



Effects of an 8-week unstable core training on trunk muscle strength and sprint performance among kayakers

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ABSTRACT

Background. Unstable core training (UCT), widely used in various sports to enhance trunk muscle strength and sprint performance, results in significantly greater gains in both outcomes compared to traditional core training (TCT). The study aimed to examine the impact of UCT performed on unstable surfaces (Both Side Up (BOSU) balls, Swiss balls and Wobble boards) *versus* TCT performed on stable surfaces (floor and bench) on trunk muscle strength and sprint performance among flatwater sprint kayakers.

Method. A randomized controlled trial was conducted, recruiting 60 eligible kayakers aged 14–19 years from the Ganzhou training base, China. Participants were randomly assigned to the UTC group and the TCT group. Both groups completed an 8-week core training program consisting of 1-hour sessions, 3 times/week. The difference is that the core training exercises of the UTC group were performed on unstable surfaces, while the TCT group was performed on stable surfaces. Trunk stability strength was assessed using the abdomen, back, and side bridge tests, while trunk dynamic strength was measured using the 1-minute sit-up, 1-minute back extension, and 1-minute trunk rotation tests. Sprint performance was evaluated using the 200 m single flatwater sprint time test. Statistical analyses were conducted *via* Multivariate Analysis of Variance (MANOVA), with the significance level set at $p < 0.05$.

Results. Both the UTC and TCT groups demonstrated significant improvements from pre- to post-intervention across all dependent variables. However, the analysis of between-group effects revealed statistically significant greater improvements in the UTC group compared with the TCT group at post-test. These differences included trunk stability strength in terms of abdomen ($p < 0.001$, $\eta^2 = 0.228$), back ($p < 0.001$, $\eta^2 = 0.285$), left side ($p < 0.001$, $\eta^2 = 0.280$), and right side ($p < 0.001$, $\eta^2 = 0.291$); trunk dynamic strength in terms of flexion ($p < 0.001$, $\eta^2 = 0.243$), extension ($p < 0.001$, $\eta^2 = 0.212$), left rotation ($p < 0.001$, $\eta^2 = 0.182$), and right rotation ($p < 0.001$, $\eta^2 = 0.303$); as well as sprint performance in terms of 200m single flatwater sprint time ($p < 0.001$, $\eta^2 = 0.739$).

Conclusion. The findings suggest that UTC may lead to greater improvements in trunk muscle strength and sprint performance compared with TCT over an 8-week intervention among young male Chinese kayakers. However, given methodological limitations (field-based strength tests and manual timing), results should be interpreted cautiously and require confirmation with more precise measurement methods in future research.

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INTRODUCTION

Kayaking is a highly competitive, speed-based water sports event, and the goal is for competitors to cross the finish line in the shortest time possible in a race, as kayakers must propel their kayaks across the water with high-intensity periodic paddling over the distances ([Harrison, Cleary & Cohen, 2019](#)). The sprint performance in kayaking is a comprehensive reflection of an athlete's physical fitness, paddling technique, tactics, and psychological ability, and it holds significant value for both training and competition ([Lum, Barbosa & Balasekaran, 2021](#); [Edriss et al., 2024](#)). Due to the lack of stable support for land, all paddling techniques for kayakers are performed in a sitting position in an unstable water environment, which requires kayakers to have strong trunk strength. Specifically, good trunk stability strength is essential for stabilizing posture, maintaining balance, and transferring momentum from the lower limbs to the upper limbs, while strong trunk dynamic strength is crucial for actively exerting force, coordinating trunk movements, and driving the upper limbs to paddle effectively ([Brown, Lauder & Dyson, 2010](#); [Bjerkefors et al., 2018](#); [Brown, Peters & Lauder, 2023](#)). Therefore, focusing on trunk muscle strength is crucial for the athletic performance development of kayakers.

Chinese kayakers have yet to win a gold medal in flatwater sprint kayaking, including at the 2024 Paris Olympics. Compared with China's dominance in sports such as diving, weightlifting, and table tennis, sprint kayaking remains a non-advantageous event. Competition analyses have identified a notable gap between young male Chinese kayakers and international elite athletes, particularly in core strength and sprint performance ([Ding & Pan, 2011](#); [Wu, Liu & Fang, 2013](#); [Li, 2022](#); [He, Yu & Ni, 2018](#)). For example, [Ding & Pan \(2011\)](#) and [Wu, Liu & Fang \(2013\)](#) reported significantly lower mean sprint speeds ($p < 0.01$) in Chinese young male kayakers compared with top-ranked international athletes. In addition, [Li \(2022\)](#) found significant deficits in trunk flexion and extension strength ($p < 0.05$) relative to established performance standards, and [He, Yu & Ni \(2018\)](#) reported lower trunk stability strength compared with Russian and English athletes ($p < 0.05$). Collectively, these findings highlight persistent deficiencies in trunk strength and sprint performance among young male Chinese kayakers, underscoring the need for targeted training strategies ([Ying, 2013](#)).

Core training refers to a targeted exercise regimen designed to strengthen the muscles of the trunk, including the abdominals, lower back, pelvis, and hips. These exercises aim to enhance the stability, strength, power, and strength of the trunk region, which serves as the foundation for efficient movement, balance, and overall physical performance ([Luo et al., 2022](#); [Dong, Yu & Chun, 2023](#)). Based on the different support surfaces and external environments, studies classified core strength training methods into traditional core training (TCT) and Unstable core training (UCT). TCT is typically performed on stable surfaces (such as a floor or a bench) ([Hsu et al., 2018](#); [Oliva-Lozano & Muyor, 2020](#); [Lee, Kim & Lee, 2016](#)), while UTC is performed by using various unstable conditions, surfaces,

and platforms (such as water, sand, gravel, Swiss ball, BOSU ball, foam shaft, balance board) or special unstable training equipment (such as elastic belt, suspension chain, rope) (Xu et al., 2020; Giancesotti et al., 2018). TCT is typically performed on stable surfaces and increases trunk muscle strength and neuromuscular coordination by relying on a constant resistance load with stable support or on stable surfaces. For an extended period, TCT has been the primary method used to enhance trunk strength for sprint performance among young male Chinese kayakers (Yin, Xu & Lv, 2023). However, for young male Chinese kayakers, there has been a lack of innovative training methods specifically designed to address the unique demands of kayaking, particularly in adapting to the unstable and dynamic conditions of the water environment. Instead, the high intensity, volume, repetitive, monotonous, and tedious nature of TCT has remained the predominant approach, leading to decreased motivation and increased fatigue and risk of sports injuries, which may ultimately shorten an athlete's career. More importantly, research has pointed out that core strength gained through TCT on stable surfaces is difficult to transfer to or adapt and play in unstable water competition environments, further hindering improvements in paddling technique and sprint performance for kayakers (Gao et al., 2025a). Additionally, many scholars believe and argue that the lack of innovation in core training methods may be a key factor preventing athletes from comprehensively improving their core strength and sprint performance (Behm et al., 2010; Zemková, 2018).

A new approach to core training that has recently gained more attention in the development of trunk muscle strength and athletic performance for athletes and the general population is UTC (Cuğ et al., 2012; Granacher et al., 2013). Based on the above literature definitions, UTC is a method of trunk strength training performed in an unstable environment created by specialized equipment or conditions. This approach leverages tools such as suspension devices, vibration devices, Swiss balls, Wobble boards, BOSU balls, and balance pads to challenge the body's stability, requiring enhanced activation of deep trunk muscles (Xu et al., 2020). UTC improves trunk strength, balance, body control, proprioception, and joint stability, offering unique advantages over stable core training by increasing training difficulty and intensity, thereby improving overall exercise performance (Behm et al., 2005). Previous studies have suggested that it is well documented that even though the UTC and TCT interventions performed similar core training exercises, they lead to different neuromuscular adaptations in physiological mechanisms of effective activation, recruiting, and coordination of trunk muscles for improving trunk strength (Gao et al., 2025b; Sanghvi, Dabholkar & Yardi, 2014; Prieske et al., 2016). In addition, studies have demonstrated that UTC can significantly improve physical fitness across a variety of sports. For instance, compared to TCT methods, UTC has been shown to enhance trunk strength in collegiate athletes (Parkhouse & Ball, 2011; Nuhmani, 2021), basketball players (Fisek & Agopyan, 2021), elite golfers (García Sillero et al., 2022), Tae Kwon Do athletes (Guo, 2023), Judo athletes (Norambuena et al., 2021), and football player (Richardson et al., 2025).

Although UTC has been shown to improve trunk muscle strength and sprint performance in various athletes compared to TCT, its effects in young male Chinese kayakers remain unclear. Given the importance of trunk strength and sprint performance for kayaking, it is essential to determine whether an 8-week UTC or TCT program is

more effective. Since performance in sports like flatwater sprint kayaking occurs on unstable water surfaces, training should mimic these sport-specific demands ([Behm et al., 2010](#)). Integrating unstable elements in trunk training may provide additional stimulus, potentially resulting in greater improvements in core strength and sprint performance compared with stable-surface training. This study therefore aims to address this research gap, hypothesizing that UTC will lead to significantly greater enhancements in both trunk strength and sprint performance in young male Chinese kayakers.

METHODS

Participants

Sample size calculation: this study followed the CONSORT statement and adopted a randomized controlled trial (RCT) design ([Moher et al., 2012](#)) and used G*Power 3.1 software to compute sample size. Before confirming the sample size, the effect size was calculated based on UTC *versus* TCT intervention articles carried out in a systematic literature review in previous studies ([Gao et al., 2023](#)). *A priori* power analysis was performed using G*Power. Based on previous exercise intervention studies, a small-to-medium expected effect size was set at $f = 0.20$ (Cohen's f), which is commonly adopted in experimental research to ensure adequate statistical power ([Faul et al., 2009](#)). **Input parameters:** $\alpha = 0.05$ (two-tailed), power $(1 - \beta) = 0.80$, number of groups = 2, number of measurements = 4. The resulting minimum sample size was 36 (18 per group). Allowing for an expected dropout of 20% ([Cramer et al., 2016](#)), the target total sample size was set at 46 (23 per group).

The inclusion criteria: (1) Young male kayakers for 200m special (aged 14–19 years old); (2) A minimum of 1 years of kayak-specific training; (3) No history and recent surgery, health issues, injuries, and (4) Not systematically trained in instability core training. **The exclusion criteria:** (1) Young male kayaker with recent sports injury and health issues; (2) Presently involved in unstable core training program. Participant baseline data collected included age, height, body mass, years of kayaking experience, and prior exposure to instability and traditional core training group.

In this study, 127 young male kayakers were assessed for eligibility from the Ganzhou training base were screened. Among them, 47 did not meet the inclusion criteria. Of these, 14 declined participations due to academic examinations, while six were excluded because of parental objection. Ultimately, 60 kayakers voluntarily participated and were randomly assigned to the UTC group ($n = 30$, age: 17.23 ± 1.19) and the TCT group ($n = 30$, age: 17.60 ± 1.03), with written informed consent obtained from both the athletes and their guardians. During follow-up, no participants from the UTC or TCT group withdrew, resulting in dropout rates of 0%, respectively. Thus, 30 participants in each group completed the training protocol, and their data were included in the final per-protocol statistical analysis. Therefore, the final sample analyzed was $N = 60$ (UTC $n = 30$; TCT $n = 30$), which exceeded the target sample size estimated by G*Power and anticipated 20% dropout rate taken into account.

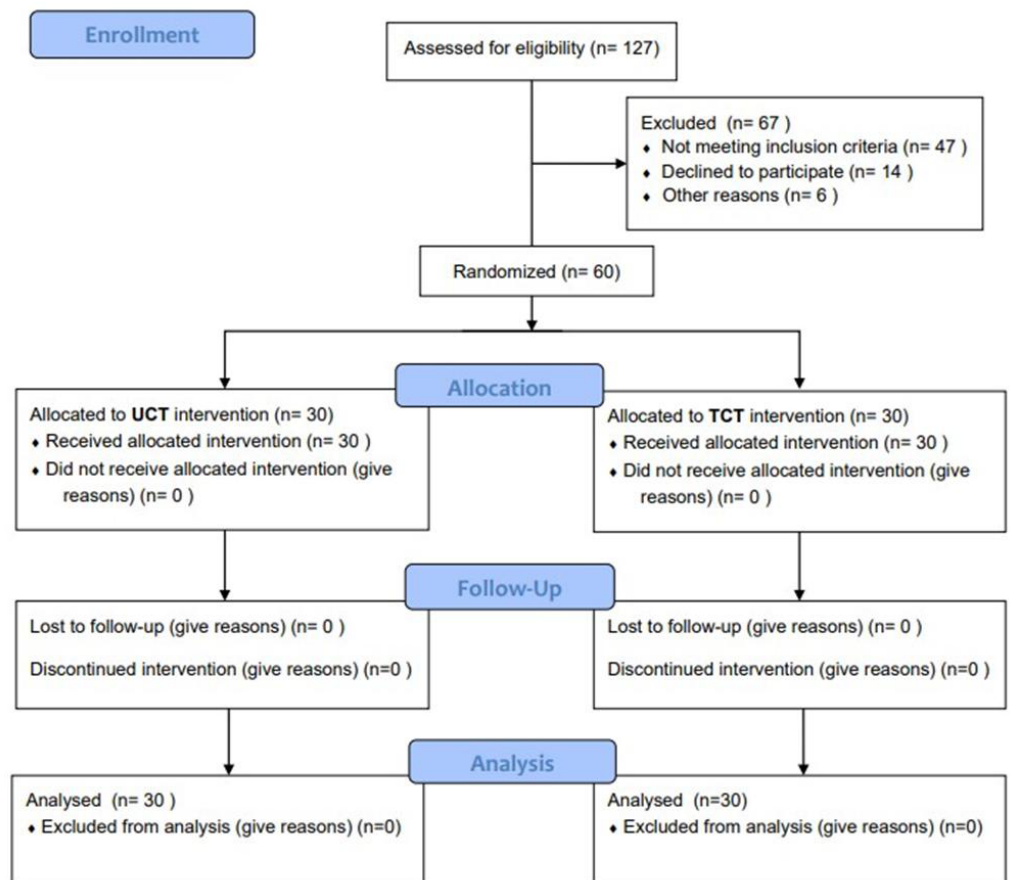


Figure 1 CONSORT flow diagram.

[Full-size](#) [DOI: 10.7717/peerj.21091/fig-1](https://doi.org/10.7717/peerj.21091/fig-1)

Figure 1 shows the CONSORT flow diagram. Randomization and allocation concealment: A computer-generated simple random sequence was created. After eligibility and baseline assessment, participant IDs were placed in sequentially numbered, sealed, opaque envelopes prepared by the independent researcher. Envelopes were opened only after participant enrollment and baseline data collection. The person who enrolled participants was blind to the sequence before opening the envelope. All assessments were conducted by evaluators who were blinded to participants' group assignments to reduce measurement bias.

All the young male kayakers voluntarily participated in the study and provided informed consent, and the study was approved by the Ethics Committee of Universiti Putra Malaysia (Approval No. JKEUPM 2023-256). This ethical approval was obtained because the present study forms part of the first author's doctoral dissertation at Universiti Putra Malaysia and is simultaneously a component of a collaborative research project with supervisors at Universiti Putra Malaysia. Our study was a prospective study, in which we actively recruited participants and collected new data.

Intervention

In this study, the core training protocol included UTC in the experimental group and TCT in the control group. In each week, the core training exercises in the UTC and TCT groups are the same, which included a total of six core training exercises, three static core training exercises (Plank, Shoulder Bridge, and Lateral Bridge), and three dynamic core training exercises (Crunch, Superman, and Russia Twist). However, the difference is that the core training exercises of the UTC group were performed on unstable surfaces (*i.e.*, BOSU ball, Swiss ball, and Wobble boards), while the traditional core training exercises of the TCT group were performed on stable conditions (*i.e.*, floor, bench). All training phases and core training exercises were followed and developed using the protocol of Modern Physical Training of Core Training Methods ([Sun, 2010](#)) and American National Strength and Conditioning Association: Core Training Guide ([Jeffrey, 2019](#)).

[Table 1](#) shows training load equivalence: Both UTC and TCT groups performed identical exercise selection, progression (weeks 1–8), session duration (60 min), frequency (3 sessions/week), number of sets and rest intervals (3–6 sets, 60–90 s). The only systematic difference between groups was the support surface (unstable *vs* stable). This study selected 60 min per session, 3 times/week, and 8 weeks as time and frequency of intervention, and the types are UTC and TCT for the improvement of Chinese young male kayakers' core muscle strength and sprint performance. In addition, during the 8-week training period, training intensity was moderate to high intensity. Moreover, the progression of the intensity of each static or dynamic core training exercise in UTC and TCT groups was provided in the form of increasing the duration (static core exercises) and repetitions (dynamic core exercises). For example, the duration of the three static core exercises of Plank, Shoulder Bridge, and Lateral Bridge was 40–60 s in the 8 weeks; the repetitions of the three dynamic core exercises of Crunch, Superman and Russia Twist were 40–60 reps in the 8 weeks. All the core training time, frequency, intensity, and load were followed and developed using the protocol of Modern Physical Training of Core Training Methods ([Sun, 2010](#)), American National Strength and Conditioning Association: Core Training Guide and standardizing the quantification of external load across different training modalities ([Jeffrey, 2019](#)).

Evaluation

All trunk muscle strength tests were administered by two trained assessors who underwent standardized training sessions to ensure consistent administration and scoring procedures. The trunk strength testing assessment included trunk stability and dynamic strength. This study measured the trunk stability strength of the trunk in terms of four parts (abdomen, back, left side, and right side) and the trunk dynamic strength of the trunk in terms of four range-of-motion (flexion, extension, left rotation, and right rotation). The abdomen bridge test (ABT), back bridge test (BBT), and left and right side bridge test (LSBT/RSBT) are standard measurements of trunk stability strength in sports, where Maximum Duration (MD) for the bridge tests was employed for the estimation of the trunk stability strength of athletes ([Parkhouse & Ball, 2011](#); [Nuhmani, 2021](#)). These bridge tests are widely used to evaluate the core stability strength of athletes across various sports disciplines, providing

Table 1 Training routine for the UTC vs TCT groups (week 1–8).

Week	Time	Core training exercises		Duration & Repetitions	Set (s)	Rest (s)	Intensity
		EG/UTC	CG/TCT				
Week 1–8	1 Time	Warm-up	Warm-up	10–20 min			
	3 Times/ Week 1 Hour	Plank on BOSU ball	Plank on the floor	40–60 s	3–6	60–90 s	Moderate-High intensity
		Shoulder Bridge on Swiss ball	Shoulder Bridge on a bench	40–60 s	3–6	60–90 s	
		Lateral Bridge on Wobble boards	Lateral Bridge on the floor	40–60 s	3–6	60–90 s	
		Crunch on a Swiss ball	Crunch on the floor	40–60 reps	3–6	60–90 s	
		Superman on Swiss ball	Superman on the floor	40–60 reps	3–6	60–90 s	
		Russian Twist on the BOSU ball	Russian Twist on the floor	40–60 reps	3–6	60–90 s	
	1 Time	Relax	Relax	10–20 min			

Notes.

This exercise sequence was conducted by the instability core training, UTC group on unstable surfaces (*i.e.*, BOSU ball, Swiss ball, and Wobble boards) and traditional core training, TCT group on stable surfaces (*i.e.*, floor, bench), whereas participants two training groups performed the same core training exercise, s=second, reps=repetitions.

reliable indicators of their strength and muscular control ([Han & Wang, 2014](#); [Zemková, 2018](#)). Therefore, in this study, the bridge test protocol of core stability strength included the abdomen bridge test (ABT), back bridge test (BBT), and left and right side bridge test (LSBT/ RSBT) for Chinese young male kayakers. In addition, the 1-min sit-up test (1-min SUT), 1-min back extension test (1-min BET), and 1-min trunk left and right rotation test (1-min TLRT/1-min TRRT) are standard measurements of core dynamic strength in sports, where these tests assess performance based on the Maximum Repetitions (RM) completed within one minute, serving as reliable indicators of core dynamic strength in athletes ([Oliver & Brezzo, 2009](#); [Parkhouse & Ball, 2011](#); [Brotons-Gil et al., 2013](#)). These 1-min repetition format tests are widely used to evaluate the core dynamic strength of athletes across various sports disciplines, providing reliable indicators of their strength and muscular control ([Parkhouse & Ball, 2011](#); [I-Shaikh et al., 2019](#)). Therefore, in this study, the 1-min repetitions format test protocol of core dynamic strength included the 1-min sit-up test (1-min SUT), 1-min back extension test (1-min BET), and 1-min trunk left and right rotation test (1-min TLRT/1-min TRRT) for Chinese young male kayakers. [Tables 2 and 3](#) show six experts familiar with sports science and exercise training evaluated the core static and dynamic strength tests, and the results showed excellent content validity ($I-CVI = 0.833–1.000$, $Kappa = 0.816–1.000$). Prior to the formal core static and dynamic strength testing, inter-rater reliability was assessed in a pilot trial with 10 participants, and high agreement was observed (intraclass correlation coefficient, $ICC = 0.881–0.987$).

The sprint performance testing assessment only included flatwater sprint performance of kayaking. This study measured the sprint time. The 200 m single flatwater sprint time test (200 m SFSTT) is a standard measurement of sprint performance in flatwater sprint kayaking, where kayakers are timed as they paddle a 200 m distance on flatwater as quickly as possible ([Someren & Palmer, 2003](#)). In research, 200 m SFSTT can be an indicator of performance outcomes related to variables like core strength training interventions for muscle activation patterns for kayakers ([Garnier et al., 2023](#)). 200 m sprint times were measured using handheld digital stopwatches, with two trained timing assistants positioned

Table 2 Relevancy and clarity agreement of the instruments items.

Dependent variables			Measuring method	Number agreement	Relevance		Number agreement	Clarity	
					I-CVI	KAPPA		I-CVI	KAPPA
Trunk Muscle Strength	Trunk Stability Strength	Abdomen	ABT	6	1.000	1.000	6	1.000	1.000
		Back	BBT	6	1.000	1.000	6	1.000	1.000
		Left side	LSBT	6	1.000	1.000	6	1.000	1.000
		Right side	RSBT	6	1.000	1.000	6	1.000	1.000
	Trunk Dynamic Strength	Flexion	1-min SUT	6	1.000	1.000	6	1.000	1.000
		Extension	1-min BET	6	1.000	1.000	6	1.000	1.000
		Left rotation	1-min TLRT	5	0.833	0.816	5	0.833	0.816
		Right rotation	1-min TRRT	5	0.833	0.816	5	0.833	0.816
Sprint Performance	200 m Single Flatwater Sprint Time	200 m SFSTT	6	1.000	1.000	6	1.000	1.000	

Notes.
 ABT, Abdomen bridge test; BBT, Back bridge test; LSBT, Left side bridge test; RSBT, Right side bridge test; 1-min SUT, 1-min sit-up test; 1-min BET, 1-min back extension test; 1-min TLRT, 1-min trunk left rotation test; 1-min TRRT, 1-min trunk right rotation test; 200 m SFSTT, 200 m single flatwater sprint time test.

Table 3 Test-retest reliability of instruments ($N = 10$).

Dependent Variables			Measuring Method	(ICC)	95% Confidence Interval	
					Lower bound	Upper bound
Trunk Muscle Strength	Trunk Stability Strength	Abdomen	ABT	0.987	0.947	0.997
		Back	BBT	0.976	0.904	0.994
		Left side	LSBT	0.906	0.622	0.977
		Right side	RSBT	0.839	0.352	0.960
	Trunk Dynamic Strength	Flexion	1-min SUT	0.886	0.541	0.972
		Extension	1-min BET	0.887	0.546	0.972
		Left rotation	1-min TLRT	0.881	0.523	0.971
		Right rotation	1-min TRRT	0.912	0.644	0.978
Sprint performance	200 m Single Flatwater Sprint Time	200 m SFSTT	0.974	0.896	0.994	

Notes.
 ABT, Abdomen bridge test; BBT, Back bridge test; LSBT, Left side bridge test; RSBT, Right side bridge test; 1-min SUT, 1-min sit-up test; 1-min BET, 1-min back extension test; 1-min TLRT, 1-min trunk left rotation test; 1-min TRRT, 1-min trunk right rotation test; 200 m SFSTT, 200 m single flatwater sprint time test.
 ICC values calculated using two-way mixed-effects model for absolute agreement (Multiple measures). 95% confidence intervals are shown.

at the finish line. A visual cue was used as the start signal, and the final sprint time was calculated as the mean of the two independent timers. Because electronic timing was not available at the testing site, we acknowledge as a limitation that manual timing may have introduced human reaction time bias. Therefore, in this study, the sprint performance test protocol of flatwater sprint kayaking included a 200 m single flatwater sprint time test (200 m SFSTT) for Chinese young male kayakers. Tables 2 and 3 show six experts familiar with sports science and exercise training evaluated the 200 m SFSTT test, and the results showed excellent content validity ($I-CVI = 1.000$, $Kappa = 1.000$). Prior to the formal sprint

performance testing, inter-rater reliability was assessed in a pilot trial with 10 participants, and high agreement was observed (intraclass correlation coefficient, $ICC = 0.974$).

Reliability analysis: Inter-rater and test–retest reliability was assessed using Intraclass Correlation Coefficients (ICC). We computed ICC using a two-way mixed-effects model for absolute agreement, and report the point estimate with 95% confidence intervals (CI). ICC interpretation: <0.5 poor, $0.5–0.75$ moderate, $0.75–0.9$ good, >0.9 excellent. Multiple trials were performed; scores were averaged before reliability analysis.

Blinding and performance bias: Due to the visible nature of the interventions, participant blinding was not feasible. Assessors conducting the core and sprint tests were blinded to group allocation. However, as participants were aware of their group, this may have influenced self-paced effort (*e.g.*, motivation, pacing, perceived exertion) during performance tests. To minimize this potential bias, we implemented several procedures: (1) outcome assessors remained blinded to group allocation throughout the testing process, (2) all participants received standardized instructions and verbal encouragement during performance assessments, and (3) the testing order was randomized to reduce systematic effects related to fatigue or expectation. Despite these precautions, we acknowledge that lack of participant blinding remains a source of potential performance bias.

Statistics

In this study, data were recorded using the Statistical Package for Social Sciences software (SPSS) version 28.0 (IBM Corp., Armonk, NY, USA). The assumptions of normality and homogeneity of variances were met, as indicated by acceptable skewness and kurtosis values and non-significant results from Levene’s test. To determine the effects of the UTC and TCT intervention on core strength and sprint performance, multivariate analysis of variance (MANOVA) was used for data analysis. This study used partial eta squared (partial η^2) and interpreted the results according to [Cohen \(1988\)](#) guidelines: small effect <0.01 , medium effect <0.06 , and large effect >0.14 which represents a large effect, suggesting potentially meaningful clinical/training implications. However, its practical applicability should still be judged in conjunction with the absolute change values and sport-specific performance thresholds ([Debusho et al., 2025](#)). Finally, the data were statistically processed with differences considered statistically significant at $p < 0.05$. Moreover, for participant flow, a total of 127 athletes were screened; 60 assessed for eligibility; 60 consented and were randomized (UTC $n = 30$; TCT $n = 30$). During the intervention, no participants in the UTC group and TCT group withdrew due to competition commitments, leaving 30 participants in each group for final per-protocol analysis.

RESULTS

[Tables 4](#) and [5](#) summarizes the comparative results of core strength and sprint performance between unstable core training (UTC) and traditional core training (TCT). While both UTC and TCT methods led to improvements, UTC is more effective than TCT over an 8-week intervention among young male Chinese kayakers.

Table 4 Pre- and post-intervention means ($M \pm SD$), within-group changes, and between-group (Group $\times$ Time) interaction statistics for trunk strength and 200 m sprint time (UTC vs TCT).

Variables	Test time	Baseline		Between-group comparison		Within-group comparison	
		UTC ($M \pm SD$)	TCT ($M \pm SD$)	UTC vs TCT $p(\eta^2)$	UTC vs TCT Multivariate Wilks' Lambda	UTC (T0 vs T8) $p(\eta^2)$	TCT (T0 vs T8) $p(\eta^2)$
Trunk Stability Strength	Abdomen	T0	162.57 $\pm$ 67.02 s	164.93 $\pm$ 57.18 s	.884 (0.000)		
		T8	275.93 $\pm$ 71.35 s	207.40 $\pm$ 56.11 s	<.001** (0.228)	<.001** (0.410)	= 0.005** (0.127)
	Back	T0	281.03 $\pm$ 129.14 s	291.17 $\pm$ 97.44 s	.733 (0.002)		
		T8	490.50 $\pm$ 117.73 s	354.60 $\pm$ 100.55 s	<.001** (0.285)	<.001** (0.462)	= 0.016* (0.096)
	Left side	T0	72.97 $\pm$ 23.01 s	70.77 $\pm$ 29.13 s	.747 (0.002)	$F = 34.110$ $p < 0.001$ ** $\eta^2 = 0.370$	
		T8	141.73 $\pm$ 26.31 s	105.03 $\pm$ 33.14 s	<.001** (0.280)	<.001** (0.667)	<.001** (0.238)
	Right side	T0	80.17 $\pm$ 25.38 s	77.60 $\pm$ 26.49 s	.703 (0.003)		
		T8	141.73 $\pm$ 26.30 s	110.03 $\pm$ 24.02 s	<.001** (0.291)	<.001** (0.595)	<.001** (0.298)
Trunk Dynamic Strength	Flexion	T0	40.63 $\pm$ 6.83 reps	39.56 $\pm$ 4.85 reps	.448 (0.008)		
		T8	57.13 $\pm$ 6.60 reps	49.83 $\pm$ 6.51 reps	<.001** (0.243)	<.001** (0.609)	<.001** (0.453)
	Extension	T0	37.30 $\pm$ 6.23 reps	35.37 $\pm$ 5.85 reps	.220 (0.026)		
		T8	52.07 $\pm$ 5.81 reps	45.70 $\pm$ 6.64 reps	<.001** (0.212)	<.001** (0.516)	<.001** (0.414)
	Left rotation	T0	34.67 $\pm$ 7.82 reps	32.63 $\pm$ 6.73 reps	.285 (0.020)	$F = 31.143$ $p < 0.001$ ** $\eta^2 = 0.349$	
		T8	51.03 $\pm$ 8.29 reps	42.53 $\pm$ 9.95 reps	<.001** (0.182)	<.001** (0.667)	<.001** (0.260)
	Right rotation	T0	35.90 $\pm$ 6.70 reps	34.27 $\pm$ 8.06 reps	.397 (0.012)		
		T8	54.03 $\pm$ 8.14 reps	43.23 $\pm$ 8.50 reps	<.001** (0.303)	<.001** (0.605)	<.001** (0.233)
Sprint Performance	200 m Single Flatwater Sprint Time	T0	110.20 $\pm$ 6.03 reps	108.25 $\pm$ 5.79 reps	.208 (0.270)	$F = 163.988$ $p < 0.001$ ** $\eta^2 = 0.739$	
		T8	66.43 $\pm$ 6.78 reps	89.46 $\pm$ 7.14 reps	<.001** (0.739)	<.001** (0.923)	<.001** (0.683)

Notes.
 UTC, instability core training; TCT, traditional core training; T0, preintervention test; T8, 8-week postintervention test; M, mean; SD, standard deviation; p , p value; d , effect size; s, second; reps, repetitions.
 *The mean difference is significant at the 0.05 level.
 **The mean difference is significant at the 0.01 level.

In Table 4, regarding the variables of core stability and dynamic strength, both groups showed significant time effects from the pretest (T0) to the posttest (T8) for within-group comparison. However, the improvements in the UTC group were notably greater than those in the TCT group. Specifically, for between-group comparison, the UTC group demonstrated significantly greater effect sizes of the trunk stability strength in terms of the abdomen ($p < 0.001$, $\eta^2 = 0.228$), back ($p < 0.001$, $\eta^2 = 0.285$), left side ($p < 0.001$, $\eta^2 = 0.280$), right side ($p < 0.001$, $\eta^2 = 0.291$), the trunk dynamic strength in terms of the flexion ($p < 0.001$, $\eta^2 = 0.243$), extension ($p < 0.001$, $\eta^2 = 0.212$), left rotation ($p < 0.001$, $\eta^2 = 0.182$), right rotation ($p < 0.001$, $\eta^2 = 0.303$), indicating that the unstable core training (UTC) was more effective in enhancing of trunk stability and dynamic strength among young male Chinese kayakers. Moreover, the multivariate analysis (Wilks' Lambda) revealed significant overall between-group differences for both trunk stability strength ($F = 34.110$, $p < 0.001$, $\eta^2 = 0.370$) and trunk dynamic strength ($F = 21.040$, $p < 0.001$, $\eta^2 = 0.349$), confirming that UTC induced a more comprehensive improvement across multiple dimensions of trunk function compared with TCT.

Table 5 Pairwise comparisons of MANOVA for dependent variables among post-test between UTC and TCT groups.

Variables		(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% CI for difference	
							Lower	Upper
Trunk Stability Strength	Abdomen	UTC	TCT	68.533*	16.572	<.001**	35.361	101.706
		TCT	UTC	-68.533*	16.572	<.001**	-101.706	-35.361
	Back	UTC	TCT	135.900*	28.267	<.001**	79.318	192.482
		TCT	UTC	-135.900*	28.267	<.001**	-192.482	-79.318
	Left side	UTC	TCT	36.700*	7.725	<.001**	21.236	52.164
		TCT	UTC	-36.700*	7.725	<.001**	-52.164	-21.236
	Right side	UTC	TCT	31.700*	6.504	<.001**	18.682	44.718
		TCT	UTC	-31.700*	6.504	<.001**	-44.718	-18.682
Trunk Dynamic Strength	Flexion	UTC	TCT	7.300*	1.693	<.001**	3.911	10.689
		TCT	UTC	-7.300*	1.693	<.001**	-10.689	-3.911
	Extension	UTC	TCT	6.367*	1.61	<.001**	3.143	9.59
		TCT	UTC	-6.367*	1.61	<.001**	-9.59	-3.143
	Left rotation	UTC	TCT	8.500*	2.365	<.001**	3.766	13.234
		TCT	UTC	-8.500*	2.365	<.001**	-13.234	-3.766
	Right rotation	UTC	TCT	10.800*	2.149	<.001**	6.498	15.102
		TCT	UTC	-10.800*	2.149	<.001**	-15.102	-6.498
Sprint Performance	200 m Single Flatwater Sprint Time	UTC	TCT	-23.034*	1.799	<.001**	-26.635	-19.433
		TCT	UTC	23.034*	1.799	<.001**	19.433	26.635

Notes.
 UTC, instability core training; TCT, traditional core training; T0, preintervention test; T8, 8-week postintervention test; M, mean; SD, standard deviation; *p*, *p* value; *d*, effect size.
 *The mean difference is significant at the 0.05 level.
 **The mean difference is significant at the 0.01 level.

With respect to sprint performance, for within-group comparison, both UTC and TCT groups showed significant improvements in the 200 m single flatwater sprint time from the pretest (T0) to the posttest (T8). However, for between-group comparison, the improvements were more pronounced in the UTC group. Compared with the TCT group, the UTC group presented greater effect sizes in the 200 m single flatwater sprint time ($F = 163.988, p < 0.001, \eta^2 = 0.739$), indicating that the UTC method was more effective in enhancing of sprint performance among young male Chinese kayakers.

In Table 5, in addition, we applied the Bonferroni correction in the *post hoc* analyses, the *post hoc* pairwise comparisons further demonstrated that the UTC group significantly outperformed the TCT group across nearly all measured variables. For example, UTC participants showed larger mean differences in abdominal strength ($p < 0.001$), back strength ($p < 0.001$), left side strength ($p < 0.001$), right side strength ($p < 0.001$), as well as core dynamic strength in flexion ($p < 0.001$), extension ($p < 0.001$), left rotation ($p < 0.001$), and right rotation ($p < 0.001$). Similarly, sprint performance showed a significant advantage for the UTC group, with a mean sprint time improvement compared to TCT ($p < 0.001$). These *post hoc* results reinforce that UTC training provided superior benefits across both trunk muscle strength and sprint performance measures.

DISCUSSION

Effect of UTC vs TCT on trunk stability strength

The observed improvement in trunk stability strength across all tested areas (abdomen, back, left, and right side) highlights the effectiveness of UTC in recruiting deep trunk muscles and enhancing coordination among trunk muscle groups. Such improvements are particularly relevant in kayaking, where maintaining balance in the athlete-paddle-boat system, ensuring an erect posture, and facilitating effective force transfer from lower to upper limbs are critical for performance. These gains support safer and more efficient paddling across all race phases (preparation/start, acceleration, midcourse, and final sprint) (Bjerkefors et al., 2018). The findings are consistent with previous research demonstrating that unstable surface training enhances neuromuscular activation and stabilization mechanisms (Behm et al., 2010; Agrebi et al., 2024), particularly through improved coordination of agonist and antagonist trunk muscles and activation of deep stabilizers such as the transverse abdominis and multifidus (Brown, Peters & Lauder, 2023).

The results of this 8-week UTC program, incorporating unstable surface exercises on BOSU balls, Swiss balls, and Wobble boards, support previous studies showing that UTC promotes adaptive responses enhancing trunk stability strength across a variety of sports (Parkhouse & Ball, 2011; Nuhmani, 2021; Fisek & Agopyan, 2021; García Sillero et al., 2022; Guo, 2023; Norambuena et al., 2021; Richardson et al., 2025). The experimental group demonstrated superior core stability strength gains compared to the control group, reinforcing evidence that UTC is more effective than TCT in improving trunk strength. This is because UTC, utilizing unstable surfaces such as Swiss balls, BOSU balls, stability trainers, balance discs, and Wobble boards, activates a greater number of stabilizing core muscles by engaging both global and local core muscle systems, thereby enhancing neural control, deep muscle activation, and motor coordination. In kayaking, UTC-induced neuromuscular adaptations improve trunk control and muscular strength, which are essential for maintaining balance, optimizing force transfer, and preventing capsizing, ultimately boosting competitive performance in flatwater sprint kayaking (Gomes et al., 2022; Goreham, 2023). In contrast, TCT primarily targets larger trunk muscle groups on stable surfaces, with less emphasis on proprioception and stabilization, potentially limiting its effectiveness in improving core stability strength under dynamic, sport-specific conditions (Dong, Yu & Chun, 2023).

Effect of UTC vs TCT on trunk dynamic strength

Significant improvements in core dynamic strength were observed in trunk flexion, extension, and left and right rotation, which are directly relevant to kayaking performance. Paddling power (stroke force) generation and transfer during the catch, drive/power, and exit phases, as well as minimizing air time and maintaining stroke rate during the recovery phase, rely heavily on these trunk movements (Abellán-Aynés et al., 2022). The UTC program, utilizing unstable surfaces such as BOSU balls, Swiss balls, and Wobble boards, likely enhanced activation of both global and local core muscles, including the rectus abdominis, erector spinae, external obliques, and internal obliques, thereby improving dynamic strength and intermuscular coordination in young Chinese male kayakers. These

findings align with previous studies showing that instability core training enhances core dynamic strength and functional performance in sport-specific tasks for collegiate athletes (*Parkhouse & Ball, 2011; Nuhmani, 2021*), basketball (*Fisek & Agopyan, 2021*), and football players (*Richardson et al., 2025*).

The experimental group exhibited superior improvements in core dynamic strength (flexion, extension, and rotation) compared to the control group, further supporting the effectiveness of UTC. Research indicates that exercises performed on unstable surfaces promote greater activation of superficial large core muscles involved in dynamic trunk movements, enhancing proprioceptive feedback and muscular coordination, both essential for sports requiring rapid and forceful trunk actions (*Fuentes-García, Malchrowicz-Mosko & Castañeda Babarro, 2024*). Enhanced core dynamic strength enables athletes to execute trunk movements with greater power and efficiency, as observed in various sports disciplines such as basketball (*Fisek & Agopyan, 2021*), Tae Kwon Do (*Guo, 2023*), and Judo (*Norambuena et al., 2021*). Unlike TCT, which primarily focuses on isotonic core exercises with constant resistance loads that may not simulate the dynamic conditions of sports, UTC prepares athletes for the unpredictable ability of competition by increasing training difficulty, engaging core muscles dynamically, and improving adaptability to varying resistance and body torque changes (*Gao, Abdullah & Omar Dev, 2024*). In contrast, TCT often isolates larger muscle groups while neglecting the integrative, sport-specific movements necessary for optimal performance under dynamic conditions, potentially limiting its effectiveness in sports requiring high motion adaptability and muscle synchronization (*Lin et al., 2022*). These improvements are particularly vital in kayaking, where continuous, forceful trunk movements contribute significantly to propulsion and kayak control, directly influencing stroke efficiency and speed (*McDonnell, Hume & Nolte, 2012; Prétot et al., 2022*).

Effect of UTC vs TCT on sprint performance

The observed reduction in 200 m single flatwater sprint time following the 8-week intervention indicates that targeted core training can enhance paddling efficiency and speed in young male Chinese kayakers. Specifically, improvements in core stability strength likely contributed to better balance of the athlete-paddle-boat system and more effective power transmission from the lower to upper body during paddle strokes, optimizing force production across all race phases. Similarly, enhanced core dynamic strength may have supported greater stroke force generation and increased stroke frequency during paddling (*Wu et al., 2023*). Although this study did not include direct biomechanical assessments, the performance gains likely reflect improved postural control and trunk stability under high-intensity paddling conditions. The UTC program, by incorporating unstable surfaces, appears to have facilitated smoother and more efficient paddling mechanics, reducing energy leaks and enhancing overall performance (*López-Plaza et al., 2017*). These findings align with previous research demonstrating positive associations between core strength and sprint performance in kayaking (*Bjerkefors et al., 2018; Brown, Peters & Lauder, 2023*).

The observed differences in core strength and sprint performance may be attributed to the distinct training mechanisms of UTC. Unlike TCT, which primarily targets isolated muscles under stable conditions, UTC emphasizes integrated functional training by

engaging deep and small core muscle groups, promoting intermuscular coordination, and enhancing proprioceptive feedback (Clark, Lambert & Hunter, 2018; Glass & Wisneski, 2023). Although the specific neuromuscular or biomechanical pathways of transfer were not directly assessed, this type of integration appears particularly advantageous for kayakers, whose performance relies on the coordinated effort of upper-body, core, and lower-body movements (Brown, Peters & Lauder, 2023). The findings of this study support the inclusion of UTC in core training regimens for sprint kayakers, offering potential benefits over TCT, especially in sports requiring high levels of balance and dynamic core control. Coaches and sports scientists should consider incorporating core exercises on unstable surfaces to better simulate the complex demands of kayaking competitions. This recommendation is in line with prior literature advocating for the application of sport-specific instability training to enhance athletic performance (Li, 2017). Mechanistic considerations and future directions: While we hypothesized that UTC may improve force transmission and reduce energy leakage through enhanced trunk stability, this study did not include EMG, kinetic, or kinematic measurements to directly test these mechanisms. Therefore, mechanistic explanations remain speculative. Future studies should combine UTC interventions with sEMG, 3D motion capture, instrumented paddles, or IMUs to evaluate neuromuscular activation patterns and kinematic changes underlying performance improvements (Bonaiuto et al., 2022; Fernandes et al., 2024; Romagnoli et al., 2024; Tay & Kong, 2018).

Importantly, although UTC demonstrated superior improvements compared with TCT, it should be emphasized that TCT also produced significant time effects in trunk stability strength, trunk dynamic strength, and sprint performance. These findings indicate that traditional core training performed on stable surfaces remains an effective method for enhancing core-related physical qualities in young male kayakers. The observed improvements in the TCT group may be attributed to progressive overload, increased neuromuscular recruitment of primary trunk muscles, and enhanced muscular endurance over the 8-week intervention period. While TCT may not provide the same level of proprioceptive challenge or deep stabilizer activation as UTC, its structured and controlled loading conditions likely contributed to meaningful gains in trunk strength, which in turn may have supported improvements in sprint performance. Therefore, rather than viewing TCT as ineffective, the present findings suggest that both training approaches are beneficial, with UTC providing additional advantages under sport-specific unstable conditions. This perspective offers a more balanced interpretation of the comparative effectiveness of UTC and TCT in sprint kayaking.

LIMITATIONS

This study has several limitations that should be acknowledged. Firstly, it focused only on Wobble boards, Swiss balls, and BOSU balls as the unstable surfaces in UTC intervention. This limits the generalizability of the findings to other unstable devices. Future research could explore additional unstable environments, such as elastic bands, foam rollers, suspension chains, snow, sand, and water, to further optimize the effectiveness of UTC. Secondly, one limitation is the potential for measurement bias due to the lack

of assessor blinding, which may have inadvertently influenced outcome assessments. Although evaluators were blinded to group allocation during testing, participants could not be blinded to the type of intervention due to the visible differences between UTC and TCT exercises. This lack of participant blinding may have introduced expectation bias, potentially influencing effort levels and performance outcomes. Future studies may consider strategies such as sham interventions to minimize this risk. Thirdly, the study relied on basic assessment methods, including non-dynamometric tools and manual stopwatch timing, without incorporating advanced technologies. Specifically, sprint performance was measured using a manual stopwatch, which may introduce measurement bias due to human reaction time. Advanced biomechanical tools such as surface electromyography (sEMG), 3D motion capture systems, and instrumented paddles were not used due to practical and resource constraints. Instead, field-based tools (*e.g.*, stopwatch timing, non-dynamometric strength tests) were employed, which are widely adopted in applied sports settings and provide feasible, reliable measures of performance. While these are valid methods, they offer less precision and mechanistic insight compared to advanced technologies. Future studies are encouraged to employ electronic timing systems, such as photocell timing gates or GPS-based paddling sensors, isokinetic dynamometers, sEMG, pressure biofeedback units, 3D motion capture systems, IMUs, instrumented paddles, and on-water video motion analysis, to more precisely evaluate core strength, muscle activation patterns, and paddling performance. Lastly, as the study focused solely on young male kayakers in Jiangxi province, this limits the generalizability of the findings to other populations. Future studies should investigate the effects of UTC on kayakers of different genders, ages, and training levels, as well as athletes from other aquatic sports, such as sailing, swimming, and rowing, to examine the broader applicability of UTC interventions.

CONCLUSION

In conclusion, after eight weeks of intervention, although there was a significant increase in core strength and sprint performance using traditional core training, unstable core training proved to be significantly more effective in enhancing trunk strength—including trunk stability strength (abdomen, back, left side, and right side) and trunk dynamic strength (flexion, extension, left rotation, and right rotation)—as well as sprint performance (200 m single flatwater sprint time) in young male kayakers in China. These findings contribute to the growing body of literature emphasizing the value of individualized and sport-specific approaches in training. For practical application, coaches are encouraged to incorporate UTC methods, such as exercises performed on unstable surfaces (*e.g.*, balance boards, Swiss balls, or suspension systems), to better simulate the demands of kayaking and improve athletes' postural control, core integration, and stroke efficiency. Athletes can benefit from integrating UTC into their regular training routines to maximize performance gains while reducing potential energy leaks during paddling. These insights offer a robust framework for future studies and practical guidance for enhancing training effectiveness in sprint kayaking. To our knowledge, this is the first randomized controlled trial directly comparing UTC and TCT in young male Chinese kayakers, addressing a notable gap in

sport-specific training literature. The integration of instability core training tailored to flatwater sprint kayaking provides novel insights into performance enhancement strategies in this underrepresented athletic population.

Abbreviations

UTC	Unstable Core Training
TCT	Traditional Core Training
M	Mean
SD	Standard Deviation
η^2	Eta Square (Effect Size)
RCT	Randomized Controlled Trial
MANOVA	Multivariate Analysis of Variance
ABT	Abdomen bridge test
BBT	Back bridge test
LSBT	Left side bridge test,
RSBT	Right side bridge test
1-min SUT	1-min sit-up test
1-min BET	1-min back extension test
1-min TLRT	1-min trunk left rotation test
1-min TRRT	1-min trunk right rotation test
200m SFSTT	200 m single flatwater sprint time test

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Jianxin Gao conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Hang Xu performed the experiments, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Weinan Zhang performed the experiments, prepared figures and/or tables, and approved the final draft.
- Shamsulariffin Bin Samsudin conceived and designed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (i.e., approving body and any reference numbers):

The study was approved by the Ethics Committee of Universiti Putra Malaysia (Approval No. JKEUPM 2023-256).

Data Availability

The following information was supplied regarding data availability:

The raw data are available in the [Supplemental File](#).

Supplemental Information

Supplemental information for this article can be found online at <http://dx.doi.org/10.7717/peerj.21091#supplemental-information>.

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