ORIGINAL ARTICLE

Effects of a 12-week core strength training program on physical fitness and fundamental movement skills in children aged 6–8 years: A randomized controlled trial

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ABSTRACT

This study evaluated the effects of a 12-week core strength training program on physical fitness and fundamental movement skills (FMS) in children aged 6–8 years. A total of 128 primary school children (mean age: 7.01 ± 0.82 years; BMI: 12.78 ± 2.55 kg/m²) were randomly assigned to an experimental group (35 boys, 29 girls) or a control group (33 boys, 31 girls). The experimental group underwent three 40-minute core strength training sessions weekly, while the control group participated in standard physical education classes. Assessments were conducted at baseline and after 12 weeks using the 50-meter sprint, sit-and-reach, and one-minute jump rope tests. FMS were evaluated with backward balance walking and single-leg jumping. Independent samples t-tests compared pre- and post-intervention outcomes, and correlation analyses examined the relationship between core strength, physical fitness, and FMS. The experimental group showed significant improvements over the control group in the 50-meter sprint (-0.57 ± 0.87 s, $p < .05$), single-leg jump (5.86 ± 6.08 s, $p < .01$), side-to-side jump (10.75 ± 12.91 reps, $p < .01$), plank support (26.92 ± 16.86 s, $p < .01$), and back muscle strength (5.28 ± 4.23 kg, $p < .01$). Plank support correlated strongly with back muscle strength ($r = 0.41$, $p < .01$) and inversely with sprint time ($r = -0.47$, $p < .01$). Core strength, lower limb power, coordination, and stability were significantly enhanced in the experimental group, while the control group showed minimal changes. In conclusion, core strength training effectively improves physical fitness and FMS in young children, providing practical guidance for age-appropriate training programs.
Keywords: Physical education, Core strength training, Children, Physical fitness, Fundamental movement skill.

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INTRODUCTION

A lack of adequate physical activity (PA) and exercise can lead to underdeveloped muscle strength in children, negatively impacting their daily activities and sports performance (Masanovic et al., 2024). Developing fundamental movement skills (FMS), in early childhood is important because it has the potential to improve children's ability to successfully participate in games and sports in adolescence and adulthood and helps them retain these skills throughout life (Joschtel et al., 2021). At this stage, children experience rapid development in strength, flexibility, balance, and endurance, which are essential for participating in daily activities and sports (Bull et al., 2020). Physical fitness involves the performance of daily PA or physical exercise (King et al., 2019). Physical fitness, the ability of the human body to effectively and efficiently complete an activity or sport, is widely recognized as an important component of health and a crucial indicator of PA outcomes (Dong et al., 2020). A study involving 212 first-grade children (mean age: 6.95 years) examined gender differences in physical fitness, and found a decline in PA and fitness levels as children transitioned into formal schooling. Boys outperformed girls in endurance and strength tests (e.g., 20-meter run, sit-ups, six-minute run, standing broad jump), while girls excelled in flexibility (Lisowski et al., 2020). Bauer et al. (2022) found that youth who were of normal weight at baseline but became overweight or obese at follow-up exhibited lower academic performance. However, higher cardiorespiratory fitness was shown to potentially counteract the negative effects of excess BMI on academic outcomes. The study suggests that PA programs focusing on both aerobic fitness and motor skills could not only improve physical health but also enhance academic success. Moreover, research examining the relationship between physical fitness and mental health in children and adolescents has found a small to moderate positive association between physical fitness and overall mental well-being (Cadenas-Sanchez et al., 2021). Also, both cardiopulmonary endurance and muscle strength were also positively correlated with self-esteem, self-concept, physical self-perception and well-being, while cardiopulmonary endurance was negatively correlated with depression and muscle strength with anxiety. While speed agility showed a small to moderate positive correlation with self-concept and physical self-perception, and flexibility did not show a correlation with any mental health indicator (Cadenas-Sanchez et al., 2021). A prior study revealed that skill development is enhanced by physical attributes (e.g., fitness, weight status) and psychological attributes (e.g., perceived competence, self-efficacy) (Hulteen et al., 2021).

Fundamental movement skills (FMS) include body movement skills, object manipulation skills and stability control skills. FMS can be classified into three categories: Object control/manipulation skills, such as throwing, catching, dribbling, kicking, hitting, and rolling; Movement skills such as walking, running, jumping, jumping, running, sliding, and jumping; Balance/stability skills such as body roll, bend, dodge, stick balance, one-foot balance, stretch, swing, turn, and twist. These skills are generally recognized as the building blocks of both complex and sport-specific movement skills (Junker et al., 2019; Norup et al., 2023). The FMS acquired in early childhood are essential for future health and the development of more complex movement skills. Children with better FMS are more likely to engage in higher levels of PA, whereas those with poorer movement skills are more likely to adopt a sedentary lifestyle to avoid the challenges associated with PA participation (Graham et al., 2022). Importantly, childhood is a critical period for proficiency in FMS. If children do not receive adequate instruction in movement skills, they may experience developmental delays in proficiency in FMS (Wang et al., 2022). The FMS acquired in early childhood are valuable for future health and the development of complex movement skills.

Core strength, often defined as the capacity of the trunk muscles to stabilize the spine and pelvis during dynamic movements, is increasingly acknowledged as a cornerstone of overall physical function, athletic prowess, and injury prevention (Yilmaz et al., 2022). Moreover, core strength is a fundamental component of physical fitness in children, playing a crucial role in maintaining posture, balance, and overall movement coordination. It involves the development of the torso muscles responsible for stabilizing and mobilizing the trunk. Developing strong core muscles can enhance sports performance by improving force production in upper and lower extremities (Gong et al., 2024). Moreover, core strength training is beneficial for reducing the risk of sports-related injuries by enhancing musculoskeletal health. Core strength supports children's ability to maintain their position and move effectively. This is vital for developing gross motor skills like running, jumping, climbing, as well as fine motor skills such as writing or drawing. A strong core helps improve posture by preventing slouching or leaning forward while seated. It also enhances balance during various movements (Gong et al., 2024; Chang et al., 2020). A 12-week study by Kumar and Zemková (2022) highlighted the positive impact of core strength training on muscle strength, endurance, and flexibility in school-aged athletes. The study found that core strength training led to significant improvements in abdominal strength, endurance (as measured by the Cooper 12-minute run), and flexibility (assessed via the sit-and-reach test) compared to a control group (Kumar & Zemkova, 2022). Similarly, Lu et al. (2022) investigated the combined effects of SMART goal-setting and 12-week core strength training (CST) on adolescent fitness and exercise attitudes. Results showed that the SMART+CST group outperformed the control group in core endurance and behavioural control. Additionally, the CST group exhibited notable improvements in grip strength, sprint time, long jump performance, and running endurance. These findings underscore the important role of core strength training in improving adolescent fitness, particularly in core endurance, stability, and overall strength (Chang et al., 2020; Kumar & Zemkova, 2022). Another study investigated the effects of a core muscle training (CMT) program on trunk strength and balance in young male soccer players (mean age: 10.8 years). The findings demonstrated significant improvements in trunk flexion and extension strength at both 6 and 12 months. Additionally, performance on the Y Balance Test indicated enhanced dynamic balance. These results underscore the efficacy of CMT in improving core strength and balance among young athletes (Gong et al., 2024).

Therefore, core strength is essential for children's physical fitness and FMS. According to research, core strength training not only increases muscle strength, balance, and flexibility, but it also supports the development of fundamental movement abilities, improves athletic performance, and lowers the risk of sports-related injuries. Furthermore, core strength is linked to physical health and movement skills, allowing youngsters to gain greater control over their body movements and participate in more physical activities. Based on these findings, the present study aimed to investigate the effects of a 12-week core strength training program on physical fitness and FMS scores in children aged 6–8 years. Additionally, the study examined the correlation between core strength and various movement ability indicators, aiming to provide scientific evidence to support physical training programs that promote PA and improve health outcomes in children.

MATERIALS AND METHODS

Participants

A total of 128 primary school students aged 6–8 years (mean age = 7.01 ± 0.82 years, BMI = 12.86 ± 2.25, 66 boys, 62 girls) were recruited from primary school in Maoming city, Guangdong province, China. Children in good health, without severe chronic diseases or congenital conditions, who voluntarily agreed to participate and provided written consent along with their parents or legal guardians, were included in the study. Participants with prior experience in core strength training or similar programs were excluded. Eligible participants were then randomly assigned to either the control or experimental group using stratified randomization based on gender, age, and body mass index (BMI). Each group comprised 64 students, with the control group consisting of 33 boys and 31 girls, and the experimental group including 35 boys and 29 girls. The study protocol was approved by the Center for Ethics in Human Research, Khon Kaen University (Approval No. HE672147).

Experimental protocol

The experimental group has undergone a 12-week training program (Table 1) consisting of three sessions per week of core strength training and regular physical education classes (Table 2). Each session lasted 40 minutes. This core strength training session have included exercises such as abdominal bracing, abdominal contractions (in the quadruped position), lateral bridges, supine bridges, and lateral trunk rotations on a Swiss ball. Each session has included a 5-minute warm-up (jogging and dynamic stretching), 30 minutes of core training (aerobic, strength, or a combination of both), and a 5-minute cool-down featuring static stretching to promote recovery and reduce muscle stiffness.

The control group has undergone a 12-week physical education training program (Table2), engaging in regular physical exercises for 40 minutes, three times per week, following the standard physical education curriculum. Each session has included a 5-minute warm-up with jogging and dynamic stretching, aimed at increasing muscle flexibility and range of motion, followed by aerobic exercises, strength training, or a combination of both. Each session began with a 5-minute warm-up and ended with a 5-minute cool-down.

Physical fitness tests

1) Fifty-meter sprint

Before the 50-meter sprint, the participants performed a three-minute warm-up. They then sprinted at maximum effort on a straight track. Running times were recorded using a stopwatch (PC80, Shenzhen Tianxing Electronics Co., Ltd., China) with an accuracy of 0.1 seconds.

Table 1. Core strength training program.

Week	Training content	Sets	Reps/ Duration	Intervals
1-2	Forward/Backward Jumps, Left/Right Jumps, Hip Flexion Abduction Jumps, Arms Knees Jumps, Contralateral Elbow-Knee Pad Jumps, Supine Alternating Heel Contact, Supine Hip Raise, Left/Right Bent Knee Lateral Support	2	8-10 reps	60 s
3-4	Forward/Backward Jumps, Left/Right Jumps, Hip Flexion Abduction Jumps, Arms & Knees Jumps, Contralateral Elbow-Knee Pad Jumps, Supine Alternating Heel Contact, Supine Hip Raise, Left/Right Bent Knee Lateral Support	2	10-12 reps	50 s
5-6	Reverse Curls, Lateral Leg Curls, Supine Core Curls, Side Plank, Push-ups & Abdominal Jumps, Swiss Ball Incline Bridge Lift, Swiss Ball Supinated Alternating Forward Knee Lift, Swiss Ball Overhead Stooping Bridge Leg Raise, Swiss Ball Opposite Side Alternating Hand & Foot Raises	2	8-12 reps	45 s
7-8	Reverse Curls, Lateral Leg Curls, Supine Core Curls, Side Plank, Push-ups & Abdominal Jumps, Swiss Ball Incline Bridge Lift, Swiss Ball Supinated Alternating Forward Knee Lift, Swiss Ball Overhead Stooping Bridge Leg Raise, Swiss Ball Opposite Side Alternating Hand & Foot Raises	2	12 reps	45 s
9-10	Swiss Ball Incline Plank Support Toe Brace, Swiss Ball Supine Dynamic Hip Bridge, Swiss Ball Downward Sloping Push-up with Bent Knees, Swiss Ball Supine Straight Leg Hip Lift, Swiss Ball Upper Incline Alternating Shoulder Turns, Swiss Ball Supine Leg Raise, Swiss Ball Overhead "Y", Swiss Ball Supine Ball Curl, Swiss Ball Downward Slanting Overhead Bridge Alternating Leg Lifts, Swiss Ball Supine Leg Curl	2	10-12 reps/ 40-60 s	45 s
11-12	Swiss Ball Incline Plank Support Toe Brace, Swiss Ball Supine Dynamic Hip Bridge, Swiss Ball Downward Sloping Push-up with Bent Knees, Swiss Ball Supine Straight Leg Hip Lift, Swiss Ball Upper Incline Alternating Shoulder Turns, Swiss Ball Supine Leg Raise, Swiss Ball Overhead "Y", Swiss Ball Supine Ball Curl, Swiss Ball Downward Slanting Overhead Bridge Alternating Leg Lifts, Swiss Ball Supine Leg Curl	2	12 reps/ 45-60 s	45 s

Table 2. Regular physical education program.

Week	Training Content	Sets	Reps/Time	Intervals
1-2	30m sprint practice	2	2 laps	60 s
	Basketball passing & catching	5	10 reps	60 s
3-4	30m running exercise	3	2 laps	60 s
	Basketball dribbling	4	5×15m	30 s
5-6	Standing long jump	2	5 reps	30 s
	Basketball shooting	5	10 reps	30 s
7-8	Standing long jump	3	5 reps	30 s
	Soccer passing & catching	5	12×3 m	60 s
9-10	Rope skipping	2	1 min/session	60 s
	Soccer dribbling	4	3×25 m	45 s
11-12	Rope skipping	3	1 min/session	60 s
	Soccer shooting	4	5 reps	30 s

2) Sit-and-reach test

The flexibility test was conducted using an electronic sit-and-reach tester (Model HWD21-1231, Li Ning Co., Ltd., China), which has a measurement range of 60 cm and a resolution of 0.1 cm. Participants were instructed to sit barefoot with their knees fully extended and their heels positioned firmly against the footplate of the device, maintaining a distance of 10–15 cm between the feet. They then leaned forward gradually, using their middle fingers to push a sliding cursor. The best performance from two trials was recorded. The results were measured in centimetres.

3) One-minute jump rope

A counter-equipped jump rope (Li Ning Co., Ltd., China) with a standard base length of 2.8 meters was utilized for the test. Participants adjusted the rope length by raising the handles to chest level to ensure proper fit. They were instructed to perform as many jumps as possible within 1 minute, only successful jumps were counted. The built-in counter automatically recorded the total number of completed jumps (times).

Fundamental movement skill test

1) Backward balance walking test

This test was designed to assess balance and coordination. Participants were instructed to walk backward three times on three balance beams, each 3 meters in length, with widths of 6 cm, 4.5 cm, and 3 cm, respectively. The total number of steps taken across all attempts was recorded. The measurement unit used was steps.

2) Lateral movement test

Participants were asked to stand on two wooden platforms (25 cm × 25 cm × 5.7 cm) and moved them alternately as fast as possible within 20 seconds. Two trials (one for each leading leg) were conducted, and the total number of completed movements (times) was recorded.

3) Single-leg jump test

This test evaluated leg coordination, strength, and dynamic stability. Participants performed a single-leg jump over a 25 cm-high mat following a short run-up. Scores were assigned based on performance (3 points for a successful first attempt, 2 points for the second, and 1 point for the third). The measurement unit of this test is centimetres (cm.).

4) Side-to-side jump test

Participants were instructed to perform lateral jumps over a wooden bar (60 cm × 4 cm × 2 cm) as many times as possible within a 15-second interval. Each participant completed two attempts, and the total number of successful jumps was recorded. The results were measured in counts (times).

Core strength and flexibility tests

1) Sit-ups test

Participants lay on their backs with knees bent, feet secured, and arms crossed over their chests. They were instructed to perform as many sit-ups as possible within one minute, with only properly executed repetitions being counted. The results were recorded as the number of repetitions, measured in counts (times).

2) Plank support test

Participants were instructed to maintain a plank position with their elbows positioned 30 cm apart, while keeping both the shoulders and hips elevated approximately 25 cm above the floor. Timing began at the command "*begin*" and ended when any part of the body made contact with the mat. The duration held was recorded in seconds (s).

3) Back muscle strength test

The back strength test was conducted using an electronic back strength meter (BCS-400, HFD Tech Co., Beijing, China), Participants were instructed to pull the handle with maximum effort while keeping their legs straight and avoiding any backward bending of the torso. Back strength was measured in kilograms (kg).

4) One-legged stand test

Participants were instructed to stand on their non-dominant leg with their hands placed on their hips and their eyes fixed on a designated point on the wall. The duration for which balance was maintained was recorded in seconds (s) to assess static balance.

Statistical analysis

All data were analysed using SPSS version 28.0 (IBM Corp., Armonk, NY, USA) to determine statistical significance. Descriptive statistics, including means and standard deviations, were calculated for all variables both before and after the intervention. To examine the effects of core strength training, independent sample t-tests were used to compare post-intervention outcomes between experimental and control groups. If the assumption of normality was violated, non-parametric tests, such as the Mann-Whitney U test, were applied for between-group comparisons. Additionally, Pearson’s correlation coefficient was calculated to assess the relationships between variables, such as the link between improvements in core strength and physical performance measures. The significance level was set at $p < .05$, and effect sizes (Cohen’s d) were computed to quantify the magnitude of differences between groups. All analyses were conducted with a significance threshold of $\alpha = .05$.

RESULTS

The baseline characteristic of the participants

Table 3 shows, before the intervention, the experimental group (EG) and control group (CG) exhibited some differences in height, weight, BMI, and physical fitness tests (50-meter dash, sit and reach, 1-minute rope skipping). Overall, the EG tended to have higher values in height, weight, and BMI compared to the CG. This difference was particularly significant within the 6-year-old subgroup, where the EG showed notably greater height and weight than the CG. Regarding physical fitness tests, the EG performed slightly better in the 50-

meter dash and 1-minute rope skipping, especially among the 6-year-olds. However, these differences were not statistically significant, and the overall disparities were relatively small. This suggests that, prior to the experiment, the physical fitness levels of both groups were comparable, with some expected individual variation.

Table 3. The baseline characteristic of the participants.

Age (year)	Group	n	Height (cm)	Weight (kg)	BMI (kg/m²)
6	CG	20	116.59 ± 4.49	15.37 ± 2.87	11.23 ± 1.39
	EG	22	121.82 ± 4.28	18.81 ± 3.43	12.59 ± 1.68
7	CG	23	124.99 ± 5.59	20.05 ± 4.95	12.71 ± 2.21
	EG	20	125.29 ± 5.30	20.24 ± 4.16	12.80 ± 1.72
8	CG	21	129.51 ± 7.50	24.37 ± 7.32	14.32 ± 2.89
	EG	22	131.10 ± 6.29	23.21 ± 4.88	13.45 ± 2.28
Total	CG	64	123.85 ± 7.92	20.01 ± 6.42	12.78 ± 2.55
	EG	64	126.09 ± 6.56	20.77 ± 4.54	12.95 ± 1.93
Age (year)	**Group**	**n**	**Fifty Meter Sprint (s)**	**Sit-and-Reach Flexibility (cm)**	**1-Minute Jump Rope (reps)**
6	CG	20	12.05 ± 1.00	5.17 ± 4.18	27.80 ± 12.19
	EG	22	11.99 ± 1.01	5.47 ± 4.47	28.55 ± 17.59
7	CG	23	11.41 ± 1.05	6.38 ± 3.96	34.65 ± 14.21
	EG	20	11.15 ± 1.11	6.57 ± 5.09	37.10 ± 16.15
8	CG	21	11.41 ± 1.26	8.17 ± 6.37	43.90 ± 19.48
	EG	22	11.31 ± 1.19	8.58 ± 4.13	43.95 ± 20.68
Total	CG	64	11.61 ± 1.13	6.59 ± 5.02	35.55 ± 16.69
	EG	64	11.50 ± 1.15	6.88 ± 4.68	36.52 ± 19.13

Note. No statistically significant differences were found between groups across all variables (p > .05).

Comparison of each index between control group and experimental group in pre-test

Data analysis of Table 4 revealed minimal baseline differences between the CG and EG across various physical fitness tests, with most differences not reaching statistical significance ($p > .05$). Specifically, in the 50-meter sprint, the CG averaged 11.61 ± 1.13 seconds and the EG 11.50 ± 1.15 seconds ($p = .38$), indicating no significant difference in sprint performance. In the sit-and-reach test, scores were 6.59 ± 5.02 cm for the CG and 6.88 ± 4.68 cm for the EG ($p = .73$), showing comparable flexibility. Similarly, the one-minute jump rope test results were 35.55 ± 16.69 repetitions for the CG and 36.52 ± 19.13 repetitions for the EG ($p = .64$), with no significant difference in aerobic endurance and coordination. Other measures, including backward balance walk, lateral movement, single-leg jump, side-to-side jump, sit-ups, plank support, back muscle strength, and one-legged stance, all showed p-values > .05, confirming no statistically significant differences between groups. These findings indicate that the baseline physical fitness and motor skills of both groups were highly similar before the intervention, validating the comparability of groups and providing a solid foundation for assessing the effects of the 12-week core strength training program.

Comparison of each index between control group and experimental group in post-test

Table 5 compared the physical performance and FMS of the CG and the EG to analyse their differences. The results indicate that EG outperformed CG in most tests, with significant differences observed in the 50-meter sprint, single-leg jump, side-to-side jump, plank support, and back muscle strength tests ($p < .05$). The effect sizes (Cohen's d) ranged from moderate to large, demonstrating EG's clear advantage in these aspects. Specifically, EG performed better in the 50-meter sprint, with a p-value of .019 and a moderate effect size (d = 0.37), indicating a significant difference. In the single-leg jump test, EG showed superior explosive power ($p = .006$, d = -0.51), and the side-to-side jump test also highlighted EG's advantage ($p = .008$, d = -0.44). The most notable differences were found in the plank support and back muscle strength tests, where

EG showed remarkable superiority ($p < .01$ and $p = .005$, respectively), with large effect sizes (d = -0.73 and d = -0.6), emphasizing EG's dominance in core stability and back strength.

Although CG showed slightly weaker performance in some tests, not all differences were statistically significant. For example, in the sit-and-reach and backward balance walking tests, the differences between CG and EG were not significant ($p > .05$), with small effect sizes (d = -0.27 and d = -0.36), suggesting minimal differences in flexibility and balance. However, in the jump rope and sit-up tests, CG still underperformed compared to EG, with p-values of .009 and .043 and moderate effect sizes (d = -0.43 and d = -0.37), indicating EG's superiority in endurance and core strength. Overall, EG demonstrated a higher level of physical fitness across multiple tests, particularly in explosive power, endurance, and core strength. CG exhibited weaker performance in most areas, suggesting possible deficiencies in training, strength, and endurance.

Table 4. Comparison of pre-test measured outcomes between control and experimental groups.

Test	CG (Mean ± SD)	EG (Mean ± SD)	p	95% CI of CG		95% CI of EG		Cohen's d
				Lower Bound	Upper Bound	Lower Bound	Upper Bound	
50-meter sprint (s)	11.61 ± 1.13	11.50 ± 1.15	.38	11.3304	11.8949	11.2089	11.7814	-0.09
Sit-and-reach (cm)	6.59 ± 5.02	6.88 ± 4.68	.73	5.335	7.84	5.715	8.054	-0.07
1minute jump rope (rep)	35.55 ± 16.69	36.52 ± 19.13	.64	31.38	39.72	31.74	41.29	-0.06
Backward balance walking test (step)	42.78 ± 15.11	43.41 ± 14.57	.88	39.01	46.56	39.77	47.05	-0.04
Lateral movement test (rep)	15.03 ± 3.38	15.30 ± 3.34	.66	14.19	15.88	14.46	16.13	-0.08
Single leg jump Test (cm)	51.17 ± 7.75	52.66 ± 8.07	.30	49.24	53.11	50.64	54.67	-0.19
Side-to-side jump test (rep)	37.63 ± 11.09	39.30 ± 11.93	.41	34.86	40.39	36.32	42.28	-0.14
Sit-ups test (rep)	23.63 ± 8.85	23.70 ± 8.90	.96	21.41	25.84	21.48	25.93	-0.01
Plank support (s)	54.86 ± 16.65	56.13 ± 14.26	.94	50.7	59.02	52.56	59.69	-0.08
Back muscle strength (kg)	19.14 ± 7.18	20.05 ± 7.27	.56	17.35	20.93	18.23	21.86	-0.14
One legged stand (s)	48.23 ± 26.87	49.09 ± 25.57	.75	41.52	54.94	42.71	55.48	-0.03

Note. CG = Control group, EG = Experimental group. Sit-and-reach, Lateral movement test, Side-to-side jump test were tested by means independent sample t-test. 50-meter sprint, 1minute jump rope, Backward balance walking test, Single leg jump test, Sit-ups test, Plank support, Back muscle strength, One legged stand were tested using non-parametric test (Mann-Whitney U-test).

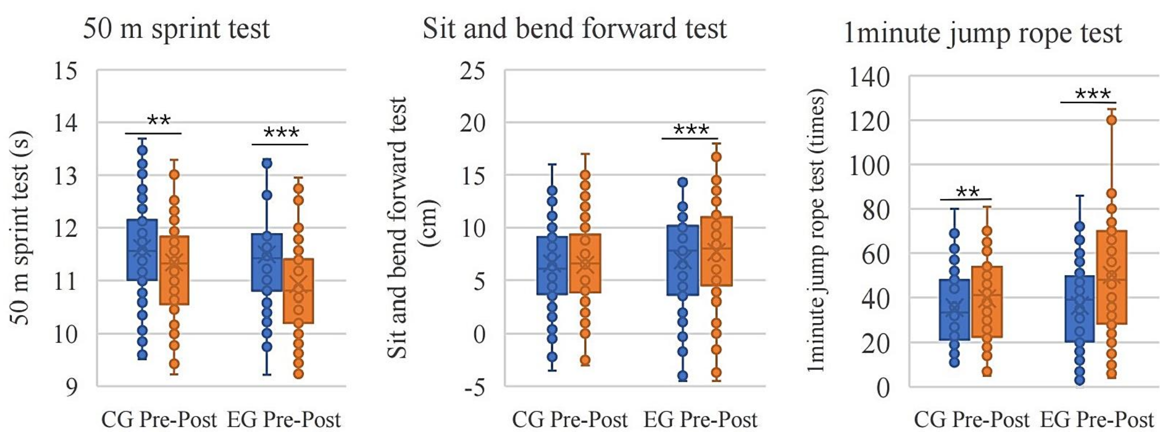
Comparison of physical fitness between experimental and control groups before and after intervention

Figure 1 illustrates the performance changes in the experimental group (EG) and control group (CG) before and after 12 weeks of core strength training in the 50-meter sprint, sit-and-reach test, and one-minute jump rope test. Overall, the EG demonstrated significant improvements in speed and endurance, while flexibility showed minimal change. In contrast, the CG exhibited only minor overall changes. In the 50-meter sprint test, the running time of the EG was significantly reduced after training, leading to a notable improvement in sprint speed, which reached statistical significance ($p < .05$). This finding indicates that core strength training is effective in enhancing sprint performance. Meanwhile, the CG showed little change in performance, suggesting that sprint speed did not improve significantly without training. In the sit-and-reach test, both the EG and CG showed slight improvements in flexibility; however, the differences were not statistically significant ($p > .05$). This suggests that core strength training has a limited effect on flexibility, and specialized stretching exercises may be required to achieve substantial improvements in this parameter. In the one-minute jump rope test, the number of repetitions performed by the EG increased significantly post-training, demonstrating a highly significant improvement (*p* < .01). This indicates that core strength training effectively enhances endurance, coordination, and lower limb muscular endurance. In contrast, the CG's performance showed no significant change, suggesting that physical fitness does not improve substantially without training intervention. In summary, 12 weeks of core strength training significantly improved sprint speed and jump rope endurance in the EG but had minimal impact on flexibility. The CG exhibited negligible changes, reinforcing the role of core training in enhancing athletic performance, particularly in speed and endurance development.

Table 5. Comparison of each index between control group and experimental group in post-test.

Test	CG (Mean ± SD)	EG (Mean ± SD)	*p*	95% CI of CG		95% CI of EG		Cohen's d
				Lower Bound	Upper Bound	Lower Bound	Upper Bound	
50-meter sprint (s)	11.34 ± 1.07	10.93 ± 1.19	.01	11.0712	11.6152	10.6306	11.2329	0.37
Sit-and-reach (cm)	6.46 ± 4.59	7.67 ± 4.76	.15	5.282	7.613	6.435	8.848	-0.27
1minute jump rope (rep)	39.70 ± 17.98	50.23 ± 26.15	.009	35.22	44.34	43.66	56.94	-0.43
Backward balance walking test (step)	44.72 ± 15.27	50.39 ± 14.34	.07	41.59	48.99	47.18	54.31	-0.36
Lateral movement test (rep)	15.63 ± 3.64	17.36 ± 4.69	.04	14.73	16.57	16.27	18.62	-0.4
Single leg jump Test (cm)	53.75 ± 8.26	58.52 ± 9.46	.006	51.72	55.9	56.02	60.8	-0.51
Side-to-side jump test (rep)	44.64 ± 10.34	50.05 ± 12.22	.008	42.08	47.32	46.9	53.1	-0.44
Sit-ups test (rep)	24.92 ± 7.96	27.83 ± 8.16	.04	22.87	26.91	25.75	29.9	-0.37
Plank support (s)	68.78 ± 19.01	83.05 ± 19.13	<.01	63.92	73.57	78.72	88.26	-0.73
Back muscle strength (kg)	21.11 ± 6.71	25.33 ± 8.44	.005	19.53	22.91	23.28	27.55	-0.6
One legged stand (s)	64.05 ± 30.84	75.72 ± 32.79	.04	56.54	72.15	67.3	83.94	-0.39

Note: CG = Control group, EG = Experimental group. Sit-and-reach, 1-minute jump rope test, Side-to-side jump test, and sit-up test were tested by independent sample t-test. 50-meter sprint, Backward balance walking test(step), Lateral movement test, Single leg jump test, Plank support, Back muscle strength, One legged stand were tested using non-parametric test (Mann-Whitney U-test).

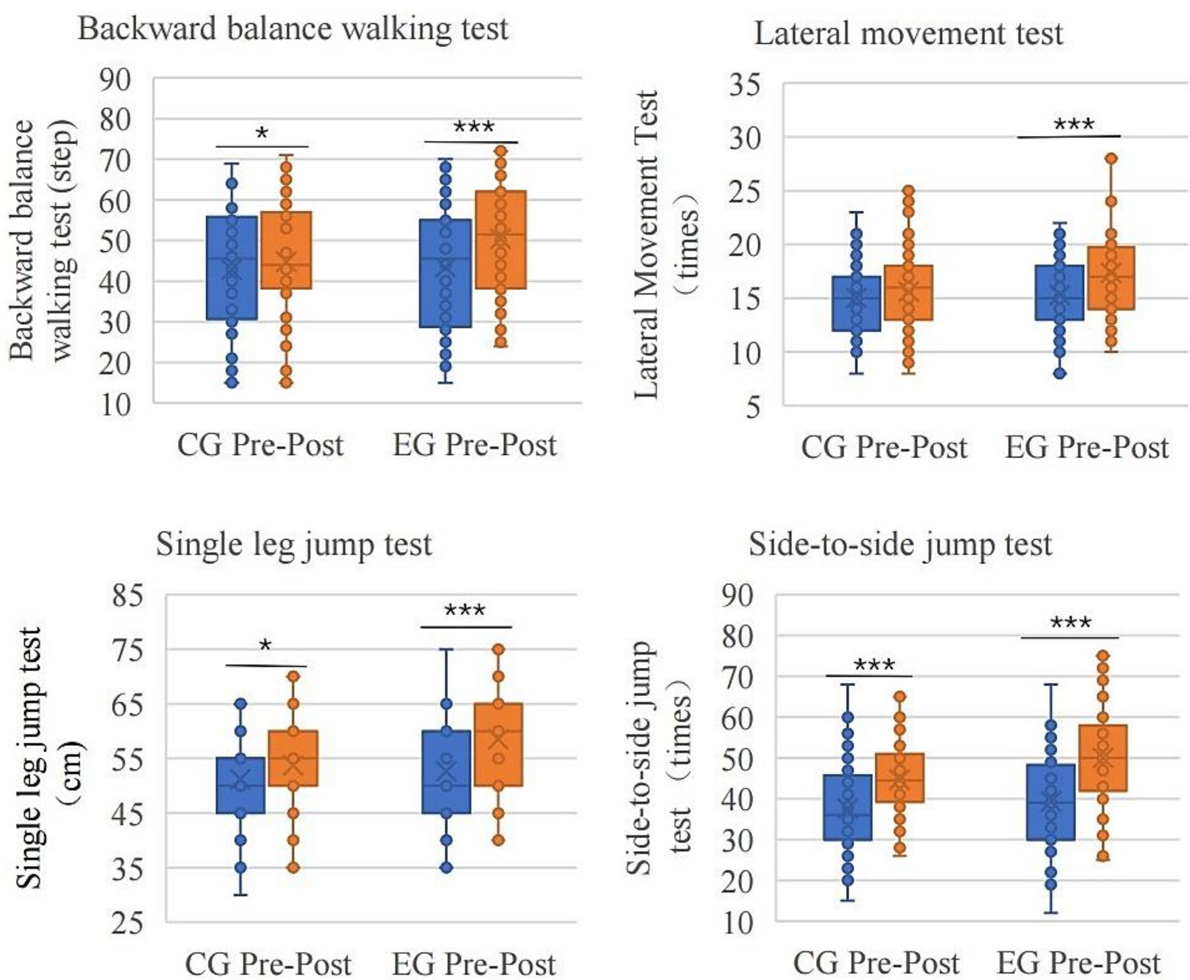


*Note: EG = Experimental group, CG = Control group; Pre = pre-test, Post = Post-test. * Indicates that the significance level is p < .05. ** Indicates that the significance level is p < .01.*

Figure 1. Comparison of physical fitness between experimental and control groups before and after intervention.

Comparison of FMS between experimental and control groups before and after intervention

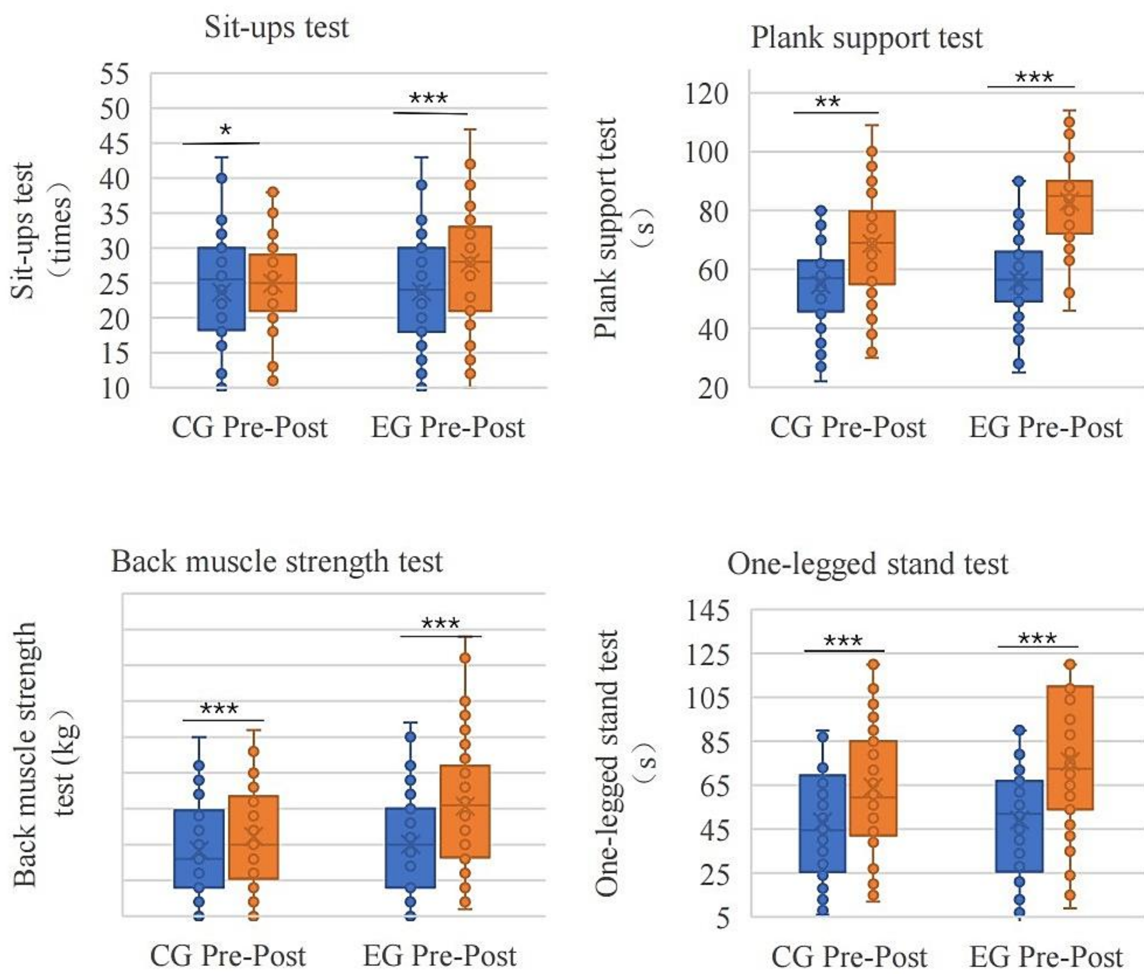
Figure 2 illustrates that after 12 weeks of core strength training, the experimental group (EG) demonstrated significant improvements across multiple fitness tests, particularly in lower limb explosiveness, coordination, and endurance. Specifically, in the Lateral Movement Test, the EG showed a statistically significant improvement ($p < .05$), indicating that core strength training enhances flexibility and lateral movement ability. In the Single-Leg Jump Test, the EG's performance improved significantly, reaching a highly significant level ($p < .01$), suggesting that core training effectively enhances lower limb explosive power and stability. Additionally, in the Side-to-Side Jump Test, the EG exhibited a statistically significant improvement post-training ($p < .01$), further reinforcing the crucial role of core strength training in enhancing lower limb endurance and coordination. However, in the Backward Balance Walking Test, neither the EG nor the CG demonstrated significant changes, suggesting that core training alone has a limited effect on balance, and additional balance-specific training may be necessary to achieve further improvements. In contrast, the CG showed minimal changes across all tests, indicating that individuals who did not undergo core strength training experienced limited progress in physical fitness. These findings suggest that core strength training not only enhances athletic performance—particularly lower limb endurance, explosiveness, and coordination—but also serves as a foundation for further improvements in balance and other motor skills.



*Note: EG = Experimental group, CG = Control group; Pre = pre-test, Post = Post-test. * Indicates that the significance level is p < .05. ** Indicates that the significance level is p < .01.*

Figure 2. Comparison of FMS between experimental and control groups before and after intervention.

Comparison of core strength between experimental and control groups before and after intervention
Figure 3 illustrates the effects of core training on physical fitness by comparing the performance of the EG and the CG before and after 12 weeks of core strength training. The results of the sit-up test show that the experimental group increased the number of repetitions after the training, while the control group showed no significant change. The plank test revealed a significant improvement in the experimental group's support time, indicating enhanced core muscle endurance, whereas the control group showed minimal change. In the back muscle strength test, grip strength increased in the experimental group, suggesting that core training improved back muscle strength, while the control group exhibited no change. Furthermore, in the one-leg standing test, the experimental group showed a significant improvement in balance, with increased time spent standing on one leg, whereas the control group showed little to no improvement. These findings suggest that systematic core training not only enhances muscle endurance and strength but also improves physical balance, which can positively impact athletic performance and daily activities.



*Note: EG = Experimental group, CG = Control group; Pre = pre-test, Post = Post-test. * Indicates that the significance level is p < .05. ** Indicates that the significance level is p < .01.*

Figure 3. Comparison of core strength between experimental and control groups before and after intervention.

Correlation between core strength and physical fitness
Table 6 shows that plank support is positively correlated with back muscle strength, one-legged stance, and 1-minute jump rope, with a particularly strong correlation with back muscle strength (r = 0.412) and a

significant negative correlation with the 50-meter sprint (r = -0.477). This suggests that individuals with greater core muscular endurance tend to have stronger back muscles and improved sprint performance (as a shorter sprint time indicates better performance). Back muscle strength is significantly correlated with one-legged stance, sit-and-reach, and 1-minute jump rope ($p < .05$), indicating that back strength plays a role in balance, flexibility, and aerobic capacity. One-legged stance is significantly correlated with plank support, back muscle strength, and 1-minute jump rope ($p < .05$), reinforcing the critical role of core strength in maintaining balance. The 50-meter sprint is negatively correlated with core-related abilities such as sit-ups, plank support, back muscle strength, one-legged stance, and 1-minute jump rope, indicating that greater core strength is associated with faster sprint times (i.e., shorter times). The sit-and-reach test is significantly correlated with back muscle strength and 1-minute jump rope, suggesting that flexibility may be related to muscular strength and endurance but does not have a significant relationship with sprint performance. The 1-minute jump rope test shows a significant positive correlation with most core strength indicators (sit-ups, plank support, back muscle strength, and one-legged stance), indicating that jump rope is not only a measure of cardiorespiratory endurance but also closely linked to core strength. Core muscles (as assessed by sit-ups, plank support, and back muscle strength) have a significant impact on sprint performance, balance, jumping ability, and flexibility. Sprint performance (50-meter sprint) is negatively correlated with core strength, suggesting that a stronger core contributes to better sprint results. The 1-minute jump rope test is associated with multiple physical fitness indicators, making it a potentially effective measure of overall fitness. Flexibility (sit-and-reach) is linked to back strength and aerobic capacity but has no significant correlation with sprint performance.

Table 6. Correlation between core strength and physical fitness.

	Sit-ups	**Plank support**	**Back muscle strength**	**One legged stand**	**Fifty meter sprint**	**Sit and reach**	**One minute jump rope**
Sit-ups	1						
Plank support	.258**	1					
Back muscle strength	.324**	.412**	1				
One legged stand	.141	.385**	.221*	1			
Fifty meter sprint	-.365**	-.477**	-.408**	-.415**	1		
Sit-and-reach	.196*	.212*	.360**	.129	-.154	1	
One minute jump rope	.260**	.316**	.405**	.319**	-.382**	.303**	1

*Note. ** Correlation is significant at the .01 level (2-tailed). * Correlation is significant at the .05 level (2-tailed).*

Correlation between core strength and FMS

Table 7 shows that core strength metrics, such as sit-ups, plank support, and back muscle strength, are highly correlated with each other (Plank Support & Back Muscle Strength: r = 0.55), indicating a close relationship between different aspects of core stability (dynamic and static support, muscular strength). Core Strength and Balance Ability: One-legged stance is significantly correlated with all core strength indicators (Sit-ups: r = 0.29, Plank Support: r = 0.45, Back Muscle Strength: r = 0.34), suggesting that a stronger core helps in maintaining static balance. Backward balance walk is associated with plank support (r = 0.44), one-legged stance (r = 0.33), and side-to-side jump (r = 0.26), indicating that core stability plays an essential role in dynamic balance. Core Strength and Dynamic Movement Skills: Lateral movement is significantly correlated with core strength (Sit-ups: r = 0.29, Plank Support: r = 0.42, Back Muscle Strength: r = 0.41), suggesting that greater core stability enhances lateral mobility. Single-leg jump is strongly correlated with core strength (Sit-ups: r = 0.341, Plank Support: r = 0.52, Back Muscle Strength: r = 0.50), highlighting the importance of core engagement in single-leg explosive movements. Side-to-side jump is also significantly related to core strength (Sit-ups: r = 0.36, Plank Support: r = 0.28, Back Muscle Strength: r = 0.44), demonstrating that core strength positively influences agility and lateral jumping ability. Core strength plays a vital role in both static balance (one-legged stance, backward balance walks) and dynamic movement skills (lateral movement, single-leg jump, side-to-side jump). The stronger the core, the better the balance, agility, and jumping performance, reinforcing the importance of core training for athletic performance. Back muscle strength and plank support appear to be the most influential factors affecting multiple movement skills, suggesting that core stability and back strength are crucial for overall movement efficiency.

Table 7. Correlation between core strength and FMS.

	Sit-ups	Plank support	Back muscle strength	One legged stand	Backward balance walking	Lateral movement	Single leg jump	Side-to-side jump
Sit-ups	1							
Plank support	.18	1						
Back muscle strength	.39**	.55**	1					
One legged stand	.29*	.45**	.34**	1				
Backward balance walking	.23	.44**	.21	.33**	1			
Lateral movement	.29*	.42**	.41**	.33**	.09	1		
Single leg jump	.34**	.52**	.50**	.37**	.16	.30*	1	
Side-to-side jump	.36**	.28*	.44**	.43**	.26*	.34**	.43**	1

*Note. ** Correlation is significant at the .01 level (2-tailed).* Correlation is significant at the .05 level (2-tailed).*

DISCUSSION

This study aimed to evaluate the effects of a 12-week core strength training program on physical fitness and FMS in children aged 6 to 8 years. Specifically, it examined whether such training could lead to improvements in speed, explosive power, endurance, coordination, and core stability. The results indicate that core strength training not only enhances core muscle endurance and strength but also contributes to significant improvements in various components of physical fitness, including sprint performance, cardiovascular endurance, and lower limb explosive power. Moreover, a strong correlation was observed between core strength, physical fitness, and FMS, emphasizing the critical role of core stability in overall athletic performance and motor skill development.

In tests pertaining to the core, such as the plank support and sit-up tests, the experimental group demonstrated notable gains, suggesting that the core strength training program effectively increased the endurance and strength of the core muscles. These results are in line with earlier studies, the trunk muscular endurance test (dynamic curl-up, static curl-up, plank, and lateral plank), the single-leg balancing test, and the functional mobility screen were used to assess the children both before and after the intervention. When measured by FMS scores at the end of the session, the experiment group demonstrated a significant improvement in trunk muscular endurance, flexibility, balance, and movement capability (Chang et al., 2020; Kumar & Zemkova, 2022; Lu et al., 2022). Research has shown that core strength training enhances muscle endurance, balance, and overall physical performance. The EG showed significant improvements in the 50-meter sprint and one-minute jump rope tests, indicating that core strength training contributes to enhanced speed and endurance. After a 12-week intervention, both the core strength and weight training groups showed significant improvements in abdominal strength (sit-ups: 18.70 ± 3.20 to 22.21 ± 3.50; 17.60 ± 3.29 to 21.60 ± 3.63), endurance (12-min run: 1817 ± 185.78 m to 2008.97 ± 214.79 m; 1806 ± 237.25 m to 2002.59 ± 83.32 m), and flexibility (sit and reach: 23.48 ± 2.75 cm to 25.96 ± 2.38 cm; 23.66 ± 2.92 cm to 25.86 ± 2.55 cm). In contrast, the control group showed declines in all areas. The weight training group improved slightly more in strength and endurance, while the core training group saw greater gains in flexibility (Kumar & Zemkova, 2022). The EG demonstrated significant improvements in the single-leg jump and lateral jump tests, supporting the findings of Chang et al. (2020), who noted that core strength training enhances both muscular endurance and motor coordination. Similarly, another study found that core stability training significantly improved balance in young male basketball players, emphasizing the role of core strength in dynamic movements that require rapid changes in direction and jumping (Gong et al., 2024). These improvements were also evident in the experimental group, further supporting the positive impact of core strength training on children's motor skills. The CG which did not undergo core strength training, showed minimal improvements, highlighting the importance of targeted core training for enhancing physical fitness. This lack of significant change in the CG suggests that regular physical education classes alone may not be sufficient to improve core strength and related fitness components. The scores were significantly different in both groups before and after the single-leg standing with eyes closed test. In the star excursion balance test, the experimental group showed a significant difference or highly significant difference with an average effect size of when the left or right foot supported in the other directions before and after the training (Junker & Stoggl, 2019).

The experimental group (EG) exhibited significant improvements in FMS, particularly in tests assessing lower limb explosiveness, coordination, and lateral movement. For example, the single-leg jump and side-to-side jump tests showed highly significant improvements, indicating that core strength training enhances lower limb explosive power and agility. These findings are consistent with the work of Hulteen et al. (2018), who emphasized the importance of core stability in the development of foundational movement skills. However, the backward balance walking test did not show significant improvements in either group, suggesting that core strength training alone may not be sufficient to enhance balance. This finding aligns with the study by Junker and Stoggl (2019) which concluded that while core training improves muscle performance, additional balance-specific exercises may be necessary to achieve significant improvements in balance. A study by Kumar and Zemkova (2022)[17] found that 12 weeks of core strength training significantly improved muscle strength, endurance, and flexibility in school-aged athletes. The intervention group, both core strengthening and weight training programs were effective in improving abdominal strength. Significantly increase endurance. Significantly enhance flexibility. Their findings align with those of the current study, indicating that core strength training not only enhanced core muscle endurance but also improved overall physical performance, particularly in endurance and strength. They also noted that core strength training had a significant effect on improving athletes' explosive power and flexibility, which corresponds with the significant improvements observed in the experimental group in the 50-meter sprint and jump rope tests. Marani et al. (2020) showed that core stability training enhanced the posture and propulsion efficiency of teenage swimmers while also considerably increasing their core muscular strength. Their results further confirm the beneficial effects of core strength training on children's physical fitness and performance, as evidenced by the experimental group's notable gains in the plank and back muscular strength tests. The study discovered that junior swimmers' core muscle strength increased when they used a Swiss ball for core stability exercises (Kumar & Zemkova, 2022).

The correlation analysis revealed strong relationships between core strength and various physical fitness indicators. Plank support, a measure of core endurance, was positively correlated with back muscle strength, one-legged stance, and the one-minute jump rope test, indicating that individuals with greater core endurance tend to have stronger back muscles and better balance. Additionally, the 50-meter sprint was negatively correlated with core strength, suggesting that a stronger core contributes to faster sprint times. These findings are consistent with the previous work (Marani et al., 2020) who reported that core stability exercises improved swimming performance by enhancing body position and propulsion efficiency. The experimental group's posttest score of 7.5 was higher than the control group's score of 2.24. It means that junior swimmers can strengthen their core muscles by performing core stability workouts using a Swiss ball. Core strength was also significantly correlated with FMS, particularly in tests assessing dynamic movement skills, such as lateral movement, single-leg jumps, and side-to-side jumps. This suggests that core stability plays a crucial role in enhancing agility, coordination, and explosive power. The strong correlation between core strength and FMS supports the model proposed by Hulteen et al. (2018), which posits that motor skills develop in conjunction with physical fitness and perceived competence. A study by Chang et al. (2020) showed that a six-week core strength training program significantly improved the physical fitness, motor skills, and balance abilities of school-aged children. Their findings align with the results of the current study, suggesting that core strength training can effectively enhance children's physical performance, particularly in balance and motor coordination. After the intervention, the experiment group showed significant improvement in trunk muscular endurance, movement capability (FMS scores), flexibility, and balance. Additionally, the experiment group outperformed the control group in all outcome measures. Chang et al. (2020) also noted that core strength training not only improved children's muscular endurance but also enhanced their motor coordination, which aligns with the significant improvements observed in the experimental group in the single-leg jump and lateral jump tests in the current study. The experiment group showed significant improvments in all outcomes, with moderate to high effect sizes, especially in muscular fitness, FMS scores, and balance (Cohen's d = 0.79-1.3). In contrast, the GPE group exhibited only minor improvements, with increases in side plank, FMS scores, and flexibility but decreases in static curl-up and plank performance. Overall, the experiment group program outperformed in all measured domains. . These results align with previous research highlighting the role of core stability training in enhancing balance and dynamic movement, particularly for athletes (Marani et al., 2020). Their study emphasized the importance of core strength in dynamic movements, especially in sports requiring rapid direction changes and jumping. After ten weeks of experimental intervention, traditional strength training and core stability training had differing effects on the rise of scores in static balance ability assessments. Significant gains were observed in single-leg standing with eyes test scores for both groups. After 10 weeks of core stability training demonstrated substantial improvements in prone, supine, and left lateral positions, as well as a significant improvement in left lateral position. This is consistent with the significant improvements observed in the experimental group in the lateral movement and single-leg jump tests, further supporting the positive impact of core strength training on children's motor skills. The results of this study have important implications for physical education and training programs aimed at children. Incorporating core strength training into regular physical education curricula could significantly enhance children's physical fitness and motor skill development. Given the strong correlation between core strength and various aspects of physical fitness, such as sprinting, jumping, and endurance, core training should be considered a fundamental component of any physical education program. Moreover, the findings suggest that core strength training can be particularly beneficial for children who are at risk of physical inactivity or who have underdeveloped motor skills. By improving core stability, children may be more likely to engage in physical activities, thereby reducing the risk of chronic diseases such as obesity and cardiovascular disease.

This study is the first to systematically examine the effects of 12 weeks of core strength training on physical fitness and FMS in children aged 6-8 years. The study provides valuable insights into how core strength training enhances multiple aspects of physical fitness, including speed, endurance, explosive power, coordination, and core stability. Additionally, the research utilized a well-designed randomized controlled trial (RCT) with a clear intervention protocol, ensuring high internal validity. By including a range of physical tests (e.g., 50-meter sprint, sit-and-reach, one-minute jump rope) and FMS (e.g., single-leg jump, side-to-side jump), the study offers a comprehensive assessment of children's physical development. The study's findings contribute not only to the academic understanding of core strength training in early childhood but also have practical implications for the design of physical education programs aimed at improving children's overall fitness and motor skills. Overall, this research fills a critical gap in the literature regarding the impact of core strength training on young children's physical development.

Despite its strengths, the study has several limitations. The 12-week intervention may not be enough to assess long-term effects, and a longer follow-up is needed. Conducted in a single school, the findings may not be generalizable. The study also did not account for confounding factors like nutrition, sleep, or other activities, and may overlook psychological benefits. Future research should use a longitudinal approach, a larger, more diverse sample, and explore psychological and external factors affecting children's fitness.

CONCLUSION

The findings of this study indicate that children aged 6 to 8 who participated in a 12-week core strength training program experienced significant improvements in physical fitness and FMS. The experimental group demonstrated enhanced speed, explosive power, endurance, and motor coordination, outperforming the control group in tests such as sprinting, jumping, planking, back muscle strength, and jump rope. Core strength was positively associated with coordination, jumping ability, and sprint speed. However, no significant improvement was observed in the backward balance walking test, suggesting that additional or targeted training may be necessary to enhance dynamic balance. Overall, these results highlight the effectiveness of core strength training in improving FMS and physical fitness in young children.

AUTHOR CONTRIBUTIONS

Xueliang Zou conceived and designed the study, drafted the manuscript, conducted data collection, and performed the data analysis. Kurusart Konharn contributed to the study design, critically reviewed the manuscript, finalized its content, and prepared the manuscript for submission. Wichai Eungpinichpong participated in revising the manuscript. All authors have read and approved the final version of this manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS APPROVAL

The study was approved by the Ethics Committee of Khon Kaen University (HE672147).

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