

Effects of multidirectional stabilization exercises on postural stability in adolescent boys

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Abstract

Introduction. Dynamic postural stability is an important component of motor performance, neuromuscular control, and injury prevention in adolescents. During adolescence, rapid biological growth and neuromuscular maturation may influence balance performance, making targeted stabilization training particularly relevant in this age group. Despite increasing interest in stabilization-based interventions, evidence regarding the effectiveness of multidirectional stabilization exercises in school-aged adolescents remains limited. **Material and methods.** The aim of this study was to analyze the effects of three multidirectional stabilization exercise programs on postural stability in 13-year-old boys assessed using the 8-directional Star Excursion Balance Test (SEBT), the 4-directional SEBT, and the 3-directional Y Balance Test (YBT). The research sample consisted of 30 boys who regularly attended an extracurricular football program. Following baseline assessment, participants were randomly assigned to one of three experimental groups according to the type of stabilization exercises performed: an 8-directional group (n = 10), a 4-directional group (n = 10), and a 3-directional group (n = 10). The intervention lasted eight weeks and was performed twice weekly. Dynamic postural stability was assessed before and after the intervention using the 8-directional Star Excursion Balance Test (SEBT), the 4-directional SEBT, and the 3-directional Y Balance Test (YBT). Statistical analysis included paired-sample t-tests, analysis of variance (ANOVA), and effect size calculations. **Results.** Statistically significant improvements were observed across all analyzed directions in all three intervention groups ($p < 0.05$). The greatest improvements were recorded in the posterior, posteromedial, and posterolateral directions. Composite score analysis confirmed significant enhancements in overall dynamic postural stability for both lower limbs following the intervention. Although slightly greater improvements were observed in the Y Balance Test protocol, no statistically significant differences were identified among the three intervention approaches. **Discussion.** The findings indicate that multidirectional stabilization exercises contribute to improved neuromuscular coordination, proprioceptive function, and dynamic balance performance. The positive adaptations observed across all intervention groups suggest that stabilization training promotes global improvements in postural control regardless of the number of movement directions included in the exercise program. **Conclusions.** Multidirectional stabilization exercises represent an effective and practical method for improving postural stability in adolescent boys. The results support the inclusion of stabilization training in physical education and extracurricular sports programs and suggest that simplified balance assessment protocols may provide comparable information regarding dynamic postural stability.

Key words: dynamic balance, neuromuscular control, proprioception, balance assessment, functional performance, youth athletes

Introduction

Postural stability represents a complex ability to maintain control of body position under both static and dynamic conditions through the integration of vestibular, proprioceptive and visual systems. It is a fundamental prerequisite for effective motor control, coordination and injury prevention (Shumway-Cook & Woollacott, 2017; McKeon & Hertel, 2008). Dynamic stability plays a crucial role particularly in activities that require continuous adjustment of body position in changing environments, such as sports and physical activities in children and adolescents.

In recent decades, functional tests assessing dynamic balance have become widely used in sports science and rehabilitation. One of the most commonly used tools is the Star Excursion Balance Test (SEBT), which was originally developed as a rehabilitation exercise and has since been established as a valid and reliable method for assessing dynamic postural control (Gray, 1995; Hertel, 2000; Gribble et al., 2012; Powden et al., 2019). The SEBT evaluates dynamic stability through maximal reach distance in multiple directions while maintaining single-leg stance. Performance in this test is influenced by a combination of lower limb strength, joint mobility, proprioception and neuromuscular coordination (Hertel et al., 2006; Plisky et al., 2006). An

important methodological aspect is the normalization of reach distance relative to leg length, which allows for more accurate comparison between individuals.

A commonly used modification of the SEBT is the Y Balance Test (YBT), which includes three primary reach directions and provides a time-efficient alternative while maintaining high diagnostic validity (Plisky et al., 2009; Picot et al., 2021; Shaffer et al., 2013). Previous studies have demonstrated a strong relationship between SEBT and YBT performance, suggesting that both tests provide comparable information about dynamic balance.

Dynamic postural stability is also considered an important predictor of lower limb injury risk. Reduced reach distances or asymmetries between limbs have been associated with an increased risk of sports injuries (Hegedus et al., 2015; Gribble et al., 2012; Plisky et al., 2006). Therefore, these tests are widely used not only for assessment but also for monitoring the effectiveness of training and rehabilitation programs.

In recent years, research on dynamic balance has increasingly focused on children and adolescents (Broďáni et al., 2025). Findings suggest that postural stability is strongly influenced by neuromuscular development and muscle strength, with a close relationship between these factors (Muehlbauer et al., 2024; Płoszaj et al., 2024; Granacher et al., 2011; Myer et al., 2011). Balance training has been shown to induce adaptations in the central nervous system, leading to improved coordination and movement control (Broďáni et al., 2024). Recent evidence suggests that neuromuscular training interventions represent one of the most effective approaches for improving balance performance and postural stability in physically active youth populations (Akbar et al., 2022; Shi et al., 2026). These adaptations are closely related to core stabilization mechanisms and intra-abdominal pressure regulation (Lenková et al., 2026).

Postural stability during adolescence is influenced not only by training stimuli but also by rapid biological growth and neuromuscular maturation. Around the age of 13 years, adolescents often experience temporary changes in movement coordination resulting from accelerated growth of body segments and ongoing development of sensorimotor control. This period has been described as a critical stage for the development of balance, coordination, and movement efficiency, making adolescents particularly responsive to appropriately designed neuromuscular and stabilization training interventions (Lloyd & Oliver, 2012; Myer et al., 2011).

Effective postural control depends on the integration of visual, vestibular, and somatosensory information. These sensory inputs are continuously processed by the central nervous system to generate appropriate motor responses that maintain balance and movement control (Horak, 2006; Shumway-Cook & Woollacott, 2017). Previous research has demonstrated that deficits in neuromuscular control and proprioception may negatively affect dynamic stability and increase the risk of lower-limb injuries, particularly in physically active youth populations (McKeon & Hertel, 2008; Hegedus et al., 2015).

Recent evidence has further confirmed the effectiveness of stabilization-based interventions in adolescent populations. Broďáni et al. (2026) reported significant improvements in postural stability and balance performance in middle adolescents following a structured stabilization exercise program. Their findings support the role of neuromuscular training in enhancing dynamic balance and suggest that stabilization exercises may represent an effective strategy for improving movement control during adolescence. Nevertheless, additional research is needed to examine the effectiveness of multidirectional stabilization programs using different balance assessment protocols and to determine their applicability within school-based physical education settings. Despite the growing body of research, the effectiveness of multidirectional stabilization exercises in school settings remains insufficiently explored. In particular, there is limited evidence examining their effects on postural stability in adolescents while simultaneously comparing multiple dynamic balance assessment protocols.

The aim of this study was to analyze the effects of three multidirectional stabilization exercise programs on postural stability in 13-year-old boys assessed using the 8-directional Star Excursion Balance Test (SEBT), the 4-directional SEBT, and the 3-directional Y Balance Test (YBT).

Methodology

Participants and study design

The research sample consisted of 30 adolescent boys aged 13 years who regularly attended an extracurricular football club program. All participants were free from musculoskeletal injuries and neurological disorders that could affect balance performance. Written informed consent was obtained from parents or legal guardians prior to participation. Initial testing was conducted during regular training sessions on 14 and 16 May 2025. Following baseline assessment, participants were randomly assigned to one of three experimental groups according to the type of multidirectional stabilization exercises performed: an 8-directional group ($n = 10$), a 4-directional group ($n = 10$), and a 3-directional group ($n = 10$).

Intervention program

The experimental program focused on multidirectional stabilization exercises and lasted eight weeks. Participants performed the exercises twice weekly in accordance with the protocol assigned to their experimental group. The duration of the intervention was selected based on previous research indicating that significant adaptations in dynamic postural stability may occur following six to eight weeks of stabilization training (Granacher et al., 2011; Muehlbauer et al., 2024).

Training sessions were integrated into extracurricular physical and sports education activities with a focus on football. Following a standardized warm-up conducted by the coach, participants were divided into small groups of three to four individuals and completed the assigned stabilization exercises in an indoor environment. Exercise protocols differed according to experimental group allocation and reflected the number of movement directions included in the stabilization program.

Procedures and measurements

Research data were obtained using functional tests of dynamic postural stability, including the Star Excursion Balance Test (SEBT), its modified version, the Y Balance Test (YBT), and the 4-directional balance test. Each experimental group was assessed using the test protocol corresponding to its intervention program (3-, 4-, or 8-directional variant). This approach enabled the evaluation of specific changes in dynamic postural stability according to the extent of multidirectional loading.

Pretest measurements were performed one week before the intervention, and posttest measurements were conducted one week after its completion. Both assessments were carried out under identical conditions, using the same testing procedures, equipment, and environment to ensure objectivity and comparability of the results.

Statistical analysis

Descriptive statistics were calculated for all variables and included means and standard deviations. Differences between pretest and posttest measurements were analyzed using paired-sample t-tests. Analysis of variance (ANOVA) was used to compare outcomes among the three intervention protocols. Effect sizes were calculated using Cohen's d and eta squared (η^2). Statistical significance was established at $p < 0.05$.

The study was approved by the Ethics Committee of Constantine the Philosopher University in Nitra under approval number UKF-2020/1355-1:191013 and was conducted in accordance with the ethical standards of the Declaration of Helsinki.

Results

Table 1 presents changes in postural stability assessed using the 8-directional SEBT test for both the left and right stance legs. The results indicate statistically significant improvements in all analyzed directions. For the left leg stance, the greatest improvements were observed in the posterolateral ($d_M = 13.18$ cm), lateral ($d_M = 12.32$ cm) and posteromedial directions ($d_M = 12.01$ cm). All differences were statistically significant ($p < 0.001$), with effect sizes ranging from 0.53 to 1.18, indicating moderate to large effects.

Table 1 Changes in Postural Stability Assessed by the 8-Directional Star Excursion Balance Test (SEBT)

		Pretest		Posttest		Differences			
		M	SD	M	SD	d_M	t	p	d
Left stance	Anterior	67.03	8.73	77.76	9.52	10.73	13.12	0.00	1.18
	AnteroLateral	68.04	6.95	73.40	7.80	5.35	4.82	0.00	0.72
	Lateral	71.16	14.94	83.47	13.30	12.32	8.04	0.00	0.87
	PosteroLateral	78.64	12.63	91.81	11.82	13.18	12.48	0.00	1.08
	Posterior	82.02	12.06	93.15	12.13	11.13	13.32	0.00	0.92
	PosteroMedial	85.32	12.64	97.33	12.20	12.01	19.68	0.00	0.97
	Medial	90.56	10.56	100.36	10.54	9.80	10.34	0.00	0.93
	Anteromedial	80.06	9.87	85.41	10.50	5.35	14.74	0.00	0.53
Right stance	Anterior	66.99	7.01	75.22	6.91	8.23	7.90	0.00	1.18
	AnteroLateral	66.73	7.49	70.05	8.53	3.32	3.73	0.00	0.41
	Lateral	74.85	15.25	85.04	14.10	10.20	12.66	0.00	0.69
	PosteroLateral	81.94	14.01	90.53	12.61	8.58	6.56	0.00	0.64
	Posterior	81.62	13.10	93.93	13.40	12.31	14.69	0.00	0.93
	PosteroMedial	88.46	12.76	98.12	13.48	9.67	13.69	0.00	0.74
	Medial	89.19	12.10	98.90	12.24	9.71	12.89	0.00	0.80
	Anteromedial	80.38	9.43	86.12	9.29	5.75	6.99	0.00	0.61

A similar trend was observed for the right leg stance. The largest improvements were found in the posterior ($d_M = 12.31$ cm), lateral ($d_M = 10.20$ cm) and medial directions ($d_M = 9.71$ cm). All changes were statistically significant ($p < 0.001$), with effect sizes ranging from 0.41 to 1.18.

Table 2 presents the results of the 4-directional SEBT test. The findings show statistically significant improvements in postural stability across all analyzed directions.

For the left leg stance, the largest improvements were recorded in the medial ($d_M = 11.40$ cm), posterior ($d_M = 10.77$ cm) and lateral directions ($d_M = 10.75$ cm). The effect sizes were large, reaching values up to 1.97. For the right leg stance, improvements were also observed in all directions, with the greatest change in the posterior direction ($d_M = 7.61$ cm). All differences were statistically significant ($p \leq 0.01$), with effect sizes ranging from 0.72 to 1.05.

Table 2 Changes in Postural Stability Assessed by the 4-Directional Star Excursion Balance Test (SEBT)

		Pretest		Posttest		Differences			
		M	SD	M	SD	d_M	t	p	d
Left stance	leg Anterior	72.69	4.49	78.89	5.44	6.20	4.74	0.00	1.24
	leg Medial	88.11	4.72	99.51	6.69	11.40	4.61	0.00	1.97
	leg Posterior	81.19	7.00	91.96	6.23	10.77	5.97	0.00	1.63
	leg Lateral	70.54	7.38	81.29	5.88	10.75	6.23	0.00	1.61
Right stance	leg Anterior	72.95	3.85	78.60	6.53	5.65	3.43	0.01	1.05
	leg Medial	90.73	7.80	96.93	5.75	6.21	3.41	0.01	0.91
	leg Posterior	82.92	8.88	90.53	5.95	7.61	4.50	0.00	1.01
	leg Lateral	72.51	9.07	78.45	7.34	5.94	3.52	0.01	0.72

Table 3 presents the results obtained using the Y Balance Test. Statistically significant improvements were observed in all analyzed directions for both stance legs.

For the left leg stance, the greatest improvements were found in the posteromedial ($d_M = 12.65$ cm) and posterolateral directions ($d_M = 12.16$ cm).

For the right leg stance, the largest improvement was recorded in the posteromedial direction ($d_M = 12.44$ cm).

All differences were statistically significant ($p < 0.001$), with effect sizes ranging from 0.82 to 1.43, indicating large effects.

Table 3 Changes in Postural Stability Assessed by the Y Balance Test (YBT)

		Pretest		Posttest		Differences			
		M	SD	M	SD	d_M	t	p	d
Left stance	leg Anterior	68.14	5.30	74.75	7.44	6.60	3.58	0.00	1.02
	leg PosteroMedial	84.59	10.32	97.24	11.47	12.65	3.63	0.00	1.16
	leg PosteroLateral	77.05	6.74	89.21	9.92	12.16	4.18	0.00	1.43
Right stance	leg Anterior	67.97	7.60	77.23	6.94	9.26	4.15	0.00	1.27
	leg PosteroMedial	83.32	14.02	95.77	14.99	12.44	3.52	0.00	0.86
	leg PosteroLateral	79.92	8.98	88.17	11.04	8.25	4.01	0.00	0.82

Table 4 summarises the results using the composite score, which reflects overall dynamic postural stability.

For the left leg stance, composite score increased by 8.40% in the 8-directional SEBT test, 8.19% in the 4-directional SEBT test and 10.26% in the Y Balance Test.

For the right leg stance, improvements were 7.50%, 5.60% and 10.45%, respectively. All changes were statistically significant ($p < 0.001$), with effect sizes ranging from 0.72 to 1.98, indicating moderate to large effects.

Table 4 Effect of the 8-Week Multidirectional Stabilization Program on Composite Score of Postural Stability

			Composite score							
			Pretest		Posttest		Differences			
			M	SD	M	SD	d _M	t	p	d
Left stance	leg	8 directional SEBT test	82.45	9.55	90.85	9.25	8.40	25.76	0.00	0.89
		4 directional SEBT test	82.54	4.43	90.72	3.84	8.19	5.26	0.00	1.98
		3 directional YBT test	81.10	8.42	91.36	9.62	10.26	7.81	0.00	1.14
Right stance	leg	8 directional SEBT test	82.31	10.35	89.81	10.57	7.50	23.12	0.00	0.72
		4 directional SEBT test	84.70	6.40	90.30	4.91	5.60	4.86	0.00	0.98
		3 directional YBT test	79.64	9.83	90.08	11.36	10.45	6.05	0.00	0.98

Table 5 presents the comparison of composite scores between individual test protocols using ANOVA. The analysis showed no statistically significant differences between the tests at either the pre-test or post-test measurements ($p > 0.05$). These findings suggest that all three diagnostic tools provide comparable information about the level of postural stability.

Table 5 Comparison of Composite Scores Between Balance Assessment Tests (ANOVA Results)

			Differences Composite score					
			Pretest			Posttest		
			F(2, 27)	p	η^2	F(2, 27)	p	η^2
Left stance	leg	8 directional SEBT test	0.580	0.898	0.007	0.001	0.982	0.001
		4 directional SEBT test						
		3 directional YBT test						
Right stance	leg	8 directional SEBT test	0.780	0.466	0.054	0.006	0.993	0.001
		4 directional SEBT test						
		3 directional YBT test						

Figure 1 illustrates changes in composite score for the left leg stance across all test protocols. An increase in composite score was observed in all tests following the intervention.

The highest post-intervention values were recorded in the Y Balance Test (increase of 10.26%), followed by the 8-directional SEBT (8.40%) and the 4-directional SEBT (8.19%). These results indicate an overall improvement in postural stability.

Figure 2 presents changes in composite score for the right leg stance. Similar to the left leg, improvements were observed in all test protocols.

The greatest increase was found in the Y Balance Test (10.45%), followed by the 8-directional SEBT (7.50%) and the 4-directional SEBT (5.60%). The results confirm a consistent improvement in dynamic postural stability.

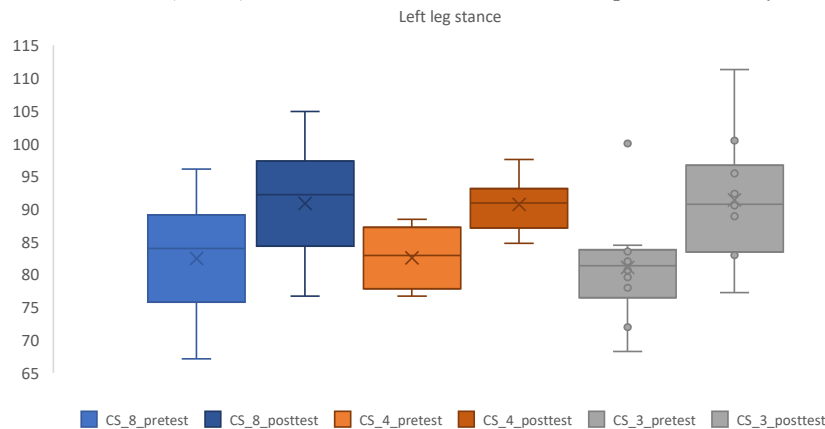


Figure 1 Changes in Composite Score of Postural Stability – Left Leg Stance (cm)

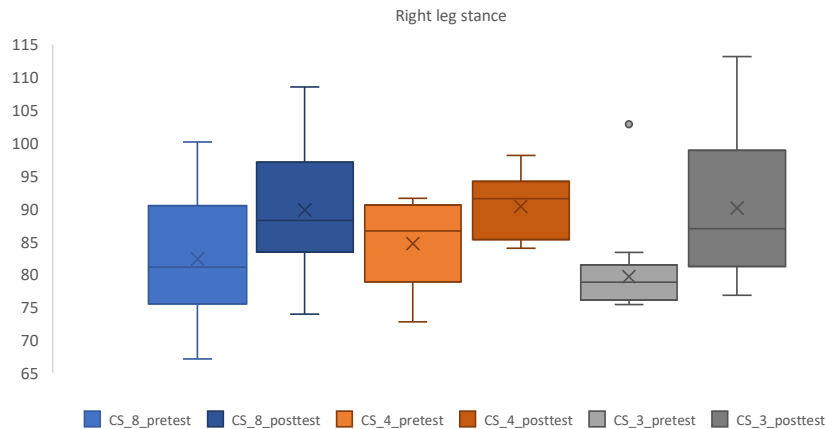


Figure 2 Changes in Composite Score of Postural Stability – Right Leg Stance (cm)

Discussion

The present study demonstrated that an eight-week multidirectional stabilization exercise program significantly improved dynamic postural stability in adolescent boys. Improvements were observed across all analyzed directions and in both lower limbs.

The findings of Table 1 indicate substantial improvements in postural stability in all directions of the 8-directional SEBT. The greatest improvements were observed in the posterior and posterolateral directions. These findings are consistent with previous studies suggesting that posterior directions are particularly sensitive to changes in neuromuscular control due to increased demands on hip musculature and postural stabilization (Hertel et al., 2006; Gribble et al., 2012).

The improvements in reach distances can be explained by neuromuscular adaptations resulting from regular stabilization training. These adaptations include enhanced proprioception, improved motor control and increased coordination of stabilizing muscle groups (Hertel, 2000; Granacher et al., 2011).

The results of Table 2 further confirm that significant improvements in postural stability can be achieved even when using a reduced number of testing directions. The most pronounced changes were observed in the medial and posterior directions. These directions are considered particularly sensitive indicators of dynamic balance and lower limb control (Picot et al., 2021).

Similarly, the results obtained from the Y Balance Test (Table 3) demonstrated significant improvements, especially in the posteromedial and posterolateral directions. These findings support previous research indicating that these directions are strongly associated with neuromuscular control and functional stability of the lower extremities (Plisky et al., 2009; Bodden et al., 2024).

The analysis of composite scores (Table 4) revealed a consistent improvement in overall postural stability across all testing protocols. These results suggest that multidirectional stabilization exercises lead to global improvements in dynamic balance rather than isolated improvements in specific movement directions. Similar findings were reported by Wang et al. (2024), who highlighted the effectiveness of neuromuscular training in enhancing dynamic stability.

The ANOVA results (Table 5) showed no statistically significant differences between the testing protocols, indicating that all three tests provide comparable information about postural stability. This finding supports the use of simplified testing protocols, such as the Y Balance Test, in both research and practical settings. The absence of statistically significant differences among the three intervention protocols suggests that improvements in postural stability may be achieved regardless of whether stabilization exercises are performed in three, four, or eight movement directions. From a practical perspective, this finding is particularly relevant for school-based physical education and extracurricular sport programs, where time constraints often limit the complexity of training interventions. The results indicate that even simplified stabilization programs may produce meaningful improvements in dynamic balance and neuromuscular control. Similar positive effects of stabilization-based interventions in adolescent populations have been reported by Broďáni et al. (2026), who observed significant improvements in balance performance and postural stability following structured stabilization training.

As shown in Figures 1 and 2, composite scores increased in both lower limbs following the intervention. The greatest improvements were consistently observed in the Y Balance Test, suggesting its high sensitivity in detecting changes in dynamic stability.

The overall findings of this study confirm the effectiveness of stabilization training in improving postural stability in adolescents. The observed improvements are likely the result of enhanced neuromuscular coordination and more efficient activation of stabilizing muscle groups. These findings are consistent with Muehlbauer et al. (2024), who reported significant improvements in balance performance in healthy children following structured balance-oriented training interventions.

These findings are in agreement with previous studies highlighting the positive effects of balance training on postural control and injury prevention in youth populations (Granacher et al., 2011; Gribble et al., 2012; Lesinski et al., 2015; Azor et al., 2025). Recent systematic reviews and meta-analyses have further confirmed that neuromuscular training interventions significantly improve both dynamic and static postural stability in young athletes and may contribute to injury prevention and enhanced athletic performance (Shi et al., 2026; Zhou et al., 2026).

The practical significance of these findings extends beyond sports performance. Improved postural stability may contribute to more efficient movement patterns, enhanced motor competence, and a reduced risk of lower-limb injuries during adolescence. Given the simplicity and accessibility of the implemented exercises, multidirectional stabilization training may represent a valuable component of physical education curricula and youth sport development programs.

Limitations

The study has several limitations. The relatively small sample size may limit generalization. The sample consisted exclusively of boys, which limits applicability to female populations. Additionally, the absence of a control group may reduce the strength of causal conclusions. Future studies should include larger and more diverse samples, including female participants.

Practical implications

The findings confirm that stabilization exercises are an effective tool for improving dynamic balance in adolescents. These exercises can be easily implemented in physical education without special equipment and may contribute to injury prevention. These findings may also contribute to injury prevention strategies in adolescent populations.

Conclusions

The present study demonstrated that an eight-week multidirectional stabilization exercise program performed twice weekly significantly improved dynamic postural stability in 13-year-old boys. Significant improvements were observed across all intervention groups and assessment protocols, including the 8-directional Star Excursion Balance Test (SEBT), the 4-directional SEBT, and the 3-directional Y Balance Test (YBT). The most pronounced improvements were recorded in the posterior, posteromedial, and posterolateral directions, highlighting the positive influence of stabilization training on neuromuscular control and balance performance. The findings contribute to the growing body of evidence supporting the effectiveness of stabilization-based interventions during adolescence, a developmental period characterized by substantial neuromuscular and motor changes. The observed improvements suggest that multidirectional stabilization exercises enhance proprioceptive function, movement coordination, and dynamic postural control, which are essential components of motor performance and injury prevention.

From a practical perspective, the results indicate that stabilization exercises can be effectively integrated into physical education lessons and extracurricular sports programs without requiring specialized equipment or extensive training time. Furthermore, the absence of statistically significant differences among the three intervention protocols suggests that even simplified stabilization programs may provide meaningful benefits for postural stability in adolescent populations.

Future research should examine the long-term effects of multidirectional stabilization training, include larger and more diverse samples, and investigate potential differences between male and female participants. Additional studies may also explore the relationship between improved postural stability, sports performance, and injury prevention outcomes in youth populations.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist with language editing, improvement of academic writing, and refinement of manuscript structure. After using this tool, the authors carefully reviewed, revised, and approved the final version of the manuscript and take full responsibility for the content of the publication. No generative AI tools were used for data collection, data analysis, interpretation of results, or generation of scientific conclusions.

Conflict of Interest

The authors declare no conflict of interest.

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