness and diminished mood among German university students during the COVID-19 pandemic, consistent with evidence of a potential link between physical activity and social and mental well-being (Wenig et al., 2023). Research integrating cross-cultural samples has demonstrated that physical activity, especially in socially interactive contexts (e.g., team sports or group activities), is associated with diminished loneliness and improved social integration among college students (Gestsdóttir et al., 2021; Nie et al., 2025; Akoth & Enoksen, 2022). This study's findings extend the observed associations to international students within an Indonesian context, suggesting that opportunities for social interaction, shared routines, and communal experiences may relate to social integration across diverse campus settings.

The literature suggests a potential bidirectional relationship between physical activity and loneliness. Increased physical activity can reduce loneliness, whereas heightened loneliness may diminish the urge to participate in activities, establishing a feedback loop that can obstruct the acculturation processes of international students (Wenig et al., 2023; Zhang et al., 2024). This study design does not establish causality; however, the observed association aligns with theoretical models suggesting that social engagement during physical activity is a vital mechanism for social integration and psychological resilience among newcomer students (Gao et al., 2025; Lei et al., 2025). The amalgamation of these findings with extensive loneliness research in university demographics—emphasising emotional and social loneliness as interconnected yet separate constructs—reinforces the notion that physical activity interventions may target various dimensions of loneliness pertinent to international students acclimating to a novel educational and cultural environment (Diehl et al., 2018; Ruz et al., 2020).

Participation in team- or group-oriented physical activities provides contexts for social interaction, friendship formation, and network development, which are associated with lower perceived social isolation. This pattern is supported by research showing that sports involvement fosters interpersonal relationships and social inclusion, therefore alleviating loneliness among university students (Nie et al., 2025; Han et al., 2025). Physical activity is consistently associated with improvements in mood and reductions in depressive and anxious symptoms, which might indirectly alleviate loneliness by enhancing overall well-being and diminishing perceived social threat or the risk of social disengagement. This aligns with evidence emphasising the mental health benefits of physical activity, which may mitigate loneliness by enhancing mood and resilience (Rahgozar & Giménez-Llort, 2024; Perone et al., 2025). In our environment, international students experiencing acculturative stress may encounter loneliness, in part due to negative affect; positive affect may disrupt rumination and foster pleasant emotions, thereby reducing perceived loneliness and enhancing the willingness to connect socially (Feng et al., 2024).

Consistent physical activity is associated with elevated mood, diminished anxiety and depression symptoms, and

enhanced overall well-being, which may foster greater engagement in social interactions and campus life, thereby indirectly alleviating loneliness (Wenig et al., 2023; Gestsdóttir et al., 2021; Coco et al., 2025). Exercise enhances self-regulatory abilities and stress management, perhaps helping international students manage acculturative stress, social obstacles, and language difficulties. This pathway has been well documented in exercise psychology research, linking physical activity to enhanced emotional regulation and social adaptation, which in turn affect loneliness (Zhang et al., 2024; Lei et al., 2025).

Engaging in physical activity enhances sleep quality, which is associated with improved emotional regulation and diminished feelings of loneliness. Although not all studies identify sleep as a mediator, numerous investigations have shown that physical activity enhances sleep quality and concurrently improves mental health outcomes in student populations (Wang et al., 2023; Wenig et al., 2023). Self-efficacy and competence assessments may modulate the impact of physical activity on loneliness. Regular physical activity can enhance self-efficacy regarding social engagement (e.g., "I can participate in group activities" or "I can navigate new social contexts"), which social-cognitive theories propose diminishes loneliness by augmenting agency and perceived social competence (Maj et al., 2024; Das, 2024). The extensive research on migration highlights self-efficacy as a protective factor against acculturative stress and loneliness among foreign students across diverse environments. In contrast, internet-based self-efficacy therapies have demonstrated efficacy in alleviating loneliness among migrant populations (Maj et al., 2024).

Team-oriented physical activities provide opportunities for social engagement, foster a sense of community, and facilitate the development of social identity in unfamiliar settings. This aligns with theories of social integration that highlight the significance of shared activities in building friendships and social networks, which subsequently diminish. In Java, PA settings for international students, including intramural sports, fitness classes, and outdoor activities, serve as accessible social hubs that bridge linguistic and cultural divides, promoting a sense of belonging among peers (Nilsson & Stålnacke, 2019; Bešić et al., 2020). PA can serve as a low-stigma environment that broadens social networks beyond academic spheres. In the literature concerning migrants and international students, social support and peer networks are pivotal for adaptation and wellbeing; activities that unite students—particularly in physically engaging environments—promote informal social connections, the sharing of information regarding campus life, and integration into the host culture. As networks develop through preferential attachment, loneliness is expected to decrease due to increased perceived social support (Nwokedi, 2020; Dhanji et al., 2023; Fong et al., 2024).

Regular physical exercise regulates physiological stress responses (e.g., diminished cortisol reactivity, enhanced autonomic functioning) and reduces indicators of chronic stress, thereby reducing the physiological basis for loneliness-associated discomfort. This corresponds with studies indicating that physical activity has stress-buffering effects, enhancing mental health and social functioning in migrants and students (Rahgozar & Giménez-Llort, 2024; Perone et al., 2025). Regular physical activity enhances sleep quality and energy levels, promoting daytime social interaction and alleviating weariness that may hinder social involvement. Sleep and fatigue are recognised factors that contribute to loneliness and social disengagement; enhancements through physical activity have been reported across many populations, including students and migrants (Feng et al., 2024; Perone et al., 2025). Moreover, a previous study among international students in Java found a strong positive association between physical exercise and life satisfaction, indicating that regular physical activity is not only directly related to physical fitness but also to emotional health and quality of life (Salman et al., 2025).

Social integration theory suggests that engagement in collective physical activities fosters mutual adaptation between international students and local peers, hence improving integration and alleviating loneliness. The identified correlation endorses the notion that physical activity-facilitated social integration may serve as an effective therapeutic approach for loneliness during cross-cultural transitions (Nilsson & Stålnacke, 2019; Bešić et al., 2020). The stress-buffering concept posits that positive affect mitigates the detrimental health effects of acculturative stress and isolation, thereby safeguarding well-being and facilitating social functioning. Our findings substantiate the role of PA as a protective factor against loneliness during cultural adjustment, consistent with the literature on international students and migrant studies, which indicates that PA and organised social activities alleviate stress and loneliness during transitional phases (Dhanji et al., 2023; Perone et al., 2025). The literature suggests that the benefits of physical activity for loneliness and well-being are applicable across many migration and student contexts; however, the processes may be influenced by gender, culture, and social norms. Certain studies indicate gender-specific pathways, such as a greater reduction in loneliness with physical activity among women in specific samples, highlighting social self-efficacy as a mediating factor. We recognise these subtleties and the potential for context (Java) and cultural expectations to alter how PA affects loneliness (Feng et al., 2024; Kupcewicz et al., 2024).

Establish and finance campus-oriented group physical activity initiatives aimed at international students. Universities ought to introduce consistent, culturally inclusive group activities (e.g., guided walks, novice-friendly team sports, social exercise clubs) that prioritise social engagement and a sense of belonging. Research from many studies indicates that these formats are particularly efficacious in alleviating loneliness and fostering social connectedness among students (Nie et al., 2025; Akoth & Enoksen, 2022). PA programmes may be integrated into comprehensive orientation and intercultural integration initiatives, combining physical activities with peer mentoring, language assistance, and social events to promote cross-cultural connections and a sense of belonging (Han et al., 2025; Lei et al., 2025). Policies must guarantee affordable access to facilities, transportation options for campus activities, and scheduling that accommodates international students' academic commitments and potential caregiving duties. The social-spatial aspect of constructed environments can affect loneliness, suggesting that university designers should facilitate activity-friendly areas and accessible routes to communal activities (Deng et al., 2025).

The study did not account for potential seasonal or environmental factors, such as variations in weather or differences between urban and rural campus settings, which may influence physical activity patterns and opportunities for social interaction. Physical activity was measured solely in terms of total MET-minutes per week, without distinguishing between solitary and group-based activities, potentially overlooking the distinct social benefits of group engagement. Additionally, participants' academic workload and stress levels were not assessed, which could independently affect both loneliness and physical activity participation. The sample was limited to international students in Java, limiting generalizability to other geographic or cultural contexts. Finally, important confounding variables, including personality traits, social support availability, and language proficiency, were not considered and may have influenced perceptions of loneliness.

Future research employing longitudinal or experimental methodologies is necessary to clarify causal links between physical exercise and loneliness. Generalizability could be improved by including participants from other areas and educational systems. Additionally, examining supposed mediators, such as social integration, acculturative stress, and psychological resilience, is necessary to clarify the influence of physical activity on loneliness. An applied viewpoint must also evaluate the efficacy of structured physical activity programs in alleviating loneliness among international student groups.

Conclusion

This study identified a significant negative association between physical activity and loneliness among international students in Java, Indonesia. Participants reporting higher levels of physical activity tended to report lower levels of loneliness. A substantial number of students continued to experience moderate to high loneliness, indicating that social isolation remains common in this population. These findings emphasise the importance of promoting opportunities for physical activity within university settings as part of broader student support initiatives.

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Ethical Approval

This study was approved by the Institutional Review Board (IRB) of the Faculty of Sports and Health Sciences, Universitas Negeri Yogyakarta, Indonesia. The study was approved in accordance with the ethical guidelines of the Declaration of Helsinki. All subjects were informed of the aims and procedures of the study prior to participation and provided written informed consent electronically before completing the online questionnaire. Participation was voluntary, and respondents were guaranteed anonymity and confidentiality. That no personally identifiable information was collected.

Informed Consent

Participation in the study was based on informed written consent of all participants. Participation was voluntary, and respondents were told that they could withdraw at any time without consequence.

Data Availability Statement

The data that support the results of this study are available from the corresponding author upon request.

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The authors also declare that no artificial intelligence (AI) assisted technologies were utilised in the writing, analysis, or preparation of this manuscript.

Conflict of Interest

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Зв'язок між фізичною активністю та відчуттям самотності серед іноземних студентів на острові Ява

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 4 табл., 1 рис., 34 джерела.

Обґрунтування. Суб'єктивне відчуття самотності та соціальна ізоляція є серйозними викликами для іноземних студентів, які адаптуються до іншого культурного та академічного середовища. Фізична активність розглядається як ключовий фактор, пов'язаний із психічним здоров'ям, соціальною взаємодією та емоційним благополуччям.

Мета дослідження. Дослідження мало на меті вивчити зв'язок між фізичною активністю та відчуттям самотності серед іноземних студентів, які проживають на острові Ява (Індонезія).

Матеріали і методи. Проведено поперечне опитування 164 іноземних студентів із вищих навчальних закладів Яви, відібраних методом рандомізованої вибірки. Рівень фізичної активності оцінювали за допомогою Міжнародного опитувальника фізичної активності (IPAQ), а відчуття самотності — за допомогою Переглянутої шкали самотності Каліфорнійського університету в Лос-Анджелесі (UCLA). Описову статистику та множинний лінійний регресійний аналіз виконано у програмі SPSS (v. 2025).

Результати. Більшість учасників мали високий рівень освіти, при цьому 56,1% повідомили про високу фізичну активність. Відчуття самотності було поширеним явищем: 68,9% студентів відчували його на помірному або високому рівні. Множинний регресійний аналіз показав значущий негативний зв'язок між фізичною активністю та самотністю ($\beta = -0{,}42$, $p = 0{,}001$), що пояснює 23% дисперсії.

Висновки. Отримані результати свідчать про те, що вищі рівні фізичної активності пов'язані з нижчим рівнем відчуття самотності серед іноземних студентів, підкреслюючи потенційну роль фізичної активності у підтримці соціальної інклюзії та благополуччя. Закладам вищої освіти варто розглянути можливість впровадження структурованих заходів із фізичної активності для сприяння залученості та адаптації студентів.

Ключові слова: іноземні студенти, фізична активність, самотність.

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