

## Article

# Morphology and Maturity Status and Their Relationship with Stroke Steadiness in Young Sprint Paddlers

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**Featured Application:** Coaches and sport managers in charge of talent identification processes in sprint canoeing might take into considerations these findings not only to select potential successful paddlers but also to enhance their attributes during early stages.

**Abstract:** Elite kayakers are characterized by robust somatotypes and a high degree of technical skills acquired from early ages along the biological maturity process. This study aimed to analyze the interdependence of anthropometric attributes, maturity status, and new stroke kinematics variables such as long- and short-term stroke steadiness in young sprint paddlers. Twenty-two elite young male canoeists, aged  $13.5 \pm 0.4$  years, volunteered for the investigation. A battery of anthropometric measurements was obtained for each individual while stroke kinematics were determined by lateral recordings in an all-out 200 m test. Frame-to-frame analysis of consecutive strokes allowed the determination of short-term and long-term steadiness. Significant and positive correlations ( $p < 0.05$ ) between maturity status, canoeing experience, and stroke steadiness were identified, especially in long-term steadiness ( $r = 0.60$ – $0.83$ ). In addition, upper-body dimensions in the chest and arms exhibited strong associations with both short- and long-term steadiness ( $p < 0.05$ ). These findings suggest that biological maturity, but particularly experience, are key factors for a higher stroke efficiency. Therefore, early identification of morphological characteristics and maturity status along with specific practice in canoeing should be taken into consideration for ideal talent development in young canoeists.

**Keywords:** kinematic analysis; canoeing; performance; biological maturity; anthropometry; talent identification



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## 1. Introduction

Optimal performance in sprint kayaking and canoeing requires a solid combination of physical, anthropometrical, and physiological attributes in athletes and a high degree of technical skill, which is partially dependent on stroke kinematics [1–4]. Since elite paddlers must generally maintain maximum efforts between 30 s and 3 min during competition, high levels of aerobic and anaerobic capacities are expected [5,6]. Previous investigations have reported significant associations between physical fitness attributes, such as upper and lower body strength, and specific on-water performance in 200 and 500 m courses [7–10].

Robust and compact morphologies have been typically described in the most successful paddlers of senior and other age-group categories [11,12]. Common anthropometric determinants of performance include large muscle mass and upper body girths and breadths in the trunk, chest, and arms [11,13–15]. However, in young paddlers, this morphological profile cannot be identified until paddlers reach their age at peak height velocity (APHV) along the maturity process [13]. During adolescence, athletes of the same age group often experience biological maturation at different tempos, resulting in greater differences in

physical fitness and morphology [16]. Performance at these ages is largely influenced by the level of maturity an athlete already possesses. Those who mature early typically achieve a maximum development of strength and power around their APHV and before the rest of the competitors [13,16]. Thus, the importance of any kind of attribute typically associated with performance is relative at early ages since their optimal development is highly related to individual maturation.

Achieving maximum stroke efficiency and boat speed relies on a balanced manipulation of kinematics parameters [17,18]. Previous studies identified higher stroke rates and stroke lengths among top kayakers, resulting in increased speed [2,4]. In fact, maximizing stroke length while maintaining stroke pace to enhance propulsion and minimize energy expenditure is particularly challenging during races [2,4]. The most common indicator of superior efficiency is the stroke index, obtained from the product of speed and stroke lengths [19,20]. Athletes with a higher stroke index exhibit higher speeds while expending less energy, leading to superior overall performance.

Within stroke efficiency, stroke and velocity steadiness holds significant importance in optimizing performance and achieving success in cyclic sports [21]. This refers to the ability to maintain a consistent and continuous stroke rate throughout a race. Recent research explored the association between stroke steadiness and performance outcomes in canoeing [22], highlighting the strong correlation between stroke steadiness and competitive success in young paddlers. However, there is limited understanding of how stroke steadiness is influenced by other variables that are related to performance in this sport.

Additionally, it is important to note that stroke steadiness can manifest in both short-term and long-term performance outcomes. Maintaining consistent stroke steadiness throughout consecutive strokes is related to the short-term dimension [23], while the long-term dimension is typically related to the overall dispersion of the strokes throughout the race [24]. Stroke steadiness has been presented in recent research by using the standard deviation of a time series of data to express long-term steadiness [22]. In the attempt to represent short-term steadiness, successive differences were used to express how one stroke varies from the immediately preceding one [22].

Stroke steadiness is directly related to performance in this sport in young athletes. Maturation factors, age, and morphology of the athletes also influence performance in this sport. The intrinsic value of this research is its examination of whether different performance determinants might be interdependent, as well as of how one factor might change depending on others when trying to improve performance in cyclic sports. It was hypothesized that stroke steadiness in canoeing will exhibit moderate to high correlation values with those anthropometric and maturation variables that have previously been determined as performance determinants. Therefore, the aim of this paper is to analyze the relationship between anthropometric and maturity variables and stroke steadiness in both the short- and long-term in order to find out whether these variables can influence performance through the improvement of stroke steadiness.

## 2. Materials and Methods

### 2.1. Participants

A total of 22 male canoeists voluntarily participated in this study. These participants were selected by the Royal Spanish Canoeing Federation to take part in the Annual National Development Camps, as they had achieved outstanding results in the previous National Championship for their respective age category. All participants were currently engaged in training for a minimum of 2 h per day, between 4 and 6 days per week. The descriptive values for the age, weight, stature, and experience of the 22 canoeists are presented in Table 1.

The research procedures followed in this study were approved by the Institutional Ethical Committee of the University of Murcia (No. 241011). Prior to the commencement of the study, written informed consent was obtained from the parents of the participants.

It is important to note that none of the participants exhibited any signs of illness or were undergoing pharmacological treatment during the testing period.

**Table 1.** Descriptive data of the sample (n = 22).

Variable	Mean	SD
Age (years)	13.5	0.4
Weight (kg)	55.2	11
Stature (cm)	163.2	8.4
Arm span (cm)	171.0	10.8
BMI (kg·m <sup>-2</sup> )	21.6	3.2
Experience (years)	2.6	0.5

SD: standard deviation; BMI: body mass index.

## 2.2. Procedures

In the present study, a descriptive correlational intragroup design was employed to investigate the interdependence between anthropometric and growth factors and steadiness kinematic variables in assessing canoeing performance and providing additional information to athletes and coaches in this sport.

Each participant completed a single all-out 200 m test on a measured flatwater course. If the wind speed exceeded 2 m/s, the test was postponed to prevent its influence on performance time. The performance test was conducted in a marked lane, with buoys positioned every 12.5 m to facilitate kinematic analysis.

Recordings of the trials were captured from a motorboat positioned laterally, following the paddler's navigation trajectory. To minimize the impact of waves, a minimum separation of 5 m was maintained between the motorboat and the canoe. The performance test was recorded using a JVC Everio MG-135 camera (Victor Company, Yokohama, Japan) at a frame rate of 30 frames per second. An experienced cameraman operated the camera to capture recordings for subsequent technical analysis.

During the recordings, the following instructions were followed: (1) the camera consistently faced the paddling side; (2) alignment was maintained between the camera, the canoe's bow, and the buoys to avoid parallax errors; (3) the frame included the paddler, the bow of the canoe, and sufficient space in front of the canoeist to provide a clear view of the distance buoys.

## 2.3. Anthropometric Measurement

A battery of anthropometric assessments was taken by a fully certified level 3 anthropometrist, following the protocols defined by Stewart et al. [25] and the International Society for the Advancement of Kinanthropometry (ISAK). Stretched stature (cm) and direct lengths (cm) were measured using a GPM anthropometer (Siber-Hegner, Zurich, Switzerland), body mass (kg) was determined using a SECA 862 digital scale (SECA, Hamburg, Germany), and girths (cm) were measured by non-extensible metallic tape (Lufkin W606PM, Missouri City, TX, USA). In addition, a Harpenden skinfold caliper (British Indicators, Surrey, UK) was used to assess the skinfold thickness (mm) at six specific sites (triceps, subscapular, supraspinale, abdominal, front thigh, and medial calf). Body composition estimation for muscular mass percentage and fat mass percentage was determined following the equations described by Poortmans et al. [26] and by Slaughter et al. [27], respectively. The equations of Carter and Heath [28] were used to calculate anthropometric somatotypes. At least two measurements were taken for each variable, and if the difference between them was greater than 5% for the skinfolds and 1% for the rest of the dimensions, a third measurement was completed. For subsequent data analysis, the mean values, or median in the case of three measurements, were used. The intra-rater technical error of measurement for skinfold thickness and for the rest of the variables was 3.17% and 0.78%, respectively. Furthermore, all instruments were calibrated before the beginning of each testing session to avoid any potential measurement errors.

#### 2.4. Maturity

The maturity status was determined by comparing the athletes' current chronological age to their age at peak height velocity (APHV). The APHV was calculated using the methods outlined in the study conducted by Mirwald et al. [29] and served as a significant milestone (with a value of 0) representing the period of maximum growth in stature. The measurement for each individual was expressed as the number of years before or after the peak height velocity (PHV), serving as an indicator of maturity offset. Negative values indicated the years remaining until APHV, while positive values indicated the years elapsed since APHV.

#### 2.5. Steadiness Variables

Kinematic analyses were conducted using frame-by-frame recordings on the software VirtualDub 1.10.4 (Avery Lee). The focus of the analysis was on stroke steadiness, which involved examining the stroke-to-stroke period (SP). To achieve this, the frame difference between the first contact of the blade with the water with the next one was calculated throughout the entire test. Once all the stroke-to-stroke intervals were determined, they were converted into milliseconds by multiplying the number of frames by 0.03. As a result, a time-series, represented as  $[SP_1; \dots; SP_i; \dots; SP_N]$ , was obtained for each performance test.

The variables computed from each time-series were the long-term steadiness (LTS) and short-term steadiness (STS).

The LTS refers to the absence of variability among all the data points that comprise the time-series. For this purpose, the inverse function of the standard deviation was calculated to obtain the inverse of the total dispersion of the time-series (1). LTS facilitates the analysis of the absence or presence of variability over a specific time series, allowing the examination of the total dispersion of the whole test, considering each stroke or time point as an independent unit.

$$LTS = \frac{1}{\sqrt{\frac{\sum_i^N (SP_i - SP)^2}{N}}} \quad (1)$$

On the other hand, STS, which refers to the absence of variability between consecutive data points within the time-series, was computed as the inverse function of the root mean square of successive differences between data points (2). This variable permits the examination of the absence or presence of variability over a specific time series. Thus, the total dispersions of the complete test can be analyzed by comparing each stroke or time point with the one immediately preceding it and subsequently observing the instantaneous stability over each period.

$$STS = \frac{1}{\sqrt{\frac{\sum_{i=1}^{N-1} (SP_i - SP_{i+1})^2}{N-1}}} \quad (2)$$

#### 2.6. Statistical Analyses

The statistical analysis was performed using the SPSS statistical package, version 23 (IBM, New York, NY, USA), for Windows. Before conducting the data analysis, the normal distribution of the variables was assessed using the Shapiro–Wilk test. The main variables of stroke steadiness, STS and LTS, were examined in relation to the rest of the anthropometric variables, age, and maturation, presenting all of them as continuous variables. To evaluate the relationships between variables, Pearson's coefficient of correlation ( $r$ ) was employed when the variables exhibited a normal distribution. Alternatively, the Spearman coefficient of correlation ( $\rho$ ) was utilized when the variables were not normally distributed. Correlations were interpreted as: no correlation ( $r < 0.2$ ), low correlation ( $0.2 < r < 0.4$ ), moderate correlation ( $0.4 < r < 0.6$ ), high correlation ( $0.6 < r < 0.8$ ), and very high correlation ( $r > 0.8$ ), respectively, for negative values. When correlations showed  $p < 0.05$ , they were considered as significant.

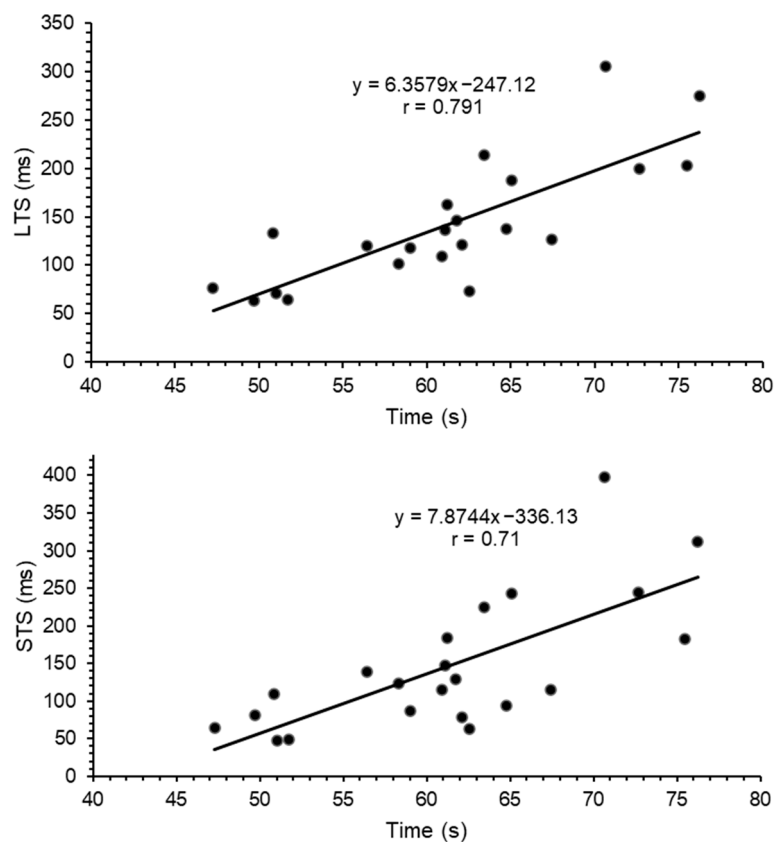
### 3. Results

Table 2 summarizes the correlations of short-term steadiness and long-term steadiness with classic kinematic variables. The results indicated significant positive correlations between STS and variables such as velocity, stroke rate, and stroke index. Furthermore, LTS showed positive correlation with the same kinematic variables. The linear relationship between performance time and LTS and STS is presented in Figure 1.

**Table 2.** Correlation values between LTS and STS with kinematic variables.

	LTS	STS	Min	Max	V	SR	SL	SI
LTS	1	0.896 *	0.767 *	0.207	0.789 *	0.550 *	0.265	0.708 *
STS		1	0.777 *	0.344	0.701 *	0.598 *	0.085	0.547 *

\*  $p < 0.05$ . LTS: long-term steadiness; STS: short-term steadiness; Min: shortest stroke cycle; Max: longest stroke cycle; V: velocity; SR: stroke rate; SL: stroke length; SI: stroke index.



**Figure 1.** Linear relationship between performance time and LTS (**upper** graph) and STS (**lower** graph).

The correlations between STS and LTS with age at peak height velocity and basic anthropometric attributes are presented in Table 3. The findings revealed a positive correlation between STS and LTS with APHV, indicating that individuals with peak height velocity at a later age tend to exhibit higher steadiness. Furthermore, both STS and LTS showed high correlation values with experience in the sport, illustrating the dependence of these variables on more years of experience. However, no significant correlations were observed between LTS and STS and height, weight, or arm span.

Table 4 shows the correlations of STS and LTS with anthropometric girths and diameters. The results indicated a moderate positive correlation between STS and various anthropometric measures, such as arm girth, chest girth, and biacromial and transverse chest breadths. In addition, these correlation values were also identified when related to LTS.

**Table 3.** Correlation values between LTS and STS anthropometric basic variables, APHV, and experience.

	Height	Weight	Arm Span	APHV	Experience
LTS	0.300	0.255	0.246	0.602 *	0.826 *
STS	0.237	0.181	0.219	0.474 *	0.701 *

\*  $p < 0.05$ . LTS: long-term steadiness; STS: short-term steadiness; APHV: age at peak height velocity.

**Table 4.** Correlation between LTS and STS and anthropometric girths and diameters.

	RAG	FAG	FG	WG	CG	MTG	MCG	BB	TCB
LTS	0.517 *	0.498 *	0.258	0.186	0.626 *	0.248	0.242	0.581 *	0.611 *
STS	0.411 *	0.337 *	0.182	0.146	0.453 *	0.189	0.205	0.456 *	0.546 *

\*  $p < 0.05$ . LTS: long-term steadiness; STS: short-term steadiness; RAG: relaxed arm girth; FAG: flexed and tensed arm girth; FG: forearm girth; WG: wrist girth; CG: chest girth; MTG: mid-thigh girth; MCG: calf girth; BB: biacromial breadth; TCB: transverse chest breadth.

Finally, the correlations between STS and LTS, body composition, and somatotype are presented in Table 5. The results revealed moderate positive correlations between STS and muscle mass but not with the rest of the body composition variables and somatotypes. Moreover, LTS showed similar correlation values to the ones presented for STS.

**Table 5.** Correlation between LTS and STS and body composition and somatotype.

	Fat Mass	Muscle Mass	Bone Mass	Endomorphy	Mesomorphy	Ectomorphy
LTS	−0.122	0.572 *	−0.346	−0.152	−0.016	−0.123
STS	−0.086	0.423 *	−0.182	−0.131	−0.050	−0.025

\*  $p < 0.05$ . LTS: long-term steadiness; STS: short-term steadiness.

#### 4. Discussion

The aim of the current investigation was to analyze the relationship between anthropometric variables, maturity status, and stroke steadiness in young elite canoeists. The main finding of this study was the strong interrelationship identified between stroke steadiness and paddler’s experience and maturity status and chronological age, especially in LTS. In addition, morphological parameters typically exhibited by the more successful paddlers, such as upper body breadths and girths, were significantly related to strong steadiness. Since this is the first study analyzing stroke steadiness and morphology in canoeing, the results might help coaches identify the determinants and develop more complete training programs for young canoeists.

The significant correlations between experience and stroke steadiness identified in the present research might suggest that early specialization would provide more practicing time in the canoe to achieve an efficient technique that might result in optimal kinematics and performance in sprint canoeing. Previous studies in young paddlers have highlighted the importance of technical ability in canoeing, identifying maturity differences in comparison with kayakers [30,31]. Traditionally, all young paddlers begin their familiarization with and acquisition of fundamental paddling skills in kayaking. It is only after gaining expertise in kayaking that they contemplate the choice of transitioning to canoeing or continue to focus on excelling in kayaking [31]. Consequently, the more practicing time in canoeing, the more efficient the technique and performance that a young athlete attains. Achieving optimal performance in kayaking requires early and robust physical development commonly related to advanced-maturity individuals [8,15], whereas canoeing places a greater emphasis on technical proficiency [31]. Consequently, talent identification and development programs should consider maturity estimation at early ages for discipline selection to ensure athletes obtain adequate experience time in kayaking or canoeing for the acquisition of fundamental skills and better propulsion efficiency.

A typical morphological profile of Olympic paddlers is characterized by a compact and robust somatotype [11]. Although greater body dimensions might result in heavier

individuals and negatively affect friction drag and boat speed, larger competitors seem to compensate, perhaps through higher or more effective propelling forces [1,32]. Similarly, the results of the current investigation indicated that more muscular athletes also presented better LTS and STS. Prior studies have reported greater values of biacromial breadth and chest and arm girths in senior and elite competitors compared to younger and lower-level paddlers [15,33–35]. These results have been supported by previous proportionality investigations where similar tendencies toward larger upper-body dimensions were observed, not only in senior competitors [11] but also along the transition from lower age groups to adult categories [13].

During a kayak race, an efficient propulsion is largely dependent on a balanced combination of kinematics that usually change from one section to another for optimal performance [20]. More successful paddlers typically use greater stroke rates and longer stroke lengths than sub-elite competitors, resulting in significantly higher boat velocities [2]. However, at the end of races, when fatigue is more pronounced, minimizing the decreases in stroke rate while maintaining stroke length seems to determine effective performances [4]. Our results revealed significant positive correlations between variables such as stroke rate and stroke index and both STS and LTS measures. These findings provide further support to the existing theory suggesting that higher values of STS and LTS are associated with improved performance in canoeing [22]. Stroke rate and stroke index are widely recognized as important kinematic variables related to performance in canoeing [20]. These variables are indicators of efficiency and effectiveness in propelling the canoe forward. Our study demonstrated that individuals with higher STS and LTS values tended to exhibit higher stroke rates and stroke indices, indicating a smoother and more consistent paddling technique.

The positive correlations observed between STS, LTS, and these classic kinematic variables suggest that steadiness measures play a crucial role in optimizing canoeing performance. Individuals with better short-term and long-term steadiness are likely to maintain a more consistent and efficient paddling rhythm, resulting in an increased stroke rate and stroke index. These findings align with previous research highlighting the importance of stability and consistency in achieving optimal performance in various sports [21]. The observed correlations between STS, LTS, and experience support the notion that these variables may depend on technique improvement through training rather than being solely related to biological aspects. Our findings suggest that individuals with more experience in the sport tend to exhibit higher STS and LTS values, indicating a greater level of steadiness in their movements. This aligns with the hypothesis that prolonged training and practice contribute to the refinement of motor skills, resulting in improved steadiness [36]. Therefore, it is reasonable to suggest that the correlations observed between STS, LTS, and experience can be attributed to the cumulative effect of dedicated training time, emphasizing the importance of technical development in achieving higher levels of steadiness in movement performance.

We considered this study to be important, as we know that stroke steadiness is directly related to performance in this sport in young athletes. Maturation factors, age, and the morphology of athletes also influence performance in this sport. The intrinsic value of this research is its examination of whether different, independently analysed factors that affect performance can be interdependent, so that they can be trained together or even changed when trying to improve performance in cyclic sports.

The main limitations of this study are the lack of previous research on stroke steadiness as well as some methodological limitations that may lead to small measurement errors, such as video cameras recording at low frames per second. However, this research could be carried out without problems with the materials presented.

As for future lines of research, there is still a wide field for further research on stroke steadiness depending on the level of the athletes, gender, or other external variables that may affect the dynamics of the boat.

## 5. Conclusions

The present study highlights the significance of steadiness in canoeing performance and underscores the need for further research to explore factors that can enhance it. Steadiness, as reflected by short-term steadiness (STS) and long-term steadiness (LTS), plays a crucial role in optimizing paddling techniques and efficiency. Understanding the factors that influence steadiness can provide valuable insights for training programs aimed at improving performance in canoeing. Continued investigation into the determinants of steadiness, including biomechanical, physiological, and technical factors, is essential to uncover strategies for enhancing steadiness and ultimately improve performance in this sport.

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**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee from the University of Murcia with the reference No. 241011.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

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