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# Contributions of Anthropometric and Strength Determinants to Estimate 2000 m Ergometer Performance in Traditional Rowing

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Received: 29 August 2020; Accepted: 18 September 2020; Published: 20 September 2020



**Abstract:** The purpose of this study was to analyze the contribution of anthropometric and strength determinants of 2000 m ergometer performance in traditional rowing. Nineteen rowers competing at national level participated in this study. Anthropometric characteristics, vertical jumps and bench pull tests were assessed to determine conditional factors, whereas the 2000 m test was used to set rowing performance. Pearson correlation coefficient, linear stepwise and allometric regression analyses were used to predict rowing performance ( $R^2 > 50\%$ ). Height, body mass and body muscle correlated with rowing performance in male and female rowers. Similarly, power output for squat jump and countermovement jump power correlated with performance. Finally, mean propulsive velocity, mean power and maximum power in bench pull also correlated with the test. Stepwise multiple regression analysis identified body mass ( $R^2 = 0.69$ ,  $p < 0.001$ ) and mean propulsive velocity in bench pull ( $R^2 = 0.76$ ,  $p < 0.001$ ) for male rowers and body muscle ( $R^2 = 0.89$ ,  $p = 0.002$ ) and maximum power in bench pull ( $R^2 = 0.62$ ,  $p = 0.036$ ) for female rowers as the best predictors of rowing performance. These results determine the relevance of anthropometric characteristics and, in contrast to Olympic rowing, support the greatest importance of upper body power in traditional rowing training.

**Keywords:** bench pull; vertical jump; power; talent detection; training

## 1. Introduction

Rowing is a cyclic, strength-endurance sport that requires high levels of aerobic and anaerobic capacity to displace a boat through the water [1,2]. Rowers use the whole body to perform the rowing stroke for a distance that differs according to the modality [3]. There are two different rowing modalities, traditional—or fixed—rowing and Olympic rowing, with different performance indicators: distance, race time, mean force, total number of strokes and power per stroke and velocity of the boat [4]. Traditional rowing is a non-Olympic modality that demands high physical condition to carry out between 35–40 strokes per minute throughout a 19–20-min race, slightly longer than in Olympic rowing [4]. Traditional rowers show a 250–350 W average force applied for an optimal stroke length [4,5]. The power-capacity at each stroke has been identified as a key factor of rowing performance [4,6], together with other factors like large body size, relatively large limbs, high muscular strength, high muscular and cardiovascular endurance and proper balance [6–9].

Whereas approximately 46% of the power produced in Olympic modalities is generated by legs, the remaining is produced by trunk and arms [10]. In traditional rowing, the contribution of legs is slightly lower (40%) and the role of trunk and arms are slightly higher (60%) [11]. This fact may be due, among other factors, to the semi-flexed position of legs during the recovery of the traditional

rowing cycle [12]. This position must be adopted as a consequence of the fixed seat, which entails an increase in the degree of body extension [13].

Traditional rowing is experiencing a significant increase in athletes worldwide and has attracted the attention of sports scientists in the same way as in Olympic rowing. International research interest has enhanced due to physiological, performance and championships differences [4], the professionalization of this modality and the rise of worldwide championships in Europe (Spain, Italy, United Kingdom, etc.), America (Canada, USA, etc.) and other regions like Saudi Arabia [13]. Traditional rowing studies has increased in the field of sports profile [14], championships performance [13], supplementation [15], physiological factors [4] and different training characteristics and methodologies [4,16].

Most studies have mainly focused on describing performance factors in Olympic rowing [11], mainly those related with physiological and anthropometric variables and, to a lesser extent, in traditional rowing [4,13,16,17]. In the same way, research conducted to date relates the importance of some anthropometric characteristics like height, body mass, muscle mass or body fat in Olympic rowing performance [1]. Most of these studies have investigated the determinants of both Olympic and indoor rowing using correlation and linear regression techniques, assuming a linear relationship between rowing performance and determinants [8,18,19]. For curvilinear relationships between various measures of power output, a proportional allometric model can also be used [20,21]. However, the contribution of these determinants to rowing ergometer performance in traditional rowing has not been widely demonstrated. Several studies showed the relationship between 1500 m or 2000 m rowing ergometer performance in Olympic modality and lower body power obtained from different types of jump [8,22,23]. Similarly, a link has been shown between rowing ergometer performance and power produced by the upper body during different protocols of bench pull (BP) tests [4,24,25]. Even peak power output sustained during maximal incremental testing is an overall index of physiological rowing capacity and rowing efficiency and allows predicting rowing ergometer performance [26]. However, to the knowledge of the authors, there are no studies that relate the rowing ergometer performance in traditional rowing, considering that the contribution of the upper body is slightly higher in traditional rowing than in Olympic rowing [11,27]. Likewise, no available studies in the literature have considered the use of proportional allometric modeling to predict 2000 m ergometer rowing performance in traditional rowing.

Therefore, the purpose of this study was to analyze the contribution of anthropometric and strength determinants of rowing ergometer performance in traditional rowing. To that end, the relation of anthropometric characteristics and upper/lower body contribution with 2000 m rowing ergometer performance test was carried out using correlation, linear and allometric regression techniques.

## 2. Materials and Methods

### 2.1. Participants

Nineteen sweep (board) rowers competing at the national level participated in this study: 12 males (7 port and 5 starboard, 10 heavyweight and 2 lightweight, age:  $24.6 \pm 3.9$  years, height:  $178.4 \pm 8.9$  cm, body mass:  $77.3 \pm 7.9$  kg) and 7 females (3 port and 4 starboard, 2 heavyweight and 5 lightweight, age:  $25.7 \pm 4.4$  years, height:  $166.3 \pm 7.5$  cm, body mass:  $59.9 \pm 8.3$  kg). The requirement to participate was to have classified for the national championship, to train regularly a minimum of five days per week ( $> 12$  h/week) for the last 3 years and not to have any musculoskeletal or neurological disorders, heart or respiratory failures, or any circulatory disturbance that may influence the results of the investigation. Rowers were requested to abstain from caffeine and alcohol consumption for 24 h and to avoid high-intensity training for 48 h before testing. All participants gave their written consent after project information, which was previously approved by the research ethics committee of the University of Alicante (IRB No. UA-2019-07-23).

## 2.2. Procedures

To determine the contribution of the different variables in rowing ergometer performance, the strength of lower/upper body and 2000 m rowing ergometer performance were tested. Data collection was conducted on three sessions carried out at the same time of the day in a controlled laboratory environment. Dynamic muscle strength and power tests appear to discriminate better between levels of rowing performance than isometric strength tests [28,29]; therefore, during the second session, rowers performed vertical jump tests and the bench pull test (BP). Finally, rowers completed a 2000 m test on a rowing ergometer in the third session. All athletes were familiarized with the testing protocols used in the present study. Pearson correlation statistical test and stepwise multiple linear regression calculations were used to establish strong common variances shared between predictors.

Anthropometric measurements were collected with an astra stadiometer with a mechanical scale to measure height (0.1 cm) and with a body composition analysis device for body mass (0.1 kg), body muscle (0.1 kg) and percentage of fat mass (0.1%) (TanitaBC-545N) [1], through the use of bioelectrical impedance analysis, which is based on the rate at which a weak electrical current travels through the body [30,31].

### 2.2.1. Vertical Jump Test

Three vertical jump types, squat jump (SJ), countermovement jump (CMJ) and repeat jump (RJ) [13], were used to evaluate the lower body power with a jump-mat system (Chronojump, Bosco-System, Barcelona, Spain), capturing 1000 samples per second. Each participant completed three trials of each type of jump with a rest period between actions of 2 min. The best performance was used for data analysis. In SJ, participants began from a flexed position with knees to 90 degrees and hold this position for 3 s before executing jump without any countermovement. The CMJ test started with the standing position, hands on hips and using the countermovement to jump as high as possible after descending to the half squat position. The RJ followed the same procedure that CMJ but with a continuous execution during 30 s. Elastic index (EI) was calculated from the difference between two jump types (SJ and CMJ), mechanical power (MchP) was calculated with Test time ( $T = 30$  s), flight time ( $f_i$ ) and the number of jumps ( $n$ ) as  $MchP = (g^2 \cdot T \cdot f_i) / [4n \cdot (T - f_i)]$ . Finally, to calculate the resistance index (RI) to fast strength, the average height reached in RJ was related to CMJ height as  $RI = h_{RJ} / h_{CMJ}$  [13]. Power output prediction equations based on body mass, jump height in SJ ( $h_{SJ}$ ) and CMJ ( $h_{CMJ}$ ) were: predicted power SJ =  $60.7 \cdot h_{SJ} + 45.3 \cdot \text{body mass} - 2055$  and predicted power CMJ =  $51.9 \cdot h_{CMJ} + 48.9 \cdot \text{body mass} - 2007$  [32].

### 2.2.2. Bench Pull Test

The bench pull test is a specific tool to assess the pulling strength of the upper torso in rowers owing to similar shoulder adduction that take place during rowing stroke [3,24]. BP data were recorded by an optoelectronic encoder (Velowin, Deportec, Murcia, Spain) capturing 500 samples per second from which a dedicated software calculated velocity, power and force output for each repetition. Mean and maximum values of velocity, power and force, both for the entire concentric action and for the propulsive phase during BP were recorded. In such a test, the rower is laying, face down on the bench, whose height from the floor is adjusted according to the length of the rower's arms so that both elbows are in full extension and the arms completely suspended. The barbell is held with hands apart at shoulder level or slightly wider [3,17]. A light load (30% from the 1RM) as the minimum load that can discriminate the different levels of traditional rowers [4], was used for this study. Although some studies did not find a relationship between BP test and rowing performance, it may be a consequence of having used too high intensity to perform BP. The test was cancelled when the rower was unable to flex the arms sufficiently to touch the underside of the bench phase [33].

### 2.2.3. 2000 m Rowing Ergometer Test

The performance test was carried out on a rowing ergometer (Model D; Concept 2, Inc., Morrisville, VT, USA) [11,24,34,35] with the aim of reducing external influences, such as wind, temperature and waves, that could influence the final result [36]. The control of these cofactors is advisable in traditional rowing, practiced in open waters or rough sea, and in Olympic rowing, which is practiced in flat waters, mainly rivers and lakes. Therefore, a rowing ergometer allows for individual testing in a controlled way, providing a valid proxy for rowing performance [4]. The rowers performed an all-out 2000 m test on a rowing ergometer, with the drag factor set to 130 for males and 110 for females [24]. The warm-up consisted of 10 min of moderate intensity (heart rate below 140 beats per minute and 18–20 strokes per minute). The rowers' coach was continuously motivating and giving feedback to the rowers so that they could carry out the test in the shortest time possible. The rowers could see all the power, stroke rate, distance and time information on the screen of the ergometer. Power output, stroke rate and time to complete 2000 m rowing ergometer performance test were recorded.

### 2.3. Statistical Analysis

The Statistical Package for Social Sciences (SPSS) v.24 program was used to compare the means of variables (IBM, Armonk, NY: IBM Corp). Descriptive statistics (mean  $\pm$  SD) were used to report the characteristics of conditional factors. Shapiro–Wilk statistical test was used to determine whether the quantitative variables fulfil the criterion of normality. Pearson correlation coefficient ( $r$ ) with 95% confidence intervals (CI) via bootstrapping was used to establish relationships between anthropometric characteristics, jump test, and bench pull test results with rowing performance. The magnitude of the correlation coefficient was interpreted with the following thresholds: 0.0–0.09 (trivial); 0.1–0.29 (small); 0.3–0.49 (moderate); 0.5–0.69 (strong); 0.7–0.89 (very strong); 0.9–0.99 (nearly perfect); and 1.0 (perfect) [37]. A stepwise multiple regression analysis was used to predict the 2000 m test performance. Additionally, a proportional curvilinear allometric scaling of 2000 m test performance was considered to identify key determinants of rowing performance [38,39]. For both regression techniques, predictors were iteratively adding and removing to the predictive model to find the subset of variables resulting in models which explained 50% or more of the variance of the data ( $R^2 > 0.5$ ). The resulting best-fit equations for the best predictive models of rowing performance within the current population for male and female rowers were also shown, together with adjusted  $R^2$  to account for non-significant predictors in the regression models. Statistical significance was set at  $p < 0.05$ .

## 3. Results

As shown in Table 1, height resulted in strong correlation with performance ( $r = 0.68$ ,  $p = 0.014$ ) in male rowers. Body mass ( $r = 0.83$ ,  $p < 0.001$ ) and body muscle ( $r = 0.81$ ,  $p < 0.001$ ) had a very strong correlation but percentage of body fat and Body Mass Index (BMI) were not correlated with performance test. Jump tests heights ( $h_{SJ}$ ,  $h_{CMJ}$  and  $h_{RJ}$ ), RI, EI and MP showed low correlation with performance test. Besides, the power output prediction equation based on body mass for SJ showed strong correlation with performance ( $r = 0.58$ ,  $p = 0.048$ ). Slightly higher correlations were found for CMJ ( $r = 0.70$ ,  $p = 0.012$ ). Mean velocity ( $r = 0.84$ ,  $p < 0.001$ ) and mean propulsive velocity ( $r = 0.87$ ,  $p < 0.001$ ) in BP test showed very strong correlation with performance. Likewise, mean power ( $r = 0.85$ ,  $p < 0.001$ ) resulted in very strong correlation and maximum power ( $r = 0.73$ ,  $p = 0.007$ ) showed very strong correlation with performance.

**Table 1.** Relationship of anthropometric and strength determinants with 2000 m rowing ergometer performance.

Conditional Factors	Male			Female		
	Mean ± SD	95% CI	2-km (r)	Mean ± SD	95% CI	2-km (r)
<b>Anthropometry</b>						
Height (cm)	178.4 ± 8.9	173.3–183.3	0.68 *	166.3 ± 7.5	161.3–171.9	0.67
Body mass (kg)	77.3 ± 7.9	72.8–82.0	0.83 †	59.9 ± 8.3	54.8–65.5	0.66
Body fat (%)	11.9 ± 3.8	9.9–13.9	−0.18	20.5 ± 4.1	17.8–23.4	0.24
BMI (kg/m <sup>2</sup> )	24.3 ± 1.7	23.3–25.2	0.25	21.7 ± 2.6	20.0–23.6	0.28
Body muscle (kg)	64.5 ± 7.1	60.1–68.4	0.81 †	45.9 ± 4.8	42.9–49.0	0.94 †
<b>Jump tests</b>						
H <sub>SJ</sub> (cm)	35.6 ± 6.1	32.8–39.3	−0.17	25.2 ± 1.5	24.2–26.2	−0.72
W <sub>SJ</sub> (W)	3608.0 ± 404.8	3382.9–3834.0	0.58 *	2184.2 ± 314.9	1981.0–2399.8	0.57
H <sub>CMJ</sub> (cm)	38.0 ± 5.1	35.7–41.2	−0.23	26.4 ± 1.5	25.6–27.6	−0.60
W <sub>CMJ</sub> (W)	3744.1 ± 377.3	3519.7–3948.8	0.70 *	2303.8 ± 368.1	2087.6–2568.4	0.59
H <sub>RJ</sub> (cm)	29.4 ± 4.4	27.3–32.1	−0.14	18.5 ± 3.4	16.3–21.0	−0.58
RI	0.8 ± 0.1	0.7–0.8	0.13	0.7 ± 0.1	0.6–0.8	−0.50
EI	2.4 ± 2.8	0.8–3.6	−0.03	1.5 ± 1.2	0.7–2.4	0.14
MchP (W/kg)	19.5 ± 3.5	17.7–21.7	−0.06	13.4 ± 1.3	12.6–14.3	0.01
<b>Bench Pull test</b>						
MV (m·s <sup>−1</sup> )	1.8 ± 0.1	1.7–1.8	0.84 †	1.5 ± 0.1	1.4–1.5	0.63
MPV (m·s <sup>−1</sup> )	1.8 ± 0.1	1.8–1.9	0.87 †	1.5 ± 0.1	1.4–1.6	0.67
V <sub>max</sub> (m·s <sup>−1</sup> )	2.5 ± 0.2	2.4–2.6	0.79 †	2.0 ± 0.2	1.9–2.1	0.65
MF (N)	141.3 ± 1.8	140.4–124.3	0.34	91.6 ± 0.4	91.4–91.9	−0.39
MPP (N)	296.0 ± 32.6	278.3–313.8	0.58 *	158.1 ± 11.6	150.4–165.1	0.20
F <sub>max</sub> (N)	630.3 ± 85.6	583.4–677.8	0.60 *	350.7 ± 35.6	325.3–373.8	0.07
MP (W)	238.5 ± 16.2	230.1–248.0	0.85 †	126.8 ± 10.5	119.7–133.8	0.64
MPP (W)	445.8 ± 72.6	407.8–487.8	0.71 †	200.6 ± 24.5	185.4–218.6	0.55
P <sub>max</sub> (W)	626.7 ± 93.7	573.7–676.7	0.73 †	271.9 ± 33.9	250.2–295.2	0.79 *

BMI: Body Mass Index; H<sub>SJ</sub>: squat jump height; W<sub>SJ</sub>: squat jump power; H<sub>CMJ</sub>: countermovement jump height; W<sub>CMJ</sub>: countermovement jump power; H<sub>RJ</sub>: repeat jump height; RI: resistance index; EI: elastic Index; MchP: mechanical power; MV: mean velocity; MPV: mean propulsive velocity; V<sub>max</sub>: maximum velocity; MF: mean force; MPP: mean propulsive force; F<sub>max</sub>: maximum force; MP: mean power; MPP: mean propulsive power; P<sub>max</sub>: maximum power; \* statistical significance  $p < 0.05$ ; † statistical significance  $p < 0.01$ .

Female rowers showed strong to nearly perfect correlation between the same anthropometric variables than males with performance: height ( $r = 0.67$ ,  $p = 0.101$ ), body mass ( $r = 0.66$ ,  $p = 0.107$ ) and body muscle ( $r = 0.94$ ,  $p = 0.002$ ). Similarly to male rowers, the power output prediction equation based on body mass for SJ (W<sub>SJ</sub>) showed strong correlation ( $r = 0.57$ ,  $p = 0.179$ ), and stronger correlation values were found for CMJ (W<sub>CMJ</sub>) with performance ( $r = 0.59$ ,  $p = 0.159$ ). Finally, female rowers showed strong correlation in mean velocity ( $r = 0.63$ ,  $p = 0.126$ ), mean propulsive velocity ( $r = 0.67$ ,  $p = 0.102$ ) and mean power ( $r = 0.64$ ,  $p = 0.124$ ) in BP test with performance. Furthermore, very strong correlation in maximum power ( $r = 0.79$ ,  $p = 0.036$ ) were found.

The results of the stepwise multiple linear regression analysis in male rowers indicated that body mass is the only predictor variable for anthropometric characteristics explaining 69% ( $R^2 = 0.69$ ,  $p < 0.001$ ) of W<sub>2000m</sub>. Similarly, the only predictor variable for BP test were the mean propulsive velocity that explained 76% of rowing performance ( $R^2 = 0.76$ ,  $p < 0.001$ ) (Table 2). The rest of the anthropometric and power variables in jump and BP tests did not contribute significantly and were excluded from the prediction equation. The best predictor of rowing performance among anthropometric characteristics for female rowers was body muscle, accounting for 89% of variance ( $R^2 = 0.89$ ,  $p = 0.002$ ) and maximum power for BP measures, explaining 62% of rowing performance ( $R^2 = 0.62$ ,  $p = 0.036$ ). As with the male linear regression models, the inclusion of the remaining variables resulted in models predicting less than 50% of the variance so they were excluded from the equations.



**Table 2.** Stepwise multiple regression analysis and proportional allometric scaling to predict rowing performance in male and female rowers according to anthropometric and power determinants.

Model	Sex	Equation	R <sup>2</sup>	Adj. R <sup>2</sup>	SEE	p
Linear	M	$W_{2000m} (W) = 5.54 \cdot \text{Body mass (kg)} - 154.97$	0.69	0.66	30.96	$p < 0.001$
	M	$W_{2000m} (W) = 384.10 \cdot \text{MPV (m}\cdot\text{s}^{-1}) - 431.99$	0.76	0.73	27.30	$p < 0.001$
	F	$W_{2000m} (W) = 4.28 \cdot \text{Body muscle (kg)} - 30.02$	0.89	0.86	8.00	$p = 0.002$
	F	$W_{2000m} (W) = 0.50 \cdot P_{\max} (W) + 30.10$	0.62	0.54	14.71	$p = 0.036$
Allometric	M	$W_{2000m} (W) = 0.34 \cdot [\text{Body mass (kg)}]^{1.537}$	0.70	0.67	0.11	$p < 0.001$
	M	$W_{2000m} (W) = 57.89 \cdot [\text{MPV (m}\cdot\text{s}^{-1})]^{2.535}$	0.76	0.73	0.10	$p < 0.001$
	F	$W_{2000m} (W) = 1.84 \cdot [\text{Body muscle (kg)}]^{1.177}$	0.88	0.85	0.00	$p = 0.002$
	F	$W_{2000m} (W) = 1.72 \cdot [P_{\max} (W)]^{0.815}$	0.60	0.52	0.10	$p = 0.040$

SEE: standard error of estimate; W: power; MPV: mean propulsive velocity in bench pull; P<sub>max</sub>: maximum power in bench pull; M: Male; F: Female.

The proportional allometric model relationships between rowing performance ( $W_{2000m}$ ) and determinants (anthropometric and BP) showed approximately linear associations, indicated by the exponent near unity. The only prediction equation showing power-function characteristics is the mean propulsive velocity for male rowers, which explained 76% of the variance. The proportional slopes of the rest of the predicting equations gave similar prediction power ( $R^2$ ) but with lower estimate errors. The same variables that explain most of the variance in the stepwise linear regression were the remaining predictor variables making a significant contribution to the proportional allometric model. The remaining predicting variables lead to models explaining less than half the variance of rowing performance, so they were excluded from the equations.

#### 4. Discussion

The main aim of the study was to analyze the relationship of anthropometric and strength determinants with 2000 m rowing ergometer performance in traditional rowing. According to several studies, high-performance rowers of both sexes are usually heavier and taller than low-performance counterparts [9,40,41]. Our results are in accordance with other studies in which height, body mass and body muscle correlated with better performance [34,42,43]. Furthermore, among all variables, body mass for male rowers and body muscle for female rowers were the best predictors of rowing performance. Akça [1] found taller and heavier Olympic male college rowers (185.8 cm and 80.2 kg) compared to traditional rowers of our study (178.4 cm and 77.3 kg). This difference can be due to traditional rowing requiring shorter and lighter rowers in some boat positions for hydrodynamic reasons, so the crew must be not homogeneous [11]. For that reason, some physical advantages of heavier and taller rowers in Olympic rowing could become a disadvantage in boat hydrodynamics and rowing technique in traditional rowing [4,11,27].

In line with our findings, Yoshiga and Higuchi [44] reported that rowing performance is highly influenced by body size, in such a way that large body size increased the rowing performance. However, these authors found that female rowers were slower than males when both groups were matched based on the body size, possibly due to the larger body fat of females which deteriorates the rowing performance. Nevertheless, the differences between sexes in rowing performance were reduced when the fat-free mass was taken into consideration. Therefore, the results support the idea that muscle mass and fat-free mass are key factors related to rowing performance [45], especially in female rowers [19].

High percentage of body fat negatively affects rowing performance because body fat contributes a metabolically non-productive load [46] and low body fat percentage was associated with higher aerobic capacity [47]. Nevertheless, it is difficult to combine high level of musculature with low percentage of body fat [9]. In this study, body fat showed a small correlation with rowing performance [1,34]. This finding was consistent with previous studies which showed significant differences between age categories, although the differences between elite and sub-elite categories were minimal [4,41].

Despite this fact, it seems accepted that rowers with low body fat percentage perform a shorter time in the 2000 m test [4,48].

In this study, traditional male rowers had a low percentage of body fat of 11.9%, which is in accordance with Majumdar et al. [34], who reported similar values (11.1%) in the combined group (light body mass and open category), although elite rowers showed lower percentage of body fat (7.8%). The same trend is observed when the female group (20.9%) were compared with female elite rowers (16.3%). The difference between sex showed higher body fat percentage in the female group compared with the male group ( $\Delta 56.8\%$ ), usually accumulated around hips and thighs due to physiological and hormone characteristics [49]. Hence, rowers with high height and lean body mass values as well as low percentage of body fat seem to contribute to a greater power output stroke [9].

In the present study, there was a strong correlation in both sexes between power output in SJ ( $W_{SJ}$ ) and CMJ ( $W_{CMJ}$ ) with performance when body mass was considered. Greater muscle volume of the vastus lateralis could explain variance in rowing ergometer performance, sprint, and endurance capacity [50]. Battista et al. [8] did not find correlations between jump test and endurance test, probably since body mass, an important variable for rowing performance, has not been considered as an additional factor to assess vertical jump height [50]. To solve this problem, different authors proposed methods to estimate the lower limb power output during squat jump adding body mass variable to the equations [32,51]. Considering the contributions of these authors, the correlations between rowing performance test and jumps increased considerably. Comparing sex categories, our results showed a strong to very strong correlation between lower limb strength and rowing performance, although results were only significant in the male group. Similarly, Ingham et al. [20] reported a higher correlation between lower limb strength and rowing performance in male than female rowers, although these differences in correlation were considerably larger than our results.

The BP test, in contrast to Olympic rowing, showed higher correlations with rowing performance for all variables compared to jump tests. This fact can be due to the major contribution of the upper body in traditional rowing stroke. High correlation values between BP power average and rowing performance suggest that upper body power is one of the most important factors influencing the performance of traditional rowing, possibly due to the use of lower limbs in a flexed position and the greater degree of body extension compared to Olympic rowing [13]. In the same way, our results showed that mean propulsive velocity in BP was the best predictor of rowing performance for male rowers and maximum power in BP for female rowers, both for linear and proportional curvilinear (allometric) models, suggesting approximately linear associations between these determinants and rowing performance. The fact that seats are fixed in traditional rowing reduces legs freedom of movement and consequently their intervention in the stroke, although legs still have an important role in the first phase of paddling (isometric contraction). Comparing sex categories, male group showed higher correlation between BP power average and 2000 m test. These differences could be related to higher values of body muscle and less percentage of body fat of the male group since BP, 2000 m test is strongly correlated with the ratio between power and body mass [4]. Moreover, Attenborough, Smith, and Sinclair [52] studied the upper contribution to rowing performance of female rowers compared to male rowers and suggest to spend time to specific upper body conditioning as a key factor to improve rowing performance in the female category.

#### 4.1. Limitations

In this study, the vertical jump test was performed to evaluate the power of the lower body by the similarity of the jumping movement gesture and the first phase of the leg drive. Further research could perform other measures, such as the Wingate test, to assess lower-body power, more specifically, peak power, mean power and fatigue index, and the possible relationship with traditional rowing performance.

Another limitation of this study is the small sample size and, therefore, the findings of the study should be interpreted with caution. Future studies are required to confirm our results in a larger

population, including other traditional rowing modalities and nationalities to avoid a possible bias derived from an exclusively Spanish sample.

#### 4.2. Practical Applications

The results of this study provide further insight regarding the influence of different determinants of anthropometry and strength on 2000 m rowing ergometer performance in traditional rowing. This study demonstrates that some anthropometric characteristics may influence rowing success and a higher correlation between the upper body and rowing performance than lower body. Therefore, coaches should consider it to perform effective talent identification programs for rowing and training planning.

### 5. Conclusions

In summary, the data presented within this investigation suggest that large values of height, body mass and body muscle were highly correlated with 2000 m rowing ergometer performance in traditional rowing. Furthermore, body mass for male rowers and body muscle for female rowers were found to be good predictors. The main results showed a strong correlation of  $W_{SJ}$  and  $W_{CMJ}$  with 2000 m rowing ergometer performance in traditional rowing. However, BP variables were those that most strongly correlated with performance, highlighting the relevant role of the upper trunk in traditional rowing. Mean propulsive velocity in BP in male rowers and maximum power in bench pull in female rowers were found to be good predictors of rowing performance.

**Author Contributions:** Conceptualization, S.S.-A., A.P.-T. and B.P.; Data curation, A.P.-T. and J.M.J.-O.; Formal analysis, S.S.-A., A.P.-T. and B.P.; Investigation, S.S.-A. and J.M.J.-O.; Methodology, A.P.-T., J.M.J.-O. and B.P.; Project administration, S.S.-A.; Resources, A.P.-T. and J.M.J.-O.; Software, S.S.-A. and B.P.; Supervision, B.P.; Validation, S.S.-A. and B.P.; Visualization, J.M.J.-O.; Writing—original draft, S.S.-A.; Writing—review and editing, S.S.-A., A.P.-T., J.M.J.-O. and B.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study was supported by a pre-doctoral grant (ACIF/2018/209) from the Generalitat Valenciana, Spain, and vice-rectorate program of research and knowledge transfer for the promotion of R+D+I at the University of Alicante (Ref. GRE18-19).

**Acknowledgments:** The authors would like to express their gratitude to Jennifer Guerra, from the Department of Chemistry and Biochemistry, and to Elena Gandía García, from the Department of World Languages and Cultures, at the University of Nevada, Las Vegas, NV, USA, for providing assistance in preparing this manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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