ORIGINAL ARTICLE

Anthropometric and biomechanical factors to predict rowing ergometer performance among collegiate rowers

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ABSTRACT

Purpose: This study examined the relationships between anthropometric and biomechanical variables and 2000 m rowing ergometer performance in novice collegiate rowers. Methods: Sixty-six university-level students with basic rowing instruction completed a 2000 m ergometer test. Anthropometric measures (height, mass, wingspan, sitting height, leg length) and biomechanical variables (start output, mean and peak power, distance per stroke) were recorded. Results: Significant correlations were found between performance and all anthropometric variables ($p < .01$), with mass (r = -0.807) and height (r = -0.702) showing the strongest associations. Peak output watts (r = -0.705) also correlated strongly with performance. Conclusion: Anthropometric and biomechanical variables are significant predictors of 2000 m ergometer performance even in novice rowers, supporting their use for early talent identification and training guidance.
Keywords: Biomechanics, Rowing ergometer, Anthropometric factors, Power output, Stroke length, Performance analysis.

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INTRODUCTION

Rowing is widely recognized as one of the most physically and technically demanding sport disciplines. It is a predominant endurance sport in which muscles of the whole body are used, involving coordinated efforts from the legs, arms, glutes, back, abdominals, pectorals, and shoulders to cover a certain distance (Penichet-Tomás and Pueo, 2017). Steinacker (1993) states that 70% of all of muscle mass is activated in a rowing cycle. But all muscles do not contribute equally to power production (Baudouin and Hawkins, 2002). Telmo (2016) indicates that 46% of the power is provided by the legs, 32% by the trunk and 22% by the arms and Kornecki and Jaszczak (2010), concluded that hip and knee extensors along with shoulder girdle flexors and extensors were those most involved in the production of power during the stroke. Furthermore, since nearly all muscles groups are used in the rowing stroke, a greater range of motion, particularly during the drive, allows for increased muscle recruitment. By optimizing body compression at the catch position, rowers can engage more muscle mass and generate greater force, thereby enhancing the effectiveness of each stroke and improving overall performance. (Akça, 2014; Mikulik, 2009; Yoshiga and Higuchi, 2003). For this reason, some authors have looked for relationships between anthropometric characteristics and performance (Sánchez-Sixto and Floria, 2017).

Bourgois et al. (2000) performed anthropometric measurements on 383 rowers aged 15 to 18 years from 41 different countries who had participated in the World Rowing Championship. Their results showed that height, wingspan and muscle mass were directly related to performance. In a study with rowers of the Croatian national team, Mikulic (2009) found that fat-free mass was the most important anthropometric parameter with a correlation coefficient of 0.767 ($p < .001$) with performance in a 6000 m rowing test. Weight (r = 0.693; $p < .001$) and with wingspan (r = 0.505; $p < .05$) also showed significant correlations. Penichet-Tomás and Pueo (2017) obtained similar results with 22 elite Spanish rowers using a 2000m rower test: fat-free mass (r = 0.973; $p < .001$), height (r = 0.873; $p < .001$), mass (r = 0.894; $p < .001$) and fat mass (r = - 0.705; $p < .001$). At a lower performance level, but still with high-level rowers and using a 2000m test, Akça (2014), found correlations in the same direction as those cited above: fat-free mass (r = 0.822; $p < .001$), mass (r = -0.812, $p <. 001$), height (r = -0.801; $p < .001$), wingspan (r = 0.715; $p < .001$), length of legs (r = 0.703; $p < .001$) and sitting height (r = 0.687; $p < .001$). Among the limited studies involving novice rowers, Podstawski et al. (2014) investigated 196 physically inactive Polish girls aged between 19 and 23 who had been instructed in rowing techniques in physical education classes. Unlike elite or sub-elite rowers, they found no significant correlation with muscle mass, but they found correlation with height, mass and arm spam.

Focusing on the relationship between power output during the stroke and stroke rate, Muniesa et al. (2011) reported that, in the central section of the rowing competitions, the stroke rate is usually between 34 and 40 strokes per minute, and that there is a linear relationship between power and stroke rate. This contribution is confirmed by Telmo (2016) who explains that the power per stroke increases by 12% when stroke rate rises from 20 to 35 strokes per minute. Therefore, at a higher stroke rate is associated with greater power output per stroke, which in turn contributes to improved overall performance. (Holt et al., 2022).

Finally, regarding the relationship between start strategy and performance, Anderson (2011) compared a fast start versus a continuous start with performance in two tests that lasted less than four minutes. The rowers who had done the fast start finished the test with a 4% advantage. Holt et al. (2021) investigates boat acceleration metrics and their relationship to rowing performance, using quantitative biomechanical data to determine how acceleration at different stroke phases (including the start) correlates with race outcomes. While the study doesn't focus exclusively on the start phase of a race, its findings are relevant. The start involves rapid, powerful strokes to quickly accelerate the boat. The identified acceleration patterns during the drive and recovery phases can influence the effectiveness of these initial strokes. Therefore, optimizing these acceleration metrics during regular rowing can enhance performance during the critical start phase. Despite the research of Anderson (2011) and Holt et al. (2021) no studies have been published with beginner or intermediate level rowers.

Although numerous studies have examined anthropometric and biomechanical predictors of rowing performance, most focus on elite athletes. Limited research exists on novice or collegiate populations. Understanding these predictors at early stages can inform talent identification and training strategies.

MATERIALS AND METHODS

Participants

A total of 66 male sports science students participated voluntarily in this study (age: 20.65 ± 3.96 years). All participants provided informed consent and were recruited from sports science courses and had received basic ergometer instruction. Anthropometric variables were measured and are presented in Table 1 (Penichet-Tomás, 2016).

Table 1. Mean and standard deviation (SD) of anthropometric variables.

Anthropometric parameter	Mean ± SD
Height (m)	1.76 ± 0.07
Body mass (kg)	71.77 ± 7.43
Wingspan (m)	1.78 ± 0.08
Sitting height (m)	1.36 ± 0.03
Trunk length (m)	0.92 ± 0.03
Leg length (m)	0.84 ± 0.05

Procedure

Performance was analysed by a 2000 m rowing test (Smith and Hopkins, 2012), using a Concept II model D row ergometers (Lawton et al., 2012) with PM5 monitor, connected to the ErgData application via Bluetooth on the mobile phone and digital tablet. This instrument allowed measuring two power variables (mean and peak output power) and three kinematics (start distance, distance per stroke and mean pace during the test).

Before the 2000m rowing test, participants performed a standard warm-up consisting in: 1 minute rowing with only the arms, 1 minute incorporating the trunk (trunk-arms), 1 minute including the legs but without doing the full stroke length and 7 minutes of full rowing length at 18-20 strokes per minute (at minute 6 from the start, there was an increase of 8 kicks at 28 strokes per minute and at minute 8 another increase of 10 strokes at 30 strokes per minute).

Statistical analysis

Statistical analyses were performed by the Package Social Sciences (SPSS) version 26. First, descriptive statistics were extracted for all variables, and a normality test was carried out. After checking normality and homoscedasticity parametric (Pearson) correlations were done with a 95% (p < .05) significance level. Later, lineal regression equations were obtained using those anthropometric variables that had a correlation value of r > 0.6.

RESULTS

Kinematic descriptive statistics are presented in Table 2 and its correlation with performance is presented in Table 3. As can be seen, except for the mean pace during the test (p > .05) all they present statistically significant correlations, highlighting the peak output watts (r = -0.705, p < .01).

Table 2. Kinematic descriptive statistics and correlations with performance.

Variable	Mean ± SD	Range
Mean output watts (W)	217.05 ± 33.44	156-497
Peak output watts (W)	408.12 ± 70.15	218-610
Start distance (m)	36.1 ± 8.43	22.9-58.7
Mean distance per stroke (m)	9.28 ± 0.98	6-11.3
Mean pace during the test (strokes/min)	28.35 ± 2.89	23-36

Table 3. Correlation between biomechanical variables and performance.

Variable	r	*p*
Mean output watts (W)	-0.520	<.01
Peak output watts (W)	-0.705	<.01
Start distance (m)	-0.488	<.01
Mean distance per stroke (m)	-0.497	<.01
Mean pace during the test (strokes/min)	-0.186	.138

All anthropometric variables present significant negative correlations with performance as can be seen in Table 4. Among all of them, the correlation between mass (r = -0.807, p < .01) and height (r = -0.702, p < .01) with performance stands out. Negative correlations indicate that higher values of anthropometric measures were associated with faster 2000 m times.

Table 4. Correlations between anthropometric variables and performance.

Anthropometric parameter	r	*p*
Height (m)	-0.702	<.01
Mass (kg)	-0.807	<.01
Wingspan (m)	-0.682	<.01
Sitting height (m)	-0.550	<.01
Trunk length (m)	-0.547	<.01
Leg length (m)	-0.623	<.01

Table 5. Linear regression equations.

Variable	Equation	R^2	SEE
Height (m)	y = 938.666 + (-2.650 x)	0.49	17.84
Mass (kg)	y = 664.529 + (-2.684 x)	0.64	14.97
Wingspan (m)	y = 866.955 + (-2.219·x)	0.46	18.33
Leg length (m)	y = 754.723 + (-3.347 x)	0.39	19.6
Multiple equation considering these variables	y = 966.218 + (-308 height) + (-2.545 mass) + (-1.436 wingspan) + (-0.022 leg length)	0.809	18.76

Note. R^2: determination coefficient; SEE: standard error of the estimate.

Linear regression equations

Using anthropometric variables with correlations greater than 0.6, the linear regression equations presented in Table 5 were calculated.

DISCUSSION

There are several papers that confirm the importance of anthropometric factors in performance in the sport of rowing (Akça, 2014; Mikulic, 2009; Yoshiga and Higuchi, 2003; Penichet-Tomás and Pueo, 2017; Podstawski et al. 2014) but almost all studies focus on experienced (high-level) rowers. Therefore, the aim of this study was to check whether these anthropometric parameters influenced the performance of beginner rowers.

Results showed in Table 2 indicate the associations between performance and the anthropometric parameters analysed. Highlights the great correlation obtained with body mass (r = -0.807; $p < .01$) which coincides with the results obtained by Akça (2014), Bourdin et al. (2017), Mikulik (2009), Penichet-Tomás and Pueo (2017) and Secher (1983). In contrast, the results of Podstawski et al., (2014), with a sample of sedentary high school students did not show this level of correlation. This highlights the importance of muscle mass in this sport as explained by Cosgrove et al., (1999), who indicate that a high value of muscle mass is one of the most important predictors of rowing performance in both men and women.

Height also showed a high correlation with performance (r = -0.702; $p < .01$). These results agree with those found in the literature in a whole range of different samples: Bourdin et al., (2017) with rowers of international level, Penichet-Tomás and Pueo (2017) with experienced rowers, Akça (2014) with university rowers, and Riechaman et al., (2002) with rowers from a rowing meter championship. Although correlation does not imply causation, the consistency of this result across multiple studies suggests that height may provide a performance advantage in rowing. This relationship can also be seen in the results of top-level competitions, for example, at the 2024 Paris Olympic Games, the medallists for the single sculls event were over 2m tall for men and 1.80m tall for women. The effect of height on performance can be justified on the one hand by the fact that rowing uses the muscles of the whole body (legs, trunk and arms) and, therefore, a larger body size implies more muscles to perform the stroke. On the other hand, because a greater height allows the rower to perform a longer kick and therefore cover more meters in each kick (Huang, 2007).

Leg length (r = -0.623; $p < .01$) and wingspan (r = -0.682; $p < .01$) shoved a medium-to-high correlation with performance. These results agree with those found by Akça (2014), Mikulik (2009) and Penichet-Tomás (2016). Leg action plays a critical role during the initial part of the drive phase, particularly during leg extension. Therefore, greater leg length implies a larger muscular contribution and allows the rower to achieve a longer stroke length. As a result, rowers with longer legs may require fewer strokes to cover the same distance compared to those with shorter legs. (Podstawski et al., 2014; Sebastia-Amat et al., 2020).

Sitting height (r = -0.550; $p < .01$) and trunk length (r = -0.547; $p < .01$), showed a medium intensity correlation with performance which contrasts with the correlation obtained by Penichet-Tomás (2016). This discrepancy could be explained by the difference in technical level in the samples used, beginners vs international level. It is likely that the advanced technique of high-level rowers enables them to more effectively engage their trunk muscles during the rowing stroke.

Focusing on start variables (average watts, peak watts and distance travelled) results show that peak watts obtained the greatest correlation (r = -0.705; $p < .01$), followed by average watts (r = -0.520; $p < .10$) and start distance (r -0.488; $p < .01$). These results agree with those presented by Mäestu et al., (2005) who indicated the importance of a powerful and fast start in rowing tests. Nevertheless, these correlations are not too high, which may be because the duration of the test was more than four minutes, and as Anderson (2011) indicates fast starts are important when doing distances that last less than 4 minutes. Regarding the average distance per stroke, results are like those of Muniesa et al., (2011) who indicate that the greater the distance per stroke, the better the performance because fewer strokes are needed to finish a regatta. However, the intensity of this correlation is not too high (r = -0.497; $p < .01$). No significant correlations ($p > .05$) were obtained between stroke rate and performance unlike the results presented by Muniesa et al., (2011) who indicated the linear relationship between stroke rate and performance if the rate does not exceed 40 strokes/minute. The absence of a significant correlation may be attributed to the participants' limited experience with the rowing ergometer, potentially preventing them from maintaining a high stroke rate without compromising technique. Coordinating proper rowing mechanics becomes more challenging at higher stroke frequencies compared to slower ones. Additionally, sustaining a faster pace requires a more developed anaerobic energy system, which likely demands a higher level of training than what novice rowers possess.

By integrating all the results, regression equations have been obtained. These equations may be useful for coaches who want to predict the performance of rowers in amateur categories, without the need to perform a maximum test over 2000 m. Similar to Akça (2014) who establishes equations to predict performance in the 2000 m test, one based on strength tests, another on anthropometric parameters, another on anaerobic tests and a final one that combines all variables.

These findings suggest coaches working with novice rowers can use simple anthropometric assessments to identify potential performance advantages early in training programs.

Although rowing ergometer tests are widely validated in the scientific literature, it is not the natural condition in which canoeing is practiced, so to have greater ecological validity, in future studies it would be desirable to use tests carried out in canoes.

CONCLUSION

This study confirms that anthropometric and kinematic variables are significantly associated with rowing ergometer performance in novice university-level rowers. Greater height, body mass, wingspan, sitting height, and leg length were all correlated with improved performance, suggesting that anthropometric characteristics play a key role even at early stages of rowing development. Among the kinematic variables, peak power output during the start phase showed the strongest relationship with overall performance, highlighting the importance of explosive strength in initial acceleration. In contrast, stroke rate did not correlate significantly with performance, possibly due to the participants' limited technical proficiency and lack of anaerobic conditioning, which may hinder their ability to sustain high stroke frequencies without compromising form. These findings underscore the value of considering both morphological and biomechanical factors in the early identification and training of rowing talent. Future research should examine longitudinal changes in these predictors as rowers advance in training and competition.

AUTHOR CONTRIBUTIONS

Ainoa Santana-Micó: literature review, study design, data collection, data interpretation. Enrique Moreno-Mañas: writing, reviewing/editing a draft of the manuscript, literature review. Salvador Llana-Belloch: study design, research concept, data analysis, supervision. Alfonso Penichet-Tomas: conceptualization, methodology, data interpretation, statistical analyses.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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