DOI: 10.37190/abb/224458

Effects of an 8-Week Core-Strength Program on Smash Accuracy in Female Badminton Athletes

Shuzhen Ma,[1,2] Kim Geok Soh,[2] Haili Feng[3], Huajun Hu[3], Jing Li[4*],Xinzhi Wang[5*]

[1]College of Public Administration, Guilin University of Technology, Guilin, China
[2]Faculty of Educational Studies, Department of Sports Studies, Universiti Putra Malaysia, Selangor, Malaysia
[3]College of Physical Education and Health, Guangxi Normal University, Guilin, China
[4]Yuncheng Advanced Normal College, Department of Physical Education, Yuncheng, China
[5]Faculty of Sports Studies, Shandong University of Technology, Zibo, Shandong, China
*Corresponding author: Jing Li, Yuncheng Advanced Normal College, Department of Physical Education, Yuncheng, China, e-mail address: silence6888@gmail.com; Xinzhi Wang, Faculty of Sports Studies, Shandong University of Technology, Zibo, Shandong, China, e-mail address: wangxinzhi714@gmail.com

Submitted: 5th January 2026
Accepted: 11th June 2026

Abstract

Background: To investigate the effects of an 8-week core-strength training program on smash accuracy in female badminton athletes.

Methods: Forty female badminton players were randomly assigned to an experimental group (EG) or a control group (CG). Both groups continued regular badminton training, while the EG additionally completed an 8-week structured core-strength program. Smash accuracy was assessed under three conditions—stationary, jumping, and moving smashes—at baseline, mid-intervention (posttest 1), and post-intervention (posttest 2). Data were analyzed using generalized estimating equations (GEE) to examine group effects, time effects, and group × time interactions, with age, training experience, height, and body mass included as covariates.

Results: GEE analysis revealed significant group, time, and group × time interaction effects for in-situ, jumping, and moving smash accuracy ($p < 0.05$). Post hoc analyses showed that the EG demonstrated significant improvements in smash accuracy from baseline to posttest 2 across all three smash conditions, whereas improvements in the CG were limited or non-significant. Effect size analysis further indicated that the magnitude of improvement in smash accuracy was substantially greater in the EG than in the CG. None of the covariates showed a significant influence on smash accuracy outcomes.

Conclusion: An 8-week core-strength training program significantly enhances in-situ, jumping, and moving smash accuracy in female badminton athletes. These findings highlight the importance of core stability and strength in optimizing technical performance and suggest that systematic core training should be incorporated into routine badminton training programs to improve smash accuracy and overall competitive performance.

Keywords: Core strength training; Badminton; Smash accuracy; Female athletes; Generalized estimating equations

Introduction

The smash is widely considered one of the most decisive offensive techniques in badminton, a primary means of breaking through the opponent's defense and creating direct scoring opportunities. Given the extremely light weight and high speed of the shuttlecock, the ability to deliver a powerful and accurate smash is crucial for controlling the rally and the pace of the game[15]. A high-quality smash—characterized by greater speed, accuracy, and consistency—forces the opponent into a passive position, allowing the athlete to convert tactical advantages into winning points[1, 22]. With the increasingly fast pace and power-based nature of modern badminton matches, improving smash ability has become a core focus of competitive training[1] .

Core strength training is increasingly valued in various sports due to its important role in stabilizing the torso, improving kinetic chain efficiency, and promoting effective power transfer from the lower limbs to the upper limbs[9, 23]. Currently, core training has been proven to improve performance in various sports, such as football, handball, basketball, swimming, dance, karate, Muay Thai, gymnastics, and so on[16]. Although these findings suggest that core muscles play a crucial role in enhancing athletic performance, empirical studies specifically investigating their contribution to badminton performance, particularly smashes, remain limited.

This research gap is particularly prominent in the context of the development of badminton in China. As shown in Figure 1, data was collected on the performance of provincial badminton teams in the National Games of the People's Republic of China to understand the reasons for the decline in the performance of the Chinese national badminton team. Figure 1 shows that athletes from Guangxi Province performed worse than their peers from other stronger provinces. Currently, China is committed to training a large number of female university students to become professional athletes, making the training of female athletes a key focus. However, compared to male athletes, female athletes often suffer from insufficient physical training, particularly in trunk stability and neuromuscular coordination, which is considered a potential cause of this performance gap. To date, however, no research has systematically evaluated whether structured core strength training programs can effectively improve the smash performance of female badminton players in this region.

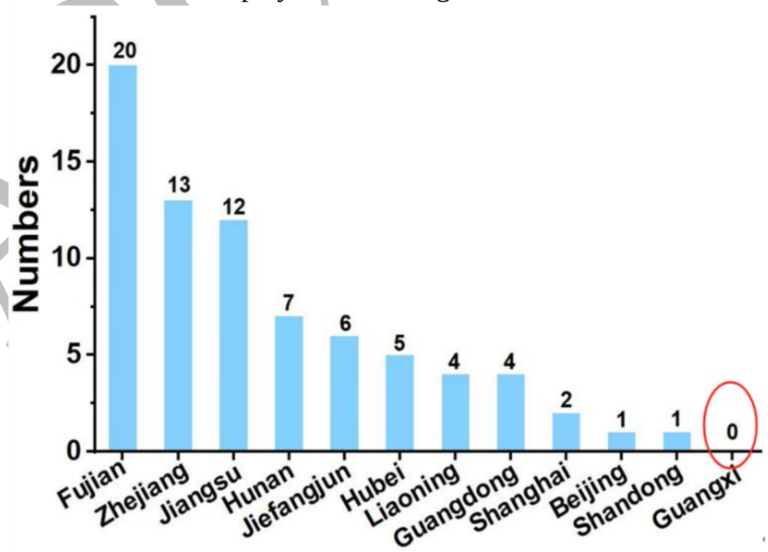

Figure 0 : Achievements of Provincial Badminton Teams in China

Therefore, this study aimed to investigate the impact of an 8-week core strength training program on smash accuracy in female competitive badminton players in Guangxi. Participants were randomly assigned to either the core training group or the control group, which continued with standard training. We hypothesized that athletes receiving core strength intervention would show a significant improvement in smash accuracy compared to athletes who only underwent standard training.

Methods

Research Design

This study employed a pre-test-post-test experimental design, conducted as a cluster randomized controlled trial (cRCT). cRCTs are a type of randomized trial involving a population or community [21] widely used in research on competitive sports training. Researchers registered an account on ClinicalTrials.gov and obtained prior authorization (approval number: NCT06219070). To investigate the difference in effectiveness between core training and conventional training in badminton players' smash-specific training, researchers used a fishbowl sampling method to randomly select two universities from the 15 universities in Guilin, the city with the most universities in Guangxi, as research subjects: the badminton teams of Guilin University of Technology and Guangxi Normal University. The subjects were randomly divided into two groups: an experimental group (receiving core training) and a control group (continuing conventional training).

The dependent variable in this study was the smash performance of badminton players, and the independent variable was core training. Both the experimental and control groups received the same technical training; the control group received a standard training regimen, while the experimental group received core training (see Appendix B, Table 2). The study lasted eight weeks, with training three times a week for one hour each time. During the intervention period, the dependent variable was measured three times: before intervention (baseline), post-intervention 1 (four weeks later), and post-intervention 2 (eight weeks later). The specific research framework is shown in Figure 2.

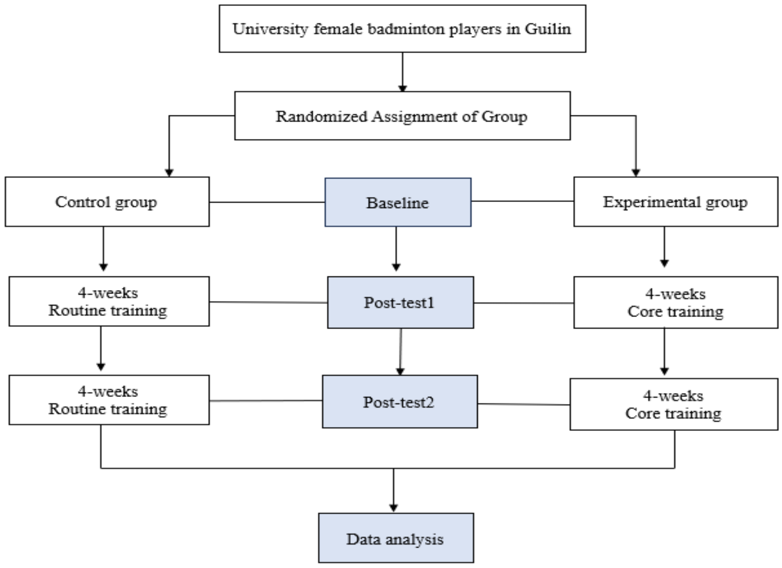

Figure 2 : Research Framework

Participants

First, this study used G*Power 3.1.9.7 software to estimate the prior sample size based on the effect sizes reported in previous studies on core strength interventions in racket sports[11, 24]. Assuming an effect size of $f = 0.23$, a significance level of $\alpha = 0.05$, and a statistical power of 0.80, the minimum required sample size was calculated to be 36.8 participants. Considering an expected dropout rate of 20%, the target sample size was set at 46 athletes.

Of the 58 female badminton players initially screened, 46 met the inclusion and exclusion criteria. At baseline, 3 athletes from each group withdrew due to injury and were excluded from the intervention group. Ultimately, 40 athletes completed the study and were included in the final analysis, with 20 assigned to the core training group and 20 to the control group.

All participants signed written informed consent forms, and this study protocol was approved by the Ethics Committee of Guangxi Normal University (Approval No. 20230805001).

Randomization

Participants were randomly assigned to either the Core Strength Training Group (CTG, n = 20) or the Control Group (CG, n = 20) using a computer-generated random sequence. The assignments were kept confidential by an independent researcher not involved in the testing or training. Coaches and athletes were only informed of their assignments after baseline measurements were completed.

Instruments

This study measured the accuracy of badminton players' smashes in In-situ, Jump smashes, and

Moving smashes. The instruments used to calculate these technical indicators are detailed in Table 1.

Table 1 : Instrument Used to Measure Smash Performance

Variables	Measure method	Instrument	Unit	Reference
In-situ smash accuracy	Ball placement test	Coloured string. Leopard Smart shuttlecock throwing machine.	Count	[6, 7]
Jump smash accuracy	Ball placement test			
Move smash accuracy	Ball placement test			

Reliability and Validity

Ensuring the validity of data collection methods in a study is crucial[18]. In this study, the face validity and content validity of these methods were evaluated by an expert panel. Face validity was established after the research tools were finalized. A panel of six badminton experts reviewed these tools and provided evaluation results. The result shows tha all tools used in this study had demonstrated good validity in previous studies.

Furthermore, this study used the Item Content Validity Index (I-CVI) for statistical analysis of content validity. The Kappa correction coefficient was used to assess the relevance of the I-CVI[20]. This study followed the I-CVI criteria proposed by Lynn (1986) (I-CVI = 1 with 3 to 5 experts, and at least 0.78 with 6 to 10 experts) and Fleiss's criteria, where a Kappa value above 0.75 was considered excellent, 0.40 to 0.75 was good, and below 0.40 was poor [8, 17]. Items with an I-CVI value below 0.78 were revised or deleted based on expert feedback.

All items demonstrated acceptable content validity indices, as shown in Table 2. The relevant indices are as follows: Spike performance: I-CVI = 0.833–1.000, Kappa = 0.816–1.000. Similarly, all items met the acceptable clarity thresholds (Spiking performance: I-CVI = 1.000, Kappa = 1.000). Therefore, this test scheme exhibits good content validity.

Table 2 : Validity of Smash Performance Instruments

Item	Measurement Method	Number of Agreement	Relevance		Number of Agreement	Relevance	
			I-CVI	Kappa		I-CVI	Kappa
In-situ smash accuracy	Ball placement test	5	0.833	0.816	6	1.000	1.000
Jump smash accuracy	Ball placement test	5	0.833	0.816	6	1.000	1.000

Move smash accuracy	Ball placement test	5	0.833	0.816	6	1.000	1.000

In this study, researchers used a test-retest method to determine the reliability of the dependent variable (smash performance). According to Fleiss's classification, an within-class correlation coefficient (ICC) value above 0.75 indicates "excellent" reliability, an ICC value between 0.40 and 0.75 indicates "good" reliability, and an ICC value below 0.40 indicates "poor" reliability[4] . The ICC values for the selected smash performance components ranged from 0.762 to 0.807, indicating that the assessment of smash skills in female badminton players in this study had high reliability (see Table 3 for details).

Table 0: Test-Retest Reliability of Smash Performance Instruments (n = 40)

Variables	Measurement method	Intra-class correlation coefficient	95% Confidence Interval	
			Lower bound	Upper bound
In-situ smash accuracy	Ball placement test	0.771	0.569	0.878
Jump smash accuracy	Ball placement test	0.762	0.552	0.874
Move smash accuracy	Ball placement test	0.807	0.637	0.898

Intervention Measures

The data in this study were obtained from field testing rather than laboratory testing, thus exhibiting higher exercise specificity. To ensure the validity of the results, external variables such as environment, participant condition, pre-competition preparation, and testing procedures needed to be controlled. Participants and coaches should strictly adhere to standardized training and testing procedures to obtain accurate test results. During training, the quality, frequency, and rest intervals of each training movement should be strictly controlled. During testing, staff should set up and check the equipment in advance and strictly regulate the order of physical fitness and spiking performance tests, as well as the recovery time between tests. In addition, potential covariates that might interfere with core strength, such as training time, age, height, and weight, were tested, and their potential influence was excluded from the statistical analysis.

Testing Procedure

Two weeks prior to the test, participants received training on the testing procedure to minimize the learning effect. The study consisted of three phases: a baseline phase where pre-test data was collected and core training and the testing procedure were introduced; an intervention phase where training was supervised by coaches, culminating in the first post-test (posttest1) in week 4; and a post-intervention phase where the second post-test (posttest2) was conducted in week 8. All data were subsequently processed for analysis.

Data Analysis

This study collected participant data before and after the intervention and performed statistical analysis using SPSS 30.0, with a significance level set at $p < 0.05$. The analysis included two parts: descriptive statistics to present demographic characteristics and inferential statistics for hypothesis testing. To assess the impact of the intervention on smash performance, the generalized estimating equation (GEE) was used to analyze repeated measures data[13] . Data analysis determined whether core training had a significant impact on the smash performance of female badminton players. Significant differences were found between the control and experimental groups in In-situ smash accuracy, Jumping smash accuracy, and Moving smash accuracy at baseline, posttest 1, and posttest 2.

Results

Demographic Analysis

Table 4 presents the basic demographic characteristics of the two groups of subjects. The results show that although there were mean differences between the control group and the experimental group in indicators such as age, height, weight, and training duration, these differences did not reach statistical significance ($p>0.05$) as verified by the t-test. Therefore, the two groups can be considered to be well-comparable in terms of baseline characteristics, laying a reliable foundation for subsequent intervention effect analysis.

Table 0 : Demographic Characteristics

Demographic Characteristics	Group	Mean	Std. Deviation	t	*p*-value
Age	EG	21.15	0.745	-0.740	0.464
	CG	21.40	1.314		
Height	EG	167.25	3.998	-1.298	0.127
	CG	168.95	3.410		
Weight	EG	57.85	4.815	-1.131	0.190
	CG	59.15	4.977		
Training Time	EG	9.65	1.954	-0.564	0.576
	CG	10.00	1.974		

Note: EG, Experimental Group; CG, Control group.

Baseline Situation

Before conducting data analysis, we assessed the assumption of intra-group homogeneity for all variables at baseline. Since all variables were normally distributed, we used an independent samples t-test as the baseline to assess homogeneity between the two groups in the deduction accuracy performance variable. The results showed no significant difference between the two groups in the deduction accuracy performance variable ($p>0.05$), indicating homogeneity between the two groups at baseline. Table 5 provides a comparison of the means between the two groups.

Table 5 : Comparing between Groups for Smash Accuracy Performance Variables at Baseline

Variable	Group	Mean	Std. Deviation	t	*p*-value
In-situ smash accuracy	EG	0.68	0.125	1.021	0.314
	CG	0.64	0.123		
Jump smash accuracy	EG	0.68	0.064	-0.324	0.748
	CG	0.69	0.123		
Move smash accuracy	EG	0.73	0.092	0.277	0.783
	CG	0.72	0.132		

Note: EG, Experimental Group; CG, Control group.

The Impact of Core Training on Smash Accuracy

In-situ Smash Accuracy

The first aspect of smash accuracy is in-situ smash accuracy. The impact of core training intervention on in-situ smash accuracy was observed through a multi-stage fitness test. Specific descriptive data are shown in Table 6.

Table 6 : Descriptive Statistics of In-situ Smash Accuracy between Groups Across the Time

Variable	Group	Baseline		Posttest1		Posttest2	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
In-situ smash accuracy	EG	0.68	0.125	0.70	0.103	0.84	0.067
	CG	0.64	0.123	0.69	0.121	0.71	0.105

Note: EG, Experimental Group; CG, Control group.

Table 7 presents the results of the in-situ kill accuracy analysis based on the generalized estimating equation (GEE). First, the main effect of group was significant ($\chi^2 = 4.154$, $p < 0.05$), indicating a statistically significant difference in overall kill accuracy between the experimental group (EG) and the control group (CG). Second, the main effect of time was also significant ($\chi^2 = 61.997$, $p < 0.001$), indicating a significant change in in-situ kill accuracy among the three measurements. Furthermore, the interaction effect of group × time was significant ($\chi^2 = 11.933$, $p < 0.05$), showing that the trends of change over time differed between the experimental and control groups, indicating that the improvement brought by core training is time-dependent.

Regarding covariates, age ($\chi^2 = 0.010$, $p = 0.919$), years of training ($\chi^2 = 0.005$, $p = 0.943$), height ($\chi^2 = 0.073$, $p = 0.787$), and weight ($\chi^2 = 0.003$, $p = 0.958$) were not statistically significant, indicating that these variables had no significant impact on the accuracy of in-situ smashes.

Table 7 : Results of GEE on In-Situ Smash Accuracy Score

Variable	Source	Wald Chi-Square	df	*p*-value
In-situ smash accuracy	Group	4.154	1	<0.05
	Time	61.997	2	<0.001
	Group * Time	11.933	2	<0.05
	Age♦	0.01	1	0.919
	Training time♦	0.005	1	0.943
	Height♦	0.073	1	0.787
	Weight♦	0.003	1	0.958

Note: df, degrees of freedom; ♦, covariates.

This study used the Bonferroni correction method to examine the differences in smash accuracy between two groups of young female badminton players at three time points. Results showed that the experimental group (EG) showed significant improvements in Posttest2 compared to Posttest1 and baseline (mean differences of 0.135 and 0.16, respectively, $p < 0.05$), while there was no significant difference between Posttest1 and baseline ($p > 0.05$). In the control group (CG), there were significant differences between Posttest2 and baseline, and between Posttest1 and baseline (mean differences of 0.07 and 0.055, respectively, $p < 0.05$), but no statistically significant difference between Posttest2 and Posttest1 ($p > 0.05$). Effect size further indicated that the time effect was more pronounced in the experimental group ($d = 1.595$), significantly greater than that in the control group ($d = 0.612$), suggesting that core strength training has a stronger promoting effect on improving smash accuracy.

Table 8 : Within Groups Comparison of In-Situ Smash Accuracy Mean Scores across the Time for Different Groups

Variable	Group	(I) time	(J) time	Mean Difference (I-J)	SE	*p*-value	95% CI for Difference Lower	95% CI for Difference Upper	Effect size (d)
In-situ smash accuracy	EG	Posttest2	Posttest1	0.1350*	0.015	0.000	0.100	0.170	1.595
		Posttest2	Baseline	0.1600*	0.016	0.000	0.121	0.199	
		Posttest1	Baseline	0.0250	0.017	0.434	-0.016	0.066	
	CG	Posttest2	Posttest1	0.0150	0.022	1.000	-0.037	0.067	0.612
		Posttest2	Baseline	0.0700*	0.026	0.019	0.009	0.131	
		Posttest1	Baseline	0.0550*	0.022	0.035	0.003	0.107	

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Bonferroni correction was used to compare the seated striking accuracy of the two groups of subjects at baseline, post-test 1, and post-test 2 (Table 9). The results showed that there were no significant differences between the two groups at baseline and post-test 1 (mean differences were 0.04 and 0.01, respectively, $p > 0.05$), but significant differences were observed at post-test 2 (mean difference = 0.13, $p < 0.05$). Further effect size calculation showed that the seated striking accuracy had the largest effect at post-test 2 ($d = 1.476$), significantly higher than post-test 1 ($d = 0.089$) and baseline ($d = 0.323$), indicating that the training effect gradually increased over time and reached its most significant level in the later stage.

Table 9 : Between Groups Comparison of Mean Score for In-Situ Smash Accuracy at Three Different Time

Variable	Time	Mean difference (EG-CG)	SE	*p*-value	95% CI for difference		Effect size (d)
					Lower	Upper	
In-situ smash accuracy	Baseline	0.040	0.03818	0.295	-0.0348	0.1148	0.323
	Posttest1	0.010	0.03457	0.772	-0.0578	0.0778	0.089
	Posttest2	0.130*	.02716	0.000	0.0768	0.1832	1.476

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Figure 3 shows the average score of in-situ spiking accuracy at different time points. Under the core training intervention, the experimental group (EG) had a higher average score than the control group (CG) at all three different time points (baseline, post-test 1, and post-test 2).

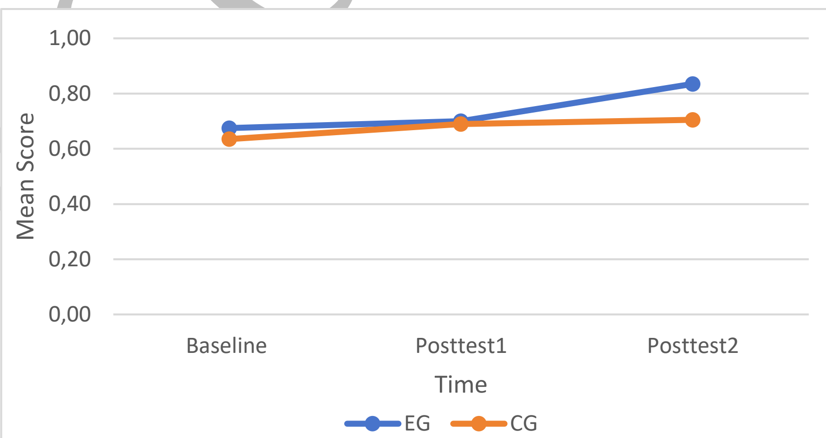

Figure 3 : The Mean Score of In-situ Smash Accuracy across Time for Both Groups

Jump Smash Accuracy

The second aspect of spike accuracy is jump smash accuracy. The impact of core training intervention on jump smash accuracy was observed through multi-stage fitness tests, and the descriptive data are shown in Table 10.

Table 10 : Descriptive Statistics of Jump Smash Accuracy between Groups Across the Time

Variable	Group	Baseline		Posttest1		Posttest2	
		Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
Jump Smash accuracy	EG	0.68	0.064	0.72	0.083	0.84	0.060
	CG	0.69	0.123	0.69	0.121	0.72	0.114

Note: EG, Experimental Group; CG, Control group.

Table 11 presents the GEE analysis results for jump smash accuracy. First, the between-group effect was significant ($\chi^2 = 5.359$, $p < 0.05$), indicating a statistically significant difference in overall performance between the experimental group (EG) and the control group (CG). Second, the time effect was also significant ($\chi^2 = 69.413$, $p < 0.001$), indicating that jump smash accuracy changed significantly at all three measurement time points. Furthermore, the interaction effect between group and time was significant ($\chi^2 = 34.962$, $p < 0.001$), meaning that the two groups showed different trends over time, with the experimental group showing a significantly greater improvement.

For covariates, age, years of training, height, and weight did not have a significant impact on jump smash accuracy. Specifically, age ($\chi^2 = 0.303$, $p = 0.582$), training time ($\chi^2 = 1.536$, $p = 0.215$), height ($\chi^2 = 0.497$, $p = 0.481$), and weight ($\chi^2 = 0.401$, $p = 0.526$) did not show statistical significance. This indicates that the changes in jump smash accuracy were mainly driven by intervention and time factors, rather than by the aforementioned individual difference variables.

Table11 : Results of GEE on Jump Smash Accuracy Score

Variable	Source	Wald Chi-Square	df	*p*-value
Jump smash accuracy	Group	5.359	1	<0.05
	Time	69.413	2	<0.001
	Group * Time	34.962	2	<0.001
	Age♦	0.303	1	0.582
	Training time♦	1.536	1	0.215
	Height♦	0.497	1	0.481
	Weight♦	0.401	1	0.526

Note: df, degrees of freedom; ♦, covariates.

This study used the Bonferroni correction method to compare the changes in jump smash accuracy at three time points between two groups of young female badminton players (Table 12). The results showed that the experimental group (EG) showed significant improvements at Posttest2 compared to Posttest1 (mean difference = 0.12, $p < 0.05$) and at baseline (mean difference = 0.165, $p < 0.05$), while there was no significant difference between Posttest1 and baseline (mean difference = 0.045, $p > 0.05$). The control group (CG) showed no statistically significant differences at any of the three time points. Effect size analysis further indicated that the experimental group had the largest time effect size in jump smash accuracy ($d = 2.579$), significantly higher than the control group (d = 0.253), suggesting that core strength training has a more significant effect on improving jump smash accuracy.

Table 12: Within Groups Comparison of Jump Smash Accuracy Mean Scores across the Time for Different Groups

Variable	Group	(I) time	(J) time	Mean Difference (I-J)	SE	*p*-value	95% CI for Difference		Effect size (d)
							Lower	Upper	
Jump smash accuracy	EG	Posttest2	Posttest1	0.120*	0.013	0.000	0.088	0.152	2.579
		Posttest2	Baseline	0.165*	0.016	0.000	0.126	0.204	
		Posttest1	Baseline	0.045	0.019	0.060	-0.001	0.091	
	CG	Posttest2	Posttest1	0.025	0.024	0.915	-0.033	0.083	0.253
		Posttest2	Baseline	0.030	0.020	0.408	-0.018	0.078	
		Posttest1	Baseline	0.005	0.027	1.000	-0.059	0.069	

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Bonferroni correction was used to compare the jump smash accuracy of the two groups at baseline, post-test 1, and post-test 2 (see Table 13). The results showed that there were no significant differences in the mean between the experimental group (EG) and the control group (CG) at baseline and post-test 1 (baseline: mean difference = -0.01; post-test 1: mean difference = 0.03; both $p > 0.05$), but the difference between the two groups reached statistical significance at post-test 2 (mean difference = 0.125, $p < 0.05$). Effect size analysis further showed that the between-group effect size of jump smash accuracy was largest at post-test 2 (d = 1.317), followed by baseline (d = 0.102), and smallest at post-test 1 (d = 0.096).

Table 13 : Between Groups Comparison of Mean Score for Jump Smash Accuracy at Three Different Time

Variable	Time	Mean difference (EG-CG)	SE	*p*-value	95% CI for difference		Effect size (d)
					Lower	Upper	
Jump smash accuracy	Baseline	-0.010	0.030	0.740	-0.069	0.049	0.102
	Posttest1	0.030	0.032	0.349	-0.033	0.093	0.096
	Posttest2	0.125*	0.028	0.000	0.070	0.180	1.317

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Figure 4 shows the average score of jump smash accuracy over time. Under the core training intervention, the experimental group (EG) had a higher average score than the control group (CG) at all three different time points (baseline, post-test 1, and post-test 2).

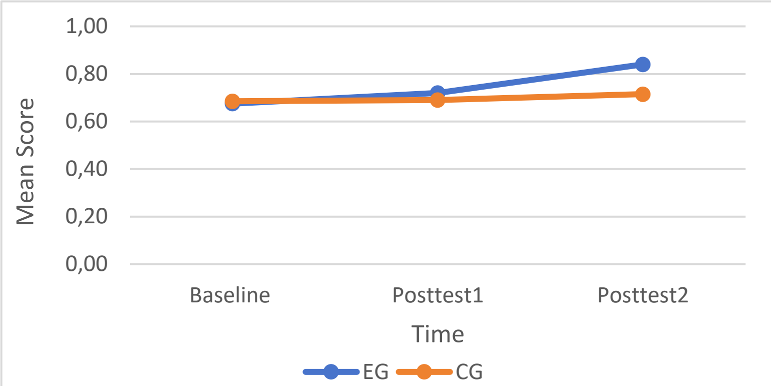

Figure 4 : The Mean Score of Jump Smash Accuracy across Time for Both Groups

Move Smash Accuracy

The third aspect of smash accuracy is move smash accuracy. The impact of core training intervention on move smash accuracy was observed through multi-stage fitness tests, and the descriptive data are shown in Table 14.

Table 14 : Descriptive Statistics of Move Smash Accuracy between Groups across the Time

Variable	Group	Baseline		Posttest1		Posttest2	
		Mean	**Std. Deviation**	**Mean**	**Std. Deviation**	**Mean**	**Std. Deviation**
Move smash accuracy	EG	0.73	0.092	0.79	0.104	0.86	0.089
	CG	0.72	0.132	0.73	0.121	0.76	0.082

Note: EG, Experimental Group; CG, Control group.

Table 15 reports the results of the move smash accuracy analysis based on GEE. First, the main effect of group was statistically significant ($\chi^2 = 4.298$, $p < 0.05$), indicating a significant difference in overall performance between the experimental group (EG) and the control group (CG). Second, the main effect of time was significant ($\chi^2 = 22.44$, $p < 0.001$), indicating a significant change in move smash accuracy over time among the three measurements. Furthermore, the interaction between group and time was also significant ($\chi^2 = 5.895$, $p < 0.05$), meaning that the two groups showed different trends over time, with the experimental group showing a significantly greater improvement than the control group.

Regarding covariates, age ($\chi^2 = 0.279$, $p = 0.597$), training time ($\chi^2 = 0.777$, $p = 0.378$), height ($\chi^2 = 0.434$, $p = 0.510$), and weight ($\chi^2 = 0.011$, $p = 0.915$) did not significantly affect the accuracy of move smash. This indicates that the aforementioned individual characteristic variables did not interfere with the trend of move smash performance, strengthening the explanatory power of core training intervention as the main influencing factor.

Table 15 : Results of GEE on Move Smash Accuracy Score

Variable	Source	Wald Chi-Square	df	*p*-value
Move smash	Group	4.298	1	<0.05

accuracy	Time	22.44	2	<0.001
	Group * Time	5.895	2	<0.05
	Age♦	0.279	1	0.597
	Training time♦	0.777	1	0.378
	Height♦	0.434	1	0.51
	Weight♦	0.011	1	0.915

Note: df, degrees of freedom; ♦, covariates.

This study used the Bonferroni correction method to compare the differences in move smash accuracy between two groups of young female badminton players at baseline, Posttest 1, and Posttest 2 (Table 16). The results showed that in the experimental group (EG), the mean differences between Posttest2 and baseline, and between Posttest1 and baseline, were statistically significant (mean differences were 0.125 and 0.055, respectively, $p < 0.05$), while the difference between Posttest2 and Posttest1 was not significant (mean difference = 0.07, $p > 0.05$). In the control group (CG), the mean differences between the three time points were not statistically significant ($p > 0.05$). Effect size analysis further showed that the time effect of move smash accuracy in the experimental group ($d = 1.436$) was significantly greater than that in the control group ($d = 0.364$), indicating that core strength training has a stronger impact on improving move smash accuracy.

Table 16 : Within Groups Comparison of Move Smash Accuracy Mean Scores across the Time for Different Groups

Variable	Group	(I) time	(J) time	Mean difference (I-J)	SE	*p*-value	95% CI for difference		Effect size (d)
							Lower	Upper	
Move smash accuracy	EG	Posttest2	Posttest1	0.07	0.033	0.106	-0.010	0.150	1.436
		Posttest2	Baseline	0.125*	0.028	<0.001	0.058	0.192	
		Posttest1	Baseline	0.055*	0.023	0.049	0.000	0.110	
	CG	Posttest2	Posttest1	0.035	0.023	0.368	-0.019	0.089	0.364
		Posttest2	Baseline	0.04	0.023	0.238	-0.015	0.095	
		Posttest1	Baseline	0.005	0.013	1.000	-0.027	0.037	

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Bonferroni correction was used to compare the move smash accuracy of the two groups at baseline, post-test 1, and post-test 2 (Table 17). The results showed that the mean differences between the two groups at baseline and post-test 1 were not significant (baseline: mean difference = 0.01, $p > 0.05$; post-test 1: mean difference = 0.06, $p > 0.05$), but the difference reached statistical significance at post-test 2 (mean difference = 0.095, $p < 0.05$), indicating that the experimental group showed a more significant improvement after intervention. Effect size analysis further confirmed this trend; the effect size of move smash accuracy was largest at post-test 2 ($d = 1.169$), higher than post-test 1 ($d = 0.532$) and baseline ($d = 0.088$).

Table17 : Between Groups Comparison of Mean Score for Move Smash Accuracy at Three Different Time

Variable	Time	Mean	SE	*p*-	95% CI for	Effect

		difference		value	difference		size (d)
		(EG-CG)			Lower	Upper	
Move smash accuracy	Baseline	0.010	0.035	0.776	-0.059	0.079	0.088
	Posttest1	0.060	0.035	0.084	-0.008	0.128	0.532
	Posttest2	0.095*	0.026	0.000	0.043	0.147	1.169

Note: *, the mean difference is significant at 0.05 level; EG, Experimental Group; CG, Control group; SE, Standard Error.

Figure 5 shows the average scores for move smash accuracy at different time points. Under the core training intervention, the experimental group (EG) had higher average scores than the control group (CG) at all three different time points (baseline, post-test 1, and post-test 2).

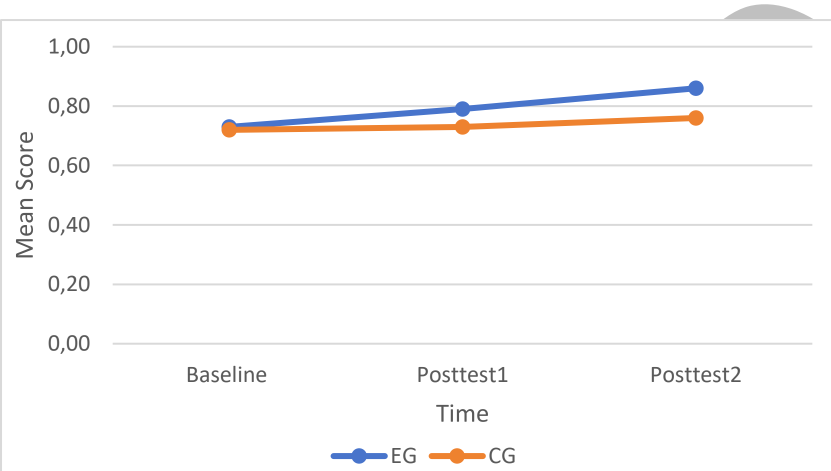

Figure 4 : The Mean Score of Move Smash Accuracy across Time for Both Groups

Discussion

This study provides compelling evidence that an 8-week core training program significantly improves female badminton players' performance in stationary smashes, jump smashes, and moving smashes, highlighting the systemic and contextual benefits of core-focused interventions. This aligns with previous studies emphasizing the crucial role of core stability in power generation and trunk control[3, 14, 25]. The significant improvement in the accuracy of the standing smash indicates that strengthening core strength not only contributes to power output but also improves the coordination and timing between upper limb and trunk rotation[12] . This aligns with biomechanical models that positize the lumbar-pelvic region as the central hub of kinetic chain efficiency, enabling more precise and stable hitting motions.

The improved accuracy of jump smashes further reveals the profound value of core training. A jumping smash requires the rapid integration of lower limb propulsion, trunk rotation, and upper limb striking force. The increased effect size in the experimental group indicates improvements in postural stability, landing control, and energy transfer efficiency[2]. This result supports the view that the core region plays a role in multi-layered sensorimotor control during high-speed movements[2, 26] , the findings of this study expand upon previous research, demonstrating that core strength training not only enhances static stability but also promotes dynamic force regulation during high-speed aerial maneuvers, highlighting the multi-layered sensorimotor function of the core in competitive sports.

The significant improvement in move smashes highlights the "contextual transfer effect" of core training. Compared to in-situ and jumping smashes, move smashes demand a higher level of kinetic chain integrity, requiring stability and control of the hitting motion amidst continuous movement, rapid footwork adjustments[5] , and complex posture changes. The results of this study show that core training not only improves the quality of athletes' shots under static and semi-dynamic conditions but also plays a role in highly dynamic actual match situations, demonstrating the decisive significance of the core area in kinetic chain integration, power transmission path stability, and multi-muscle group coordination[5, 10]. The observed progress indicates that core training enhances intersegmental coordination and the stability of power transfer, providing a physiological basis for better performance in real matches. Interestingly, these results echo recent conceptual frameworks emphasizing "dynamic stability" and "coherent kinetic chains" in badminton, suggesting that core-focused training programs can directly improve specific technical execution[19].

In summary, this study not only confirmed the benefits of core training for women's badminton in various situations, but also emphasizes the systematic contribution of core strength to kinetic chain efficiency, body control strategies, and the precision of movement execution. These results provide empirical support for designing specialized training programs for women's badminton based on the kinetic chain, clearly indicating that systematic core training should be incorporated into routine training programs to improve hitting performance , and it also emphasized that core functions are crucial for optimizing technical execution and athletic efficiency. Importantly, this study reveals that core training can generate consistent advantages across different movement types, which has significant implications for constructing kinetic chain-based training models and provides direction for future exploration of the coupling mechanism between core functions and specific movements[10] .

Limitations

While this study revealed the positive impact of core training on smash accuracy in female badminton players, several limitations remain. First, the sample size was limited to young female athletes in Guangxi (n = 40), potentially affecting the external generalizability and robustness of statistical tests. Second, the intervention period was 8 weeks, insufficient to assess the sustained effects of core training over long-term training cycles and its long-term impact on athletic performance. Furthermore, this study primarily assessed smash accuracy through on-site testing, which, while improving sport specificity, did not incorporate detailed analysis using laboratory instruments (such as high-frequency imaging or biomechanical measurements), potentially limiting a deeper understanding of the movement mechanisms and details of motor control. Finally, this study did not rigorously monitor athletes' psychological state, fatigue levels, or training adherence, factors that could influence training effectiveness and test results.

Future research could consider expanding the sample size, extending the intervention period, and combining laboratory measurements with psychological and cognitive indicators to further explore the mechanisms and long-term benefits of core training on badminton performance.

Conclusion

The results of this study indicate that 8 weeks of core training significantly improved the accuracy of smashes in female badminton players in Guangxi Province, both in in-situ, jumping and moving. The experimental group showed higher time effect sizes in all smash accuracy tests compared to the control group, demonstrating that core training enhances core stability and strength, thereby optimizing body control, improving shot accuracy, and enhancing athletic performance. This suggests that systematically incorporating core training into regular training programs is an effective strategy for improving the technical level and competitive performance of female badminton players.

Acknowledgments

The authors are grateful to all the authors' contribution during the completion of this study.

Authors' contributions

Conceptualization: Shuzhen Ma

Data curation: Shuzhen Ma, Kim Geok Soh

Investigation: Shuzhen Ma

Methodology: Shuzhen Ma

Supervision: Shuzhen Ma, Xinzhi Wang, Jing Li

Writing – original draft: Shuzhen Ma

Writing – review & editing: Shuzhen Ma, Haili Feng, Huajun Hu

Funding

The authors received no specific funding for this work.

Competing interests

The authors declare no conflict of interest.

Availability of data and materials

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Acknowledgments

Thanks to all authors for their contributions to this study.

References

[1]Biao Z, Lu X. Influence of strength training on physical fitness of badminton players.***Revista Brasileira de Medicina do Esporte***. 2023;29:e2023_0062.[1]

[2]Borghuis J, Hof AL, Lemmink KA. The importance of sensory-motor control in providing core stability: implications for measurement and training.***Sports medicine***. 2008;38(11):893-916.[2]

[3]Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain.***Clinical biomechanics***. 1996;11(1):1-15.[3]

[4]Dang NR, Moreau MJ, Hill DL, Mahood JK, Raso J. Intra-observer reproducibility and interobserver reliability of the radiographic parameters in the Spinal Deformity Study Group's AIS Radiographic Measurement Manual.***Spine***. 2005;30(9):1064-9.[4]

[5]De Blaiser C, Roosen P, Willems T, Danneels L, Vanden Bossche L, De Ridder R. Is core stability a risk factor for lower extremity injuries in an athletic population? A systematic review.***Physical therapy in sport.*** 2018;30:48-56.[5]

[6]Ferreira A, Górski M, Gajewski J. Gender differences and relationships between upper extremity muscle strength, lower limb power and shuttle velocity in forehand smash and jump smash in badminton.***Acta of Bioengineering and Biomechanics***. 2020;22(4):41-9.[6]

[7]Ferreira A, Górski M, Gajewski J. Gender differences and relationships between upper extremity muscle strength, lower limb power and shuttle velocity in forehand smash and jump smash in badminton.***Acta of Bioengineering Biomechanics***. 2020;22(4).[7]

[8]Fleiss JL. The measurement of interrater agreement.***Statistical methods for rates and proportions***. 1981:212-36.[8]

[9]Fröhlich M, Felder H, Reuter M. Training effects of plyometric training on jump parameters in D-and D/C-squad badminton players.***Journal of Sports Research***. 2014;1(2):22-33.[9]

[10]Hibbs AE, Thompson KG, French D, Wrigley A, Spears I. Optimizing performance by improving core stability and core strength.***Sports medicine***. 2008;38(12):995-1008.[10]

[11]İlbak İ, Gönültaş B, Stojanovic S, Jorgic B. Investigation of chronotypes of individuals engaging in exercise in terms of certain variables.***Journal of Sports Research and Innovation***. 2024;1(1):48-55.[11]

[12]Ireland ML, Willson JD, Ballantyne BT, Davis IM. Hip strength in females with and without patellofemoral pain.***Journal of orthopaedic & sports physical therapy***. 2003;33(11):671-6.[12]

[13]Karun KM, Deepthy M. Generalized estimating equations in longitudinal studies: A non-parametric alternative for two-way repeated measures mixed ANOVA.***Research Journal of Pharmacy and Technology***. 2023;16(5):2381-4.[13]

[14]Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes.***Medicine & Science in Sports & Exercise***. 2004;36(6):926-34.[14]

[15]Lim A, Lim J, Girard O, Aziz A, Tan F, Ihsan M. Effet du préconditionnement ischémique sur l'endurance spécifique au badminton et les modifications subséquentes de la performance physique.***Science and Sports***. 2023;38(1):102. e1-. e7.[15]

[16]Luo S, Soh KG, Soh KL, Sun H, Nasiruddin NJM, Du C, et al. Effect of core training on skill performance among athletes: A systematic review.***Frontiers in physiology***. 2022;13:915259.[16]

[17]Lynn MR. Determination and quantification of content validity.***Nursing research***. 1986;35(6):382-6.[17]

[18]Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: an international Delphi study.***Quality of life research***. 2010;19(4):539-49.[18]

[19]Phomsoupha M, Laffaye G. The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics.***Sports medicine***. 2015;45(4):473-95.[19]

[20]Polit DF, Beck CT, Owen SV. Is the CVI an acceptable indicator of content validity? Appraisal and recommendations.***Research in nursing & health***. 2007;30(4):459-67.[20]

[21]Puffer S, Torgerson DJ, Watson J. Cluster randomized controlled trials. ***Journal of evaluation in clinical practice***. 2005;11(5):479-83.[21]

[22]Singh J, Raza S, Mohammad A. Physical characteristics and level of performance in badminton: a relationship study. ***Journal of education and practice***. 2011;2(5):6-10.[22]

[23]Solanki HG, Gill MA. The effect of core stability training on dynamic balance and smash stroke performance in badminton players-an evidence based study. ***International Journal of Science and Healthcare Research***. 2021;6(3):93-8.[23]

[24]Thibault RT, Zavalis EA, Malički M, Pedder H. An evaluation of reproducibility and errors in published sample size calculations performed using G* Power.***medRxiv***. 2024:2024.07. 15.24310458.[24]

[25]Tsai Y-J, Chia C-C, Lee P-Y, Lin L-C, Kuo Y-L. Landing kinematics, sports performance, and isokinetic strength in adolescent male volleyball athletes: Influence of core training.***Journal of sport rehabilitation***. 2020;29(1):65-72.[25]

[26]Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: prospective biomechanical-epidemiologic study.***The American journal of sports medicine***. 2007;35(7):1123-30.[26]