



The Effects of Combined TRX Suspension and Functional Circuit Training on Biomotor and Physiological Adaptations in Adolescent Basketball Players

Vijaya Kumar^{1ABCD} and D. Harigaran^{1ACD}

¹Hindustan Institute of Technology and Sciences (Deemed to be University)

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Corresponding Author: D. Harigaran, e-mail: harigarand@hindustanuniv.ac.in

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Abstract

Objectives. This study aimed to compare the effects of an 8-week intervention combining TRX suspension and functional circuit training, as well as functional circuit training alone, and regular basketball practice on biomotor abilities and physiological adaptations in adolescent basketball players.

Materials and Methods. A total of 60 adolescent male basketball players were randomly divided into three groups: combined TRX suspension and functional circuit training group (TRXG, $n = 20$); functional circuit training group (FCG, $n = 20$); and control group (CG, $n = 20$). The training lasted 8 weeks, with sessions performed three times per week. Sprint speed, agility, countermovement jump (CMJ) performance, body fat percentage, skeletal muscle mass, resting heart rate, and systolic and diastolic blood pressure were measured before and after the intervention. A mixed design ANOVA with Bonferroni comparisons was used for data analysis.

Results. All biomotor and physiological variables showed significant Group $\times$ Time interactions (all $p < .001$; partial $\eta^2 = 0.64\text{--}0.82$). The TRXG exhibited a greater improvement across all outcomes compared to both the FCG and CG. Notably, there were large interaction effects for sprint performance ($F_{(2,57)} = 75.32$, $p < .001$, $\eta^2 = 0.73$), agility ($\eta^2 = 0.82$), countermovement jump ($\eta^2 = 0.78$), body composition, resting heart rate, and blood pressure.

Conclusions. The findings suggest that functional circuit training enhances biomotor and physiological parameters. Furthermore, incorporating TRX suspension exercises yields greater improvements than functional circuit training alone and may provide additional benefits when integrated into a progressively structured and supervised conditioning programme.

Keywords: adolescent basketball players, TRX suspension training, functional circuit training, biomotor abilities, physiological adaptations, conditioning.

Introduction

Basketball is a high-intensity, intermittent sport with frequent changes in direction, jumping, landing, and multidirectional movements with different competitive demands. To perform successfully requires the development of the biomotor skills, especially speed, agility, and the lower body's power, as well as physiological elements that enable repetition of high-intensity efforts (Scanlan et al., 2019; Stojanović et al., 2017). In the adolescent period, conditioning programmes should improve these performance-related qualities, but must also consider the continued developmental processes of the neuromuscular

system and physiology of young athletes (Lesinski et al., 2020). Therefore, finding training techniques that will enhance more than one aspect of physical fitness is a primary goal in youth basketball conditioning.

Although considerable research has been conducted on youth strength and conditioning, one scientific issue remains unresolved. Current evidence supports the effectiveness of suspension-based resistance training and functional training for improving selected components of athletic performance; however, these training approaches have been investigated predominantly as independent interventions rather than in combination (Cao et al., 2024; Zhang et al., 2024). Consequently, it remains unclear whether incorporating TRX suspension exercises into functional circuit training provides greater benefits than functional circuit training alone. This uncertainty extends beyond

a simple gap in the literature, as it limits evidence-based coaching and physical education decisions regarding the use of specialised suspension-training equipment, technical supervision, and implementation costs. Direct comparative evidence is therefore needed to determine whether these additional demands are justified by superior performance and physiological adaptations (Beato et al., 2024).

Studies have demonstrated that resistance training can improve muscular strength, power, and movement performance in adolescent athletes. When appropriately supervised, resistance training is considered safe and effective for enhancing athletic performance and reducing injury risk in youth (Zhang et al., 2024). Likewise, functional circuit training has been shown to improve speed, agility, muscular endurance, and explosive power by incorporating multi-joint, sport-specific movement patterns that closely reflect the physical demands of basketball. Collectively, the available evidence indicates that functional training is an effective approach for developing multiple components of physical fitness simultaneously (Cao et al., 2024). However, most previous studies have evaluated functional circuit training as a standalone intervention, with limited investigation of its combined application with other training modalities.

TRX suspension training has gained popularity over the years since it adds instability during the exercise, which means that the trunk and stabilizing muscles are constantly engaged while performing functional movements during the exercises. Electromyographic tests have shown that core muscles are more engaged when performing suspension exercises than similar exercises performed on stable surfaces (Aguilera-Castells et al., 2018; Oliva-Lozano & Muyor, 2020). Improved neuromuscular activation may contribute to better lumbopelvic stability, postural control, force transfer, and movement efficiency, which are crucial for basketball-specific movements like sprinting, cutting, jumping, landing, and quick changes of direction. While these theoretical mechanisms offer the potential for improved transfer to sport performance, the limited available evidence has not been consistent, and the majority of TRX studies have included healthy adults, recreational participants, or rehabilitation populations, and not competitive adolescent basketball players. In addition, few studies have investigated whether there are any added adaptations to a functional conditioning programme when using suspension-based instability training (Bao et al., 2025).

A second limitation of the existing literature concerns the outcome measures used to evaluate training effectiveness. Previous studies have primarily focused on isolated aspects of performance, such as muscular strength or jump height, whereas basketball performance depends on the simultaneous development of multiple biomotor and physiological characteristics (Cao et al., 2024; Lesinski et al., 2020). Physiological adaptations, including favourable changes in body composition, resting heart rate, and blood pressure, may also contribute to training tolerance, recovery, and long-term athlete development. Resistance and functional training have been associated with improvements in these health-related outcomes (Guillem et al., 2020; Liu et al., 2024). However, the extent to which these parameters change following combined TRX suspension and functional circuit training in adolescent basketball players remains unclear.

The effectiveness of combined training programmes is also uncertain because of methodological limitations. Some prior research has assessed only passive controls or not included a randomly allocated control group with active basketball practice. This is because such designs are hard to differentiate intervention-specific effects from those that may be due to normal basketball participation, growth, maturation, and/or repeated testing (Liu & Li, 2025; Maggioni et al., 2018). Therefore, well-designed RCTs with active comparison groups should be used to establish whether combined suspension and functional circuit training results in adaptations not observed in regular basketball practice or functional circuit training alone.

Thus, there is a clear and unaddressed scientific need in the current literature. Although TRX suspension training and functional circuit training have each demonstrated positive effects when applied independently, limited experimental evidence has examined whether combining these training modalities produces greater improvements in biomotor performance and physiological adaptations in adolescent basketball players (Bao et al., 2025; Delextrat et al., 2018). Addressing this question is important for developing evidence-based conditioning programmes that maximize performance while making efficient use of time, equipment, and coaching resources in youth basketball. Thus, this study aimed to evaluate the effects of an 8-week TRX suspension plus functional circuit training (TRX+FCT) programme, a functional circuit training (FCT) programme, and regular basketball training on selected biomotor abilities (speed, agility, and explosive power) and physiological adaptations (body composition, resting heart rate, and blood pressure) in adolescent basketball players.

The hypotheses were: (1) that both intervention groups would show significant improvements in the biomotor and physiological variables compared to the control group; (2) that the combined TRX suspension and functional circuit training group would show significantly greater improvements than the functional circuit training only group, suggesting an additive effect of suspension-based instability training; and (3) that the functional circuit training only group would show significant improvements compared to the control group.

Materials and Methods

Study Participants

In this randomized controlled trial, 60 male adolescent basketball players (mean age: 17.4 ± 0.8 years; height: 180.0 ± 5.5 cm; body mass: 72.5 ± 5.5 kg; years of basketball training: 4.1 ± 0.8) from regional basketball clubs and collegiate teams in Chennai, India, participated. Subjects included people aged 16-18 who had at least 3 years of organized basketball training, who attended team practice and played regularly in team competition, and were physically capable of vigorous exercise. Exclusion criteria were an injury or illness of the musculoskeletal system at the time of study, structured resistance training, suspension training, functional circuit training in the last 6 months, cardiovascular, metabolic, or neurological disease that precluded exercise, use of performance-enhancing substances, or failure to complete the intervention. Written informed consent was obtained

from all participants, with parental/legal guardian consent also obtained for participants under the age of 18. The study protocol was approved by the Institutional Ethics Committee of Hindustan Institute of Technology and Science, Chennai, India (Approval ID: HITS/CRC/004/22703049). All procedures were carried out following the guidelines of the Declaration of Helsinki.

Study Organization

The design was a three-arm randomized controlled pre-test–post-test. After eligibility screening and familiarization, all participants took part in baseline assessments followed by random assignment (1:1:1) to the TRX suspension combined with functional circuit training group (TRXG, $n = 20$), functional circuit training group (FCG, $n = 20$), and control group (CG, $n = 20$). The number of participants is presented in Figure 1. Randomization was done using a computer-generated sequence prepared by an independent researcher, and the allocation was hidden in sequentially numbered, opaque, sealed envelopes. Baseline assessments were taken two days before the intervention, while post-intervention assessments were performed two days following the eight-week training programme under standardised conditions by the same trained assessors at around the same time of day. The reporting of this randomized controlled trial followed the CONSORT 2010 statement (Moher et al., 2010).

Outcome Measures

The effects of the study were measured at baseline and post-8 weeks. Biomotor abilities (speed, agility, explosive power, body fat percentage, and skeletal muscle mass) and physiological variables (resting heart rate, systolic and diastolic blood pressure) were the primary outcomes. Assessment procedures are detailed for each of the following subsections. All the measurements were taken by trained staff under standardized conditions, using established and

validated protocols with established reliability in adolescent athletes (American College of Sports Medicine, 2021; Zhao et al., 2019).

Biomotor Abilities

The 8-week intervention was evaluated for biomotor abilities before and after the intervention, under standardized testing conditions. The 50 m sprint test, Illinois Agility Test, and the Countermovement Jump test (CMJ) were used to assess speed, agility, and explosive power, respectively. Each performance test was performed three times using passive recovery for 3 minutes between each trial, and the best performance was kept for statistical analysis. Body composition variables were evaluated by a multi-frequency bioelectrical impedance analyzer (BIA) after an overnight fast of at least 8 hours and 24 hours of abstinence from strenuous exercise before testing, body fat percentage (%), and skeletal muscle mass (kg). Assessments were performed in line with standardized procedures described in previous studies (American College of Sports Medicine, 2021; Reijnen & Soeters, 2020).

Physiological Adaptations

Physiological adaptation was measured before and after the 8-week intervention, under standard resting conditions. Participants sat quietly for 10 minutes before measurement. HR was recorded for 5 minutes, and the lowest stable one-minute average HR was taken in beats per minute (bpm). Blood pressure was measured by an automated digital sphygmomanometer with a cuff that was the correct size for the arm, using the arm at heart level. Three readings were taken every minute, and the average of the second and third readings was recorded in millimetres of mercury (mmHg). These procedures were in line with the recommended guidelines for resting cardiovascular assessment and standardized blood pressure measurement (American College of Sports Medicine, 2021; Muntner et al., 2019).

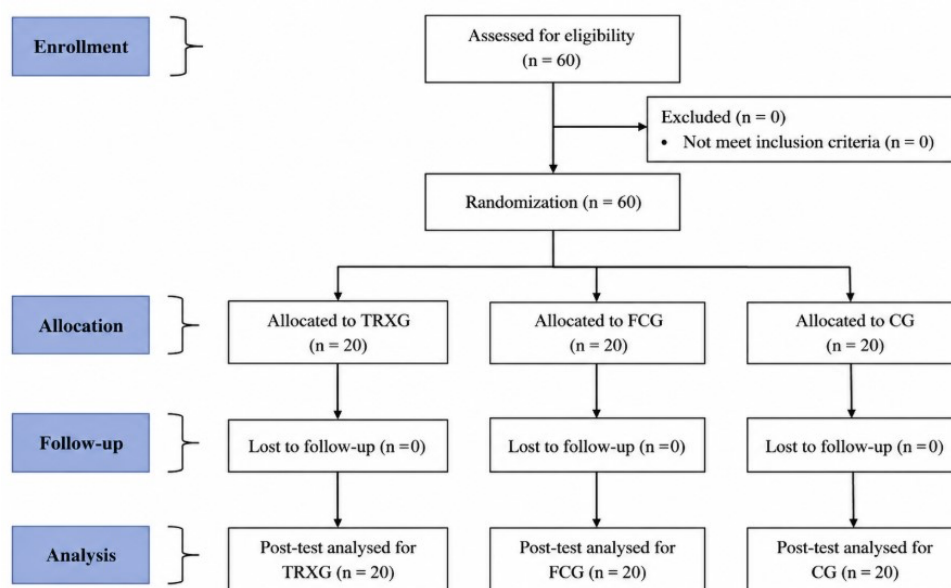


Fig. 1. Schematic representation of the research study

Training Intervention Procedure

The intervention took place for 8 weeks, with three sessions per week (non-consecutive days) (24 sessions). Each session was 50-60 minutes long with a 10-minute warm-up, 35-40 minutes of main training, and a 5-10-minute cool down. The Borg Category Ratio-10 scale was used to track training intensity from 5-6 in Weeks 1-2, up to 8-9 in Weeks 7-8. Each phase of the intervention involved increased exercise volume, complexity, and speed of movement. The TRX suspension combined with functional circuit training group (TRXG) performed TRX suspension exercises that were combined with functional circuit training exercises, while the functional circuit training group (FCG) performed bodyweight and free-weight exercises of the same movement patterns. The training frequency, duration, progression, recovery intervals (2 min between sets; 30-40 s between exercises), and training volume were identical for both groups, as detailed in Tables 1 and 2. Progressions were made by adding exercises, reps, complexity of movement, unilateral loading, resistance, and velocity. The control group (CG) completed the same amount of basketball practice as the experimental group, but without the structured suspension or functional circuit training. The control group performed the same number of sessions of basketball practice as the experimental group (three sessions per week, 60-90 minutes per session), which included technical drills, tactical activities, small-sided games, and scrimmages. All sessions were attended and the participants had to attend at least 85% of the planned sessions (20/24). There were no adverse events reported related to the intervention.

Statistical Analysis

IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA) was used for data analysis.

Table 1. TRX suspension combined with a functional circuit training programme

Training period	Exercises per session	Volume (sets × reps)	Rest between sets	Rest between exercises
Weeks 1-2	5	3 × 6-8 repetitions	2 min	30-40 s
Weeks 3-4	6	3 × 8 repetitions	2 min	30-40 s
Weeks 5-6	7	3 × 8-10 repetitions	2 min	30-40 s
Weeks 7-8	8	3 × 6-10 repetitions	2 min	30-40 s

Exercises: TRX squat, TRX row, TRX chest press, TRX mountain climber, TRX lunge, TRX inverted row, TRX push-up, TRX jump squat, TRX chest fly, box jump, lateral bound, medicine-ball throw, agility run, burpee, and TRX power pull.

Table 2. Functional circuit training programme

Training period	Exercises per session	Volume (sets × reps)	Rest between sets	Rest between exercises
Weeks 1-2	5	3 × 6-8 repetitions	2 min	30-40 s
Weeks 3-4	6	3 × 8 repetitions	2 min	30-40 s
Weeks 5-6	7	3 × 8-10 repetitions	2 min	30-40 s
Weeks 7-8	8	3 × 6-10 repetitions	2 min	30-40 s

Exercises: goblet squat, inverted row, push-up, lunge, plank hold, glute bridge, Bulgarian split squat, box jump, lateral bound, medicine-ball throw, burpee, skater jump, and agility run.

Data are reported as the mean ± SD. The normality and homogeneity of variance were checked by the Shapiro-Wilk and Levene's tests, respectively. One-way analysis of variance (ANOVA) was used to determine differences between groups at baseline. A 3x2 repeated measures ANOVA was used to analyse the effects of intervention with Group (TRXG, FCG, and CG) as the between-participants factor and Time (pre-test and post-test) as the within-participants factor. If there were significant interactions between groups and time, Bonferroni corrections were used to make post hoc comparisons. With only two measurement occasions, the assumption of sphericity was assumed. The effect size for ANOVA effects was reported as partial eta squared (η^2) and for pairwise comparisons, Cohen's d. When appropriate, 95% confidence intervals (95% CI) and exact p-values were presented, when $p < .001$. $P < .05$ was used as the cut-off for statistical significance. Analysis was conducted per protocol, meaning only those who finished both assessments and had at least 90% attendance were included.

Results

All 60 participants took both the baseline and post-intervention assessments, and were analyzed. There were 20 participants in each group. All numerical values reported in previous versions of the manuscript have been replaced by the recalculated results presented here, which have been drawn from the participant-level data.

Biomotor Variables

The pre-test and post-test results for sprint speed, agility, and explosive power are shown in Table 3. All three biomotor variables showed significant Group × Time interactions. For the 50-m sprint, the interaction effect was significant and large, $F_{(2, 57)} = 75.32$, $p < 0.001$, $\eta^2 = 0.73$. All three groups had a significant reduction in sprint time, but the TRXG had the largest improvement. The reduction in sprint time was 0.17 s greater in the TRXG than in the FCG (95% CI: 0.11-0.23, Bonferroni-adjusted $p < 0.001$, $d = 1.85$) and 0.29 s greater than in the CG (95% CI: 0.24-0.34, $p < 0.001$, $d = 3.59$). The FCG also improved more than the CG by 0.12 s (95% CI: 0.09-0.15, $p < 0.001$, $d = 2.67$).

A significant and large interaction was also found for the Illinois Agility Test, $F_{(2, 57)} = 129.56$, $p < 0.001$, $\eta^2 = 0.82$. The TRXG achieved a 0.48 s greater improvement than the FCG (95% CI: 0.36-0.61, $p < 0.001$, $d = 2.46$) and a 0.82 s greater improvement than the CG (95% CI: 0.72-0.93, $p < 0.001$, $d = 5.03$). The improvement in the FCG exceeded that in the CG by 0.34 s (95% CI: 0.27-0.42, $p < 0.001$, $d = 2.86$). The countermovement-jump performance was similar, with a significant Group × Time interaction, $F_{(2, 57)} = 98.37$, $p < 0.001$, $\eta^2 = 0.78$. The increase in jump height was 1.48 cm greater in the TRXG than in the FCG (95% CI: 0.96-1.99, $p < 0.001$, $d = 1.84$) and 2.94 cm greater than in the CG (95% CI: 2.51-3.36, $p < 0.001$, $d = 4.43$). The FCG also improved more than the CG by 1.46 cm (95% CI: 1.15-1.77, $p < 0.001$, $d = 3.01$).

Physiological Variables

Significant Group × Time interaction effects were observed for all five physiological variables shown in Table 4.

Table 3. Comparisons of changes in biomotor variables among the TRX suspension combined with functional circuit training, functional circuit training, and control groups

Variables	Group	Mean $\pm$ SD Baseline	Mean $\pm$ SD After	Paired t-test p-value	MD (95% CI)	Main effect Group p (η^2)	Main effect Time p (η^2)	Interaction Group $\times$ Time p (η^2)
Speed (seconds)	TRXG	7.38 $\pm$ 0.26	7.05 $\pm$ 0.25	<0.001	0.33 (0.27 to 0.38)			
	FCG	7.68 $\pm$ 0.41	7.52 $\pm$ 0.39	<0.001	0.16 (0.13 to 0.19)	0.004 (0.18)	<0.001 (0.85)	<0.001 (0.73)
	CG	7.46 $\pm$ 0.39	7.43 $\pm$ 0.38	<0.001	0.04 (0.03 to 0.04)			
Agility (seconds)	TRXG	16.94 $\pm$ 0.74	16.01 $\pm$ 0.79	<0.001	0.93 (0.83 to 1.04)			
	FCG	16.69 $\pm$ 0.76	16.24 $\pm$ 0.73	<0.001	0.45 (0.37 to 0.52)	0.176 (0.06)	<0.001 (0.91)	<0.001 (0.82)
	CG	16.90 $\pm$ 0.71	16.80 $\pm$ 0.71	<0.001	0.11 (0.08 to 0.13)			
Explosive power (centimetres)	TRXG	35.27 $\pm$ 1.80	38.64 $\pm$ 1.77	<0.001	-3.37 (-3.80 to -2.94)			
	FCG	33.95 $\pm$ 2.67	35.84 $\pm$ 3.06	<0.001	-1.90 (-2.20 to -1.59)	<0.001 (0.26)	<0.001 (0.90)	<0.001 (0.78)
	CG	33.58 $\pm$ 2.11	34.02 $\pm$ 2.05	<0.001	-0.44 (-0.52 to -0.35)			

Note. TRXG = TRX suspension combined with functional circuit training group; FCG = functional circuit training group; CG = control group; MD = mean pre-test minus post-test difference; CI = confidence interval; η^2 = partial eta squared. Positive mean differences for speed and agility indicate reduced completion time and improved performance. Negative mean differences for explosive power indicate increased jump height.

Body-fat percentage demonstrated a large interaction effect, $F(2, 57) = 86.99$, $p < 0.001$, $\eta^2 = 0.75$. The reduction was 0.71 percentage points greater in the TRXG than in the FCG (95% CI: 0.51–0.90, $p < 0.001$, $d = 2.29$) and 1.04 points greater than in the CG (95% CI: 0.86–1.21, $p < 0.001$, $d = 3.70$). The FCG also showed a greater reduction than the CG (mean difference = 0.33 points, 95% CI: 0.24–0.42, $p < 0.001$, $d = 2.35$). The Group $\times$ Time interaction for skeletal muscle mass was significant and large, $F(2, 57) = 71.23$, $p < 0.001$, $\eta^2 = 0.71$. The increase was 0.51 kg greater in the TRXG than in the FCG (95% CI: 0.28–0.73, $p < 0.001$, $d = 1.47$) and 1.09 kg greater than in the CG (95% CI: 0.88–1.29, $p < 0.001$, $d = 3.31$). The FCG increased skeletal muscle mass by 0.58 kg more than the CG (95% CI: 0.48–0.68, $p < 0.001$, $d = 3.87$).

Resting heart rate also showed a significant interaction, $F(2, 57) = 50.62$, $p < 0.001$, $\eta^2 = 0.64$. The reduction was greater in the TRXG than in the FCG by 1.95 bpm (95% CI: 1.15–2.75, $p < 0.001$, $d = 1.57$) and greater than in the CG by 3.35 bpm (95% CI: 2.60–4.10, $p < 0.001$, $d = 2.87$). The FCG also demonstrated a greater reduction than the CG (mean difference = 1.40 bpm, 95% CI: 0.97–1.83, $p < 0.001$, $d = 2.11$). Large interaction effects were found for systolic blood pressure, $F(2, 57) = 117.35$, $p < 0.001$, $\eta^2 = 0.80$, and diastolic blood pressure, $F(2, 57) = 75.56$, $p < 0.001$, $\eta^2 = 0.73$. The ordering of improvement was also consistent for both outcomes, as confirmed by pairwise comparisons: TRXG > FCG > CG. After the Bonferroni correction ($p < 0.001$), all comparisons between groups were statistically significant. Pairwise comparisons demonstrated statistically significant differences among the groups after Bonferroni adjustment (all $p < .001$). The percentage changes in biomotor and physiological outcome measures across the three groups are presented in Figure 2.

Discussion

This study was based on two related hypotheses. First, it would be important to see that structured conditioning programmes would bring about more changes in biomotor

abilities and physiology than regular basketball training. Second, adding TRX suspension exercises to functional circuit training would elicit greater adaptations than functional circuit training alone. The present results are in favour of both hypotheses. The following significant Group $\times$ Time interactions were found: sprint speed, agility, countermovement-jump performance, body fat percentage, skeletal muscle mass, resting heart rate, and blood pressure. The magnitude of improvement was consistently in the following order: TRXG > FCG > CG, with the combined TRX suspension and functional circuit training programme being the most effective.

The enhanced sprint speed, agility, and explosive power of the intervention groups are in line with the physical demands of basketball as described in the introduction. During offensive and defensive movements in basketball, repeated acceleration, deceleration, multidirectional movements, and jumping are required (Scanlan et al., 2019; Stojanović et al., 2017). Functional circuit training can meet these demands by using multi-joint repetition, very quick transitions, using only one side of the body, jumping, and change of direction exercises. The superior results of the FCG compared with the control group are consistent with the previous findings that structured resistance and functional training can enhance speed, power, and movement performance in young athletes and basketball players (Cao et al., 2024; Lesinski et al., 2020).

The greater improvements observed in the TRXG may be associated with the additional postural and stabilization demands imposed by suspension-based exercises. During TRX movements, participants generated force while continuously controlling body position and balance. This training condition may increase the activation and coordination demands placed on the trunk and stabilizing muscles compared with similar exercises performed on stable surfaces (Aguilera-Castells et al., 2018; Bao et al., 2025). Greater stabilization demands could contribute to improved proximal control and coordinated force transmission during sprinting, jumping, and rapid changes of direction (Oliva-Lozano & Muyor, 2020). However, electromyographic

Table 4. Comparisons of changes in physiological variables among the TRX suspension combined with functional circuit training, functional circuit training, and control groups

Variables	Group	Mean $\pm$ SD Baseline	Mean $\pm$ SD After	Paired t-test p-value	MD (95% CI)	Main effect Group p (η^2)	Main effect Time p (η^2)	Interaction Group $\times$ Time p (η^2)
Body fat (%)	TRXG	13.46 $\pm$ 1.33	12.34 $\pm$ 1.34	<0.001	1.12 (0.94 to 1.30)	0.630 (0.02)	<0.001 (0.83)	<0.001 (0.75)
	FCG	13.06 $\pm$ 1.62	12.65 $\pm$ 1.57	<0.001	0.42 (0.33 to 0.50)			
	CG	12.54 $\pm$ 1.43	12.45 $\pm$ 1.41	<0.001	0.09 (0.06 to 0.11)			
Skeletal muscle mass (kg)	TRXG	32.82 $\pm$ 2.84	34.05 $\pm$ 2.99	<0.001	-1.24 (-1.45 to -1.02)	0.019 (0.13)	<0.001 (0.86)	<0.001 (0.71)
	FCG	31.09 $\pm$ 1.86	31.82 $\pm$ 1.89	<0.001	-0.73 (-0.82 to -0.64)			
	CG	33.36 $\pm$ 2.56	33.51 $\pm$ 2.59	<0.001	-0.15 (-0.20 to -0.10)			
Resting heart rate (bpm)	TRXG	64.35 $\pm$ 3.92	60.40 $\pm$ 3.50	<0.001	3.95 (3.21 to 4.69)	0.073 (0.09)	<0.001 (0.82)	<0.001 (0.64)
	FCG	65.70 $\pm$ 3.36	63.70 $\pm$ 3.29	<0.001	2.00 (1.63 to 2.37)			
	CG	63.15 $\pm$ 3.03	62.55 $\pm$ 2.98	<0.001	0.60 (0.36 to 0.84)			
Systolic blood pressure (mmHg)	TRXG	116.35 $\pm$ 3.69	111.15 $\pm$ 3.79	<0.001	5.20 (4.58 to 5.82)	0.189 (0.06)	<0.001 (0.89)	<0.001 (0.80)
	FCG	117.20 $\pm$ 5.55	114.75 $\pm$ 5.64	<0.001	2.45 (2.03 to 2.87)			
	CG	116.10 $\pm$ 3.14	115.55 $\pm$ 3.03	<0.001	0.55 (0.31 to 0.79)			
Diastolic blood pressure (mmHg)	TRXG	74.45 $\pm$ 3.30	70.60 $\pm$ 3.30	<0.001	3.85 (3.30 to 4.40)	0.873 (0.01)	<0.001 (0.85)	<0.001 (0.73)
	FCG	73.95 $\pm$ 3.89	72.05 $\pm$ 3.85	<0.001	1.90 (1.50 to 2.30)			
	CG	73.25 $\pm$ 3.49	72.85 $\pm$ 3.39	0.002	0.40 (0.16 to 0.64)			

Note. TRXG = TRX suspension combined with functional circuit training group; FCG = functional circuit training group; CG = control group; MD = mean pre-test minus post-test difference; CI = confidence interval; η^2 = partial eta squared; bpm = beats per minute. Positive mean differences for body fat, resting heart rate, and blood pressure indicate reductions. Negative mean differences for skeletal muscle mass indicate increases

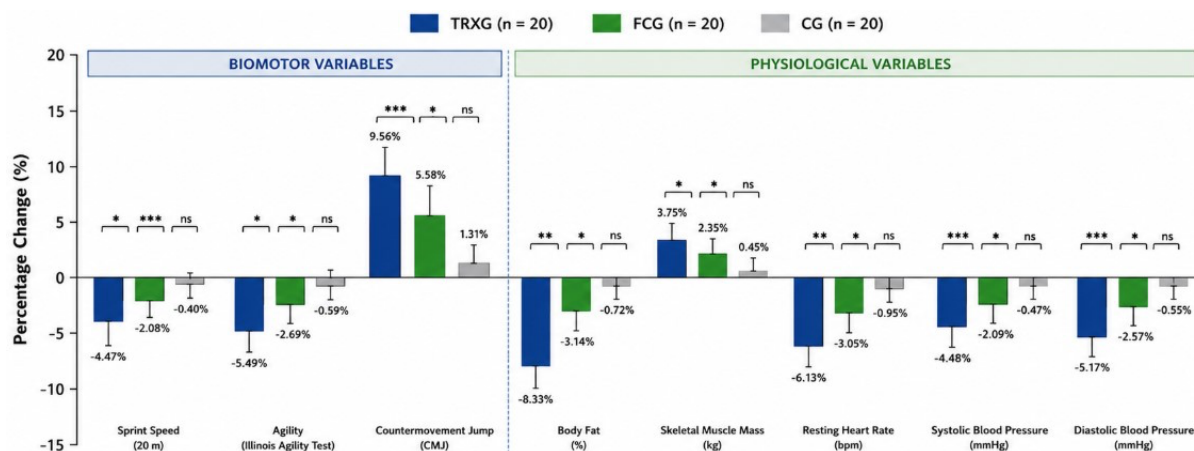


Fig. 2. Pre- and post-intervention percentage changes in biomotor and physiological outcome measures following the eight-week intervention

activity, postural control, muscle coordination, and force-transfer characteristics were not measured in the present study. These mechanisms should therefore be regarded as plausible explanations for the observed differences rather than effects demonstrated directly by the study.

Countermovement jump performance also improved most in the TRXG, followed by the FCG and the CG. Exercises such as squats, lunges, box jumps, and lateral bounds involve rapid hip, knee, and ankle extension and are directly associated with lower-body power development. These findings are consistent with previous evidence showing that appropriately prescribed resistance and functional training

can improve muscular power and jump performance in young athletes (Hind et al., 2020; Lesinski et al., 2020). The modest improvement observed in the control group may be attributable to regular basketball practice, normal growth and maturation, or increased familiarity with the jump test. The greater improvements observed in the intervention groups are consistent with an additional effect of structured conditioning beyond regular technical and tactical training.

The physiological findings further support the effectiveness of the interventions. The greater reduction in body fat percentage and the increase in skeletal muscle mass observed in the training groups are consistent with previous

evidence showing that resistance and functional training can improve body composition in children and adolescents (Lesinski et al., 2020; Liu et al., 2024). The multi-joint, stabilizing, and circuit-based components of the combined programme may have provided a greater training stimulus. However, these findings should be interpreted with caution because body composition was assessed using bioelectrical impedance analysis, which may be influenced by hydration status and other testing conditions despite standardized assessment procedures (Mao et al., 2023).

Resting heart rate and blood pressure also showed greater improvements in the intervention groups than in the control group. These adaptations are consistent with evidence that structured exercise may positively influence resting cardiovascular health and health-related fitness in youth (Guillem et al., 2020). The repeated muscular activity and limited recovery periods during the circuit sessions may have increased the cardiovascular demands of training. However, oxygen consumption, autonomic function, and vascular responses were not assessed; therefore, the physiological mechanisms underlying these adaptations remain unclear.

The agility findings are particularly relevant to the scientific problem identified in the Introduction. Most previous studies have investigated resistance training, functional training, or suspension training as independent interventions rather than evaluating their combined effects (Aguilera-Castells et al., 2018; Cao et al., 2024). Consequently, it remained unclear whether suspension-based exercises provided additional benefits when incorporated into an existing functional training programme. In the present study, the TRXG demonstrated greater improvements than the FCG despite identical training frequency, duration, progression, and perceived exercise intensity. These findings suggest that the unstable training environment and increased postural demands of the combined programme may induce adaptations beyond those achieved with functional exercises performed on stable surfaces (Zuo et al., 2022). Although the randomized controlled design supports causal inference for the intervention effects on the measured outcomes, the physiological and neuromuscular mechanisms responsible for these adaptations were not directly evaluated and therefore require confirmation in future mechanistic studies.

The active control design strengthened the interpretation of the findings. Compared with passive control groups, an active control better distinguishes intervention-specific effects from those attributable to normal basketball participation, growth, maturation, and repeated testing (Schulz et al., 2010). Participants in the control group continued their regular basketball training and showed only modest improvements over the 8-week intervention. These findings are consistent with an additional effect of structured functional conditioning beyond regular basketball practice (Lesinski et al., 2020).

The present study has several limitations. First, a formal a priori sample-size calculation was not performed, which may have reduced the precision of the estimated effects. Second, the findings are limited to male adolescent basketball players who completed an 8-week intervention, which may restrict the generalizability of the results. Third, body composition was assessed using bioelectrical impedance analysis, and physiological adaptations were evaluated using

resting cardiovascular measures only. Future studies should incorporate criterion body-composition techniques, direct physiological measurements, larger samples, longer follow-up periods, female athletes, and mechanistic assessments to strengthen the evidence and improve generalizability.

The findings suggest that functional circuit training is a practical conditioning approach for adolescent male basketball players. When TRX suspension equipment and qualified supervision are available, incorporating suspension exercises into a progressively structured functional circuit programme may provide additional improvements in sprint speed, agility, countermovement-jump performance, body composition, and resting cardiovascular measures over an 8-week training period. These recommendations are limited to the population, intervention duration, and outcomes evaluated in the present study. Coaches should emphasize correct movement technique before progressing to unilateral, unstable, or explosive exercises.

The main scientific contribution of this study was the direct comparison of combined TRX suspension and functional circuit training with functional circuit training alone and regular basketball practice. The consistent graded response observed across all measured outcomes suggests that incorporating suspension exercises into a structured functional training programme may provide additional benefits beyond functional circuit training alone. However, the physiological and neuromuscular mechanisms underlying these adaptations were not directly assessed and therefore require confirmation in future mechanistic studies. Future research should examine longer intervention periods, follow-up retention, maturation status, female athletes, and basketball-specific performance outcomes (e.g., repeated sprint ability and match performance). In addition, studies incorporating electromyography, force-time analysis, and direct physiological monitoring are needed to further elucidate the mechanisms underlying the observed adaptations.

Conclusion

The present study demonstrated that structured conditioning programmes produced greater improvements in biomotor abilities and physiological adaptations than regular basketball practice in adolescent male basketball players. The combined TRX suspension and functional circuit training programme resulted in the greatest improvements in sprint speed, agility, countermovement-jump performance, body fat percentage, skeletal muscle mass, resting heart rate, and blood pressure, whereas functional circuit training alone produced intermediate improvements. These findings suggest that functional circuit training is an effective conditioning approach for adolescent male basketball players and that incorporating TRX suspension exercises into a progressively structured and supervised programme may provide additional benefits. The conclusions are limited to the 8-week intervention, the male adolescent sample, and the outcomes measured in the present study.

Ethics Approval

The study protocol received approval from the Institutional Ethics Committee of Hindustan Institute of

Technology & Science, Chennai, India (Approval ID: HITS/CRC/004/22703049). All the procedures were carried out in adherence with the principles of the Declaration of Helsinki. All parents/legal guardians gave informed consent before participation in the study.

Data Availability Statement

All datasets have been analyzed during the present study and can be obtained from the corresponding author on reasonable request.

Conflicts of Interest

The authors have no conflicts of interest.

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AI Transparency Statement

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Вплив комбінованого тренування з використанням підвісних петель та функціонального колового тренування на біомоторні й фізіологічні адаптації баскетболістів підліткового віку

Віджая Кумар^{1ABCD}, Д. Харігаран^{1ACD}

¹Гіндустанський університет технологій і наук

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

Реферат. Стаття: 10 с., 4 табл., 2 рис., 24 джерела.

Мета дослідження. Це дослідження мало на меті порівняти вплив 8-тижневої тренувальної інтервенції комбінованого тренування з використанням підвісних петель (TRX-тренування) та функціонального колового тренування, а також застосування виключно функціонального колового тренування та регулярної тренувальної практики з баскетболу, щодо біомоторних здібностей та фізіологічних адаптацій у баскетболістів підліткового віку.

Матеріали та методи. Загалом 60 баскетболістів підліткового віку чоловічої статі були розподілені за методом рандомізації на три групи: групу комбінованого тренування з використанням підвісних петель та функціонального колового тренування (TRXГ, n = 20), групу функціонального колового тренування (ФКГ, n = 20) та контрольну групу (КГ, n = 20). Тренування тривали 8 тижнів із періодичністю занять тричі на тиждень. На перед- та постінтервенційному етапах дослідження проведено вимірювання показників швидкості спринту, спритності, результативності стрибка з контрпрухом (КРС), відсотка жирової маси в організмі, скелетно-м'язової маси, частоти серцевих скорочень у стані спокою, а також систолічного і діастолічного артеріального тиску. Для статистичного аналізу даних використовувався метод змішаного дисперсійного аналізу з порівняннями Бонферроні.

Результати. Для всіх біомоторних та фізіологічних змінних було виявлено статистично значущу взаємодію факторів Група × Час (усі $p < .001$; часткова $\eta^2 = 0.64\text{--}0.82$). У TRXГ зафіксовано статистично значущо вищі показники покращення за всіма досліджуваними параметрами порівняно з учасниками ФКГ та КГ. Зокрема, великі ефекти взаємодії спостерігалися для показників спринту ($F(2.57) = 75.32, p < .001, \eta^2 = 0.73$), спритності ($\eta^2 = 0.82$), стрибка з контрпрухом ($\eta^2 = 0.78$), компонентного складу тіла, частоти серцевих скорочень у стані спокою та артеріального тиску.

Висновки. Отримані результати свідчать про те, що функціональне колове тренування підвищує біомоторні та фізіологічні параметри. Крім того, інтеграція вправ із використанням підвісних петель забезпечує вищі показники покращення, ніж застосування виключно функціонального колового тренування, та може створювати додаткові переваги за умови включення до прогресивно структурованої програми кондиційної підготовки під керівництвом тренера.

Ключові слова: баскетболісти підліткового віку, тренування з використанням підвісних петель, функціональне колове тренування, біомоторні здібності, фізіологічні адаптації, кондиційна підготовка.

Information about the Authors:

Kumar Vijaya: mvk910@gmail.com; <https://orcid.org/0009-0005-6594-8358>; Department of Physical Education and Sports Sciences, Hindustan Institute of Technology and Sciences (Deemed to be University), No. 1, Rajiv Gandhi Salai, Padur, Tamil Nadu, India.

D. Harigaran: harigarand@hindustanuniv.ac.in; <https://orcid.org/0000-0003-4251-925X>; Department of Physical Education and Sports Sciences, Hindustan Institute of Technology and Sciences (Deemed to be University), No. 1, Rajiv Gandhi Salai, Padur, Tamil Nadu, India.

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