Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Correlations Between Trunk Static and Dynamic Muscle Strength and Sprint Performance in Adolescent Male Sub-Elite Flatwater Kayakers

Jianxin Gao
gs60382@student.upm.edu.my

Jiangxi Teachers College
Hang Xu
Jiangxi Teachers College
Xinwen Wang
Yingtan Vocational and Technical College
Shamsulariffin Samsudin
University Putra Malaysia
Zhigang Gong
Key Lab of Aquatic Sports Training Monitoring and Intervention of the General Administration of Sport of China, Faculty of Physical Education, Jiangxi Normal University
Dan Liu
Jiangxi Teachers College
Liaoliang Nie
Jiangxi Teachers College

Research Article

Keywords: Correlations, Trunk Muscle Strength, Sprint Performance, Adolescent, Flatwater Kayakers

Posted Date: March 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8695791/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Background

Flatwater sprint kayaking is a high-intensity speed-based Olympic water sport with substantial physical, technical, tactical, and psychological demands. Among its performance determinants, sprint performance is the key factor for competitive success. However, the role of trunk dynamic and static muscle strength and the sprint performance are yet to be established in adolescent male sub-elite flatwater kayakers. The purpose of this study was to determine the associations between trunk dynamic and static muscle strength, and sprint performance.

Method

Thirty eligible adolescent male sub-elite flatwater kayakers completed assessments of trunk dynamic and static muscle strength, as well as 200 m sprint trials on a kayak ergometer/dynamometer. Trunk static strength of the abdominal, back, left and right lateral regions was assessed using the Abdomen Bridge Test (ABT), Back Bridge Test (BBT), Left Side Bridge Test (LSBT) and Right Side Bridge Test (RSBT), whereas trunk dynamic strength, including trunk flexion, extension, left and right rotation strength, was evaluated using the 1-min sit-up test (1-min SUT), 1-min back extension test (1-min BET), 1-min Trunk Left Rotation Test (1-min TLRT) and 1-min Trunk Right Rotation Test (1-min TRRT). Sprint performance indicators for the K1 200 m flatwater sprint performance were assessed using a kayak-specific ergometer (Dansprint PRO) and included sprint time (SP), stroke rate (SR), mean and peak velocity (V-Mean and V-Peak), as well as bilateral symmetry of paddling force output (BS-PFO). All tests data for normality (Shapiro-Wilk and Kolmogorov-Smirnov[a]), and Pearson's correlation coefficients were calculated with significance set at the standard alpha level (0.05).

Results

Results indicated that lateral trunk static strength was significantly associated with 200 m sprint performance. Both left and right side trunk static strength were negatively correlated with sprint time ($r = -0.409$ to -0.420, $p < 0.05$) and positively correlated with peak velocity ($r = 0.313$ to 0.466, $p < 0.05–0.01$), whereas no significant relationships were observed for abdominal or back bridge strength (all $p > 0.05$). In contrast, dynamic trunk muscle strength showed stronger and more consistent associations with sprint performance. Trunk flexion strength (1-min SUT) was strongly related to faster sprint time ($r = -0.658$, $p < 0.01$) and higher stroke rate, mean velocity, and peak velocity ($r = 0.328–0.577$, $p < 0.05–0.01$). Trunk extension strength (1-min BET) was positively associated with mean and peak velocity ($r = 0.428–0.459$, $p < 0.01$). Additionally, trunk rotational strength (1-min TLRT and TRRT) was significantly correlated with sprint time, stroke rate, and velocity outcomes ($|r| = 0.313–0.501$, $p < 0.05–0.01$). No trunk strength variables were significantly associated with bilateral symmetry of paddling force output (all $p > 0.05$).

Conclusion

The findings of this study indicate that trunk muscle strength, particularly dynamic trunk flexion and rotational strength as well as lateral trunk static endurance, is closely associated with sprint performance variables in adolescent male sub-elite flatwater kayakers. These results suggest that effective force generation and transfer during sprint kayaking rely heavily on coordinated trunk muscle function rather than ventral or dorsal static endurance alone. Accordingly, training programs for young kayakers should prioritize the development of dynamic trunk strength and lateral trunk stability to optimize sprint performance.

1 Introduction

Trunk muscle strength, produced by the contraction of the core muscles, is the comprehensive strength that can stabilize the spine and pelvis of the body, maintain body posture, improve body control and balance, and improve the power output from the core to the limbs during exercise, playing a crucial role in controlling body balance and stabilizing the center of gravity [1, 2]. Moreover, it actively participates in the energy transmission of the core muscle group during competitive sports, serving as an important "power source" and "bridge" for the human body in the process of movement [3]. Furthermore, scholars have divided trunk muscle strength into two main types: trunk static strength and trunk dynamic strength [4, 5]. Trunk static strength refers to the ability to maintain spinal alignment and posture under static conditions. The Trunk static strength is primarily generated by the deep and small muscle groups in the abdomen, back, and lateral sides of the core area (especially the deep and small muscle groups between the spine, lumbosacral region, and sacroiliac region) to stabilize vital core area; Trunk dynamic strength is mainly produced by the contraction of larger surface muscle groups, mainly including the rectus abdominis, erector spinae, and internal obliques and external obliques, while trunk dynamic strength involves the force to facilitate trunk flexion, extension, and rotation [2].

Flatwater sprint kayaking is a highly competitive, speed-based water sports event, and the goal is that competitors from the start line to 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 [6]. 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 [7, 8]. 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 static 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 [9]. Therefore, focusing on the relationship between sprint performance and trunk strength is crucial for the athletic development of adolescent kayakers.

Research indicates that trunk static strength is a crucial factor in flatwater sprint kayaking performance [10, 9]. Trunk static strength helps kayakers maintain control over their center of gravity, reducing the risk of capsizing during competition [11]while also supporting an upright seated posture, which is essential for stable paddling techniques [12, 13]. Moreover, the trunk static strength enables kayakers to adapt effectively to varying conditions—such as wind, currents, and waves—allowing them to maintain a straight course and optimize their speed [9]. Furthermore, strong trunk static strength provides a stable platform for efficient force transfer, coordinating the movement between the lower and upper body to maximize paddling power [14, 15]. Therefore, trunk static strength is essential to boost competitive performance in flatwater sprint kayaking.

Efficient paddling and athletic performance in kayaking requires both strong trunk static strength and trunk dynamic strength [16]. Previous studies have shown that there are four important phases in kayaking paddling cycle—catch, drive/power, exit, and recovery/aerial—the recovery/aerial phase occurs when the paddle is in the air, not interacting with water or generating propulsion, while the other three phases involve paddle-water interaction, producing the force to propel the kayak forward [17, 18]. During these four paddling phases, the kayaker's torso undergoes a small-scale flexion, extension, and rotation at the trunk joint [19, 20]. Additionally, trunk muscles such as the rectus abdominis, erector spinae, external obliques, and internal obliques have been identified as the "active or agonist muscles" that drive the upper limb paddling while simultaneously completing the flexion, extension, and rotational movements of the torso, thus helping kayakers achieve efficient paddling technique [10]. Furthermore, taking athletes' unilateral paddling as an example, Li (2015) highlighted that the trunk dynamic strength of kayakers' trunk extension and rotation—especially rotational force—are the primary forces generating paddling force (stroke power) during the catch, drive/power, and exit phases. Meanwhile, trunk dynamic strength of flexion and reverse rotation aids the kayaker's trunk to quickly returning to erect and slightly lean forward sitting posture and shorten the air time of paddling in the recovery phase, thereby better connecting with the catch, drive/power, and exit phase on the other unilateral stroke and increasing the paddling frequency (stroke rate) [21]. Therefore, trunk dynamic strength is critical to every paddling phase when maximizing stroke force and efficiency to drive the kayak forward at high speed.

Previous literature indicated significant relationships between trunk strength and performance in kayakers [22, 10]. Brown et al. (2010) highlighted a significant correlation ($p < 0.05$) between kayakers' peak paddle force and the activation of core muscles such as the rectus abdominis and external obliques during on-water paddling, which are crucial for sprint performance. In addition, Bjerkefors et al. (2018) identified that after a certain intensity level, the stroke power output significantly increased with the range of motion (ROM) of the trunk for elite kayakers during paddling on a kayak ergometer. Furthermore, during 150m flatwater sprint trials, another study emphasized a significantly strong relationship between the activation of internal obliques and external obliques and peak velocity ($r=.684$, $p < 0.05$), as well as a significantly strong positive relationship ($r=.562$, $p < 0.05$) with mean velocity and the contralateral rectus abdominus. The study also identified multiple significant associations between the rectus femoris, rectus abdominis, and external obliques during the paddle stroke [9]. Therefore, with reference to these findings, it seems plausible to argue that core strength may have the potential to improve the sprint performance of kayakers.

Although previous studies have employed techniques such as electromyography to investigate the relationships between trunk muscle activation and paddling performance in elite adult kayakers, these investigations have primarily focused on the activation of specific individual trunk muscles, such as the rectus abdominis, erector spinae, and oblique muscles. To date, limited attention has been given to trunk muscle strength from a comprehensive perspective that integrates static strength of the abdominal, back, and lateral musculature, as well as dynamic strength encompassing trunk flexion, extension, and rotation. Moreover, evidence remains scarce regarding how the combined contribution of trunk static and dynamic muscle strength, considered at the muscle-group level rather than at isolated muscles, relates to sprint performance in adolescent sub-elite flatwater kayakers. Therefore, addressing those gaps are essential to improve the understanding of trunk musle strength characteristics and their practical relevance to sprint kayaking performance, thereby providing an evidence-based foundation for targeted training interventions in this population of adolescent sub-elite flatwater kayakers.

2 Materials and Methods

2.1 Participants

In scientific research, the interpretation of correlation coefficients is primarily guided by effect size conventions rather than statistical significance alone. According to the criteria proposed by [23], an absolute correlation coefficient ($|r|$) < 0.10 represents a negligible association, 0.10–0.29 a weak association, 0.30–0.49 a moderate association, 0.50–0.69 a large (strong) association, and values ≥ 0.70 a very large (strong) association. It is well established that the required sample size for correlation analyses depends on the expected magnitude of the correlation, as well as the selected significance level and statistical power [24]. Accordingly, an a priori sample size estimation was conducted using G*Power software (version 3.1). For a two-tailed Pearson correlation analysis, a large (strong) expected effect size ($r = 0.50$) was assumed, reflecting the hypothesized meaningful relationship between trunk muscle strength and sprint performance based on prior biomechanical and training-related evidence in sprint kayaking and similar high-intensity paddle sports. With the following parameters: correlation under the alternative hypothesis (ρH_1) = 0.50, correlation under the null hypothesis (ρH_0) = 0, α error probability = 0.05, and statistical power ($1 - \beta$) = 0.80, the analysis indicated that a minimum total sample size of 29 participants was required. For details on the sample size estimation using G*Power software, see Fig 1(Sample size estimation using G*Power software).

In this study, 30 male adolescent sub-elite flatwater kayakers specializing in the K1(kayak with single athlete) 200 m flatwater sprint event (aged 16–22 years) in Nanchang Yao lake water sprots training base in Jiangxi province, China, participated in this study. All participants had a minimum of 3 years of kayak-specific training. Exclusion criteria included any history of surgery, current or recent musculoskeletal injuries, or other health conditions. In addition, none of the participants had previously undergone systematic core training that was judged to potentially have an influence on the results of either test. All adolescent sub-elite flatwater kayakers under 18 years of age handed in an informed consent from their parents or legal guardians whereas the kayakers aged 18 years and above handed in a written consent. Before collecting data, the study was conducted with approval from the relevant authorities. The study protocol was registered in the ClinicalTrials.gov Protocol Registration and Results System (PRS) (https://clinicaltrials.gov/) (Identifier: NCT06432595;

registration date: 7 January 2024). Ethical approval was obtained from the Universiti Putra Malaysia Human Research Ethics Committee (JKEUPM 2023-256).

2.2 Testing Procedures

Testing Procedures included the assessment of demographic and anthropometric variables, trunk dynamic and static muscle strength, and sprint performance. Prior to data collection, all participants completed a brief familiarization session for each test to ensure proper understanding of the procedures and correct execution. To minimize the influence of fatigue, participants performed only one practice repetition during the familiarization phase, allowing them to become accustomed to the testing protocols before the formal assessments were conducted.

2.3 Assessment of Demographic and Anthropometric Variables

In this study, the variables of all participants' age, height, weight, and training years were essential demographic and anthropometric characteristics measurements. Firstly, the variables of age and training years were collected based on participants' self-reported information obtained prior to testing. Secondly, a collective meeting was held for all participants to explain the key precautions and guidelines to be followed during the testing phase. In addition, the variables of participants' height and weight were measured by using a height and weight meter. The measurement of height and weight was conducted on the morning of the collective meeting day for all participants before conducting the correlation study. For details on the demographic and anthropometric variables, see Table 1.

2.4 Assessment of Trunk Static and Dynamic Muscle Strength

The Trunk muscle strength testing assessment included trunk static and dynamic strength. This study measured the trunk static strength of the core area in terms of 4 parts (abdomen, back, left side, and right side) and the trunk dynamic strength of the core area in terms of 4 range-of-motion (flexion, extension, left rotation, and right rotation). The specific test methods and the instruments are shown in Table 2.

Core Stability Strength Test Protocol

The abdomen bridge test (ABT), back bridge test (BBT), and left and right side bridge tests (LSBT/RSBT) are standard measurements of trunk static strength in sports, where Maximum Duration (MD) for the bridge type tests was employed for the estimation of the trunk static strength of athletes [25, 26]. These bridge type tests are widely used to evaluate the core stability strength of athletes across various sports disciplines, providing reliable indicators of their endurance and muscular control for abdominal, back, left and right lateral regions [5, 27]. Therefore, in this study, the bridge type test protocol of trunk static strength included the abdomen bridge test (ABT), back bridge test (BBT), and left and right side bridge test (LSBT/ RSBT) for Chinese adolescent male sub-elite flatwater kayakers.

Abdomen Bridge Test (ABT). The abdomen bridge test was used to assess trunk static (core stability) strength of the abdominal musculature in adolescent male sub-elite flatwater kayakers. Prior to testing, participants completed a standardized warm-up consisting of light jogging and dynamic stretching of the upper limbs, lower limbs, and trunk. Participants were positioned prone on a floor mat, supported by the forearms and toes. Upon command, they were instructed to lift the hips off the floor and maintain a straight line from the shoulders to the heels with the spine in a neutral position. Timing commenced once the correct position was achieved and was terminated when the participant was unable to maintain proper alignment or when any part of the body deviated from the required posture. Test duration was recorded in seconds using a stopwatch, with the maximum holding time taken as the final score. Following the test, participants performed a light of 5–10 min cool-down consisting of jogging and self-massage of the upper limbs, lower limbs, and trunk. The testing procedure followed previously published protocols [25].

Back Bridge Test (BBT). To measure the core stability strength of the core muscle in terms of the back in young Chinese male sub-elite flatwater kayakers. Prior to testing, participants completed a standardized warm-up consisting of light jogging and dynamic stretching of the upper limbs, lower limbs, and trunk. Participants were positioned supine on a floor mat with the feet, head, and shoulders in contact with the mat, arms placed alongside the body with palms facing downward without providing support, and the calves perpendicular to the ground. Upon the tester's command, participants raised the hips off the mat to form a straight line from the shoulders to the knees while maintaining a neutral spinal alignment. The test commenced once the correct position was achieved and was terminated when the posture could no longer be maintained. Test duration was recorded in seconds using a stopwatch, and the maximum time maintained in the correct position was used for further analysis. Following completion of the test, participants performed a 5–10 min light cool-down, including jogging and self-massage of the upper limbs, lower limbs, and trunk. Trunk static strength of the posterior core musculature was assessed using the back bridge test (BBT) [25].

Left and Right Side Bridge Tests (LSBT / RSBT). The left and right side bridge tests were used to assess trunk static (core stability) strength of the lateral musculature in Chinese adolescent male sub-elite flatwater kayakers. Prior to testing, participants completed a standardized warm-up consisting of light jogging and dynamic stretching for the upper and lower limbs as well as the core region. For the test, participants assumed a side-lying position on a floor mat, with the upper body supported by the elbow and forearm, and the outer edge of the foot of the same side in contact with the ground. The lower limbs were kept fully extended, with the top foot positioned slightly anterior to the bottom foot. Upon the tester's command, participants raised their hips off the floor to form a straight line from head to feet, maintaining this position as long as possible. The test started once the correct alignment was achieved and was terminated when the participant was no longer able to maintain the prescribed position. Test performance was recorded as the maximum duration (s)

maintained for each side using a stopwatch. Following the test, participants performed a 5–10 min cool-down consisting of light general activities such as jogging and self-massage of the upper and lower limbs and core region. The testing procedures followed previously published protocols [26].

Core Dynamic Strength Test Protocol

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 [28, 25, 29]. These 1-min repetitions format tests are widely used to evaluate the core dynamic strength of athletes across various sports disciplines, providing reliable indicators of their endurance and muscular control for trunk flexion, extension, left and right rotation [25, 30]. 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.

1-min Sit-Up Test (1-min SUT). Trunk flexion dynamic strength was assessed using the 1-min Sit-Up Test (1-min SUT) [28]. Participants lay supine on a floor mat with the hips flexed at approximately 45° and the knees flexed at 90°, legs together, and fingers interlocked behind the neck. The feet were firmly secured by another participant or a sit-up assistive device. From this position, participants flexed the trunk until the elbows touched the knees and then lowered the torso until the shoulder blades contacted the mat. Touching the head or hands to the mat during the movement was not permitted. Each complete up-and-down cycle was counted as one valid repetition. The test was performed continuously for 1 min and timed using a stopwatch, with the total number of correctly executed sit-ups recorded as the final score. Prior to testing, participants completed a standardized warm-up consisting of light jogging and dynamic stretching of the upper and lower limbs and trunk, followed by a 5–10 min cool-down of light activity after the test.

1-min Back Extension Test (1-min BET). Trunk dynamic strength in terms of extension was assessed using the 1-min Back Extension Test. Following a standardized warm-up consisting of light jogging and stretching of the upper and lower limbs and the core region, participants lay prone on a floor mat with the pelvis stabilized to minimize hip movement and to isolate the trunk extensors. Hands were placed at the temples, and the feet were firmly anchored by another participant or an assistive device to ensure stability. From this position, participants were instructed to lift the trunk upward as far as possible until the chest was raised off the mat and the sternum was nearly perpendicular to the ground, and then to lower the trunk in a controlled manner until the chest touched the mat, constituting one complete repetition. Participants performed as many repetitions as possible within 1 min, and the total number of correctly executed repetitions was recorded as the test score. After completion of the test, participants performed a 5–10 min cool-down consisting of light general activity, including jogging and massage of the upper and lower limbs and the core region. Test duration was timed using a stopwatch, and the test procedures were based on previously published protocols [25].

1-min Trunk Left and Right Rotation Test (1-min TLRT/TRRT). The trunk left and right rotation tests were used to assess trunk dynamic strength in terms of left and right rotational capacity. Participants lay in a supine position on a floor mat with the knees flexed at approximately 90°, feet flat on the mat, legs together, and the head and back resting on the mat. The arms were extended over the trunk with the hands placed on the thighs and the thumbs interlocked. To prevent lower-limb movement during the test, an assistant knelt at the participant's feet and stabilized the knees by applying pressure with the inner sides of the fists to the outer aspects of the knees. During each repetition, participants performed consecutive trunk rotations to the same side, rotating the trunk until the hands touched the external side of the assistant's fist, and then returned to the starting position until the head touched the mat. Only correctly executed repetitions—defined as contacting the assistant's fist during trunk elevation and touching the mat with the head during trunk lowering—were counted. The maximum number of valid repetitions completed within 1 minute for left and right trunk rotation was recorded as the test score. All tests were timed using a stopwatch, and participants completed a light general cool-down following testing. The testing procedure was adapted from [29].

2.5 Assessment of Sprint Performance

The sprint performance testing assessment only included flatwater sprint performance of kayaking. This study measured the sprint time. There was K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test, included sprint time (SP), stroke rate (SR), mean and peak velocity (V-Mean and V-Peak), as well as bilateral symmetry of paddling force output (BS-PFO). The specific test methods and the instruments are shown in Table 3.

The K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test is a standard and widely used measure of sprint performance in flatwater sprint kayaking, in which athletes are required to paddle a 200 m distance on flatwater as quickly as possible [31]. In addition to sprint time (SP), this test allows for the simultaneous assessment of multiple sprint performance indicators, including stroke rate (SR), mean velocity (V-Mean), peak velocity (V-Peak), and bilateral symmetry of paddling force output (BS-PFO), which collectively reflect the athletes' paddling efficiency, speed characteristics, and force application during sprint kayaking. Previous research has demonstrated that the K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test is sensitive to performance outcomes associated with training interventions, such as core strength training, and can be used to evaluate changes in muscle activation patterns and paddling mechanics in single kayakers [32]. Therefore, in the present study, sprint performance in adolescent male sub-elite Chinese kayakers was assessed using the K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test, with the above-mentioned performance indicators recorded using a kayak-specific dynamometer/ergometer system.

K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test. Sprint time (SP), stroke rate (SR), mean and peak velocity (V-Mean and V-Peak), as well as bilateral symmetry of paddling force output (BS-PFO) were designed to assess adolescent male sub-elite Chinese kayakers' K1 200m flatwater sprint performance. This test utilized the Dansprint PRO Kayak dynamometer/ergometer, a specialized device manufactured in Denmark, and was conducted in a kayak-specific land dynamometer/ergometer sprint performance testing room of the Nanchang Yao Lake kayaking training base. Prior to the test, the tester configured the necessary parameters, including the kayak model, land performance type, wind resistance of the dynamometer, and basic

athlete data such as height and weight. Participants were given time to warm up by running and performing light stretching exercises, including a 5-10 min light general warm-up activity and light kayaking sport-specific activity, such as jogging, stretching of limbs and core area, and specialized paddling activities. Once prepared, they seated themselves on the dynamometer cushion with their feet securely fixed on the pedals and grasped the simulated paddle with both hands. Upon receiving the command, participants were instructed to perform the test to the best of their sprint ability. The test involved completing a 200-meter simulation on the land dynamometer, with the LCD digital display screen of the device automatically recording the Sprint time (SP), stroke rate (SR), mean and peak velocity (V-Mean and V-Peak), as well as bilateral symmetry of paddling force output (BS-PFO) parameters to determine performance. The final score was based on the recorded time displayed on the LCD screen. Further details on the procedure of the men's K1 200m dynamometer sprint performance tests can be found on the official website (https://dansprint.com/vare/dansprint-pro-kayak-ergometer/).

2.6 Statistical analyses

Following tests, normality of the data was first examined using the Shapiro–Wilk and Kolmogorov–Smirnov tests. Descriptive statistics, including means and standard deviations, were then computed for all variables. Pearson's product–moment correlation analyses were performed, where appropriate, to examine the relationships between trunk static and dynamic muscle strength measures and sprint performance indicators in adolescent male sub-elite flatwater kayakers. Statistical significance was set at the conventional alpha level of 0.05. All analyses were conducted using IBM SPSS Statistics (version 29; IBM Corp., USA). The magnitude of correlation coefficients was interpreted as follows: $|r| < 0.10$ indicated a negligible association; 0.10–0.29 a weak association; 0.30–0.49 a moderate association; 0.50–0.69 a large association; and values ≥ 0.70 were considered to represent very large associations.

3 Results

3.1 Descriptive Statistics

Table 4 shows the descriptive statistics (value of means and standard deviations, measuring methods, and normality test)for measures variables of the trunk static strength of the core area in terms of 4 parts (abdomen, back, left side, and right side) and the trunk dynamic strength of the core area in terms of 4 range-of-motion (flexion, extension, left rotation, and right rotation) and sprint performance including sprint time (SP), stroke rate (SR), mean velocity (V-Mean), peak velocity (V-Peak), and bilateral symmetry of paddling force output (BS-PFO) in adolescent male sub-elite flatwater kayakers.

The static core endurance tests, including the Abdomen Bridge Test (ABT), Back Bridge Test (BBT), Left Side Bridge Test (LSBT), and Right Side Bridge Test (RSBT), together with the dynamic trunk strength tests involving flexion, extension, and rotation (1-min Sit-Up Test [1-min SUT], 1-min Back Extension Test [1-min BET], 1-min Trunk Left Rotation Test [1-min TLRT], and 1-min Trunk Right Rotation Test [1-min TRRT]), provide a comprehensive evaluation of trunk muscle function from both static and dynamic strength perspectives. These bridge-based static tests are particularly effective in assessing isometric endurance capacity and neuromuscular control of the trunk, as they require sustained activation and coordinated recruitment of deep stabilizing muscles (e.g., transversus abdominis, multifidus, and internal obliques) in conjunction with the global core musculature. In contrast, the dynamic flexion, extension, and rotational tests reflect the ability of the trunk muscle groups to generate and transfer isotonic force repeatedly under sport-specific movement patterns, thereby capturing intermuscular coordination, agonist–antagonist cooperation, and fatigue resistance, all of which are critical for efficient force transmission during kayaking strokes.

In parallel, the Dansprint PRO Kayak dynamometer/ergometer represents a specialized and validated testing system for kayaking performance [33, 34], enabling precise and sport-specific assessment of sprint performance indicators, including sprint time (SP), stroke rate (SR), mean velocity (V-Mean), peak velocity (V-Peak), and bilateral symmetry of paddling force output (BS-PFO). These parameters provide an integrated evaluation of paddling efficiency, velocity characteristics, and left–right force balance, which are closely linked to the physiological and biomechanical demands of sprint kayaking. Collectively, the combination of static and dynamic core strength tests with kayak-specific dynamometer assessments allows for a multidimensional appraisal of trunk muscle function and its contribution to sprint performance, reflecting both neuromuscular control and performance-related physiological responses in kayakers.

3.2 Correlations Between Trunk Static and Dynamic Muscle Strength and Sprint Performance Variables

Correlations between trunk static and dynamic muscle strength (i.e., abdomen, back and side bridge tests, sit-up test, back extension test, and trunk rotation tests) and K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance (i.e., sprint time test, stroke rate test, mean velocity test, peak velocity test, and bilateral symmetry of paddling force output test) are displayed in Table 5.

With respect to trunk static muscle strength, significant associations were observed primarily for lateral bridge performance. Left side bridge strength (LSBT) showed a significant negative correlation with sprint time (SP; $r = -0.409$, $p < 0.05$) and a significant positive correlation with peak velocity (V-Peak; $r = 0.466$, $p < 0.01$), indicating that greater left lateral trunk endurance was associated with faster sprint performance and higher peak speed. Similarly, right side bridge strength (RSBT) was significantly and negatively correlated with SP ($r = -0.420$, $p < 0.05$) and positively correlated with V-Peak ($r = 0.313$, $p < 0.05$). No significant correlations were observed between abdomen bridge strength (ABT) or back bridge strength (BBT) and sprint time, stroke rate (SR), mean velocity (V-Mean), peak velocity, or bilateral symmetry of paddling force output (BS-PFO) (all $p > 0.05$). Overall, these findings suggest that lateral trunk static endurance, rather than ventral or dorsal static endurance, is more closely related to sprint performance characteristics during the K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test.

Dynamic trunk muscle strength demonstrated more consistent and stronger associations with K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance variables. Trunk flexion strength (1-min SUT) showed a large negative correlation with SP ($r = -0.658$, $p < 0.01$) and significant positive correlations with SR ($r = 0.328$, $p < 0.05$), V-Mean ($r = 0.577$, $p < 0.01$), and V-Peak ($r = 0.570$, $p < 0.01$). Trunk extension strength (1-min BET) was significantly correlated with V-Mean ($r = 0.459$, $p < 0.01$) and V-Peak ($r = 0.428$, $p < 0.01$), but showed no significant association with SP or SR. Furthermore, trunk rotational strength exhibited notable performance-related associations. Left trunk rotation strength (1-min TLRT) was significantly correlated with SP ($r = -0.477$, $p < 0.01$), SR ($r = -0.453$, $p < 0.01$), V-Mean ($r = 0.491$, $p < 0.01$), and V-Peak ($r = 0.501$, $p < 0.01$). Right trunk rotation strength (1-min TRRT) also demonstrated significant correlations with SR ($r = -0.478$, $p < 0.01$), V-Mean ($r = 0.313$, $p < 0.05$), and V-Peak ($r = 0.358$, $p < 0.05$). No significant relationships were found between any dynamic trunk strength variables and BS-PFO (all $p > 0.05$). Collectively, these results indicate that dynamic trunk strength, particularly flexion and rotational capacities, plays a critical role in sprint kayaking performance as assessed by kayak-specific ergometer testing.

4 Discussion

The purpose of the present study was to examine the associations between trunk static and dynamic strength and sprint performance in adolescent male sub-elite flatwater kayakers. The main findings can be summarized as follows: (1) Both left and right side trunk static strength showed negatively significant correlated with sprint time and positively correlated with peak velocity, whereas no significant relationships were observed for abdominal or back trunk static strength; and (2) Trunk flexion strength was strongly related to faster sprint time and higher stroke rate, mean velocity, and peak velocity. Trunk extension strength was positively associated with mean and peak velocity. Additionally, trunk rotational strength was significantly correlated with sprint time, stroke rate, and velocity outcomes. (3) No trunk static and dynamic strength variables were significantly associated with bilateral symmetry of paddling force output.These findings provide further evidence that trunk strength is a key physical determinant of sprint kayaking performance during in adolescent male sub-elite flatwater kayakers.

4.1 Association Between Trunk Static Strength and Sprint Performance in Adolescent Male Sub-Elite Flatwater Kayakers

The present study demonstrated that trunk static strength was significantly associated with sprint performance in adolescent male sub-elite flatwater kayakers. Athletes with greater isometric trunk endurance and stabilization capacity tended to achieve faster sprint times, particularly during short-duration, high-intensity efforts. This finding supports previous research indicating that static trunk strength contributes to efficient force transmission and mechanical stability during paddling movements [35]. From a biomechanical perspective, sprint kayaking requires the trunk to function as a stable kinetic link that enables effective transfer of forces generated by the upper limbs to the paddle and water. Insufficient trunk stabilization may result in energy leakage, reduced stroke efficiency, and impaired boat velocity. Static trunk strength tests, including isometric abdominal, back, and lateral stabilization tasks, assess the capacity of the trunk musculature to maintain postural control under sustained load. These qualities are particularly relevant during sprint kayaking, where repeated high-force paddle strokes impose continuous stabilization demands on the lumbopelvic region [36].

However, despite the overall relevance of trunk static strength, no significant relationships were observed between abdominal or back bridge strength and any sprint performance indicators. One possible explanation is that ventral and dorsal trunk muscles primarily contribute to sagittal-plane stabilization, whereas sprint kayaking propulsion is dominated by rotational and lateral force components [37]. During paddling, the trunk undergoes limited flexion–extension but substantial axial rotation and lateral stabilization to counteract asymmetric paddle forces. As a result, abdominal and back bridge tests may lack movement specificity and sensitivity in capturing the performance-relevant trunk demands of sprint kayaking, particularly in adolescent athletes whose sagittal-plane trunk endurance may already exceed the minimum threshold required for stable paddling [38, 39]. In contrast, lateral trunk static strength demonstrated significant associations with sprint time and peak velocity, highlighting its specific role in kayak stabilization. Due to the streamlined and narrow hull design of sprint kayaks, fore–aft instability is minimal, whereas lateral instability is more pronounced during high-force paddling. Consequently, athletes must continuously counteract side-to-side rolling moments generated by alternating paddle strokes. Greater lateral trunk endurance may therefore enhance the ability to resist lateral displacement, maintain an efficient boat trajectory, and optimize force transfer, ultimately contributing to superior sprint performance [40].

Interestingly, lateral trunk static strength was not significantly associated with stroke rate (SR) or bilateral symmetry of paddling force output (BS-PFO). This may be explained by the fact that SR is primarily regulated by neuromuscular coordination, technical rhythm, and pacing strategies rather than by static stabilization capacity. Similarly, BS-PFO reflects bilateral force production symmetry, which is more closely related to technical skill, motor control, and dynamic trunk rotation rather than static lateral endurance. Static tests may therefore be insufficient to capture the neuromuscular and coordinative demands underlying stroke rhythm and bilateral force symmetry during sprint kayaking.

From a neuromuscular standpoint, trunk stabilizing muscles are activated in a feed-forward manner prior to limb movement, providing a stable base for forceful upper-extremity actions [41]. In adolescent kayakers, who are still undergoing neuromuscular maturation, insufficient trunk stabilization may compromise trunk–upper limb coordination during maximal sprint efforts. Enhanced lateral trunk static strength may improve postural control, reduce unnecessary trunk oscillations, and facilitate more effective paddle force application, particularly under fatigued conditions [42].

In addition, trunk static strength may contribute indirectly to performance by enhancing fatigue resistance during short but intense sprint efforts. As sprint kayaking is characterized by rapid accumulation of fatigue, especially in the trunk musculature, athletes with superior static trunk endurance may better maintain technical consistency and boat stability throughout the race. This may be particularly important at the sub-elite level, where small differences in stabilization capacity can translate into meaningful performance differences [43, 44]. Taken together, these findings emphasize that lateral trunk static

strength represents a key foundational physical quality for sprint kayaking performance in adolescent athletes, whereas ventral and dorsal static endurance may play a more supportive or threshold-based role.

4.2 Association Between Trunk Dynamic Strength and Sprint Performance in Adolescent Male Sub-Elite Flatwater Kayakers

The results of the present study revealed stronger and more consistent associations between trunk dynamic strength and sprint performance compared with trunk static strength. In particular, dynamic trunk tests involving repeated flexion, extension, and rotational movements showed significant correlations with sprint performance variables, underscoring the importance of dynamic trunk strength for sprint kayaking performance in adolescent athletes.

Sprint flatwater kayaking is a cyclic and highly dynamic activity that relies heavily on trunk flexion–extension and rotational movements to generate propulsion. During each paddle stroke, the trunk actively contributes to stroke length, paddle force magnitude, and stroke frequency by transmitting force from the upper extremities to the kayak–water interface [45]. Trunk flexion strength demonstrated strong associations with faster sprint time, higher stroke rate, and greater mean and peak velocity, which may be explained by its role in facilitating rapid trunk-driven paddle entry and acceleration during the pull phase. Stronger trunk flexors likely enhance the ability to rapidly reposition the trunk and upper limbs between strokes, thereby supporting higher stroke rates and sustained velocity output during maximal sprint efforts [46]. In contrast, trunk extension strength was primarily associated with sprint time, mean and peak velocity rather than stroke rate. This may reflect the stabilizing and force-transmitting role of the posterior trunk musculature during the late pull and exit phases of the paddle stroke. Adequate trunk extension strength may help maintain trunk posture against high external forces, allowing more effective force transfer to the paddle and contributing to higher instantaneous and average boat velocities without necessarily increasing stroke frequency [36]. These findings suggest that trunk flexion and extension strength may contribute to sprint performance through distinct but complementary biomechanical mechanisms.

Additionally, trunk rotational strength showed significant associations with sprint time, stroke rate, and velocity-related outcomes. Trunk rotation is a fundamental component of efficient kayaking technique, as it enables greater stroke length and more effective engagement of the large muscle groups of the torso. Greater rotational strength may enhance the ability to generate and control rotational torque throughout repeated strokes, improving propulsion efficiency and allowing athletes to sustain high-intensity paddling during sprint events [47]. In adolescent kayakers, who are still developing technical proficiency, improved rotational trunk strength may also facilitate better synchronization between trunk rotation and upper-limb pulling actions.

Another important consideration is the role of fatigue. Dynamic trunk strength tests are typically performed under time-constrained or repetition-based conditions, inducing progressive fatigue similar to that experienced during sprint races [48]. Athletes with greater dynamic trunk strength may exhibit superior fatigue resistance of the trunk musculature, enabling them to maintain stroke mechanics, velocity output, and coordination throughout the race [49]. This fatigue-resistant capacity may partially explain the stronger associations observed between dynamic trunk strength and sprint performance compared with static trunk strength.

Interestingly, no significant associations were observed between any trunk dynamic strength variables and bilateral symmetry of paddling force output (BS-PFO). This finding suggests that force symmetry during sprint kayaking may be influenced more strongly by technical and neuromuscular factors than by trunk dynamic strength alone [50]. Bilateral symmetry of force output likely depends on stroke technique, limb dominance, interlimb coordination, and motor control strategies developed through long-term technical training [51, 52]. In adolescent sub-elite kayakers, asymmetries in paddling force may also reflect ongoing neuromuscular maturation, technical inconsistency, or imbalances in upper-limb strength that are not fully compensated by trunk strength. Moreover, during maximal sprint efforts, athletes may prioritize force production and stroke rate over symmetrical force application, potentially masking any relationship between trunk strength and BS-PFO.

Overall, the present findings indicate that dynamic trunk strength—particularly flexion and rotational capacities—plays a critical role in sprint kayaking performance, whereas bilateral force symmetry appears to be governed by more complex interactions between technical skill, neuromuscular control, and training experience. From a practical perspective, these results highlight the importance of incorporating dynamic, sport-specific trunk strength exercises into long-term athlete development programs, while addressing bilateral force symmetry through targeted technical training and stroke coordination drills.

5 Limitations

Several limitations of the present study should be acknowledged. First, due to the correlational study design, causal relationships between trunk static and dynamic muscle strength and sprint performance could not be established. Although significant associations were identified, it remains unclear whether greater trunk strength directly leads to enhanced sprint performance or whether athletes with superior sprint performance possess generally higher physical fitness, of which trunk strength is one component. Future studies employing longitudinal or intervention-based experimental designs are therefore warranted to clarify the causal effects of trunk strength development on sprint kayaking performance for adolescent male sub-elite flatwater kayakers. Second, the assessment of trunk static and dynamic muscle strength in the present study focused on functional muscle group performance rather than isolated single-muscle strength. The static and dynamic trunk tests used reflect the combined force-generating capacity and coordination of multiple core muscle groups. While this approach has high ecological validity for kayaking performance, it does not allow for precise quantification of the contribution of individual muscles. Moreover, advanced assessment techniques such as surface electromyography (EMG) or isokinetic dynamometry were not employed, which may have limited the accuracy and specificity of trunk muscle strength evaluation. Future research incorporating EMG analysis and isokinetic measurements could provide more detailed insights into muscle activation patterns and force production characteristics during trunk movements. Third, sprint performance was assessed exclusively using the man's K1 200 m sprint. Although this distance is highly relevant for sprint kayaking, the findings cannot be directly generalized to other competitive formats, such as K2 or K4 events, or to longer race distances (e.g., 500 m or 1000 m), which place different physiological,

technical, and tactical demands on athletes. Therefore, further studies should investigate whether the observed associations between trunk strength and sprint performance extend to different boat classes and race distances. Finally, and most importantly, sprint performance was evaluated using a kayak-specific dynamometer/ergometer rather than on-water testing. While ergometer-based testing allows for high standardization and the simultaneous collection of multiple performance variables (e.g., sprint time stroke rate, paddle force, and peak velocity), it does not fully replicate the complex environmental and technical demands of on-water kayaking, such as balance control, water resistance variability, and boat–water interaction. The absence of advanced systems capable of simultaneously capturing multiple biomechanical and physiological indicators during on-water sprinting limited the ecological validity of the performance assessment. Consequently, caution should be exercised when extrapolating the present findings to real competition settings. Future studies integrating wearable sensor technologies and on-water measurement systems may help overcome this limitation and provide a more comprehensive evaluation of sprint kayaking performance.

6 Conclusion

The present study investigated the associations between trunk static and dynamic muscle strength and sprint performance in adolescent male sub-elite flatwater kayakers. The results indicate that trunk muscle strength is an important physical factor related to sprint kayaking performance, with dynamic trunk strength showing stronger and more consistent associations with key sprint performance indicators than static trunk strength. In particular, trunk flexion and rotational strength were closely related to faster sprint times, higher stroke rates, and greater mean and peak velocities, while lateral trunk static endurance also contributed to sprint performance, albeit to a lesser extent. These findings highlight the functional role of the trunk as a central link for force generation and transmission during sprint kayaking. Dynamic trunk strength appears to be especially relevant for sustaining high-intensity paddling, optimizing stroke mechanics, and maintaining velocity throughout short-distance sprint events. In contrast, trunk static strength may primarily support postural stability and force transfer rather than directly influencing stroke frequency or velocity output. From a practical perspective, the results suggest that training programs for adolescent flatwater kayakers should place greater emphasis on developing dynamic, sport-specific trunk strength, particularly through exercises targeting trunk flexion, extension, and rotation under conditions that resemble sprint paddling demands. At the same time, lateral trunk endurance should not be neglected, as it may contribute to overall sprint efficiency and trunk stability. Coaches and practitioners are encouraged to integrate targeted trunk strength training into long-term athlete development programs to enhance sprint performance during adolescence. Future research should employ experimental intervention designs to clarify the causal relationships between trunk strength development and sprint performance. In addition, investigations involving different boat classes, race distances, age groups, and female kayakers, as well as on-water performance assessments, are warranted to further generalize and extend the findings of the present study.

Abbreviations

K1 Kayak with Single Athlete

sec=Second,

reps=Repetitions,

Maximum Duration (MD)

Maximum Repetitions (RM)

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,

SP= Sprint Time Test, SR= Stroke Rate Test,

V-Mean= Mean Velocity Test,

V-Peak= Peak Velocity Test,

BS-PFO=Bilateral Symmetry of Paddling Force Output Test

Declarations

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

Jianxin Gao: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing. Jianxin Gao, Hang Xu and Xinwen Wang: Investigation, Methodology, Project administration, Resources, Writing–review and editing. Jianxin Gao, Shamsulariffin Samsudin and Zhigang Gong: Software, Supervision, Validation, Visualization, Writing–original draft. Shamsulariffin Samsudin: Software, Supervision, Validation, Visualization, Writing–review and editing. Jianxin Gao, Dan Liu and LiaoLang Nie: Conceptualization, Funding acquisition, Data curation, Formal Analysis, Software, Writing–original draft.

Funding

The author(s) declare that this research was financially supported by the Humanities and Social Sciences Planning Project of Universities for Jiangxi Provincial Department of Education, Jiangxi, China (Grant NO. TY25107).

Acknowledgments

The authors would like to thank all athletes and coaches who participated in this study.

Conflict of Interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

Consent to participate

Written informed consent to participate in the study was obtained from all participants prior to data collection. For participants under the age of 18, written informed consent was additionally obtained from their parents or legal guardians.

Ethics approval

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Universiti Putra Malaysia (Approval No. JKEUPM 2023-256). All participants provided written informed consent prior to participation.

Consent for publication

Not applicable.

References

1. Hibbs, A. E., Thompson, K. G., French, D., Wrigley, A., & Spears, I. (2008). Optimizing Performance by Improving Core Stability and Core Strength. Sports Medicine, 38(12), 995-1008. https://doi.org/10.2165/00007256-200838120-00004
2. Wirth, K., Hartmann, H., Mickel, C., Szilvas, E., Keiner, M., & Sander, A. (2017). Core Stability in Athletes: A Critical Analysis of Current Guidelines. Sports Medicine, 47(3), 401-414. https://doi.org/10.1007/s40279-016-0597-7
3. Luo, S., Soh, K. G., Soh, K. L., Sun, H., Nasiruddin, N. J. M., Du, C., & Zhai, X. (2022). Effect of Core Training on Skill Performance Among Athletes: A Systematic Review. Frontiers in Physiology, 13(6), 1-14. https://doi.org/10.3389/fphys.2022.915259
4. Zhao. (2009). The New Development of Core Strength and Core Strength Training. Journal of TUS, 24(3), 218-220
5. Han & Wang. (2014). Research on Training and Evaluation Method of Core Strength. China School Physical Education, 1(1), 74-82.
6. Harrison, S. M., Cleary, P. W., & Cohen, R. C. Z. (2019). Dynamic simulation of flatwater kayaking using a coupled biomechanical-smoothed particle hydrodynamics model. Human Movement Science, 64(1), 252-273. https://doi.org/10.1016/j.humov.2019.02.003
7. Lum, D., Barbosa, T. M., & Balasekaran, G. (2021). Sprint Kayaking Performance Enhancement by Isometric Strength Training Inclusion: A Randomized Controlled Trial. Sports, 9(2), 1-12. https://doi.org/10.3390/sports9020016
8. Edriss, S., Romagnoli, C., Caprioli, L., Zanela, A., Panichi, E., Campoli, F., Padua, E., Annino, G., & Bonaiuto, V. (2024). The role of emergent technologies in the dynamic and kinematic assessment of human movement in sport and clinical applications. Applied Sciences, 14(3), 1-43. https://doi.org/10.3390/app14031012
9. Brown, M. B., Peters, R., & Lauder, M. A. (2023). Contribution of Trunk Rotation and Abdominal Muscles to Sprint Kayak Performance. Journal of Human Kinetics, 90(1), 5-15. https://doi.org/10.5114/jhk/169939
10. Bjerkefors, A., Tarassova, O., Rosén, J. S., Zakaria, P., & Arndt, A. (2018). Three-dimensional kinematic analysis and power output of elite flat-water kayakers. Sports Biomechanics, 17(3), 414-427. https://doi.org/10.1080/14763141.2017.1359330
11. Davidek, P., Andel, R., & Kobesova, A. (2018). Influence of Dynamic Neuromuscular Stabilization Approach on Maximum Kayak Paddling Force. Journal of Human Kinetics, 61(1), 15-27. https://doi.org/10.1515/hukin-2017-0127

12. Rynkiewicz, M., & Starostwa, W. (2011). Asymmetry of Paddling Technique, Its Selected Conditions and Changeability in Highly Advanced Kayakers. INTERGRAF Press. DOI: 10.13140/RG.2.1.3885.0085
13. Goreham, J. (2023). Investigating the determinants of sprint kayaking performance, PhD Thesis, Dalhousie University. https://DalSpace.library.dal.ca//handle/10222/83290
14. Gou. (2018). Application research of core strength training in canoeing. Sports World, 777(3), 93–94. https://doi.org/10.16730/j.cnki.61-1019/g8.2018.03.056
15. Xian. (2020). Core Strength Training in Youth Canoeing Physical Training application research. Sports Training, 10(7), 46-49. https://doi.org/10.16655/j.cnki.2095-2813.2020.07.046
16. Shao, & Xu. (2013). New Perspective on Physical Fitness Training of Kayak Players—Core stability training. Si Chuan Sports Science, 6(3), 76-84. https://doi.org/1007-6891□2013□03-0076-0
17. McDonnell, L. K., Hume, P. A., & Nolte, V. (2012). An observational model for biomechanical assessment of sprint kayaking technique. Sports Biomechanics, 11(4), 507-523. https://doi.org/10.1080/14763141.2012.724701
18. Prétot, C., Carmigniani, R., Hasbroucq, L., Labbé, R., Boucher, J.-P., & Clanet, C. (2022). On the Physics of Kayaking. Applied Sciences, 12(18), 1-14. https://doi.org/10.3390/app12188925
19. Li, M. (2017). The Progress of Biomechanical Researches in Kayaking. Yangtze Medicine, 1(1), 30-44. https://doi.org/10.4236/ym.2017.11004
20. Abelleira-Lamela, T., Vaquero-Cristóbal, R., Esparza-Ros, F., & Marcos-Pardo, P. J. (2020). Biomechanical Adaptations in Kayakers of Different Competitive Levels and the Relationship with the Kayak Elements. Applied Sciences, 10(23), 1–11. https://doi.org/10.3390/app10238389
21. Li, M. (2015). Study on Kayak Sprint Specific Core Instability Training, PhD Thesis, SuZhou University.
22. Brown, M. B., Lauder, M., and Dyson. R. (2010). Activation and contribution of trunk and leg musculature to force production during on-water sprint kayak performance. Proceedings of the 28th International Conference on Biomechanics in Sport (pp. 203-206). Marquette, Michigan, USA. https://ojs.ub.uni-konstanz.de/cpa/issue/view/ISBS2010
23. Cohen, J. (1988). Set correlation and contingency tables. Applied psychological measurement, 12(4), 425-434. https://doi.org/10.1177/014662168801200410
24. Beck, T. W. (2013). The importance of a priori sample size estimation in strength and conditioning research. The Journal of Strength & Conditioning Research, 27(8), 2323-2337. DOI: 10.1519/JSC.0b013e318278eea0
25. Parkhouse, K. L., & Ball, N. (2011). Influence of Dynamic Versus Static Core Exercises on Performance in Field Based Fitness Tests. Journal of Bodywork and Movement Therapies, 2011(15), 517-524. https://doi.org/10.1016/j.jbmt.2010.12.001
26. Nuhmani, S. (2021). Efficacy of Dynamic Swiss Ball Training in Improving the Core Stability of Collegiate Athletes. Physical Activity Review, 9(1), 9-15. https://doi.org/10.16926/par.2021.09.02
27. Zemková, E. (2018). Science and practice of core stability and strength testing. Physical Activity Review, 6(1), 181-193. https://doi.org/10.16926/par.2018.06.23
28. Oliver, G. D., & Brezzo, R. D. (2009). Functional Balance Training in Collegiate Women Athletes. Journal of Strength and Conditioning Research, 23(7), 2124-2129. https://doi.org/10.1519/JSC.0b013e3181b3dd9e
29. Brotons-Gil, E., García-Vaquero, M. P., Peco-González, N., & Vera-Garcia, F. J. (2013). Flexion-Rotation Trunk Test to Assess Abdominal Muscle Endurance: Reliability, Learning Effect, and Sex Differences. Journal of Strength and Conditioning Research, 27(6), 1602-1608. https://doi.org/10.1519/JSC.0b013e31827124d9
30. I-Shaikh, A., Nuhmani, S., Kachanathu, S., & I Muaidi, Q. (2019). Relationship of Core Power and Endurance with Performance in Random Intermittent Dynamic Type Sports. Asian Journal of Sports Medicine, 2(2), 1-7. https://doi.org/10.5812/asjsm.62843
31. Someren, K. V., & Palmer, G. S. (2003). Prediction of 200-m Sprint Kayaking Performance. Canadian Journal of Applied Physiology, 28(4), 505-517. https://doi.org/10.1139/h03-039
32. Garnier, Y. M., Hilt, P. M., Sirandre, C., Ballay, Y., Lepers, R., & Paizis, C. (2023). Quantifying Paddling Kinematics through Muscle Activation and Whole Body Coordination during Maximal Sprints of Different Durations on a Kayak Ergometer: A Pilot Study. International Journal of Environmental Research and Public Health, 20(3), 1-11. https://doi.org/10.3390/ijerph20032430
33. Borges, T. O., Bullock, N., Aitken, D., & Coutts, A. J. (2017). Accuracy and Validity of Commercially Available Kayak Ergometers. International Journal of Sports Physiology and Performance, 12(9), 1267-1270. https://doi.org/10.1123/ijspp.2016-0653
34. Nilsson, J. E., & Rosdahl, H. G. (2016). Contribution of Leg-Muscle Forces to Paddle Force and Kayak Speed During Maximal-Effort Flat-Water Paddling. International Journal of Sports Physiology and Performance, 11(1), 22-27. https://doi.org/10.1123/ijspp.2014-0030
35. Gao, J., Gong, Z., Samsudin, S. et al. The effects of instability core training on balance ability and paddling performance among young male Chinese flatwater sprint kayakers: a randomized controlled trial. BMC Sports Sci Med Rehabil 17, 191 (2025). https://doi.org/10.1186/s13102-025-01248-6
36. Zinke, F., Warnke, T., Gäbler, M., & Granacher, U. (2019). Effects of isokinetic training on trunk muscle fitness and body composition in world-class canoe sprinters. Frontiers in Physiology, 10, 21. doi: 10.3389/fphys.2019.00021
37. Resende, R. A., Jardim, S. H. O., Trede Filho, R. G., Mascarenhas, R. O., Ocarino, J. M., & Mendonça, L. D. M. (2020). Does trunk and hip muscles strength predict performance during a core stability test?. Brazilian journal of physical therapy, 24(4), 318-324.
38. Mann, R. V., & Kearney, J. T. (1980). A biomechanical analysis of the Olympic-style flatwater kayak stroke. Medicine and science in sports and exercise, 12(3), 183–188

39. Bertozzi, F., Porcelli, S., Marzorati, M., Pilotto, A. M., Galli, M., Sforza, C., & Zago, M. (2022). Whole-body kinematics during a simulated sprint in flat-water kayakers. European journal of sport science, 22(6), 817–825. https://doi.org/10.1080/17461391.2021.1930190
40. Robinson, M. G., Holt, L. E., & Pelham, T. W. (2002). The technology of sprint racing canoe and kayak hull and paddle designs. International Sports Journal, 6(2), 68-85.
41. Yamane M, Aoki M, Sasaki Y, Hayashi T. Feedforward coactivation of trunk muscles during rapid shoulder movements. JSES Int. 2022 May 5;6(4):660-668. doi: 10.1016/j.jseint
42. Zemková, E., & Zapletalová, L. (2022). The Role of Neuromuscular Control of Postural and Core Stability in Functional Movement and Athlete Performance. Frontiers in physiology, 13, 796097. https://doi.org/10.3389/fphys.2022.796097
43. Bilgi, B., Akınoğlu, B., Yılmaz, A. E., Akbulut, A., Shehu, S. U., & Çelenay, Ş. T. (2025). Trunk muscle endurance and upper extremity performance in healthy adults. Spor Hekimligi Dergisi/Turkish Journal of Sports Medicine, 60(2). DOI: 10.47447/tjsm.0860
44. Yu T, Xu Y, Zhang Z, Sun Y, Zhong J, Ding C. The impact of core training on overall athletic performance in different sports: a comprehensive meta-analysis. BMC Sports Sci Med Rehabil. 2025 May 3;17(1):112. doi: 10.1186/s13102-025-01159-6
45. Steeves, D., Thornley, L. J., Goreham, J. A., Jordan, M. J., Landry, S. C., & Fowles, J. R. (2019). Reliability and Validity of a Novel Trunk-Strength Assessment for High-Performance Sprint Flat-Water Kayakers. International journal of sports physiology and performance, 14(4), 486–492. https://doi.org/10.1123/ijspp.2018-0428
46. Lee, Y. S., Dingley, A., Lum, D., Tan, F., & Fernandes, J. F. T. (2025). Physiological and Physical Determinants of Flat-Water Kayaking. Muscles, 4(3), 32. https://doi.org/10.3390/muscles4030032
47. Rodríguez-Perea, A., Morenas Aguilar, M. D., Escobar-Molina, R., Martínez-García, D., Chirosa Ríos, I., Jerez-Mayorga, D., Chirosa Ríos, L., Janicijevic, D., & Reyes-Ferrada, W. (2023). Strength Assessment of Trunk Rotator Muscles: A Multicenter Reliability Study. Healthcare, 11(16), 2331. https://doi.org/10.3390/healthcare11162331
48. Roth, R., Donath, L., Zahner, L., & Faude, O. (2021). Acute Leg and Trunk Muscle Fatigue Differentially Affect Strength, Sprint, Agility, and Balance in Young Adults. Journal of strength and conditioning research, 35(8), 2158–2164. https://doi.org/10.1519/JSC.0000000000003112
49. Tazji, M. K., Sadeghi, H., Abbasi, A., Aziminia, M., Shahhosseini, A., Marjani, M. E., & Koumantakis, G. A. (2023). The Effects of Core Stabilization Trunk Muscle Fatigue on Lower Limb Stiffness of Basketball Players. Sports, 11(10), 200. https://doi.org/10.3390/sports11100200
50. Wakeling, J. M., Smiešková, S., Pratt, J. S., Vajda, M., & Busta, J. (2023). Asymmetries in paddle force influence choice of stroke type for canoe slalom athletes. Frontiers in Physiology, 14, 1227871. https://doi.org/10.3389/fphys.2023.1227871
51. Akca, F., & Muniroglu, S. (2008). Anthropometric-somatotype and strength profiles and on-water performance in Turkish elite kayakers. International Journal of Applied Sports Sciences, 20(1), 22-34.
52. Vando, S., Peyré-Tartaruga, L. A., Melenco, I., Dhahbi, W., Russo, L., & Padulo, J. (2026). Stroke Frequency Effects on Coordination and Performance in Elite Kayakers. Biomechanics, 6(1), 2. https://doi.org/10.3390/biomechanics6010002

Tables

Table 1 The characteristics of the study participants (N = 30)

Variables	Value
Age (years)	19.30±1.15
Height (cm)	177.68±5.39
Weight (kg)	72.00±7.67
Sitting height (cm)	94.58±2.91
Arm span (cm)	178.63±6.32
Training years (years)	4.23±1.27

Table 2 Instruments of Trunk Static and Dynamic Muscle Strength Variables

Variables			Measuring Method	Instruments
Trunk Muscle Strength	Trunk Static Strength	Abdomen Strength (sec)	ABT	(1) Stopwatch; (2) Floor mat;
		Back Strength (sec)	BBT	(1) Stopwatch; (2) Floor mat;
		Left Side Strength (sec)	LSBT	(1) Stopwatch; (2) Floor mat;
		Right Side Strength (sec)	RSBT	(1) Stopwatch; (2) Floor mat;
	Trunk Dynamic Strength	Flexion Strength (reps)	1-min SUT	(1) Stopwatch; (2) Floor mat; (3) Sit-up assistive device
		Extension Strength (reps)	1-min BET	(1) Stopwatch; (2) Floor mat;
		Left rotation Strength (reps)	1-min TLRT	(1) Stopwatch; (2) Floor mat;
		Right rotation Strength (reps)	1-min TRRT	(1) Stopwatch; (2) Floor mat;

Note: sec=Second, reps=Repetitions, 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

Table 3 Instruments of Sprint Performance Variables

Measuring Methods	Variables	Indicators	Instrument
K1 200m Flatwater Kayak-Specific Dynamometer/Ergometer Sprint Performance Test	Sprint time (sec)	SP	(1) Dansprint PRO Kayak dynamometer/ergometer (2) Kayak-specific dynamometer/ergometer sprint performance testing room
	Stroke rate (strokes·min⁻¹)	SR	
	Mean velocity (m·s⁻¹)	V-Mean	
	Peak velocity (m·s⁻¹)	V-Peak	
	Bilateral symmetry of paddling force output	BS-PFO	

Note: sec=Second, strokes·min⁻¹=strokes in 1-min, SP= Sprint Time Test, SR= Stroke Rate Test, V-Mean= Mean Velocity Test, V-Peak= Peak Velocity Test, BS-PFO=Bilateral Symmetry of Paddling Force Output Test

Table 4 Descriptive Statistics for Measures of Trunk Static and Dynamic Muscle Strength and Sprint Performance (N = 30)

Variables	Measuring Methods	Value Means and Standard Deviations	Normality Test Shapiro–Wilk or Kolmogorov–Smirnov (Sig.)
Trunk Static Muscle Strength			
Abdomen strength (sec)	ABT	165.50±58.86	.414
Back strength (sec)	BBT	295.13±102.23	.195
Left side strength (sec)	LSBT	71.50±25.63	.506
Right side strength (sec)	RSBT	81.20±21.98	.727
Trunk Dynamic Muscle Strength			
Flexion strength (reps)	1-min SUT	39.60±6.04	.764
Extension strength (reps)	1-min BET	36.60±4.70	.187
Left rotation strength (reps)	1-min TLRT	33.93±8.05	.969
Right rotation strength (reps)	1-min TRRT	34.77±7.92	.608
200m Single Flatwater Sprint Performance (dynamometer/ergometer)			
Sprint time (sec)	SP	68.48±8.97	.093
Stroke rate (strokes·min^{-1})	SP	115.90±14.21	.095
Mean velocity (m·s^{-1})	V-Mean	2.84±0.35	.404
Peak velocity (m·s^{-1})	V-Peak	3.02±0.31	.059
Bilateral symmetry of paddling force output	BS-PFO	-1.90±15.08	.269

Note: Data are group mean values ± standard deviations, sec=Second, reps=Repetitions, strokes·min^{-1}=strokes in 1-min, m·s^{-1}=meter in 1-min, 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, SP= Sprint Time Test, SR= Stroke Rate Test, V-Mean= Mean Velocity Test, V-Peak= Peak Velocity Test, BS-PFO=Bilateral Symmetry of Paddling Force Output Test

Table 5 Pearson Correlations with 95% Confidence Interval Between Trunk Static and Dynamic Muscle Strength and 200m Single Flatwater (dynamometer/ergometer) Sprint Performance Variables

Variables/Test	*K1 200m flatwater kayak-specific dynamometer/ergometer sprint performance test Variables*												
	SP (sec)			*SR (strokes·min⁻¹)*			*V-Mean (m·s⁻¹)*			*V-Peak (m·s⁻¹)*			*BS-*
	Pearson	*95% CI*		*Pearson*	*95% CI*		*Pearson*	*95% CI*		*Pearson*	*95% CI*		*Pea*
	Correlation	*Lower*	*Upper*	*Correlation*	*Lower*	*Upper*	*Correlation*	*Lower*	*Upper*	*Correlation*	*Lower*	*Upper*	*Cor*
Trunk Static Muscle Strength													
Abdomen strength (sec)/ABT	-.235	-.570	.235	.169	-.120	.562	.139	-.352	.494	.116	-.333	.531	-.01
Back strength (sec)/BBT	-.058	-.398	.287	.145	-.200	.528	.048	-.383	.466	.086	-.379	.488	-.29
Left side strength (sec)/LSBT	-.409*	-.719	.014	.058	-.291	.416	.339*	-.078	.669	.466**	.051	.732	-.07
Right side strength (sec)/RSBT	-.420*	-.713	-.035	-.186	-.479	.196	.286	-.085	.065	.313*	-.105	.660	-.04
Trunk Dynamic Muscle Strength													
Flexion strength (reps)/1-min SUT	-.658**	-.834	-.333	.328*	-.046	.660	.577**	.128	.821	.570**	.187	.795	-.01
Extension strength (reps)/1-min BET	-.328*	-.614	.063	.095	-.224	.530	.459**	.118	.749	.428**	.058	.689	.249
Left rotation strength (reps)/1-min TLRT	-.477**	-.733	-.125	-.453**	-.659	-.205	.491**	.120	.722	.501**	.168	.749	-.16
Right rotation strength (reps)/1-min TRRT	-.321*	-.664	.109	-.478**	-.691	.251	.313*	-.095	.618	.358*	-.113	.666	-.17

Note: *correlation is significant at the 0.05 level (two-tailed), **correlation is significant at the 0.01 level (two-tailed), sec=Second, reps=Repetitions, strokes·min⁻¹=strokes in 1-min, m·s⁻¹=meter in 1-min, 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, SP= Sprint Time Test, SR= Stroke Rate Test, V-Mean= Mean Velocity Test, V-Peak= Peak Velocity Test, BS-PFO=Bilateral Symmetry of Paddling Force Output Test

Figures

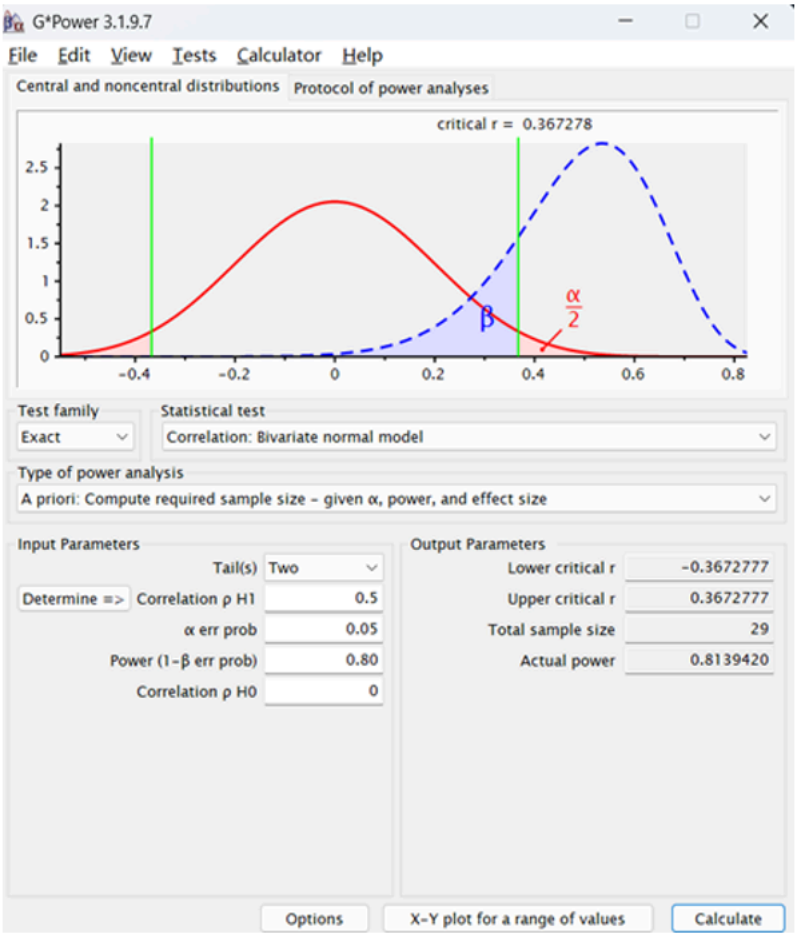


Fig. 1 Sample size estimation using G*Power software.

Figure 1

See image above for figure legend

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- data.sav