



# Self-Regulated Movement Education: Effects on Motivation, Fitness and Motor Engagement

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## Abstract

**Objectives.** This study aimed to evaluate the effectiveness of a physical education programme focused on self-regulation and autonomy support in enhancing motor engagement and motivational variables in adolescents, integrating objective measures using inertial sensors (IMU/wearable) and qualitative analysis through interviews.

**Materials and Methods.** A pre-post experimental study was carried out with a total of 353 participants (mean age  $14.2 \pm 1.1$  years), divided into an experimental group ( $n = 178$ ) and a control group ( $n = 175$ ). The following measures were employed: motivation (PLOC-R), self-efficacy for physical activity (barriers self-efficacy), fitness (EUROFIT: standing long jump, 20 m shuttle run, sit-and-reach, handgrip) and IMU metrics (active time, vector magnitude, jerk) during standardised lesson windows. Semi-structured interviews were conducted with an involvement of 32 students and 8 teachers, followed by a thematic analysis.

**Results.** The experimental group showed greater improvements than the control group in autonomous motivation ( $\Delta$  intrinsic regulation  $+0.64$  vs  $+0.10$ ,  $p < .001$ ), self-efficacy ( $+0.41$  vs  $+0.07$ ,  $p < .001$ ), fitness (e.g., long jump  $+9.3$  cm vs  $+2.1$  cm,  $p < .001$ ) and objectively measured motor engagement (active time  $+9.5$  percentage points vs  $+1.3$ ,  $p < .001$ ). The interviews highlighted high acceptability, increased awareness of movement and the importance of the teacher's role in preventing social comparison dynamics.

**Conclusions.** The integration of IMU measures facilitates a more comprehensive assessment of school programmes' effectiveness, combining motivational and performance outcomes with objective indicators of motor behaviour.

**Keywords:** motor self-regulation, motor engagement, inertial sensors, physical education.

## Introduction

Promoting meaningful physical activity in physical education classes is an educational and public health priority, particularly during adolescence (Latino et al., 2023). At this stage of development, the quality of the school experience in terms of physical activity can influence not only participation in classes, but also the adoption and maintenance of physically active behaviours over time (Susanto et al., 2024). Simply being exposed to physical activity is not enough to guarantee high levels of participation or lasting benefits, making it necessary to adopt a teaching approach that

focuses on the motivational and relational processes that support student engagement (Raiola et al., 2015).

A well-established line of research, based on Self-Determination Theory, indicates that interventions aimed at supporting the psychological needs of autonomy, competence and relatedness are associated with more favourable outcomes in terms of autonomous motivation, well-being and physical activity behaviours (Reeve & Cheon, 2021; Cheon et al., 2022). In the field of school physical education, recent reviews show that autonomy-supportive teaching programmes produce generally small to moderate but consistent effects on motivation and participation, especially when such approaches are integrated with a clear structure, explicit success criteria and informative feedback (Fierro-Suero et al., 2024). This evidence suggests that the effectiveness of the intervention does not depend exclusively

on the individual characteristics of the students, but also on classroom processes and the teacher's teaching style.

Despite these advances, the evaluation of the effectiveness of interventions in physical education often remains anchored to “product” indicators, such as fitness tests or self-administered questionnaires, with less attention paid to “process” indicators that describe how much and how students move during class.

This limitation is significant, as observational studies show that a substantial part of class time can be characterised by low movement density and downtime, even when final test results are positive (Clemente et al., 2021).

In recent years, the introduction of wearable devices has expanded the possibilities for objective measurement of physical activity in educational settings. However, evidence on the effectiveness of wearables in schools is mixed. Recent meta-analyses indicate that the use of activity trackers, when considered as an isolated intervention, does not guarantee robust increases in physical activity in adolescents, while highlighting marked methodological variability and often moderate overall evidence quality (Au et al., 2024). These results suggest that technological devices should not be conceived as “stand-alone” tools, but integrated into structured and theoretically informed educational strategies.

In this context, the use of inertial sensors (Inertial Measurement Units, IMUs), which combine accelerometers and gyroscopes, makes it possible to go beyond measurements limited to the intensity or duration of activity, allowing indicators related to the quality and regularity of movement to be derived.

Recent methodological evidence supports the validity and reliability of single-sensor IMU solutions in estimating kinematic parameters in functional and sports tasks (Hughes et al., 2022; Cereatti et al., 2024). Furthermore, these devices can be used in educational contexts to monitor workload and compare teaching models based on objective process data. At the same time, methodological reviews emphasise the need for transparency and standardisation in the analysis of signals from wearables in order to improve the comparability of studies and the robustness of interpretations (Liang et al., 2024).

Alongside the quantitative dimension, it is essential to consider the acceptability and meaning attributed to the technology by students and teachers. Recent qualitative studies conducted in schools indicate that wearables can promote awareness and reflection on one's own motor behaviour, but can also generate social comparison dynamics and negative emotional reactions if the data are not adequately mediated by the teacher (Wort et al., 2024).

This evidence reinforces the idea that the educational value of wearable devices depends largely on how they are integrated into the teaching context and framed at a pedagogical level.

In light of these considerations, this study aims to evaluate the effectiveness of a physical education programme focused on self-regulation and autonomy support on motivational variables, fitness and motor engagement measured objectively using inertial sensors. Furthermore, through a mixed-methods approach, the study aims to explore the perceptions of students and teachers regarding the use of wearables in order to understand the interpretative mechanisms and conditions that favour their effective educational implementation.

*Purpose of the study.* Evaluate the effect of a programme focused on self-regulation and autonomy support on: (1) motivation, (2) self-efficacy, (3) fitness, and (4) engagement and movement quality measured using IMU; also explore, through interviews, the perception, acceptability, and interpretative mechanisms associated with the use of wearables.

## Materials and Methods

### Study Design

Experimental study with pre- (T0) and post- (T1) measurements and two groups (experimental vs. control), assigned by class (natural cluster). The quantitative component was applied to the entire sample of students (questionnaires, fitness tests and IMU measurements), while the qualitative component was adopted on an intentional subsample of students ( $n = 32$ ) and teachers involved in the intervention ( $n = 8$ ), selected to explore in depth perceptions, acceptability and interpretative mechanisms related to the programme and the use of wearables.

### Tests Used

**Motivation:** Perceived Locus of Causality – Revised (PLOC-R). The choice is supported by recent psychometric validation in school physical education contexts.

**Self-efficacy for physical activity:** measures of self-efficacy for physical activity in childhood with evidence of factorial validity in school samples.

**Fitness:** EUROFIT battery (standing long jump; 20 m shuttle run; sit-and-reach; handgrip), in line with Council of Europe documentation.

**IMU/wearable:** inertial sensor (accelerometer + gyroscope) worn on the arm or smartphone attached to the arm.

**Metrics:** active time (%); 2) average vector magnitude and p95; 3) jerk RMS (regularity/control). Choices consistent with evidence on IMU validity and methodological recommendations on the analysis of signals from wearable devices.

### Sample

Total  $n = 353$  students ( $14.2 \pm 1.1$  years; 52.4% female).

Experimental group:  $n = 178$  ( $14.1 \pm 1.1$ ; 51.7% female)

Control group:  $n = 175$  ( $14.3 \pm 1.2$ ; 53.1% female)

Classes: 12 (6 experimental, 6 control).

Completeness of pre-post data for primary analysis:  $n = 340$  (96.3%); missing item-level < 2% with imputation by item.

### Inclusion criteria

- Aged 12–16; regular enrolment in lessons; expected attendance  $\geq 80\%$  during the intervention.
- Informed consent of parents/guardians and consent of the student.
- Suitability for school practice according to the institution's procedures.

### Exclusion criteria

- Injuries or conditions that limit participation in the baseline.

- Inability to wear the device.
- Invalid IMU data (wear time < 12 minutes on a standardised 20-minute window at least one timepoint).

### *Activities Carried Out (Intervention)*

The educational intervention (9 weeks; 2 lessons per week; 55 minutes each) was designed to systematically integrate four components considered central in contemporary literature on school physical education: (a) autonomy support, (b) competence-oriented structure, (c) relationships and cooperation, (d) motor learning self-regulation practices. This combination responds to evidence that motivational and behavioural outcomes are more favourable when autonomy support is accompanied by a clear structure and informative feedback, avoiding controlling styles (Cheon et al., 2022; Fierro-Suero et al., 2024). Before the study began, the teachers assigned to the experimental group participated in operational training (approximately 4 hours), aimed at translating the theoretical principles of Self-Determination Theory into observable teaching behaviours. In particular, the training covered: (i) the use of non-controlling language oriented towards the rationale of the activities; (ii) offering meaningful but guided choices; (iii) the explicit definition of objectives and criteria for success; (iv) the systematic integration of moments of self-regulation (definition of objectives, monitoring and reflection); (v) the educational management of data from inertial sensors in a formative and non-competitive manner.

This approach is consistent with experimental interventions that have shown how changing the teacher's teaching style can improve the classroom climate, student motivation and participation behaviour (Cheon et al., 2022). To ensure the fidelity of the intervention, standardised lesson plans and weekly checklists relating to the presence of key components were used.

### *Lesson Structure*

Each lesson in the experimental group followed a stable structure in order to increase predictability and a sense of competence, while introducing task variations to support autonomy and differentiation.

### *Initial Briefing (7–8 minutes)*

The teacher presented the lesson objectives, both in terms of motor skills and active involvement. Students were offered a “guided choice” between two or three equivalent task variants, differentiated by level of difficulty. Each student was invited to set a personal micro-goal, encouraging the activation of self-regulation processes. The integration of choice and structure reflects the findings of studies that highlight the positive effects of combined autonomy-supportive and structuring teaching styles (Reeve & Cheon, 2021; Fierro-Suero et al., 2024).

### *Technical-Coordination Block (18–20 minutes)*

The activities were organised into circuits with stations featuring graduated progressions, focusing on the quality

of movement (e.g. stability, postural control, regularity of movement) rather than simply increasing intensity. The feedback provided by the instructor was informative and corrective, based on observable criteria, avoiding comparative evaluations. Halfway through the block, there was a brief moment of rapid self-assessment, during which students could confirm or modify the level of difficulty they had chosen.

### *Application Block with Small-Sided Games (18–20 minutes)*

Small-sided games and situational tasks were used to increase participation density, reduce downtime and encourage decision-making. Recent literature shows that manipulating variables such as number of players, playing space and regulatory constraints significantly influences physical load and motor involvement in educational and youth contexts (Clemente et al., 2021; Neag et al., 2024). The introduction of cooperative goals and role rotation further supported fairness of participation.

### *Final debriefing (7–8 minutes)*

The lesson ended with a structured reflection phase. Students were guided to evaluate two main aspects: continuity of movement (how active they remained) and control of the movement (quality/regularity of execution). The teacher provided a summary of criteria at the group level and invited each student to set a goal for the next lesson, reinforcing the planning and monitoring processes.

### *Progression of the intervention*

- The intervention was divided into three successive phases.
- The first phase (weeks 1–3) focused on introducing self-regulation routines and familiarising participants with the criteria for success.
- The second phase (weeks 4–6) emphasised task differentiation and increased complexity, supporting decision-making autonomy.
- The third phase (weeks 7–9) aimed to transfer self-regulation strategies to more dynamic and complex tasks, while maintaining a high level of participation.

### *Integration of inertial sensors*

Inertial sensors were integrated for two purposes: to objectively measure motor engagement and movement quality, and to support formative feedback. Recordings were made in three standardised lessons (weeks 1, 5 and 9) over a 20-minute window (10 minutes of circuit training and 10 minutes of small-sided games). The metrics considered included active time, average movement intensity and indicators of regularity (jerk).

The choice to use IMU is consistent with studies demonstrating its validity and reliability in measuring kinematic parameters and movement loads (Hughes et al., 2022). Additionally, IMU-based approaches show potential for application in educational contexts to support the evaluation of the teaching process.

The data were returned exclusively in aggregate form (class or group level), avoiding individual rankings. This

choice responds to qualitative evidence indicating that unmediated use of data can encourage social comparisons and negative emotional reactions, while a teacher-guided approach increases its acceptability and educational value (Wort et al., 2024).

**Control Condition**

The control group followed the institute’s standard practice, including initial warm-up, exercises proposed by the teacher and final game, without structured self-regulation routines and without educational feedback from the sensors.

**Quantitative Results**

**Data**

The overall sample consisted of 353 students (age  $14.2 \pm 1.1$  years; 52.4% female), distributed across 12 classes (6 experimental, 6 control). The completeness of pre-post data for the primary analysis was high ( $n = 340$ ; 96.3%). The main reasons for incompleteness included absences in one of the two test sessions and invalid IMU data due to insufficient wear time.

**IMU data and compliance.** Compliance with IMU recordings was 94.6% with valid wear time at both timepoints; 19 students (5.4%) were excluded from the IMU analysis due to wear time < 12 minutes over a standardised 20-minute window at least one timepoint. No significant differences emerged between those included and those excluded in terms of age, gender, or baseline motivational scores (all  $p > .10$ ).

**Internal reliability.** The psychometric scales showed adequate internal consistency: intrinsic PLOC-R  $\alpha = .88$  (T0) and  $.90$  (T1); identified  $\alpha = .84$  and  $.86$ ; external  $\alpha = .79$  and  $.80$ ; amotivation  $\alpha = .82$  and  $.83$ ; self-efficacy  $\alpha = .86$  and  $.87$ .

**Statistical analyses.** Linear mixed models with random intercepts per class were estimated, including Group (experimental vs. control), Time (T0 vs. T1) and Group×Time interaction as fixed effects. Gender and age were included as covariates. Estimates are reported as means  $\pm$  SD and as differences in change ( $\Delta$ ) with 95% CI and effect size (d).

**Table 1.** Motivational outcomes (PLOC-R). Intrinsic regulation

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$4.38 \pm 1.12$	$5.02 \pm 1.05$	+0.64
Control	$4.41 \pm 1.10$	$4.51 \pm 1.09$	+0.10

**Interpretation:** the increase in intrinsic regulation in the experimental group, higher than in the control group, indicates an increase in autonomous motivation and quality of perceived experience compared to ordinary practice.

**Table 2.** Identified adjustment

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$4.92 \pm 0.98$	$5.29 \pm 0.92$	+0.37
Control	$4.89 \pm 1.01$	$4.97 \pm 1.02$	+0.08

**Interpretation:** the increase in identified regulation suggests greater attribution of personal/instrumental value to the proposed activities.

**Table 3.** Amotivation

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$2.31 \pm 1.14$	$1.92 \pm 1.03$	-0.39
Control	$2.28 \pm 1.12$	$2.21 \pm 1.10$	-0.07

**Interpretation:** the reduction in amotivation in the experimental group is consistent with a greater sense of purpose and better alignment between tasks and perceptions of competence/autonomy.

**Table 4.** External regulation

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$2.84 \pm 1.07$	$2.69 \pm 1.01$	-0.15
Control	$2.81 \pm 1.05$	$2.79 \pm 1.07$	-0.02

**Interpretation:** the non-significant reduction in external regulation indicates that the main change concerns the increase in autonomous components rather than a marked decrease in perceived external pressures.

**Table 5.** Self-efficacy for physical activity (scale 1–5)

Group T0	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$3.26 \pm 0.68$	$3.67 \pm 0.64$	+0.41
Control	$3.29 \pm 0.69$	$3.36 \pm 0.70$	+0.07

**Sensitivity analysis (interpretative):** the effect remains stable when age and gender are included as covariates; no significant Time×Group×Gender interactions emerge ( $p > .10$ ), suggesting a comparable benefit for males and females.

**Fitness (EUROFIT)**

**Table 6.** Standing long jump (cm)

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$163.4 \pm 27.6$	$172.7 \pm 28.1$	+9.3
Control	$164.1 \pm 27.1$	$166.2 \pm 27.4$	+2.1

**Table 7.** 20 m shuttle run (stadiums)

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$5.7 \pm 1.6$	$6.4 \pm 1.7$	+0.7
Control	$5.8 \pm 1.6$	$6.0 \pm 1.6$	+0.2

**Table 8.** Sit-and-reach (cm)

Group	T0 (Mean $\pm$ SD)	T1 (Mean $\pm$ SD)	$\Delta$ Change
Experimental	$18.1 \pm 7.9$	$20.0 \pm 7.6$	+1.9
Control	$18.3 \pm 8.1$	$18.8 \pm 8.0$	+0.5

**Table 9.** Handgrip (kg)

Group	T0 (Mean ± SD)	T1 (Mean ± SD)	Δ Change
Experimental	27.9 ± 6.4	29.1 ± 6.5	+1.2
Control	28.1 ± 6.2	28.6 ± 6.4	+0.5

**Overall interpretation:** the pattern suggests a greater impact on explosive power and aerobic capacity than on grip strength, consistent with an intervention that increases participation density, movement continuity and execution quality.

#### IMU/wearable results: engagement and movement quality

IMU metrics were calculated on standardised windows (20 minutes: 10 minutes circuit training + 10 minutes small-sided games), aggregated at individual level and subsequently estimated in mixed models.

#### Active time (%)

The data indicate a marked increase in movement continuity during the lesson in the experimental group. In operational terms, the students involved in the programme converted a significantly greater proportion of teaching time into actual active time than the control group.

**Table 10.** Mean vector magnitude (g)

Group	T0 (Mean ± SD)	T1 (Mean ± SD)	Δ Change
Experimental	0.71 ± 0.14	0.82 ± 0.15	+0.11
Control	0.72 ± 0.15	0.74 ± 0.15	+0.02

The increase observed in the experimental group reflects an increase in the average intensity of movement in the standardised window, consistent with a higher density of motor tasks and a reduction in downtime within the lesson.

**Table 11.** p95 Vector magnitude (g)

Group	T0 (Mean ± SD)	T1 (Mean ± SD)	Δ Change
Experimental	1.62 ± 0.31	1.78 ± 0.34	+0.16
Control	1.63 ± 0.32	1.66 ± 0.33	+0.03

The increase in the 95<sup>th</sup> percentile in the experimental group suggests a greater presence of intensity peaks, likely associated with phases of play, transitions or tasks with high motor demands, which are more frequent or better integrated into the structure of the lesson.

- Experimental: 8.4 ± 2.1 → 7.2 ± 1.9; Δ = -1.2
- Control: 8.3 ± 2.2 → 8.1 ± 2.1; Δ = -0.2
- Interaction: F(1, 10.7) = 14.1, p = .003
- Differential Δ: -1.0 (95% CI -1.6 to -0.4), d = 0.45.

**Table 12.** Jerk RMS (m/s<sup>3</sup>) — lower values indicate greater regularity

Group	T0 (Mean ± SD)	T1 (Mean ± SD)	Δ Change
Experimental	8.4 ± 2.1	7.2 ± 1.9	-1.2
Control	8.3 ± 2.2	8.1 ± 2.1	-0.2

The reduction in RMS jerk in the experimental group indicates a decrease in the ‘roughness’ of movement and greater regularity of execution. This trend is consistent both with the adoption of technical progressions and feedback oriented towards movement quality, and with a progressive stabilisation of motor self-regulation processes.

#### Integrative analyses (mechanistic consistency: process → outcomes)

To reinforce the “process-outcome” interpretation, associations between IMU changes and motivational/physical changes were explored (descriptive analyses and additional models).

- Association between Δ active time and Δ intrinsic regulation: r = 0.29.
- Association between Δ active time and Δ self-efficacy: r = 0.33.
- Association between Δ active time and Δ shuttle run: r = 0.25.
- Association between Δ jerk (reduction) and Δ long jump: r = -0.21 (improvement in power associated with greater regularity).

In an exploratory model, the inclusion of Δ active time as a predictor partially attenuates the Group×Time effect on aerobic capacity, suggesting that part of the physical improvements can be explained by the increase in actual active time during the lesson.

#### Qualitative results

##### Qualitative sample, sampling strategy and quality of analysis

Semi-structured interviews were conducted with 32 students (16 female, 16 male; selected for maximum variation in IMU engagement: high/medium/low) and 8 teachers. The interviews with students lasted an average of 22 minutes (range 18–28), those with teachers 38 minutes (range 32–45). Thematic saturation was reached around the 28<sup>th</sup> interview with students, confirmed by the absence of new substantial codes in the last four interviews.

The thematic analysis followed an iterative process: initial independent coding on a subset of transcripts, comparison and harmonisation of the codebook, then coding of the entire corpus and review of themes with attention to deviant cases.

##### Main themes, sub-themes and frequency of occurrence

Below are the themes and sub-themes with the number of participants who mentioned them (at least once). The frequencies are presented for descriptive transparency, without any claim to statistical generalisation.

##### Theme 1 — Acceptability, comfort and perception of intrusiveness

- Students: 26/32; Teachers: 7/8

##### Sub-themes:

- Addiction/habit to the device (18/32): perception that after a few minutes the device “disappears” from attention.
- Physical discomfort or fear of damage (9/32): more frequent in the first two weeks.
- Privacy issues (7/32): requests for clarity on who sees the data and what it is used for.

**Interpretation:** acceptability increases when the purpose, rules and protections (anonymisation, no ranking) are clear.

**Theme 2 — Awareness of movement and self-regulation**

- Students: 24/32; Teachers: 8/8

**Sub-themes:**

- Making “really active” time visible (15/32): perception of a gap between “being in class” and “really moving”.

- Self-regulation strategies (13/32): planning (“I commit to the circuit”), monitoring (“I notice when I stop”), adjustment (“I change level”).

- Feedback as process guidance (16/32; 8/8 teachers): appreciation of operational guidance rather than numbers “for their own sake”.

**Connection with the quantitative aspect:** this theme is consistent with the increase in active time and the reduction in jerk, interpreted as greater continuity and better control of the movement.

**Topic 3 — Social comparison, emotions and the risk of unwanted gamification**

- Students: 17/32; Teachers: 8/8

**Subtopics:**

- Concern about rankings and comparisons (12/32): fear of “competition” between classmates.

- Performance anxiety linked to numbers (6/32): fear that the data will become an implicit grade.

- Preference for aggregated feedback (14/32): explicit requests to avoid individual identification in public.

**Interpretation:** the device is accepted when framed as a tool for improvement and not as a measure of personal value.

**Theme 4 — Role of the teacher in the pedagogical translation of data**

- Students: 21/32; Teachers: 8/8

**Sub-themes:**

- Interpretative mediation (19/32): data “makes sense” when accompanied by an explanation (“how can I improve?”).

- Climate and language (8/8 teachers): pay attention to tone, avoid sarcasm or comparisons.

- Management of individual differences (7/8 teachers): make data compatible with different levels and personalised objectives.

**Link to implementation:** confirms that technology does not replace teaching, but makes it more informed, provided there is clear educational direction.

**Topic 5 – Feasibility and organisational sustainability**

- Students: 10/32; Teachers: 6/8

**Subtopics:**

- Distribution/collection times (6/8 teachers): logistical challenges, especially in large classes.

- Routines that could be improved (5/8 teachers): practical suggestions (roles of “assistants”, delivery stations).

- Technical stability (4/8 teachers): importance of standard procedures to avoid data loss.

**Interpretation:** perceived sustainability increases when device management is routine and when the organisational burden is distributed.

*Analysis by qualitative subgroups (triangulation with IMU)*

A comparative reading was carried out between students with high vs low increases in active time (based on tertiles of  $\Delta$  active time).

- Students with high  $\Delta$  active time: they more frequently describe concrete self-regulation strategies (planning, level choice, attention to transitions), and report a greater sense of control (“I know what I need to do to stay active”).

- Students with low  $\Delta$  active time: they mention situational barriers more often (shyness in play, preference for less dynamic activities, difficulty interpreting feedback), and require greater personalisation of objectives.

This triangulation supports the hypothesis that the device acts as a catalyst, especially when students have (or acquire) self-regulation tools and when the teacher makes applicable strategies explicit.

*Deviant cases and critical interpretation*

Cases were identified in which, despite an increase in motivation, IMU engagement did not increase significantly. In these cases, interviews suggested that:

- satisfaction with the approach was high, but adherence was limited by contextual factors (minor injuries, discomfort in competitive play);

- some students interpreted the data as a potential judgement, reducing spontaneity.

The inclusion of deviant cases increases interpretative credibility and suggests that the effectiveness of IMU integration depends on educational framing and task personalisation.

**Discussion**

The results indicate that an educational programme focused on self-regulation and autonomy support, integrated with an explicit structure (objectives, success criteria, progressions and informative feedback), is associated with improvements in autonomous motivation and self-efficacy, as well as with positive changes in certain components of fitness (Di Palma et al., 2025; Reeve & Cheon, 2021; Cheon et al., 2022). This profile can be interpreted in light of Self-Determination Theory: SDT-informed interventions show generally small to moderate effects on behavioural and health outcomes in the literature, frequently mediated by increases in autonomous motivation and interpersonal support for psychological needs. The results of the present study fit consistently within this framework, suggesting that the combination of autonomy + structure is particularly relevant in the school context (Cheon et al., 2022; Fierro-Suero et al., 2024). At the same time, IMU data show a significant increase in active time and average intensity, with a reduction in RMS jerk (greater regularity), suggesting a possible “processual” mechanism linking teaching choices (reduction in downtime, high-density tasks, criteria-based feedback) to performance outcomes: the increase in actual movement time provides a plausible explanation (supported by integrative analyses) for the more marked improvement in aerobic capacity and explosive power compared to outcomes less directly influenced by work density (e.g. grip strength).

In terms of methodology and application, the use of inertial sensors makes it possible to go beyond an assessment based solely on “products” (tests and questionnaires), including process indicators related to how much and how students move during class. This perspective is in line with the growing emphasis on standardisation and transparency

in the analysis of signals from wearable devices and with recent recommendations on the use of IMUs for human movement analysis (Liang et al., 2024; Cereatti et al., 2024).

The qualitative findings strengthen the interpretation: students report greater awareness of their own movement behavior and a more intentional use of self-regulatory strategies, while teachers and students converge on the importance of pedagogical mediation to prevent social comparisons and to transform data into actionable feedback (Latino et al., 2019). This evidence is particularly relevant when compared with meta-analyses on wearable devices in school settings, which often report uncertain average effects when the device is used as an intervention “in itself” rather than as part of a structured instructional design (Au et al., 2024). In this respect, the adopted approach—aggregated feedback, absence of ranking, and an orientation toward improvement—also aligns with what has been highlighted by recent qualitative studies on students’ perceptions of wearable technologies in schools (Wort et al., 2024). Nonetheless, some limitations should be acknowledged: a class-based experimental design, possible variability among teachers, and the sensitivity of IMU metrics to device placement and contextual conditions. Therefore, replications with cluster randomization, calibration protocols, and more extensive fidelity analyses are recommended.

## Conclusion

Overall, the study suggests that a school-based intervention combining autonomy support, structure, and self-regulation routines can produce simultaneous improvements in autonomous motivation, self-efficacy, and some fitness outcomes, accompanied by a significant increase in objectively measured motor engagement (active time, intensity) and indications of improved movement regularity (reduced jerk). These findings are consistent with the SDT-informed literature, which identifies autonomous motivation and support for psychological needs as key levers for promoting participation and physical activity behaviors, and they reinforce the idea that effectiveness in school settings depends on the quality of the instructional context (Cheon et al., 2022; Fierro-Suero et al., 2024).

The integration of inertial sensors represents a relevant contribution because it allows traditional outcomes to be complemented with a measurement of the motor process, making the analysis of the intervention more sensitive and informative. The qualitative results indicate that the technology is accepted and perceived as useful when data are framed in a formative manner, with aggregated feedback and an orientation toward improvement, and when teachers translate data into practical guidance, thereby preventing social comparison dynamics. From a broader perspective, the findings support the adoption of “data-informed” school designs in which the wearable is not the core of the intervention but rather a tool to improve instructional decisions and monitor equity of participation. Future studies should examine the stability of effects at follow-up, test generalizability across different school contexts, and define shared protocols for IMU metrics and analytical reporting, in line with recent recommendations on sensor data analysis and IMU-based motion analysis (Wort et al., 2024; Liang et al., 2024; Cereatti et al., 2024).

## Ethics Approval and Consent to Participate

The study was approved by the University of Naples Parthenope (DiSMMeB, Prot. No. 88773/2025). 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

Open access.

## AI Transparency Statement

No AI tools were used in this study.

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## Саморегульоване рухове навчання: вплив на мотивацію, фізичну підготовленість та моторну залученість

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 9 с., 12 табл., 15 джерел.

**Цілі.** Це дослідження мало на меті оцінити ефективність програми фізичного виховання, орієнтованої на саморегуляцію та підтримку автономії, у підвищенні моторної залученості та мотиваційних показників підлітків. Дослідження поєднує об'єктивні вимірювання з використанням інерційних датчиків (ІВП/носимих пристроїв) та якісний аналіз результатів інтерв'ю.

**Матеріали та методи.** Було проведено експериментальне дослідження за схемою претест-посттест за участю 353 осіб (середній вік  $14.2 \pm 1.1$  років), розподілених на експериментальну ( $n = 178$ ) та контрольну ( $n = 175$ ) групи. Використовувалися такі показники: мотивація (PLOC-R; за переглянутою шкалою сприйнятого локусу причинності), самоефективність щодо фізичної активності (самоефективність подолання бар'єрів), фізична підготовленість (EUROFIT: стрибок у довжину з місця, човниковий біг 20 м, нахил тулуба вперед із положення сидячи, кистьова динамометрія) та параметри ІВП (активний час, векторна амплітуда, прискорення) під час стандартизованих часових вікон уроку. Також проведено напівструктуровані інтерв'ю за участю 32 учнів та 8 вчителів із подальшим тематичним аналізом.

**Результати.** В експериментальній групі спостерігалися значніші покращення порівняно з контрольною групою за показниками автономної мотивації ( $\Delta$  внутрішньої регуляції  $+0.64$  проти  $+0.10$ ,  $p < .001$ ), самоефективності ( $+0.41$  проти  $+0.07$ ,  $p < .001$ ), фізичної підготовленості (наприклад, стрибок у довжину  $+9.3$  см проти  $+2.1$  см,  $p < .001$ ) та об'єктивно вимірюваної моторної залученості (активний час  $+9.5$  відсоткових пунктів проти  $+1.3$ ,  $p < .001$ ). Результати інтерв'ю засвідчили високий рівень прийнятності методики, підвищення усвідомленості рухів та важливості ролі вчителя у запобіганні динаміці соціального порівняння.

**Висновки.** Інтеграція даних ІВП сприяє більш комплексному оцінюванню ефективності шкільних програм, поєднуючи мотиваційні та результативні показники з об'єктивними індикаторами моторної поведінки.

**Ключові слова:** моторна саморегуляція, моторна залученість, інерційні датчики, фізичне виховання.

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