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Impact of life kinetik training on balance, agility, jumping, proprioception, and cognitive function in preadolescent recreational fencing athletes: a randomized controlled trial

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Abstract

Background The purpose of this study was to examine the impact of Life Kinetik (LK) exercises on balance, agility, jumping performance, proprioception, and cognitive functions in recreationally active preadolescents participating in fencing.

Methods The study lasted 8 weeks and included 22 preadolescents recreationally engaged in fencing, aged 11.6 ± 1.2 years, with an average weight of 49.5 ± 10.5 kg and an average height of 157.5 ± 10.0 cm. Preadolescents were randomly assigned to either the LK group or the control group. The experimental group participated in LK exercises twice per week, with each session lasting one hour.

Results The results indicate that the changes in Stroop, agility, vertical jump, and proprioception test performance between the pre-test and post-test for the control group are not statistically significant. However, the LK group showed statistically significant improvements in Stroop, agility, and vertical jump performance between the pre-test and post-test ($p < 0.001$). Conversely, the change in proprioception test performance between the pre-test and post-test for the LK training group was not statistically significant. The changes in star balance test performance between the pre-test and post-test for the control group was not statistically significant. In contrast, the LK group showed a statistically significant improvement in star balance test performance between the pre-test and post-test ($p < 0.001$).

Conclusions These findings indicate that while LK exercises are effective in boosting overall athletic performance, they may not be sufficient for developing specific skills such as proprioception.

Trial registration The randomized controlled trial was registered on 04/01/2025 at ClinicalTrials.gov, under the registration number NCT06781268.

Keywords Children, Life kinetik, Motor skills, Exercise, Physical fitness

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Introduction

Horst Lutz, the founder of Life Kinetik (LK), describes the training as a movement-based program that emphasizes cognitive challenges and is designed to be enjoyable. The primary objective of the training is to stimulate the formation of new neural connections, ultimately facilitating improved daily functioning [1]. This method combines simple motor tasks (e.g., ball catching), cognitive activities (e.g., color-word matching), and simultaneous multitasking to enhance brain function and motor coordination [2]. This method integrates physical movement, cognitive challenges, and, in particular, peripheral visual perception exercises. It brings together three core components: cognitive training, multitasking skills, and physical activity [3]. LK is a training approach designed to promote brain development and is commonly applied in various game-based sports [4]. This training is utilized by individuals across all age groups, from childhood to the elderly. In recent years, LK has gained popularity among elite athletes, including Olympic and World champions, who have increasingly incorporated LK into their training regimens [5]. As interest in LK has grown, there has been a corresponding increase in the number of scientific studies conducted on this training method [6–8]. LK training is anticipated to enhance psychological stimulation by integrating movement with cognitive demands. Psychological training programs are crucial for athletes, as they enable them to concentrate on performing at their highest potential, even when confronted with stress and challenges during competition [9]. LK can be considered a form of psychological training, as it integrates motor tasks with cognitive challenges that enhance attention, stress regulation, and adaptive decision-making in dynamic environments [9].

A review of the literature reveals that movement-based brain training, such as LK, can enhance technical skills, improve information processing efficiency, facilitate faster decision-making [10–12], and promote sustained concentration over time [13]. Komarudin and Awwaludin [14] concluded that LK training is more effective than traditional training for enhancing physical conditioning in football players. They attribute this advantage to LK training's ability to stimulate nerve cells and the nervous system as a whole. Fauzi et al. [15] indicated that this exercise model is highly effective in enhancing concentration among female volleyball players aged 13 to 15. Orhan et al. [16] reported that LK training has a beneficial impact on skill development and technical learning in athletics. Yaşar et al. [17] reported in their research that LK training had a moderately positive impact on attention and hand–eye coordination among archers. Similarly, Susilawati et al. [18] reported an improvement in students' attention during physical education classes

and suggested that implementing the LK learning model would be highly beneficial.

In contemporary sports, physical competence alone is insufficient to optimize athletic performance; the psychological performance of athletes is equally critical. Moreover, LK training plays a significant role in enabling athletes to make quick decisions and enhancing their performance based on these decisions [11]. In the present study, we define 'preadolescence' as the age range of 10 to 12 years, based on commonly accepted developmental stages in childhood research [19]. In light of this information, no specific study has been found in the literature that evaluates the effects of LK exercises on physical and cognitive performance in preadolescents. This focus enables targeted interventions during a critical period of neuro-motor development. The research seeks to comprehensively explore the impact of LK training, which integrates physical and cognitive tasks, on these key motor and cognitive domains in childhood. Accordingly, we hypothesized that an 8-week LK training program would produce significantly greater improvements in balance, agility, jump performance, proprioception, and cognitive function compared to no intervention, among preadolescent recreational fencing athletes. These outcome measures were selected because they reflect developmental domains that are highly trainable and responsive at this age, such as postural control, neuromuscular coordination, and cognitive adaptability. By examining both motor and cognitive outcomes, the study aims to contribute to the literature by highlighting the potential benefits of integrative exercise approaches for child development.

Materials and methods

Participants

A preliminary power analysis (G*Power 3.1.9.2) indicated a sample size of 20 subjects (effect size of 0.3, probability error of 0.05, power of 0.80) for a meaningful statistical effect for a repeated measures design with two groups and two measurement points [20]. Simple randomization was employed to allocate participants equally into the experimental and control groups. A computer-based random number generator was used to ensure unbiased allocation. The random allocation sequence was generated by YEY, who was not involved in participant recruitment or intervention delivery. Participants were enrolled by KK, ensuring that the enrollment process remained blinded to the allocation sequence. Interventions were assigned by OBC after allocation concealment was ensured. In consideration of a potential dropout rate of 10% following an 8-week intervention, the final calculated sample size was determined to be 22 participants. Suresh & Chandrashekara [21], recommends increasing the sample

size by approximately 10% to account for possible participant dropout or missing data. Accordingly, 2 additional participants were included, bringing the total sample to 22. The study enrolled 22 participants who were assessed for eligibility and subsequently randomized into two groups: the experimental group (LK) with 11 participants (6 boys and 5 girls) and the control group with 11 participants (7 boys and 4 girls) (Fig. 1). All of the preadolescents were engaged in recreational fencing and were registered with the same athletic club, aged 11.6 ± 1.2 years, with an average weight of 49.5 ± 10.5 kg and an average height of 157.5 ± 10.0 cm. Recreational fencing athletes were selected as they represent a population engaged in a sport that inherently integrates cognitive and motor demands. This alignment provides a suitable model for evaluating the effects of LK, which targets similar performance domains. Prior to participation, all preadolescents and their parents or legal guardians were fully informed about the objectives, procedures, potential risks, and benefits of the study. Written informed consent was obtained from the parents or legal guardians of all participants, as all were under the age of 16. Additionally, assent was obtained from each participating preadolescent. Preadolescents entered the study if they were (a) healthy (no chronic illness, musculoskeletal injury, or

physical limitation for the last six months; (b) did not use any medication for six months before the study; and (c) at the age of 10–12 years. This study was approved by the Gazi University Ethics Committee on February 27, 2024 (code: 2024–434) and was conducted following the principles stipulated in the Declaration of Helsinki (<https://sites.jamanetwork.com/research-ethics/index.html>).

Exercise intervention

The experimental group participated in LK exercises twice a week (Monday and Wednesday) for a total of 16 sessions. Each session lasted approximately one hour. Three different types of exercises were applied during these sessions. The LK exercises involved using multiple limbs simultaneously, focusing on cognitive function and motor coordination. Additionally, one or more sports equipment tools (e.g., balls, rackets, colored cards, etc.) were frequently used, requiring participants to throw, catch, bounce, or similarly manipulate them. The 8-week exercise program consisted of seven modules, including balance and coordination, reaction time, decision-making, memory cards, rhythm exercises, mirror exercises, and color and direction changes (Appendix 1 and 2).

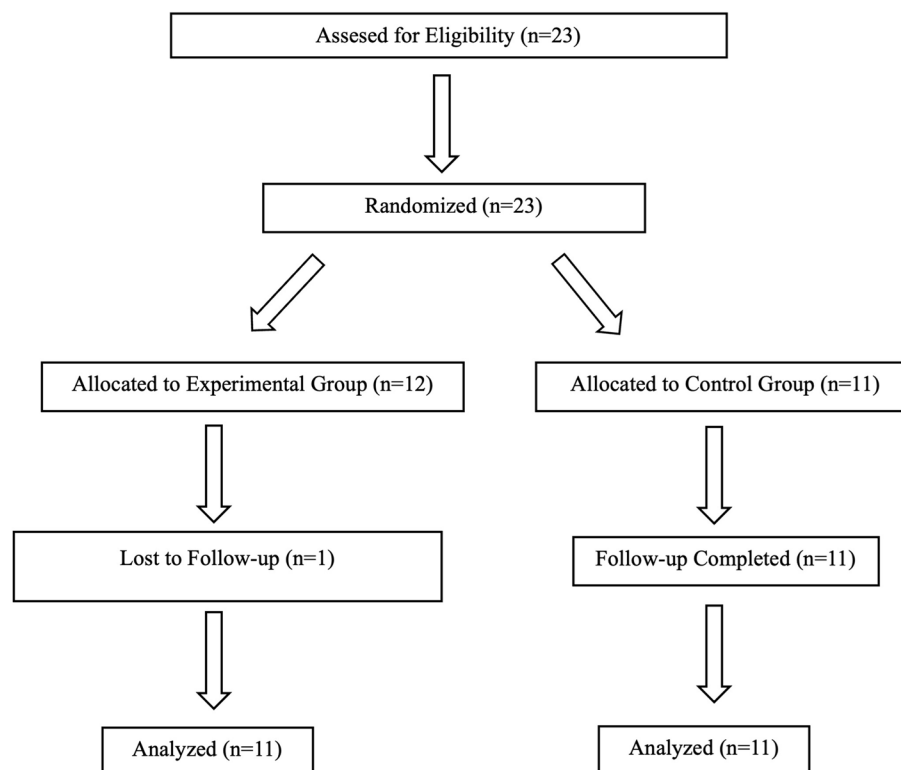


Fig. 1 CONSORT flowchart of the study

Anthropometric measurements

Anthropometric parameters were recorded which included body and leg height and weight. Body weight was measured with participants wearing light underwear, standing, and with a precision of 0.1 kg. Body height was measured with participants standing upright, feet together, back against the wall, and recorded to the nearest 0.1 cm as the maximum distance from the floor to the highest point on the head. Leg length was measured using a tape measure from the anterior superior iliac spine (ASIS) to the medial malleolus. Leg length measurements were taken three times for each limb with the participants in a lying position [22].

Pre- and post-test: counter movement jump measurement

Counter Movement Jump (CMJ) was assessed utilizing the OptoJump Next system (Microgate, Bolzano, Italy). After a self-administered warm-up session, participants performed 3 trials of the counter-movement jump without arm swings, followed by a one-minute rest period, after which they completed the actual CMJ test. Each participant completed three repetitions of the CMJ without arm swings, and the highest result in centimeters (jumping height) was documented as the primary outcome measure [23]. The OptoJump, a dual-beam optical apparatus, quantifies contact and flight durations during jump sequences (or individual jumps). Flight time (t_{air}) was employed to determine the elevation of the body's center of gravity ($height = \frac{[g \times t_{air}^2]}{8}$).

Pre- and post-test: stroop color and word test

A Stroop test comprising three distinct conditions was employed [24]. Each condition featured 60 stimuli, arranged with 6 items per line on a 21.5 × 29 cm sheet of paper. In the initial condition, referred to as the reading condition, participants were required to read words printed in black ink, which included the names of colors such as red, green, blue, and yellow. In the second condition, known as the naming condition, participants were instructed to identify the colors of various rectangles. In the third condition, termed the interference condition, participants were required to name the color of the ink used to print the words, while disregarding the semantic content of the words themselves, as they were incongruent with the ink color (e.g., the word "green" printed in red ink). This condition specifically tested the participants' inhibitory control [25]. Across all conditions, participants were instructed to respond as quickly as possible while minimizing errors. The primary variable of interest was the total reaction times (RTs). The test protocol was thoroughly explained to the participants, who were then allowed one practice trial before undertaking the actual test.

Pre- and post-test: agility t-test

The T-test was conducted as previously described [26]. Four cones were positioned in a T formation, with one cone located 9.14 m from the starting cone and two additional cones placed 4.57 m on either side of the second cone. All times were recorded using an electronic timing gate (Fusion Sport Inc.), set at a height of 0.75 m and spanning 3 m wide, aligned with the marked starting point. Participants were instructed to sprint forward 9.14 m from the starting line to the first cone, touching it with their right hand. They then shuffled 4.57 m to the left to reach the second cone, touching it with their left hand. Subsequently, they shuffled 9.14 m to the right to the third cone, touching it with their right hand, and shuffled 4.57 m back to the middle cone, touching it with their left hand. Finally, they backpedaled to the starting line. Timing commenced as participants passed through the timing gates and concluded upon their return passage through the gates. Trials were considered unsuccessful if participants did not touch a specified cone, crossed their legs during shuffling, or did not maintain forward-facing orientation throughout. Participants completed three trials, all of which were assessed to evaluate learning effects, with the best time being analyzed. A one-minute recovery period was provided between each trial.

Pre- and post-test: proprioception test

For the position perception test, the IsoMed-2000 isokinetic testing apparatus was utilized (IsoMed-2000 dynamometer; D & R Ferstl GmbH, Hemau, Germany) as described by Wang et al. [27]. Participants wore headphones and an eye mask to eliminate external auditory and visual influences. They maintained their knee joint in the testing position, allowing the isokinetic device (operating at an angular velocity of 1°/s) to automatically flex and extend to the predetermined angles of 30° and 60°. When the angle returned to 0°, the participant moved to the specified position after the automatic stop of the button movement. The difference between the actual angle and the pre-set angle was recorded. Each angle test was conducted three times to calculate the average value.

Pre- and post-test: Y balance test

Before screening, participants removed their socks and shoes, watched a brief instructional video on performing the Y Balance Test (YBT), and were allowed 4 to 6 practice trials for each limb in each of the three reach directions. Following the practice trials, we measured the lower extremity length from the inferior border of the anterior superior iliac spine to the inferior border of the medial malleolus. Participants then performed dynamic balance tests on both the right and left lower extremities,

reaching in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions with the contralateral limb. Three successful reaches were recorded, and the maximal reach distance in each direction was used for data analysis [28]. To obtain relative values for each direction for both the right and left limbs, the following formula was applied: Relative (normalized) reach distance (%) = (Absolute reach distance/Limb length) $\times$ 100.

Statistical analysis

The results were presented as mean, standard deviation, percentage change, mean difference, and effect size. The effect size was obtained from partial eta-squared values from the two-way ANOVA results in SPSS. An eta-squared value of 0.01 indicates a small effect size, 0.06 indicates a medium effect size, and 0.14 or above indicates a large effect size. The Shapiro–Wilk test was used to assess the normality of the obtained data, and the Levene test was used to evaluate the homogeneity of variances. To test the effects of different training programs on certain performance parameters, a 2 $\times$ 2 repeated measures ANOVA test was used. The statistical significance level of between-group and within-group changes was obtained from the ANOVA test. The level of significance was set at $p \leq 0.05$. When within-group changes were statistically significant, commands were written in SPSS Syntax (multiple comparisons, Bonferroni correction) to determine the statistical significance level and effect size values of within-group changes, to identify which training group had a statistical difference between pre- and post-tests. The statistical analysis of the data was performed using the SPSS 22.0 (SPSS Inc., Chicago, IL) software. In the case of a significant difference between groups as a result of ANOVA, multiple comparisons of the pre and post-tests of the groups were performed using commands written in Syntax to determine which groups and time points the difference originated from, and the significance level obtained was adjusted using the Bonferroni correction.

Results

No instances of dropout or training-related adverse events were documented following an 8-week intervention period. The results indicate that the changes in Stroop, agility, vertical jump, and proprioception test performance between the pre-test and post-test for the control group are not statistically significant (Table 1). However, the LK group showed statistically significant improvements in Stroop (Fig. 2), agility (Fig. 3), and vertical jump performance (Fig. 3) between the pre-test and post-test ($p < 0.001$) (Table 1). However, the change in proprioception test performance between the pre-test and post-test for the LK training group was not

statistically significant (Fig. 3). Based on the results of the multiple comparison test, no statistically significant differences were observed between the LK and control groups in pre-test measurements for Stroop (Fig. 2), agility (Fig. 3), vertical jump (Fig. 3), and proprioception performance (Fig. 3), indicating that the groups were similar in these parameters. When the post-test results of the groups were compared, a statistically significant difference was observed in the vertical jump (Fig. 3) and agility test performances (Fig. 3) between the LK and control groups ($p < 0.05$), with the LK group demonstrating superior performance. Based on the average differences in post-test scores between the LK and control groups for vertical jump (3.89) and agility (1.25), it can be concluded that the LK group exhibited greater improvement than the control group.

The changes in star balance test performance between the pre-test and post-test for the control group were not statistically significant (Table 2). In contrast, the LK group showed a statistically significant improvement in star balance test performance between the pre-test and post-test ($p < 0.001$) (Table 2, Fig. 4). Multiple comparison test results revealed that the pre-test measurements of star balance test performance were similar between the LK and control groups, with no statistically significant difference (Fig. 5). When comparing the post-test results of the groups, significant differences were found in star balance test performance between the LK and control groups in the left anterior (Fig. 5), right posteromedial (Fig. 5), right posterolateral (Fig. 5), and left posterolateral directions (Fig. 5) ($p < 0.05$), with the LK group demonstrating superior performance. Examination of the average differences in post-test scores revealed that the LK group outperformed the control group in the following directions: left anterior (5.07), right posteromedial (8.36), right posterolateral (14.73), and left posterolateral (10.60).

Discussion

In this study, the impact of LK exercises on cognitive and physical performance parameters in preadolescents was evaluated. The results indicate that the LK exercise program significantly affects several performance metrics. Notably, the most pronounced effect was observed in the Stroop Test results, highlighting the program's substantial impact on cognitive performance. According to the Stroop Test results, the LK group exhibited improvements of 9% in the reading condition, 14% in the naming condition, and 7.5% in the intervention condition from pre-test to post-test. In contrast, the control group demonstrated changes of 0.5%, 1%, and 1% in these respective conditions, which were not statistically significant. These findings suggest that LK exercises

Table 1 Results of 2-way ANOVA for repeated measures comparing pre- and post-tests of LK and control groups

Variables	Groups	ANOVA (Time)					ANOVA (Group)				
		Mean ± SD	Mean Square	F	p	ES	Mean Square	F	p	ES	
Stroop 1 (Pre)	LK	26.83±6.41	16.98	15.52	.001	.437	12.89	.191	.667	.009	
	Control	26.81±5.96									
Stroop 1 (Post)	LK	24.49±5.22									
	Control	26.67±5.78									
Change % (Pre to Post)	LK	%9									
	Control	%0.5									
Mean Diff. (Pre to Post)	LK	-2.34**									
	Control	.14									
Stroop 2 (Pre)	LK	42.10±7.66	109.02	32.45	.000	.619	79.43	.770	.390	.037	
	Control	42.01±7.60									
Stroop 2 (Post)	LK	36.17±6.54									
	Control	41.64±7.31									
Change % (Pre to Post)	LK	%14									
	Control	%1									
Mean Diff. (Pre to Post)	LK	-5.93**									
	Control	.36									
Stroop 3 (Pre)	LK	65.37±13.49	89.51	6.26	.021	.239	50.12	.138	.714	.007	
	Control	65.50±13.92									
Stroop 3 (Post)	LK	60.51±13.39									
	Control	64.65±14.05									
Change % (Pre to Post)	LK	%7.5									
	Control	%1									
Mean Diff. (Pre to Post)	LK	-4.86**									
	Control	.84									
Agility (Pre)	LK	15.48±1.23	10.19	6.19	.000	.644	8.55	3.372	.081	.144	
	Control	15.58±1.41									
Agility (Post)	LK	13.73±.87									
	Control	14.98±1.33									
Change % (Pre to Post)	LK	%11									
	Control	%3									
Mean Diff. (Pre to Post)	LK	-1.74**									
	Control	-.6									

Table 1 (continued)

Variables	Groups	Mean ± SD	ANOVA (Time)				ANOVA (Group)			
			Mean Square	F	p	ES	Mean Square	F	p	ES
Jump Height (Pre)	LK	21.60±4.33	65.05	25.80	.000	.563	57.96	1.368	.256	.064
	Control	21.70±4.99								
Jump Height (Post)	LK	26.42±4.52								
	Control	22.53±5.32								
Change % (Pre to Post)	LK	%22								
	Control	%4								
Mean Diff. (Pre to Post)	LK	4.82**								
	Control	.8								
Proprioception (Pre)	LK	6.06±3.43	8.29	2.06	.166	.094	7.50	.535	.473	.026
	Control	7.57±2.83								
Proprioception (Post)	LK	5.87±2.15								
	Control	6.01±3.41								
Change % (Pre to Post)	LK	%3								
	Control	%20								
Mean Diff. (Pre to Post)	LK	.18								
	Control	1.55								

ES Effect Size
*p<0.050, **p<0.001

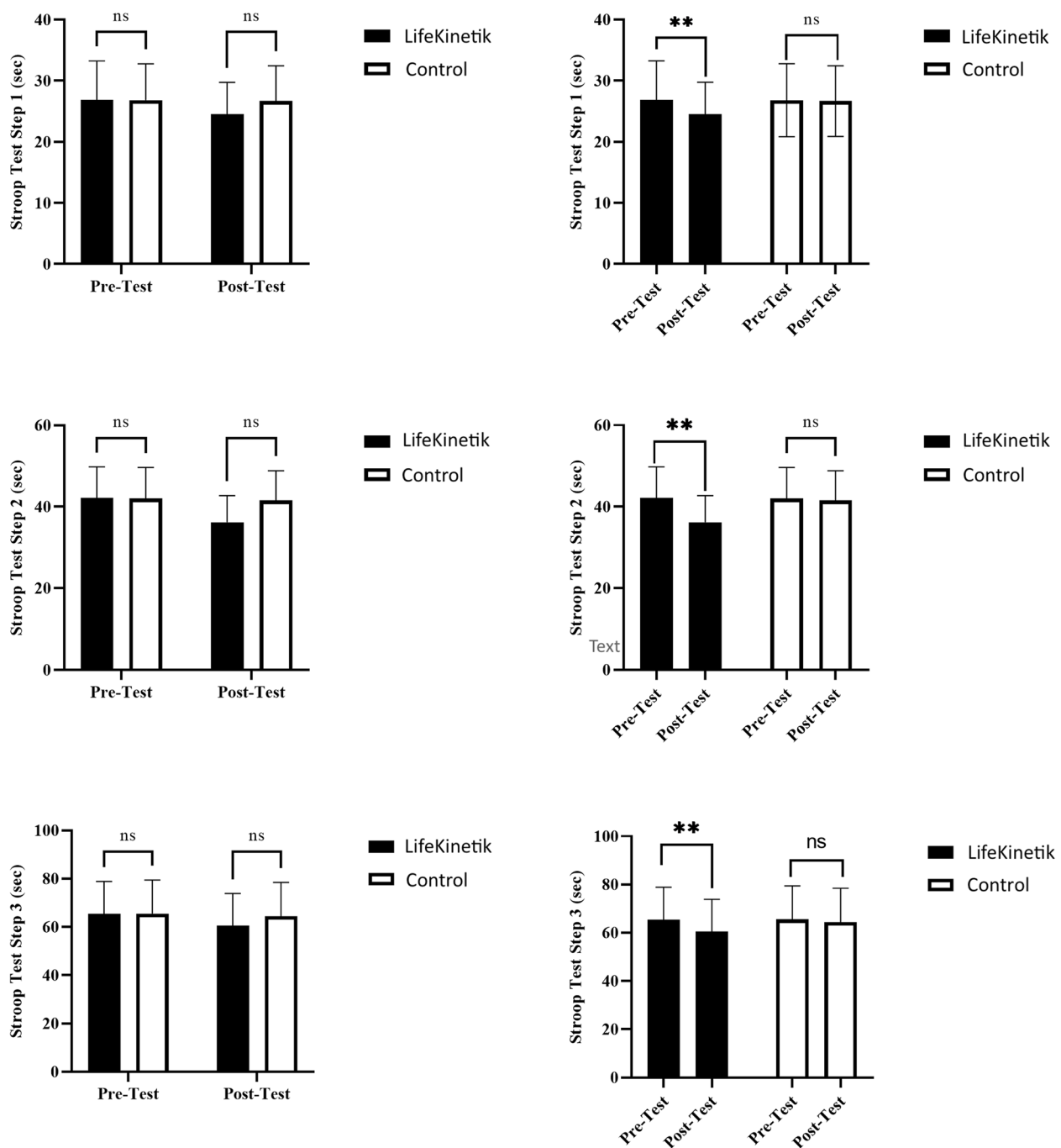


Fig. 2 Comparisons of Stroop test performance between and within groups over time. Asterisks indicate statistically significant differences: $p < 0.05$ (*), $p < 0.01$ (**); ns = not significant

positively impact cognitive functions, as evidenced by the significant enhancements observed in the Stroop Test results for the intervention group. The literature indicates that LK exercises are effective for rapidly acquiring and retaining skills. Additionally, these exercises are recognized for their benefits in developing cognitive skills,

motor skills, and perceptual abilities. This effectiveness is attributed to the requirement for simultaneous multiple movements, as well as the incorporation of perceptual elements such as colors and objects [29]. Furthermore, to determine the practical relevance of the findings, the smallest worthwhile change (SWC) was calculated as 0.2

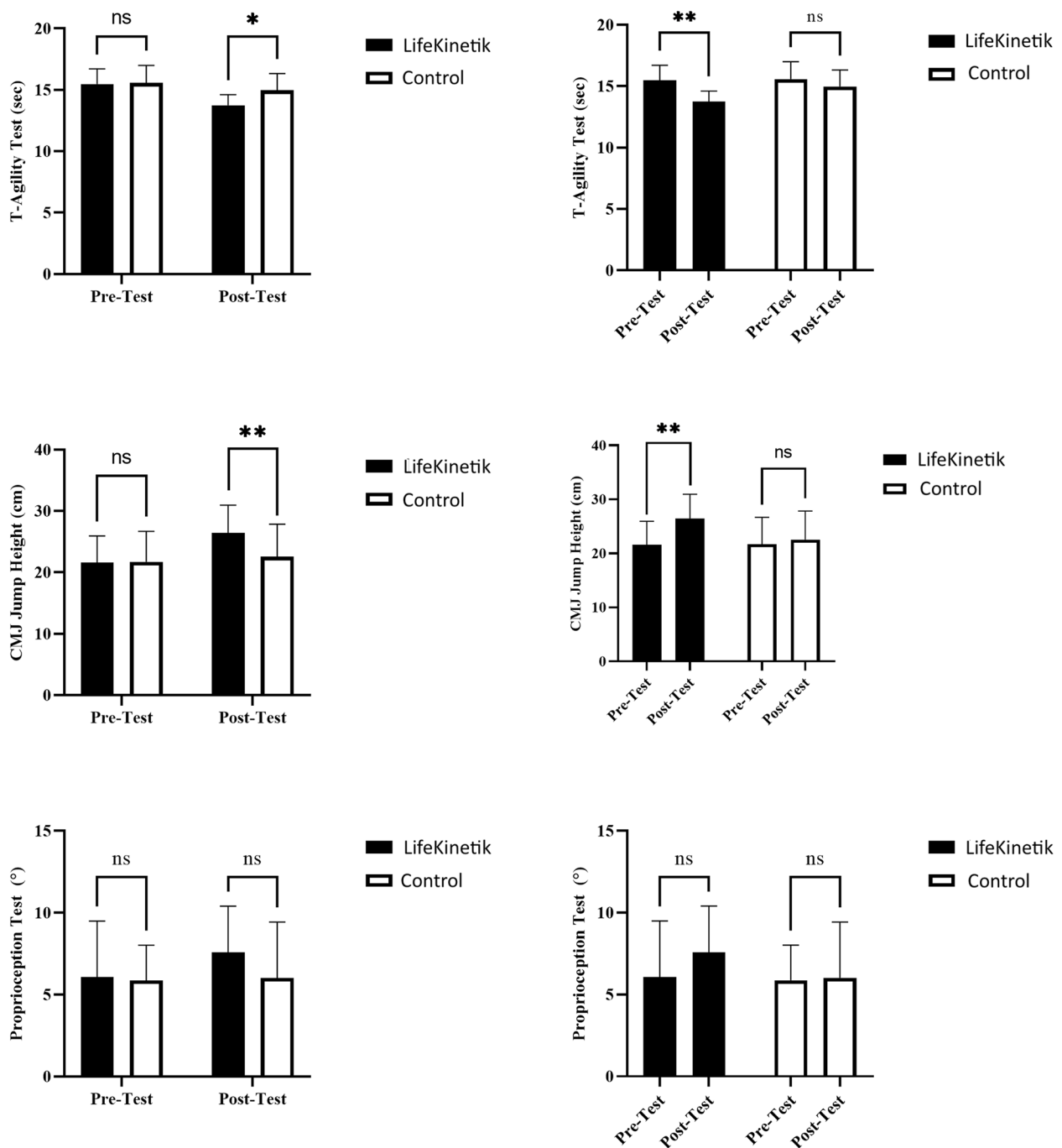


Fig. 3 Comparisons of T-agility, countermovement jump, and proprioception test performances between and within groups over time. Asterisks indicate statistically significant differences: $p < 0.05$ (*), $p < 0.01$ (**); ns = not significant

times the standard deviation of baseline scores for each outcome, as suggested by Buchheit [30] and based on the statistical framework established by Hopkins et al. [31]. Additional guidance on the interpretation and application of SWC in performance contexts can be found in practitioner-focused resources such as Science for Sport.

The observed improvements in all outcome measures—except proprioception—exceeded their respective SWC thresholds, indicating that the effects of LK training are not only statistically significant but also practically meaningful for enhancing agility, balance, and cognitive function in preadolescent recreational fencing athletes.

Table 2 Results of 2-way ANOVA for repeated measures comparing pre- and post-test performance on the y balance test (relative) between lk and control groups

Variables	Groups	Mean ± SD	ANOVA (Time)			ANOVA (Group)				
			Mean Square	F	p	ES	Mean Square	F	p	ES
R. Anterior (Pre)	LK	75.55±2.29	17.297	2.238	.150	.101	133.934	2.048	.168	.093
	Control	73.59±7.72								
R. Anterior (Post)	LK	78.33±5.87								
	Control	73.31±7.58								
Change % (Pre to Post)	LK	4%								
	Control	0.5%								
Mean Diff. (Pre to Post)	LK	2.781*								
	Control	.273								
L. Anterior (Pre)	LK	74.03±3.24	83.170	8.260	.009	.292	69.820	2.909	.104	.127
	Control	73.99±3.41								
L. Anterior (Post)	LK	68.72±6.03								
	Control	73.80±3.09								
Change % (Pre to Post)	LK	7%								
	Control	0.2%								
Mean Diff. (Pre to Post)	LK	5.308**								
	Control	.191								
R. P. Medial (Pre)	LK	101.02±6.73	128.30	27.282	.000	.577	196.008	2.260	.148	.102
	Control	100.94±7.19								
R. P. Medial (Post)	LK	108.58±6.08								
	Control	100.21±6.97								
Change % (Pre to Post)	LK	7%								
	Control	1%								
Mean Diff. (Pre to Post)	LK	7.558**								
	Control	.727								
L. P. Medial (Pre)	LK	100.61±5.50	171.66	10.790	.004	.350	129.520	1.144	.298	.054
	Control	100.56±6.63								
L. P. Medial (Post)	LK	93.18±12.06								
	Control	100.10±6.18								
Change % (Pre to Post)	LK	7%								
	Control	0.4%								
Mean Diff. (Pre to Post)	LK	7.437**								
	Control	.464								

Table 2 (continued)

Variables	Groups	Mean ± SD	ANOVA (Time)				ANOVA (Group)			
			Mean Square	F	p	ES	Mean Square	F	p	ES
R. P. Lateral (Pre)	LK	90.56±6.79	616.33	39.890	.000	.666	576.094	6.302	.021	.240
	Control	90.82±7.80								
R. P. Lateral (Post)	LK	105.54±6.88								
	Control	90.80±7.70								
Change % (Pre to Post)	LK	16%								
	Control	0.2%								
Mean Diff. (Pre to Post)	LK	14.986**								
	Control	.015								
L. P. Lateral (Pre)	LK	105.30±3.11	335.28	8.769	.008	.305	275.700	8.097	.010	.288
	Control	104.70±2.79								
L. P. Lateral (Post)	LK	94.18±10.84								
	Control	104.79±3.07								
Change % (Pre to Post)	LK	10%								
	Control	0.5%								
Mean Diff. (Pre to Post)	LK	11.124**								
	Control	.082								

ES Effect Size
*p<0.050, **p<0.001;

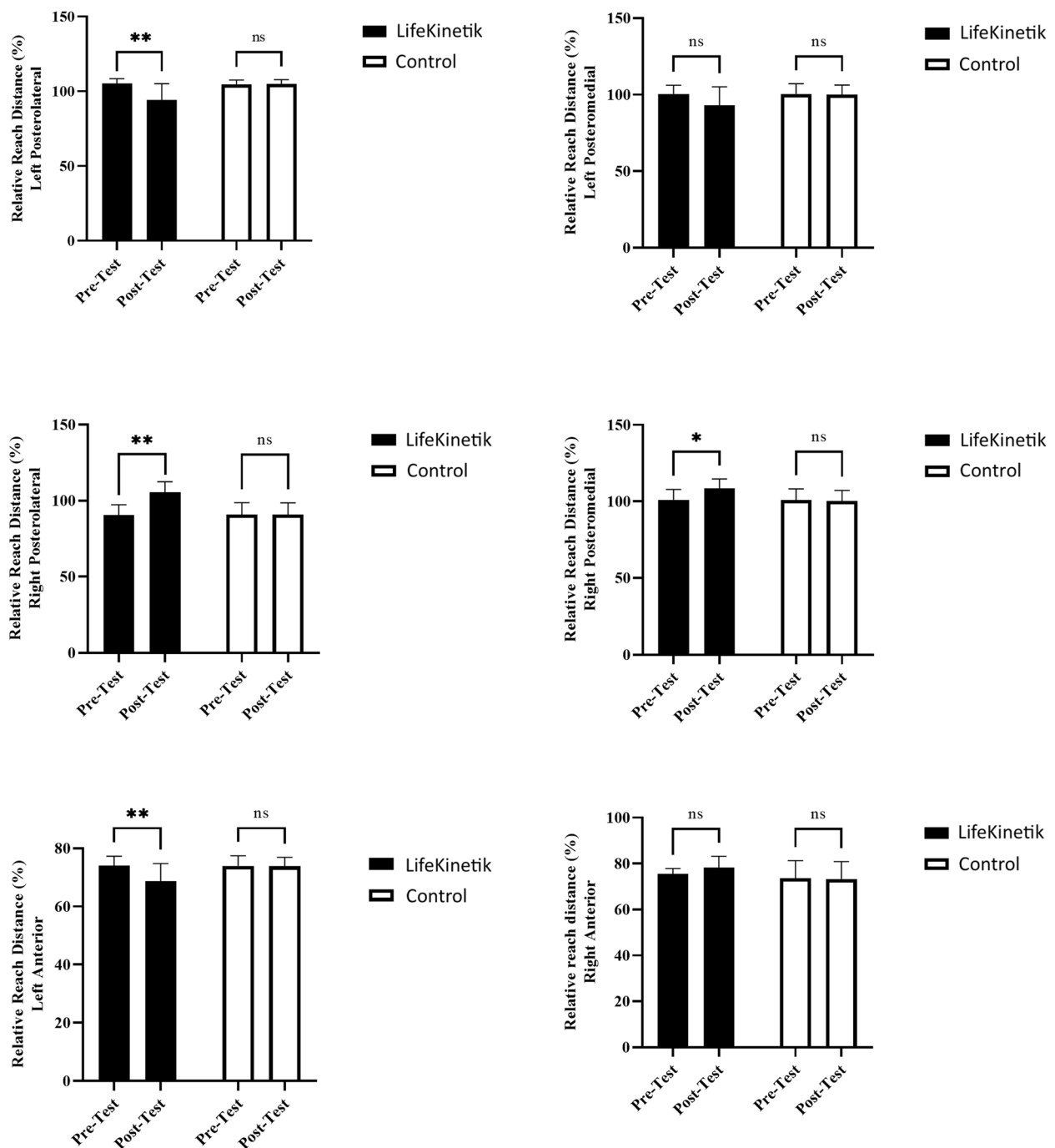


Fig. 4 Within-group comparisons of Y-Balance test reach distances (% of leg length) for Life Kinetik and control groups across six directions (left/right posterolateral, posteromedial, and anterior) from pre-test to post-test. Asterisks indicate statistically significant within-group changes: $p < 0.05$ (*), $p < 0.01$ (**); ns = not significant

For instance, Vural [32] reported that LK exercises positively influenced cognitive performance in male basketball players by enhancing attention and reaction time. Similarly, Yıldırım [33] found that LK exercises were more effective than mental training interventions in improving

attention and concentration levels, as evidenced by the evaluation of signals from the frontal lobe in volleyball players. Moreover, it has been established that LK exercises, when performed for 30 min, three times a week over a 12-week period, have significant positive effects

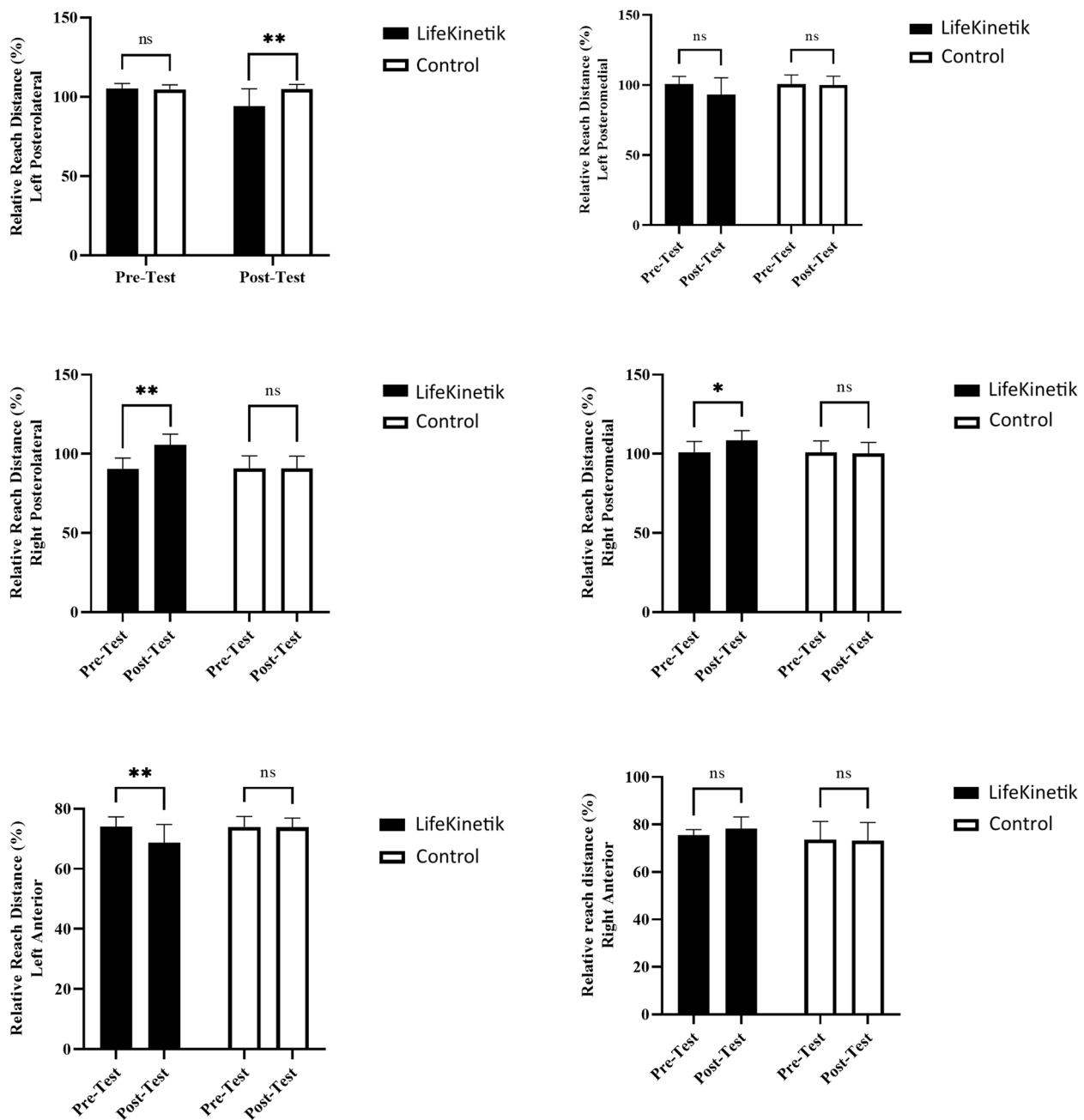


Fig. 5 Between-group comparisons of Y-Balance test reach distances (% of leg length) for Life Kinetik and control groups across six directions at both pre- and post-test. Asterisks indicate statistically significant differences between groups: $p < 0.05$ (*), $p < 0.01$ (**); ns = not significant

on the Cognitive Assessment System (CAS) total score. This score reflects cognitive functions such as planning, simultaneous cognitive operations, attention, and overall cognitive performance [34].

The findings of our study reveal that LK exercises led to significant improvements across all conditions of the Stroop Test (reading, color naming, and intervention). These results are consistent with existing literature and

support the notion that this exercise program positively influences cognitive functions. This improvement is likely attributed to the integration and coordination of visual perceptions through cognitive challenges and movement patterns, such as object manipulation. By combining cognitive training, multitasking, and physical activity, LK exercises enhance cognitive abilities, including spatial skills, memory, and executive function [5, 11, 35, 36].

Regarding physical performance, the LK group demonstrated significant improvements in both agility and jump height tests. The Agility T-Test results indicate a notable enhancement in coordination and speed within this group. Additionally, the jump height test results reveal a significant increase in lower extremity muscle strength. The literature suggests that LK exercises, which involve complex and comprehensive physical and cognitive tasks, can foster not only technical and cognitive development but also improvement in various other aspects [37]. These exercises include forms that involve intricate and diverse movements, which positively impact physical abilities, particularly coordination and agility [2]. Coordination is a fundamental skill for athletes and encompasses elements such as orientation, discrimination, reaction, balance, and technical skills.

Coordination is a fundamental ability essential for athletes, encompassing elements such as orientation, discrimination, reaction, balance, and technical skills. These components play a crucial role in the skill acquisition processes of athletes [38]. Agility, on the other hand, refers to the capacity to maintain or control body position while making rapid directional changes during movement. Agility training enhances motor programming by promoting neuromuscular conditioning and neural adaptation of muscle spindles, tendon organs, and joint proprioceptors. This, in turn, improves balance and control of body positions during movement [39]. In this context, agility encompasses both cognitive and physical components. LK training is highly effective for enhancing athletes' coordination and agility, as it targets improvements in both physical and cognitive abilities [40]. Consistent with the findings of this study, Orhan et al. [16] reported significant improvements in speed, agility, and shot-put performance following 30-min LK sessions after a general warm-up. Similarly, Komarudin [41] found that LK exercises had positive effects on the physical condition of football players. They reported that LK exercises were more effective than traditional training methods in enhancing agility and coordination among football players. Agility and coordination training using LK exercises enhances athletes' cognitive functions by promoting synaptogenesis in the motor cortex and cerebellum. This, in turn, improves their ability to move, change direction, and perform tasks rapidly and efficiently [41–45]. Consequently, it was concluded that LK training is effective in developing skills such as agility and coordination, and the results of our study are consistent with findings from similar studies in the literature.

The Y Balance Test results indicate that LK exercises lead to significant improvements in dynamic balance abilities. This finding is corroborated by various studies; for instance, Boyanmış and Akın [46] reported

that 8 weeks of LK exercises enhanced both static and dynamic balance abilities in taekwondo athletes. Similarly, Çoban [47] found that LK exercises had a positive impact on kinesthetics perception and improved static and dynamic balance values for both double-foot, left foot, and right foot conditions. Another study, utilizing military university standard measurement systems, demonstrated that LK exercises, primarily involving athletes, were effective in enhancing balance, as well as eye-hand and eye-foot coordination [48]. The literature indicates that LK exercises significantly enhance balance by stimulating the nervous system and integrating cognitive tasks with physical movements [2, 16, 17, 46]. These findings help explain the observed improvements in balance in our study.

Finally, the proprioception results indicate that LK exercises do not have a statistically significant effect on the sensory perception performance of preadolescents. This suggests that LK exercises may not be effective in developing this specific skill. In reviewing the literature, it is expected that LK exercises should positively impact proprioception (sensory perception) due to their focus on enhancing proprioceptive perception and motor skills through the integration of mental and physical tasks [5, 37]. However, our study found that LK exercises did not significantly affect proprioception. This outcome may be attributed to several factors. Firstly, the duration and intensity of the exercise program might have been insufficient for enhancing proprioceptive abilities. Research indicates that long-term and high-intensity exercise regimens are more effective in developing proprioception [49–51]. Secondly, it has been suggested that the content of the exercise program may need to be more specialized and intensive to effectively promote proprioceptive development [52]. While LK exercises have demonstrated positive effects on cognitive and physical performance, their limited impact on specific skills such as proprioception implies that this program may not be universally suitable for all individuals.

Strengths and limitations

The strengths of this study include the innovative use of LK training, a thorough evaluation of both cognitive and physical performance parameters, and a randomized controlled design, all of which enhance the validity and reliability of the results. Nevertheless, the study has several limitations. These include a limited sample size, a short duration of the training program, and a focus exclusively on preadolescents engaged in recreational fencing, which may restrict the generalizability of the findings. Moreover, the lack of significant effects on proprioception suggests that this training program may be insufficient for developing certain skills. For future research, it

is advisable to implement longer-term training programs with larger sample sizes and to explore different sports disciplines. Additionally, incorporating specific exercises aimed at enhancing proprioception and comparing LK training with alternative training methods could provide valuable insights for optimizing the effectiveness of this approach. Furthermore, future studies could examine the sport-specific effects of LK training in fencing, such as its impact on decision-making speed, movement accuracy, and tactical responsiveness during bouts.

Conclusion

In conclusion, LK exercises have been demonstrated to enhance the cognitive and physical performance of pre-adolescent recreational fencing athletes. Specifically, LK exercises resulted in significant improvements in cognitive functions, agility, jump height, and dynamic balance. However, no significant effect was observed on proprioception. These findings indicate that while LK exercises are effective in boosting overall athletic performance, they may not be sufficient for developing specific skills such as proprioception. Consequently, coaches and sports scientists should integrate LK exercises into their training programs to optimize general performance, but they should also incorporate additional, targeted strategies to address the development of specialized skills like proprioception.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13102-025-01186-3>.

Supplementary Material 1.

Supplementary Material 2.

Acknowledgements

This study acknowledges the fund support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2025R424), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Authors' contributions

Conceptualization, Y.E.Y., and K.K.; methodology, Y.E.Y., K.K., and A.B.; software, Y.E.Y., K.K., O.B.Ç., and B.C.G.; validation, Y.E.Y. and K.K.; formal analysis, Y.E.Y.; investigation, Y.E.Y., S.K., M.A., T.S., and T.A.D.; resources, O.B.Ç., B.C.G., and S.K.; data curation, Y.E.Y.; writing—original draft preparation, Y.E.Y.; writing—review and editing, A.B., G.V.G., S.B.A.M., N.H.A., B.B.S., and A.F.A.; visualization, K.K.; supervision, Y.E.Y., and A.B.; project administration, Y.E.Y.; funding acquisition, N.H.A. All authors have read and agreed to the published version of the manuscript.

Funding

This study acknowledges the fund support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2025R424), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Data availability

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Gazi University Ethics Committee on February 27, 2024 (code: 2024-434) and was conducted in accordance with the principles stipulated in the Declaration of Helsinki (<https://sites.jamanetwork.com/research-ethics/index.html>). As all participants were under the age of 16, written informed consent was obtained from their parents or legal guardians. In addition, assent was obtained from each participating child. This study adheres to the Consolidated Standards of Reporting Trials (CONSORT) guidelines to ensure transparency and comprehensive reporting of the randomized controlled trial design and methodology.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 15 November 2024 Accepted: 15 May 2025

Published online: 07 June 2025

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