Journal of Physical Education and Sport ® (JPES), Vol. 25 (issue 3), Art 59, pp. 539 - 547, March 2025
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Instructional strategies to enhance motor performance in female youth athletes

FOGLIATA ARIANNA[1]*, MAZZELLA MARIAPIA[2], GRAVINO GIANLUCA[3], AMBRETTI ANTINEA[4]
[1,3]Department of Mental and Physical Health and Preventive Medicine, University of Campania "Luigi Vanvitelli", Naples, ITALY.
[2]Department of Human, Social, and Health Sciences, University of Cassino and Southern Lazio, Frosinone, ITALY.
[4]Department of Human Sciences, Education, and Sport, Telematic Pegaso University, Naples, ITALY.

Published online: March 31, 2025
Accepted for publication: March 15, 2025
DOI:10.7752/jpes.2025.03059

Abstract

Problem Statement: During pre-adolescence and adolescence, motor development is influenced by maturation processes that impact coordination and strength abilities. Using simple, well-practiced tasks with competitive young female athletes presents an opportunity to isolate the effects of various instructional approaches (Cause-based, Effect-based, and Technical) during these critical developmental stages. This enables an exploration of how and whether these strategies can enhance motor learning. Approach: Ninety-six athletes were selected based on their competitive experience, training frequency, and medical-postural evaluations. After a one-week familiarization period, participants completed two experimental sessions, each separated by 72 h. Vertical jump performance [Squat Jump (SJ), Countermovement Jump (CMJ), and Drop Jump (DJ)] was evaluated using the BoscoSystem platform, while isometric strength was assessed with dynamometers. Each evaluation incorporated the three instructional explanation approaches. Purpose: This study explored the effects of three instructional explanation approaches (Cause-based, Effect-based, and Technical) on the motor performance of pre-adolescent (mean age = 13.5 years) and adolescent (mean age = 15.1 years) female volleyball players. Results: The Cause-based approach led to significant enhancements in jump height ($p < 0.0001$) and power ($p < 0.0001$), with more pronounced effects noted in the SJ and CMJ. These improvements were particularly evident in pre-adolescents, while the effects were less pronounced in older adolescents. No significant differences were observed in isometric strength ($p > 0.05$). Conclusions: Cause-based explanations are especially effective for individuals with lower relative motor maturation. This suggests that instructional strategies should be customized not only based on age but also considering competitive experience and readiness for motor learning.

Key words Didactics, strength evaluation, adolescent development, explanation, physical education

Introduction

The increasing focus arises from the recognition that developmental age is a crucial period for acquiring motor skills and athletic abilities (Viru et al., 1999). In recent decades, interest in integrating evidence-based approaches into sports education has grown, with a particular focus on biomechanics and motor learning psychology (D'Alpinoet al., 2022). This change highlights the need to understand not just "what" to learn but also "how" to learn effectively, especially during the critical phases of youth development (Schmidt & Lee, 2019; Davis et al., 2008). To address this need, recent studies have demonstrated that targeted teaching strategies can significantly enhance both movement quality and adaptability in young athletes (Renshaw et al., 2010). The field of sports science is increasingly converging with disciplines such as physiology, biomechanics, and pedagogy to optimize athletic performance and motor learning. Understanding how young athletes respond to specific motor instructional techniques and how their motor responses differ during growth stages, such as pre-adolescence and adolescence, is crucial for developing motor-sports interventions based on educational principles. In youth sports, instruction should not only meet technical requirements but also incorporate strategies that promote the retention and transferability of learning (Ramirez-Campillo et al., 2023; Faigenbaum et al., 2009). In this framework, a targeted approach that focuses on the underlying causes of movement could be an especially effective strategy for enhancing learning in young individuals.

This aligns with previous studies, which have shown that focusing on the causes of movement, rather than merely on observable effects or technical corrections, can lead to improvements in motor skills (Button et al., 2020). Further investigation into this approach could help educators design more effective teaching interventions that meet the specific needs of various stages of youth development. By comparing three distinct teaching methods, this study aims to provide fresh insights into optimizing both motor learning and fundamental athletic performance. In this context, innovative instructional approaches aim to combine knowledge from various disciplines to improve teaching practices (Benjaminse et al., 2015). For example, methodologies that prioritize comprehensive biomechanical explanations instead of solely relying on visual–deductive movement

Corresponding Author: FOGLIATA ARIANNA, E-mail: fogliataarianna@gmail.com

corrections have been shown to improve movement efficiency and performance quality in young athletes (Cabral et al., 2020; Myer et al., 2011; Dicesare et al., 2019). Likewise, the successful application of contextual and differential motor learning models has been demonstrated by Apidogo et al. (2024), revealing that varied instructional strategies can enhance performance efficiency, particularly in young volleyball players. In this framework, the Sincrony movement education methodology establishes a fundamental distinction between observable actions (Effect-based) and the underlying causes of visible movements (Cause-based). It emphasizes the importance of invisible muscle actions and kinetic chains in generating athletic gestures and their instruction (Fogliata et al., 2023). When applied to teaching and training, this concept can enhance motor learning and improve athletic performance, particularly in disciplines that require explosive actions, such as vertical jumping (De Bernardi, 2008). These insights have been further supported by the latest sports monitoring technologies, as highlighted by Nagorna et al. (2024), which emphasize the potential of immediate feedback in optimizing explosive movements. Various studies have highlighted differences in explosive movements, such as vertical and horizontal jumps, among pre-adolescents and adolescents, especially in females.

These variations are not necessarily linked to muscular training. However, when training strategies are tailored to the specific needs of the group, these differences tend to decrease. This suggests that the variations may stem from both physiological changes associated with growth and the methods of instruction used (Aoki et al., 2011; Smith, 2003). During adolescence, increases in muscle strength, tendon elasticity, and neuromuscular coordination typically enhance jumping abilities compared to pre-adolescents (Prieske et al., 2019). In pre-adolescents, jump performance often relies more on technique and motor coordination because limitations in muscle strength generally impede their ability to match the efficiency seen in adolescents (Pentidis et al., 2019). This study examined how various instructional approaches might affect jump test performance in adolescent and pre-adolescent volleyball players. The focus on immediate motor responses was chosen to analyze the direct and immediate effects of instructions on motor performance.

This method enables the isolation of the impact of different teaching strategies while minimizing the influence of external factors related to adaptation or repeated practice, thereby providing a clearer understanding of instructional effectiveness (McMahon et al., 2021). Vertical jump tests [Squat Jump (SJ), Countermovement Jump (CMJ), and Drop Jump (DJ)] and isometric force exercises (Pushes) were selected for their straightforward execution and their ability to reduce errors associated with technical complexity, ensuring reliable and reproducible results (Romero-Franco et al., 2019). Additionally, these tests provide an objective and quantitative assessment, offering a direct measure of how athletes apply the instructions they receive. Focusing on immediate responses is particularly beneficial in educational contexts because it enables teachers to assess the effectiveness of their strategies in real time and adjust their explanations to enhance learning outcomes. This is especially crucial during the pre-adolescent and adolescent stages, between ages 13 and 16, when the neuromuscular system exhibits high plasticity, allowing for rapid adaptation to instructions (Cudicio & Agosti, 2024). The integration of these tools and methods establishes a robust foundation for examining how various teaching styles influence the motor learning process.

Volleyball, a sport characterized by highly refined and stable jumping techniques developed through targeted training, provides a technical framework that is generally less prone to considerable changes (Sarvestan et al., 2020). Furthermore, the choice to include only female athletes was informed by evidence indicating that pubertal maturation affects physical performance differently in females compared to males, particularly concerning explosive strength and neuromuscular coordination (Almeida-Neto et al., 2020). However, there is a considerable gap in comprehensive comparative analyses regarding the effectiveness of these three instructional approaches in the context of youth motor development. This study assessed the effectiveness of three explanatory strategies, Cause-movement, Effect-based, and Technical in enhancing vertical jump performance and muscular strength among pre- and post-pubertal female athletes.

Materials and Methods

The study involved a sample of 96 female athletes from competitive youth volleyball programs. The participants were divided into two age groups: Group 1 comprised 49 pre-adolescent athletes (mean age = 13.5 years; SD = ±0.4), while Group 2 included 47 adolescent athletes (mean age = 15.1 years; SD = ±0.4). Athletes were recruited through direct invitations from a regional sports club, with selection criteria that included a detailed medical history, morphological assessments, and weekly training frequency to ensure sample homogeneity (Popi et al., 2023; Corso, 2018). Of the 120 athletes initially recruited, 24 were excluded during the preliminary screening process. The primary reasons for exclusion were failure to meet the selection criteria. All athletes selected for the study remained included in the subsequent analyses, thereby preserving the integrity of the collected data (Den Hartigh et al., 2018).

The decision to include athletes with prior vertical jumping experience was intentional, ensuring that participants possessed a homogeneous technical foundation, which minimized the potential impact of differences in basic motor skills on the results (Jager et al., 2017). Each participating athlete underwent a preliminary sports medical examination, which included a general evaluation as outlined in Table 1. These assessments included a postural test, morphological analysis, Body Mass Index (BMI) measurement, and the Cooper test to identify any physical limitations that might hinder participation in the study (Hudson, 2010). The postural analysis was performed by club physiotherapists using the adapted Trunk Control Test (TTC) (Franchignoni, 1997) to detect potential imbalances. Body composition and morphological parameters were evaluated through bioelectrical impedance analysis (BIA) using the Laica system. Athletes exhibiting abnormal parameters or postural risks were excluded from the study. Exclusion criteria also encompassed athletes whose anthropometric parameters significantly deviated from the reference values for their age group, as outlined in standardized growth charts (Cole et al., 2007), as well as those with conditions that could impair participation, such as injuries sustained in the previous six months.

A sports physician performed the anthropometric assessments, which included evaluations of body circumferences (arm, waist, hips, and thigh), segmental heights, and bone diameters. Scores were assigned on a scale of 1 to 10, with higher values indicating greater symmetry and balance (Drinkwater et al., 2008). Cardiovascular fitness levels were assessed using the Cooper test (Bandyopadhyay, 2015). Additionally, athletes were required to have a minimum of two years of competitive volleyball experience and to have attended all familiarization sessions. Testing sessions for all participants were performed during the follicular phase of the menstrual cycle to minimize performance variations that could be caused by hormonal fluctuations (Kildalsen, 2022).

Table 1. General evaluation-Screening

Variable	Group 1 Mean (SD)	Group 2 Mean (SD)
Weekly training hours	5 hours (± 2)	6 hours (± 1.5)
Years of training	3 years (± 1)	4 years (± 1.2)
BMI	22 (± 1,9)	22 (± 1,4)
Postural examination	3 (± 0.5)	3 (± 0.5)
Morphological criteria	7 (± 1.5)	8 (± 1)
Cooper	2800 m (± 400)	3000 m (± 350)
BPM	72 (± 5)	68 (± 5)

Before the experimental evaluation phases began, all athletes underwent a familiarization period consisting of three sessions. During these sessions, experimenters provided comprehensive instructions on test execution and equipment usage, ensuring that all participants had a uniform understanding of the protocols. Preliminary tests were performed to assess the accuracy of measurements and confirm the reproducibility of results, thereby minimizing potential biases or systematic errors. This approach is further supported by research emphasizing the advantages of familiarization sessions in enhancing measurement reliability (Rodriguez-Giustiniani et al., 2021). Additionally, the athletes received instructions based on three different instructional approaches: Cause-based, Effect-based, and Technical (Hibbert et al., 2017).

Execution of the First Experimental Session (FES)

During the FES, the Chrono Jump Bosco System (De Blaiser et al., 2019; D'Apino et al., 2022) was used. The athletes participated in groups of no more than four, supervised by the experimenter and two technical staff members. Each athlete performed three types of jumps: SJ, CMJ, and DJ (as detailed in Table 2). For each jump type, the metrics recorded included height (cm), speed (m/s), force (N), and power (W).

Table 2. Description: Squat Jump-Counter Movement Jump-Drop Jump

Jump Type	Description	Measured Objective	Key Features
Squat Jump (SJ)	Start from a static squat position (knees at ~90°), arms fixed along the sides, jump without pre-movement	Explosive lower-limb power	Excludes additional elastic energy generated by pre-movement
Counter Movement Jump (CMJ)	Start in a standing posi- tion, quickly squat down, then jump up using arm momentum	Jump height with pre-movement contribution	Includes arm contribu- tion and elastic energy from pre-movement
Drop Jump (DJ)	Start from a raised plat- form, drop to land on both feet and immedi- ately perform a vertical jump	Muscle reactivity and SSC efficiency	Minimizes ground con- tact time and maximizes the height of the subse- quent jump

For each jump type, a total of nine jumps were performed, with three jumps corresponding to each teaching method. Each jump type was accompanied by three different experimental instructions. The explanations were consistently repeated for all athletes, reinforcing the concepts covered during the familiarization session for each instruction type:

Cause-based explanation and instruction: "Push against the ground to achieve the highest jump possible. Focus on pushing the ground with your feet."

Effect-based explanation and instruction: "Try to jump as high as you can, focusing on reaching the maximum height." Technical explanation and instruction: "Jump as if you were on the court, trying to reach your maximum height. Remember to consider the blocking technique."

The jump sessions were structured to randomize the order of instruction presentation between the subjects, with the goal of minimizing any potential order effects on the results. Athletes were given ample recovery time between sessions, which was monitored using the Polar H10 Heart Rate Monitor (Giles et al., 2016).

Execution of the Second Experimental Session (SES)

During the SES, a dynamometer system was used to assess muscle strength, while the Polar H10 Heart Rate Monitor was used to track heart rate and recovery between test sessions. All athletes were instructed to perform a flat bench press movement, following guidelines based on the three teaching methods. Maximum isometric strength (N) values were recorded across three sets for each type of explanation:

Cause-based explanation and instruction: "Press your shoulders into the bench as if you are trying to sink it down. Use the bench for leverage as you push the dynamometers with your hands. Focus on driving your shoulders downward into the bench."

Effect-based explanation and instruction: "Push the dynamometers upward with your hands, aiming to lift them as high as possible. Focus on your upward movement."

Technical explanation and instruction: "Push the dynamometers with your hands as you would with dumbbells, using the correct pressing technique."

These sessions were organized to randomize the order of instruction types presented to the subjects, aiming to minimize any order effects on the results. Complete recovery was allowed between sessions, monitored through heart rate parameters, to prevent fatigue from affecting test outcomes. To standardize instructions and reduce the influence of uncontrolled motivational variables, each instructor provided explanations for all three experimental approaches (Cause-based, Effect-based, and Technical) using a consistent tone of voice and wording. The other two instructors observed to ensure that the explanations were delivered uniformly and consistently (Good et al., 2003). Additionally, during the familiarization sessions, the instructors recorded observations on any questions or reactions from the athletes, confirming that the instructions were clearly understood and consistently applied by all participants. Explanations were only adjusted if an athlete showed difficulty in comprehension without changing the content or format of the instructions. Furthermore, recovery periods between sessions were monitored through regular measurements of heart rate variability (HRV) to determine the optimal time for resuming activity. This approach ensured that all athletes returned to their baseline rest levels before each test, thereby minimizing the risk of residual fatigue. The use of HRV as an indicator is supported by studies that demonstrate its effectiveness in monitoring stress and recovery in sports contexts (Morales et al., 2014).

Data Analysis

The data analysis was performed using SPSS software. We assessed the normality of the data distribution for each group in FES (jumps) and SES (muscle strength) using the Shapiro–Wilk test. The results showed that the distributions in FES for Group 1 did not significantly differ from a normal distribution under the teaching conditions of Effect-based ($W = 0.979$, $p = 0.928$), Cause-based ($W = 0.97$, $p = 0.92$), and Technical ($W = 0.961$, $p = 0.814$). For Group 2, the variable distributions met the normality assumption for jump height ($W = 0.97$, $p = 0.92$), power ($W = 0.98$, $p = 0.94$), strength ($W = 0.97$, $p = 0.91$), and speed ($W = 0.97$, $p = 0.93$). In SES for Group 1, the distributions of isometric strength data did not significantly deviate from normality across all analyzed teaching conditions. The results from the Shapiro–Wilk test indicated that normality was achieved for the instructional approaches: Effect-based ($W = 0.98$, $p = 0.91$), Cause-based ($W = 0.97$, $p = 0.92$), and Technical ($W = 0.96$, $p = 0.85$). Similarly, for Group 2, the distributions exhibited values consistent with normality for the Effect-based ($W = 0.98$, $p = 0.91$), Cause-based ($W = 0.97$, $p = 0.92$), and Technical ($W = 0.97$, $p = 0.89$) conditions. Thus, a repeated measures ANOVA (3x2) was used to analyze performance differences across the three teaching types and the two groups (1 and 2). Additionally, Mauchly's test was performed to evaluate the sphericity assumption for both sessions. The results revealed that for both sessions, the sphericity assumption was satisfied for all analyzed variables ($p > 0.05$).

Results

Group 1 FES

The repeated measures ANOVA results for each variable were as follows:

No statistically significant differences were found between the instructional approaches for strength ($p > 0.05$) and speed ($p > 0.05$). However, significant differences in jump height were observed across the various teaching conditions ($p < 0.00001$) as well as for power ($p < 0.00001$). Specifically, the Tukey HSD post hoc test, which was adjusted for multiple comparisons, revealed significant differences in SJ height between the three instructional approaches ($p < 0.0001$). The Cause-based approach resulted in a significant increase compared to the Effect-based approach (3.25 cm, $p < 0.0001$) and the Technical approach (3.0 cm, $p < 0.0001$). Similarly, significant differences were found in the CMJ performance ($p < 0.0001$). The Cause-based approach surpassed both the Effect-based (by 2.6 cm, $p < 0.0001$) and the Technical approach (by 3.2 cm, $p < 0.0001$). In contrast, no significant differences were observed for the DJ between the instructional explanations ($p > 0.05$). Consequently, the significant differences were further analyzed using the Tukey HSD post hoc test, as detailed in Table 3.

Table 3. Post-hoc di Tukey HSD Group 1

Variable		DELTA MEAN (CM/N)	Significance (p)
Height	Cause-based vs. Effect-based	+3.25	<0.00001*
	Cause-based vs. Technical	+3	<0.00001*
	Effect-based vs. Technical	-0.3	>0.05
Power	Cause-based vs. Effect-based	-3100.50	<0.00001*
	Cause-based vs. Technical	-980.25	<0.01*
	Effect-based vs. Technical	-2200.75	<0.00001*

Furthermore, the effect sizes calculated using eta-squared revealed large effects for jump height ($\eta2 = 0.18$) and power ($\eta2 = 0.16$). In contrast, no significant effects were found for isometric strength ($\eta2 < 0.01$).

Group 1 SES Results

The repeated measures ANOVA did not show significant differences in muscle strength among the three instructional explanations. The mean values across conditions were similar: Effect-based (150 ± 10), Cause-based (152 ± 12), and Technical (151 ± 11), with $p > 0.05$.

Group 2 FES

The repeated measures ANOVA results for each variable were as follows:

No statistically significant differences were found among the instructional approaches for strength ($p > 0.05$) and speed ($p > 0.05$). However, significant differences were identified for jump height ($p < 0.00001$) and power ($p < 0.00001$). Specifically, the Tukey HSD post hoc test with correction for multiple comparisons revealed significant differences in SJ height among the three instructional approaches ($p < 0.0001$). Furthermore, the Cause-based approach resulted in a 2.5 cm improvement compared to the Effect-based approach ($p < 0.01$) and a 2.1 cm improvement compared to the Technical approach ($p < 0.05$). In addition, the Cause-based approach led to a +2.2 cm increase in CMJ compared to both the Effect-based ($p < 0.01$) and Technical ($p < 0.01$) approaches. No significant differences were observed for DJ among the three instructional approaches ($p > 0.05$). Therefore, significant differences were analyzed using the Tukey HSD post hoc test, as outlined in Table 4.

Table 4. Post-hoc di Tukey HSD Group 2

Variable		DELTA MEAN (CM/N)	Significance (p)
Height	Cause-based vs. Effect-based	+2.50	<0.001*
	Cause-based vs. Technical	+2.10	<0.01*
	Effect-based vs. Technical	-0.40	>0.05
Power	Cause-based vs. Effect-based	-2750.80	<0.01*
	Cause-based vs. Technical	-850.25	<0.05
	Effect-based vs. Technical	-1900.55	<0.05

For Group 2, the repeated measures ANOVA found no significant differences among the three instructional approaches concerning maximum isometric muscle strength measured with dynamometers. The mean values were comparable across conditions: Effect-based (210 ± 15 N), Cause-based (215 ± 18 N), and Technical (212 ± 16 N), with $p > 0.05$. Additionally, the effect sizes calculated using eta-squared indicated moderate effects for jump height ($\eta2 = 0.12$) and power ($\eta2 = 0.13$) in Group 2, while no significant effects were noted for isometric strength ($\eta2 < 0.01$).

Interaction Analysis (Group 1 and Group 2)

A mixed ANOVA (3 × 2) was performed, incorporating a within-subjects factor (instructional explanations) and a between-subjects factor (Groups 1–2) for FES. The analysis demonstrated a significant interaction for jump height between the two factors ($p < 0.05$), indicating that the effectiveness of the three instructional explanations varied significantly across the groups. Specifically, the effect of the Cause-based explanation was more pronounced in Group 1 than in Group 2. No significant interactions were found for strength, power, and speed ($p > 0.05$).

For SES, there were also no significant interactions between age and teaching instructional approach for these variables ($p > 0.05$). However, there was a significant interaction for jump height ($p < 0.05$), indicating that the Cause-based explanation was more effective in Group 1 than in Group 2. No significant interactions were observed for strength, speed, or power ($p > 0.05$), as detailed in Table 5.

Table 5. Key effects and group interactions summary

Variable	Group	Most Effective	Mean Delta (cm/N)	Significance (p)	Effect Size (η^2)	Group Interaction
SJ	Group1	Cause-based	+3.25 cm	< 0.00001	0.18	p < 0.05*
SJ	Group 2	Cause-based	+2.50 cm	< 0.001	0.12	p < 0.05*
CMJ	Group 1	Cause-based	+3.20 cm	< 0.00001	0.18	p < 0.05*
CMJ	Group 2	Cause-based	+2.20 cm	< 0.001	0.12	p < 0.05*
DJ	Group 1	No difference	-	> 0.05	< 0.01	p > 0.05
DJ	Group 2	No difference	-	> 0.05	< 0.01	p > 0.05
Strength	Group 1	No difference	-	> 0.05	< 0.01	p > 0.05
Strength	Group 2	No difference	-	> 0.05	< 0.01	p > 0.05

Discussion

The results of this study demonstrated that the Cause-based instructional approach was significantly more effective in enhancing vertical jump performance, both in terms of jump height ($p < 0.00001$) and power generated ($p < 0.00001$), compared to the Effect-based and Technical instructional methods, especially in pre-adolescents in Group 1. These findings are consistent with previous research highlighting the importance of age-specific instructional strategies in improving motor performance during developmental stages. Research indicates that neuromuscular coordination is crucial for vertical jump performance, particularly in pre-adolescents, who tend to depend more on biomechanical understanding and technique refinement rather than on strength-based adaptations (Etnier & Landers, 1998; Lipoma, 2019). Moreover, the significant interaction between age group and teaching method ($p < 0.05$) may be attributed to the fact that Cause-based explanations, which emphasize the muscles responsible for movement, were particularly relevant during a developmental phase when motor coordination is crucial.

The Cause-based approach showed a notable average improvement of 3.25 cm compared to Effect-based and 3 cm compared to Technical for Group 1, while Group 2 showed an improvement of 2.50 cm. This demonstrates that pre-adolescent athletes, who are still developing fundamental motor skills, benefit more from strategies that explicitly clarify the biomechanical dynamics of athletic movements (Myer et al., 2011). In contrast to the observed differences in jumping performance, no significant variations in maximum isometric muscle strength were found across the three instructional approaches in either group ($p > 0.05$). This lack of significant differences suggests that isometric strength is less affected by immediate instructional changes and is instead primarily influenced by structural and physiological factors, such as muscle mass and neuromuscular coordination, which require targeted and prolonged training (Faigenbaum et al., 2009).

The differences observed across the three jump types provide additional insights. In both SJ and CMJ, the Cause-based approach led to significant improvements in jump height and power, particularly among pre-adolescents in Group 1. However, for DJ, which involves neuromuscular components, the differences among the three instructional approaches were less pronounced. Consistent with the literature, this finding suggests that this parameter is less dependent on the type of teaching explanation used and is instead more influenced by physiological factors and muscle maturation (Malina et al., 2004). Moreover, age appears to have a smaller impact on isometric strength than on the ability to perform explosive movements (Croix et al., 2007). The primary limitations of this study include the relatively small sample size and the exclusion of male athletes. While these factors limit the generalizability of the findings, they also help reduce confounding variables. Additionally, it would be valuable to implement these three instructional approaches over a longer period and perform follow-up assessments to evaluate the longevity and intensity of their effects.

Conclusions

The findings of this study highlight the importance of adapting teaching explanations to the age and motor development needs of young athletes. The Cause-based instructional approach proved particularly effective in enhancing vertical jump height and power, demonstrating that explanations emphasizing the internal causes of movement can lead to improved performance. Furthermore, jumps such as the SJ and CMJ benefited more from Cause-based explanations compared to movements that rely heavily on neuromuscular responses. This effect was especially pronounced in pre-adolescent athletes, who are in a developmental stage where coordination plays a crucial role, making them more responsive than adolescents to strategies focused on the biomechanics of movement. Although height and power improved significantly, parameters such as strength and speed did not show significant differences across the three instructional approaches. This discrepancy may stem from the complex nature of strength and speed in jumps, which depend not only on the quality of biomechanical execution but also on intrinsic factors such as muscle capacity, tendon elasticity, and neuromuscular coordination (Komi, 2000). The force generated during jumps requires the optimization of kinetic chains; however, improvements are often more closely tied to specific training rather than short-term variations in teaching explanations. Speed, on the other hand, relies on an integration of physiological and technical components that are less responsive to instructional cues focused on movement execution and more influenced by targeted training programs for speed and reactivity development (Ross & Leveritt, 2001).

The lack of significant differences in isometric strength across the different instructional approaches and age groups may reflect the inherent nature of these abilities, which are largely shaped by physiological and neuromuscular maturation. This suggests that static motor skills respond differently than explosive ones, with the latter showing greater benefits from targeted teaching interventions (Malina, 2004). The interaction between age and instructional approaches observed in this study underscores the importance of tailoring teaching methods to the specific demands of movements and developmental stages. It demonstrates how targeted explanations can enhance motor performances related to coordination during pre-adolescence, providing educators with valuable insights into effective teaching strategies for young athletes.

The greater effectiveness of the Cause-based instructional approach in female pre-adolescents suggests that teachers should emphasize the causes of movement, linking them to a deeper biomechanical understanding while also fostering coordination development because pre-adolescents are still refining basic motor skills (Faigenbaum et al., 2009; Malina et al., 2004). In contrast, adolescents, who are undergoing more advanced neuromuscular maturation, may benefit from combining the Cause-based approach with a stronger focus on Technical refinement. While the data confirm the usefulness of focusing on the causes of movement (Gabbett et al., 2016), adolescents may benefit more from an approach that integrates technical mastery with performance optimization, leveraging their increasing strength and neuromuscular coordination. Therefore, coaches should adapt their instructional methods to incorporate both technical refinement and a deeper connection to the biomechanics of movement. This approach can enhance the quality and effectiveness of athletic performance during a critical phase of physical maturation (Renshaw et al., 2010; Myer et al., 2011).

Ethical compliance and conflict of interest

The study adhered to the Declaration of Helsinki and was approved. Consent was provided by participants' parents or caregiver. The authors declare that there are no financial or non-financial conflicts of interest associated with this study. Furthermore, they confirm that the results reported were obtained independently and without external influence. The authors have not received direct or indirect funding that could have influenced the execution of the study or the interpretation of the results.

Acknowledgments

The authors would like to thank Falcon Scientific Editing (https://falconediting.com) for proofreading the English language in this paper.

References

Almeida-Neto P. F., Matos D. G., Pinto V. C. M., Dantas P. M. S., Cesário T. M., Silva L. F., Bulhões-Correia A., Aidar F. J., & Cabral B. G. A. (2020). Can the neuromuscular performance of young athletes be influenced by hormone levels and different stages of puberty?. *International journal of environmental research and public health*, 17(16), 5637. https://doi.org/10.3390/ijerph17165637

Amri-Dardari A., Mkaouer B., Nassib S., Amara S., Amri R., Zohra F., & Salah B. (2021). The effects of video modeling and simulation on teaching/learning basic vaulting jump on the vault table. *Science of Gymnastics Journal*, 12(3), 325–344. https://doi.org/10.52165/sgj.12.3.325-344

Aoki M. S., Arruda A. F., Freitas C. G., Miloski B., Marcelino, P. R., Drago, G., Drago, M., & Moreira, A. (2017). Monitoring training loads, mood states, and jump performance over two periodized training mesocycles in elite young volleyball players. *International Journal of Sports Science & Coaching*, 12(1), 130-137. https://doi.org/10.1177/1747954116684394

Apidogo J.B, Ammar A., Salem A., Burdack J., Schöllhorn W.I. (2024). Resonance effects in variable practice for handball, basketball, and volleyball skills: A Study on Contextual Interference and Differential Learning. *Sports*, 12 (5). https://doi.org/10.3390/sports12010005

Bandyopadhyay A. (2015). Validity of Cooper's 12-minute run test for estimation of maximum oxygen uptake in male university students. *Biology of sport*, 32(1), 59–63. https://doi.org/10.5604/20831862.1127283

Benjaminse A., Gokeler A., & Dowling A. V. (2015). Optimization of the anterior cruciate ligament injury prevention paradigm: Novel feedback techniques to enhance motor learning and reduce injury risk. *Journal of Orthopaedic & Sports Physical Therapy*, 45(10), 681-686. https://www.jospt.org/doi/10.2519/jospt.2015.4986

Button C., Seifert L., Chow J. Y., & Davids K. (2020). Dynamics of skill acquisition: An ecological dynamics rationale. *Human Kinetics*.

Cabral B. G, Almeida-Neto P. F., & Dantas M. (2020). Studies on evaluation and maturation in youth sports practice. *Self-published*.

Cole T. J., Flegal K. M., Nicholls D., & Jackson A. A. (2007). Body mass index cut offs to define thinness in children and adolescents: international survey. *BMJ*, 335(7612), 194. https://doi.org/10.1136/bmj.39238.399444.55

Corso M. (2018). Developmental changes in the youth athlete: implications for movement, skills acquisition, performance and injuries. *The Journal of the Canadian Chiropractic Association*, 62(3), 150–160. PMID: 30662070; PMCID: PMC6319435.

Croix M.S. (2007). Advances in pediatric strength assessment: changing our perspective on strength development. *J Sports Sci Med.*, 6(3):292-304.

Cudicio A., & Agosti V. (2024). Beyond belief: Exploring the alignment of self-efficacy, self-prediction, self-perception, and actual performance measurement in squat jump performance, a pilot study. *Journal of Functional Morphology and Kinesiology*, 9(1), 16. https://doi.org/10.3390/jfmk9010016

D'Alpino, I. A., Moterosso, J. P. C., Botaro, W. R., Da Silva, A. O. C., Sant'Anna, P. G., Testa Junior, A., Verardi, C. E. L., & Zanini, G. S. (2022). Comparison between mood states, stress and recovery in CrossFit® competitors and non-competitors. *Journal of Physical Education and Sport*, 22(11), 2611–2617. https://doi.org/10.7752/jpes.2022.11331

Den Hartigh R. D., Niessen A., Frencken W., & Meijer R. (2018). Selection procedures in sports: Improving predictions of athletes' future performance. *European Journal of Sport Science*, 18(9), 1191–1198. https://doi.org/10.1080/17461391.2018.1480662

De Bernardi F. (2008). Movements education. *Red Edition.* 978-88-7447-771-5

De Blaiser C., De Ridder R., Willems T., Danneels L., Roosen P. (2019) Reliability of two functional clinical tests to evaluate trunk and lumbopelvic neuromuscular control and proprioception in a healthy population. *Brazilian Journal of Physical Therap*, 23(6):541-548. doi: 10.1016/j.bjpt.2018.10.014.

Davids K., Button C., & Bennett S. (2008). Dynamics of skill acquisition: A constraints-led approach. *Human Kinetics.*

Dicesare C. A., Montalvo A., Barber Foss K. D., Thomas S. M., Ford K. R., Hewett T. E., Jayanthi N. A., Stracciolini A., Bell D. R., & Myer G. D. (2019). Lower extremity biomechanics are altered across maturation in sport-specialized female adolescent athletes. *Frontiers in Pediatrics*, 7(268). https://doi.org/10.3389/fped.2019.00268

Drinkwater E. J., Pyne D. B., & McKenna M. J. (2008). Design and interpretation of anthropometric and fitness testing of basketball players. *Sports medicine* (Auckland, N.Z.), 38(7), 565–578. https://doi.org/10.2165/00007256-200838070-00004

Etnier J. L., & Landers D. M. (1998). Motor performance and motor learning as a function of age and fitness. *Research quarterly for exercise and sport*, 69(2), 136–146. https://doi.org/10.1080/02701367.1998.10607679

Faigenbaum A. D., Kraemer W. J., Blimkie C. J., Jeffreys I., Micheli L. J., Nitka M., & Rowland T. W. (2009). Youth resistance training: updated position statement paper from the national strength and conditioning association. *Journal of strength and conditioning research,* 23(1) (5 Suppl), S60–S79. https://doi.org/10.1519/JSC.0b013e31819df407

Fogliata A., Borghini R., & Ambretti A. (2023). Study on the performative effects of cause-based vs effect-based teaching in adolescent athletes: Evaluation of lower limb explosive strength. *Scientific Journal of Sport and Performance*, 2(2), 247-255. https://DOI:10.55860/LAHU8849

Franchignoni F. P., Tesio L., Ricupero C., & Martino M. T. (1997). Trunk control test as an early predictor of stroke rehabilitation outcome. *Stroke*, 28(7), 1382–1385. https://doi.org/10.1161/01.str.28.7.1382

Gabbett T. J., & Jenkins D. G. (2011). Relationship between training load and injury in professional rugby league players. *Journal of science and medicine in sport*, 14(3), 204–209. https://doi.org/10.1016/j.jsams.2010.12.002

Giles D., Draper N., & Neil W. (2016). Validity of the Polar V800 heart rate monitor to measure RR intervals at rest. *European journal of applied physiology*, 116(3), 563–571. https://doi.org/10.1007/s00421-015-3303-9

Goo C., Aronso J., & Inzlicht M. (2003). Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. *Journal of Applied Developmental Psychology*, 24(6), 645-662. https://doi.org/10.1016/j.appdev.2003.09.002

Hibbert A. W., Billaut F., Varley M. C., & Polman R. C. J. (2017). Familiarization protocol influences reproducibility of 20-km cycling time-trial performance in novice participants. *Frontiers in physiology*, 8, 488. https://doi.org/10.3389/fphys.2017.00488

Jager J., Putnick D. L., & Bornstein M. H. (2017). More than just convenient: the scientific merits of homogeneous convenience samples. *Monographs of the Society for Research in Child Development*, 82(2), 13–30. https://doi.org/10.1111/mono.12296

Kildalsen I. (2022). Effects of the menstrual cycle on sports-physiological performance in female team handball players. *UiT The Arctic University of Norway.* https://munin.uit.no/handle/10037/27849

Komi P. V. (2000). Stretch-shortening cycle: a powerful model to study normal and fatigued muscle. *Journal of biomechanics*, 33(10), 1197–1206. https://doi.org/10.1016/s0021-9290(00)00064-6

D'Alpino, I. A., Moterosso, J. P. C., Botaro, W. R., Da Silva, A. O. C., Sant'Anna, P. G., Testa Junior, A., Verardi, C. E. L., & Zanini, G. S. (2022). Comparison between mood states, stress and recovery in CrossFit® competitors and non-competitors. *Journal of Physical Education and Sport*, 22(11), 2611–2617. https://doi.org/10.7752/jpes.2022.11331

Lipoma M. (2019). The educational approach for physical and sport activities. Formazione & Insegnamento: *European Journal of Research on Education and Teaching*, 17(2). Pensa MultiMedia Editore.

Malina R. M., Bouchard C., & Bar-Or O. (2004). Growth, maturation, and physical activity. *Human Kinetics*.

Markovic G., Dizdar D., Jukic I., & Cardinale M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of strength and conditioning research*, 18(3), 551–555. https://doi.org/10.1519/1533-4287(2004)18<551:RAFVOS>2.0.CO;2

McMahon J. J., Lake J. P., Stratford C., & Comfort P. (2021). A proposed method for evaluating drop jump performance with one force platform. *Biomechanics*, 1(2), 178-189. https://doi.org/10.3390/biomechanics1020015

Myer G. D., Faigenbaum A. D., Chu, D. A., Falkel J., Ford K. R., Best T. M., & Hewett T. E. (2011). Integrative training for children and adolescents: techniques and practices for reducing sports-related injuries and enhancing athletic performance. *The Physician and Sports medicine*, 39(1), 74–84. https://doi.org/10.3810/psm.2011.02.1854

Myer G. D., Faigenbaum A. D., Ford K. R., Best T. M., Bergeron M. F., & Hewett T. E. (2011). When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance performance? *Current Sports Medicine Reports*, 10(3), 155-166. https://doi.org/10.1249/JSR.0b013e31821b1442

Morales J., Alamo J. M., García-Massó X., Buscà B., López J. L., Serra-Añó P., & González L. M. (2014). Use of heart rate variability in monitoring stress and recovery in judo athletes. *Journal of strength and conditioning research*, 28(7), 1896–1905. https://doi.org/10.1519/JSC.0000000000000328

Nagorna V., Mytko A., Borysova O., Potop V., Petrenko H., Zhyhailova L., Folvarochnyi I., & Lorenzetti S. (2024). Innovative technologies in sports games: A comprehensive investigation of theory and practice. *Journal of Physical Education and Sport* 24(3), 585–596. https://doi.org/10.7752/jpes.2024.03070

Pentidis N., Mersmann F., Bohm S., Giannakou E., Aggelousis N., & Arampatzis A. (2019). Triceps surae muscle-tendon unit properties in preadolescent children: a comparison of artistic gymnastic athletes and non-athletes. *Frontiers in physiology*, 10, 615. https://doi.org/10.3389/fphys.2019.00615

Polakovičová M., Vavák M., Ollé R., Lehnert M., & Sigmund M. (2018). Vertical jump development in elite adolescent volleyball players: effects of sex and age. *Acta Gymnica*, 48(2), 70-77. https://dx.doi.org/10.5507/ag.2018.016

Popi S., Thrush A., & Hill B.(2023) The attraction, retention, and transition of elite sport development pathways in surfing in Australia. *Managing Sport and Leisure*, 21(3), 1-18. https://DOI-10.1080/23750472.2023.2190755

Prieske O., Dalager T., Herz M., Hortobagyi T., Sjøgaard G., Søgaard K., & Granacher U. (2019). Effects of physical exercise training in the workplace on physical fitness: a Systematic Review and Meta-analysis. *Sports medicine*, 49(12), 1903–1921. https://doi.org/10.1007/s40279-019-01179-6

Ramirez-Campillo R., Sortwell A., Moran J. (2023). Plyometric-jump training effects on physical fitness and sport-specific performance according to maturity: a systematic review with Meta-analysis. *Sports Med* - Open 9 (23), https://doi.org/10.1186/s40798-023-00568-6

Renshaw I., Davids K., & Savelsbergh G. J. P. (2010). Motor learning in practice: a constraints-led approach. *Routledge*.

Rodriguez-Giustiniani P., Rollo I., & Galloway S. D. R. (2021). A preliminary study of the reliability of soccer skill tests within a modified soccer match simulation protocol. *Science and Medicine in Football*, 6(3), 363–371. https://doi.org/10.1080/24733938.2021.1972137

Romero-Franco N., Jiménez-Reyes P., & Montaño-Munuera J. A. (2017). Validity and reliability of a low-cost digital dynamometer for measuring isometric strength of lower limb. *Journal of sports sciences*, 35(22), 2179–2184. https://doi.org/10.1080/02640414.2016.1260152

Ross A., & Leveritt M. (2001). Long-term metabolic and skeletal muscle adaptations to short-sprint training: implications for sprint training and tapering. *Sports medicine* (Auckland, N.Z.), 31(15), 1063–1082. https://doi.org/10.2165/00007256-200131150-00003

Sang X. (2023). Effects of functional training on the athletic quality of aerobics practitioners. *Revista Brasileira de Medicina do Esporte*, 29(1). https://doi.org/10.1590/1517-8692202329012022_0626

Sarvestan J., Svoboda Z., Baeyens J. P., & Serrien B. (2020). Whole body coordination patterning in volleyball spikes under various task constraints: exploratory cluster analysis based on self-organising maps. *Sports Biomechanics*, 22(9), 1153–1167. https://doi.org/10.1080/14763141.2020.1788132

Schmidt R. A., & Lee T. D. (2019). Motor learning and performance: from principles to application. *Human Kinetic.*

Smith D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports medicine*, 33(15), 1103–1126. https://doi.org/10.2165/00007256-200333150-00003

Viru A., Loko J., Harro M., Volver A., Laaneots L., & Viru M. (1999). Critical periods in the development of performance capacity during childhood and adolescence. *European Journal of Physical Education*, 4(1), 75–119. https://doi.org/10.1080/1740898990040106.