Original Article

Anthropometric and motor characteristics of adolescence male and female rowers, their relationship with performance and their importance in selection

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ABSTRACT

The aim of our study is to analyse the physical characteristics and motor tests that can qualify rowers of different genders and nations. Young rowers from six nations (n = 190) were included in the study. After the anthropometric measurements, the average power (W_{100m}) and maximum power ($W_{5\ strokes}$) were examined with start tests on a rowing ergometer. The estimated relative aerobic capacity ($ErVO_{2max}$) was calculated, and the standing triple jump test (STJ) was also measured. The relationship of the individual variables to performance was also investigated. Analysing the start tests, the results of the boy group were significantly larger than those of the girl group (p < .05). The correlation between STJ and W5 strokes and W_{100m} is significant in the boy group and also in the girl group. The correlation between body weight (BW) and performance is stronger in both groups. In our study, the differences between the sexes are clear, considering all groups, we can observe the tendency that the increasing value of STJ means also increasing of maximum ($W_{5\ strokes}$) and average power (W_{100m}), and we found a relationship between anthropometrical characteristics and performance already in adolescence. It seems clear that in order to achieve a high level of rowing performance, in addition to developing endurance, attention should also be paid to the development of power (especially dynamic leg power) in the program of rowers.
Keywords: Performance analysis of sport, Rowing, Motor tests, Ergometer start test, Maximal power, Average power.

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INTRODUCTION

There are several important aspects to consider when determining a rower's performance, although the time result in a race may seem obvious. Measurements can be made by fitting boats with various instruments, most commonly based on a speed measuring device or GPS system. Information from aquatic ergometry is reliable but expensive to obtain and complex to install (Smith & Hopkins, 2011). Furthermore, in addition to individual ability, environmental factors (e.g. wind, water resistance) can have a significant impact on rowing performance when measured on water. Overall, water-based measurements are not a suitable measure of rowing performance, with measurements made on rowing ergometers having higher reliability and reflecting rowing performance on water (Nevill et al., 2010).

The anthropometric and physiological characteristics of the individual determine the effectiveness of rowing performance (Yusof et al., 2020). Anthropometric parameters of rowers have been studied in large numbers involving different genders, age groups and different levels of competitors. Greater body height has been shown to positively influence rowing performance (Adhikari, 2015; Bourgois, 2000; Forjasz, 2011), because the seated body position is advantageous for tall rowers (Tittel & Wurtscherk, 1992). Furthermore, previous studies have shown that high muscle and low body fat percentage coupled with higher lean body mass positively influence rowing performance (Bourdin et al., 2017; Mikulić & Ružić, 2008; Yoshiga & Higuchi, 2003).

Rowers need both high aerobic and anaerobic capacity, but the contribution of energy systems has been estimated differently in previous studies (Maestu et al., 2005). However, especially during the initial and final stages of the race, anaerobic metabolism plays a more important role during rowing compared to other endurance sports (Cerasola et al, 2020; Ingham et al., 2008). The anaerobic contribution of the entire 2000 m rowing race has been estimated at 21-30% (Secher, 1993), but the aerobic capacity of rowers is also one of the highest among endurance athletes (Volianitis & Secher, 2009). The majority of previous studies have identified maximum oxygen consumption (VO_{2max}) as the greatest predictor of rowing performance (Alföldi et al. 2021, Cosgrove et al., 1999). While aerobic capacity is best indicated by maximum oxygen consumption (VO_{2max}, $ml \times min^{-1}$) or its value relative to body weight (rVO_{2max}, $ml \times kg^{-1} \times min^{-1}$), it is difficult to quantify anaerobic capacity. A number of methods have been tried to test human anaerobic capacity, such as invasive intramuscular metabolite assays or measurement of peak blood lactate concentrations after intense exercise. However, the most widely used method is the ergometric assessment of mechanical work, such as measuring peak power, i.e. maximal force (F_{max}) and muscle power (W_{max}), or time to exhaustion (Volianitis et al, 2020). Mean and maximal power measured on a rowing ergometer, one repetition of maximal leg push-up and one repetition of maximal pull-up strength tests have been correlated with rowing performance (Akça, 2014). The predictive role of leg push-up and maximal vertical jump has also been investigated (Huang et al., 2007), studies that emphasize the importance of developing strength and anaerobic power.

Anthropometric, cardiorespiratory and motor skills are important complements to the identification of rowing talent. In addition to the validated shuttle test and the estimated relative aerobic capacity ($ErVO_{2max}$) calculated from it, the quality of the dynamic leg power can be inferred from the standing long jump and the standing triple jump tests. Non-instrumented motor tests are simple to perform, yet their results are informative. The rowing ergometer test can be used to determine the maximum force in watts ($W_{5\ strokes}$), the 100m sprint test to determine the average force in watts (W_{100m}). The results of various anthropometric, exercise physiology or motor tests are important feedback for coaches and athletes, as several prediction models have predicted expected performance (r = 0.82) using certain anthropometric variables (height, arm span, body surface average, sitting height) alone; (Alföldi et al, 2020). Favourable anthropometric profiles should be considered as an important criterion for sport selection. Previous studies have mostly focused on the profiles of successful athletes, with few studies looking at novice or intermediate rowers. In our study, we analyse the basic physical characteristics, ergometric and motor tests that can qualify the adolescent rowers of different genders and nations, and we investigate the relationship of anthropometric characteristics, estimated relative maximal aerobic capacity ($ErVO_{2max}$) and the standing triple jump test (STJ) with the performance ($W_{5\ strokes}$ and W_{100m}).

MATERIAL AND METHODS

Participants

Young rowers from six nations (n = 190) were included in the study, with 14.24 ± 0.38 girls (n = 96) and 14.47 ± 0.26 boys (n = 94). Adolescent rowers of French (n = 65), German (n = 61), Italian (n = 16), Hungarian (n = 16), Serbian (n = 16) and Czech (n = 16) nationalities were included into examination. The measurements were taken during an international training camp and, taking into account the requirements of the Declaration of Helsinki for volunteering and parental consent, as well as the willingness of clubs and national federations to cooperate, these conditions were met in all the required details.

Measures

Anthropometric data were recorded using certified Sieber-Hegner instruments. The International Biological Programme (Weiner & Lourie, 1969) was used as a guideline for our work. Body weight (BW), body height (BH) were measured and body mass index (BMI) was calculated by dividing body weight in kilograms by the square of body height in metres ($BW(kg)/BH(m)^2$). The power was measured on a certified rowing ergometer (Concept 2 D-model) in watts (W), average power during the 100m sprint test (W_{100m}), in the start test ($W_{5\ strokes}$); (first five maximal strokes), we examined the maximum power, i.e. the highest performance. Prior to the ergometer tests, each participant performed a 6 min warm-up for a 500 m section for 2 min 30 s. Participants then rested for 6 minutes, during which time they performed stretching exercises. Estimated relative aerobic capacity ($ErVO_{2max}$) was calculated based on the shuttle run performance taking into participants age, gender, body weight and fitness level, using the empirical formula of Léger and Lambert (1982): $ErVO_{2max}$ (ml/kg/min^{-1}) = (5.857 x speed of last distance covered (km/h)) - 19.458. In the standing triple jump test (STJ), the participants started the long jump from a standing position, with optimal execution preceded by adequate instructions. A line drawn on the ground was used as a starting line and the length of the jump was determined by a tape measure fixed to the ground. After two practice jumps, the participants were given two minutes rest and then each had to perform the jump three times. For each jump, the distance between the start line and the body part closest to the start line was measured to the nearest 1 cm.

Analysis

The data were analysed using the "*Statistica for Windows*" 13.2 software package. Differences between groups by gender and by nation were analysed using repeated ANOVA Post hoc, Tukey (HSD) with random error at the level of $p < .05$. When examining differences, we first used F test, the variances did not show significant difference, so we analysed gender differences using two-sample T-test with the random error at the level of $p < .05$. The relationship between different variables was tested using Pearson's correlation analysis.

RESULTS

The difference in the mean heights (BH; cm) was significant between the girl (167.54±5.78) and boy (175.59 ± 7.34) group ($p < .05$), the results and standard deviations of the two groups are shown in Table 1. The difference in means of body weight (BW; kg) was also real between the girl (58.89 ± 6.74) and boy (65.99 ± 9.34) group ($p < .05$), but no such difference was found between the means of the nutritional index (BMI) scores ($p > .05$).

Table 1. Anthropometric and performance results of men and women groups.

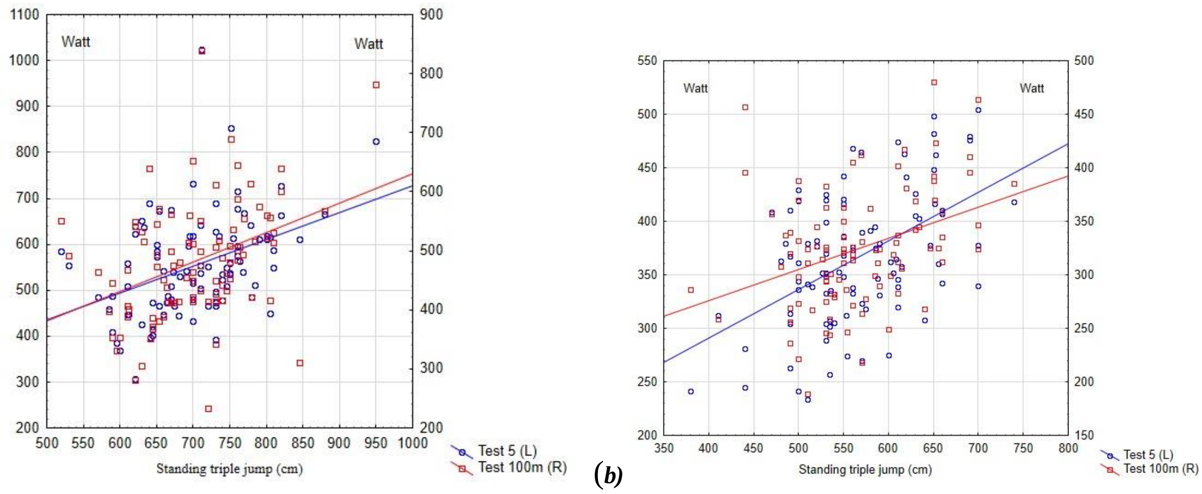
Variables	Men (Mean ± SD.); (n = 94)	Women (Mean ± SD.); (n = 96)	*p*
Age (year)	14.47(0.26)	14.24(0.38)	>.05
BH (cm)	175.59(7.34)	167.54(5.78)	.021
BW (kg)	65.99(9.34)	58.89(6.74)	.002
BMI	21,37(2.38)	20.99(2.29)	>.05
STJ (cm)	703,04(75.99)	565,40(68.05)	>.05
$W_{5\ strokes}$ (W)	554,71(109.90)	365,91(61.69)	.000
W_{100m} (W)	481,78(99.68)	324,07(54.66)	.000
$ErRVO_{2max}$ ($ml \times kg^{-1} \times min^{-1}$)	46,62(5.22)	39,56(4.80)	>.05

Note. BH = body height, BW = body weight, BMI = body mass index, STJ = standing triple jump, $W_{5\ strokes}$ = maximal power, W_{100m} = 100 m average power, $ErRVO_{2max}$ = estimated relative aerobic capacity.

Regarding the mean results of the estimated relative aerobic capacity ($ErVO_{2max}$; Mean ± SD; $ml \times kg^{-1} \times min^{-1}$) and the mean results of the triple jump from standing (STJ; Mean ± SD; cm), the boys' group ($ErVO_{2max}$ = 46.62 ± 5.22; STJ =703.04 ± 75.99) had a higher result than the girls' group ($ErVO_{2max}$ = 39.56 ± 4.80; STJ = 565. 40 ± 68.05), but the difference was not significant ($p > .05$). When examining the mean results of the groups of different genders and nationalities, no significant difference was found for the estimated relative aerobic capacity ($ErVO_{2max}$) and standing triple jump test (STJ); ($p > .05$). When analysing the average results of the start test, i.e. maximum power ($W_{5\ strokes}$; Mean ± SD; W), the result of the boy group (554.71 ± 109.90) was higher than that of the girl group (365.91 ± 61.69), the difference being significant ($p < .05$). When analysing the average results of the sprint test, i.e. average power (W_{100m}; Mean ± SD; W), the result of the boy group (481.78 ± 99. 68) was significantly higher ($p < .05$) than that of the girl group (324.07 ± 54.66). When examining the mean results of the groups of different genders and nationalities, no significant difference was found for the sprint test (W_{100m}) and the maximum power test ($W_{5\ strokes}$), ($p > .05$).

In both the boys' and girls' groups, the relationship between the standing triple jump test and the performance [maximum power ($W_{5\ strokes}$) and sprint test (W_{100m})] is significant (Figure 1/a and 1/b). While the relationship of estimated relative aerobic capacity ($ErVO_{2max}$) with performance was not significant for either the girl or the boy group ($p > .05$).

In both figures (Figures 1/a and 1/b), the set of points displaying the results also shows a significant scatter from the two trend lines, but they are located below and above the trend line in approximately equal proportions. In the figure showing the results of the boys' group (Figure 1/a), the two trend lines run parallel up to 650 cm and then gradually diverge from each other, but the divergence is not large at 950 cm. The correlation of the means [($rW_{5\ strokes}$ = 0.4336), ($p = .000$); (rW_{100m} = 0.4114), ($p = .000$)] is moderate, with a calculated common variance of only 18%, which is neither statistically nor human biologically notable. As for the girls' result (Figure 1/b), the two trend lines run with different slopes and interact with each other at 600 cm. Before and after this value, the distance between the two trendlines gradually increases. The correlation of the means [($rW_{5\ strokes}$ = 0.5402), ($p = .000$); (rW_{100m} = 0.4648), ($p = .000$)] is significant, it shows a stronger relationship than in the case of the boy group, but it is still moderate. The calculated common coefficient of determination is around 25%, which is not notable in terms of human biology or statistical content. Body height (BH) showed an overall stronger relationship in the boy group [(r$W_{5\ strokes}$ = 0.4912), (*p* = .000); (rW_{100m} = 0.4059), (*p* = .000)] than in the girl group [(rW5 strokes = 0.3983), (*p* = .000); (rW100m = 0.4371), (*p* = .000)]. However, the relationship between body weight (BW) and performance was more significant, especially in the boy group [(r$W_{5\ strokes}$ = 0.6940), (*p* = .000); (rW_{100m} = 0.6627), (*p* = .000)], with the correlation also significant in girls [(r$W_{5\ strokes}$ = 0.3867), (*p* = .000); (rW_{100m} = 0.5192), (*p* = .000)], but also moderate. When the results of the two sexes are considered together, the coefficient of determination for height (BH) and body weight (BW) with performance is found to be around 20% in both cases. The strongest correlation in our study was the relationship between maximum power ($W_{5\ strokes)}$ and sprint test (W_{100m}), with both the girl group [(r = 0.8003), (*p* = .000)] and the boy group [(r = 0.9005), (*p* = .000)] showing a strong correlation between the two means, with a calculated common coefficient of determination of the two groups close to 75%, which can be considered significant.



(a) ***(b)***

*Note. The figure on the left **(a)** shows the boys' results, the one on the right **(b)** the girls' results. The horizontal axis (x) of both graphs **(a, b)** shows the relationship between the standing triple jump (STJ); (x_a) [(500-1000); (cm)]; (x_b) [(350-800); (cm)] and performance, the left (y) axis shows the maximum power ($W_{5\ strokes}$), the right (y) axis shows the 100 m average power (W_{100m}; W).*
*(**a**): [standing triple jump (cm): $W_{5\ strokes}$ (W): r = 0.4336; (p = .000)]; [standing triple jump (cm): W_{100m} (W): r = 0.4114; (p = . 000)]*
(b): [standing triple jump (cm): $W_{5\ strokes}$ (W): r = 0.5402; (p = .000)]; [standing triple jump (cm): W_{100m} (W): r = 0.4648; (p = .000)].

Figure 1. The relationship between standing triple jump (STJ; cm) and maximal power ($W_{5\ strokes;}$ W) and 100 m average power (W_{100m}; W) by gender.

DISCUSSION

In our study, the gender differences are clear, the boys performing better, but no significant differences were found between the performance measures of the groups of different nationalities, i.e. triple jump from a standing position (STJ), maximal strength ($W_{5\ strokes}$), average strength (W_{100m}) and estimated relative aerobic capacity ($ErVO_{2max}$). This may be a consequence of the homogeneity of the sample studied and suggests that rowing federations from different nations may place similar emphasis on the physical training of their competitors. Across all groups, a trend was observed where increasing values of the triple jump from place (STJ) were associated with a parallel increase in maximum ($W_{5\ strokes}$) and average power (W_{100m}), i.e. performance. In view of the fact that 46.4 ± 4.5% of the force during rowing is derived from the legs, 30.9 ± 5.2% from the trunk and 22.7 ± 5.2% from the arms (Kleshnev, 2002b), this is perhaps not a surprising result. Thus, the power endurance of arms, and most importantly the lower limbs is also related to rowing performance (Maciejewski et al., 2019; Majumdar et al., 2017). In our study, the level of the relationship between the standing triple jump (STJ) and the performance is moderate, but in the case of the estimated relative aerobic capacity ($ErVO_{2max}$) we cannot report either significance or a similar trend. This result may be surprising, as maximum oxygen consumption (VO_{2max}) has previously been identified by several authors as the largest predictor of performance (Alföldi et al 2020, Cosgrove et al., 1999). This apparent contradiction may be explained by the fact that the sprint and start test measured in our study is more anaerobic dominant in terms of energy expenditure. In any case, the $ErVO_{2max}$ result (46.62; ml×kg^{-1}×min^{-1}) measured on the boy group in our study is almost identical to the result of a study on Croatian rowers of similar age (VO_{2max}: 48.8; ml×kg^{-1}×min^{-1}), (Mikulić and Ružić, 2008).

A relationship was found between anthropometric variables (height, body mass) and performance in both the boys' and girls' groups, with previous studies finding similar results (Akca, 2014; Mikulic, 2009; Mikulic, 2008). Studies on anthropometric characteristics of adult male and female rowers highlight the importance of body mass (Maciejewski et al, 2019), as well as body size and body proportions (Majumdar et al., 2017; Mikulic and Ružić, 2008; Penichet-Tomás et al., 2019) as determinants of rowing success at the international level. Presumably, this may be the reason why in our study, greater body height and body mass showed a significant association with better performance. Previous studies have also found similar results, i.e., rowers with larger body size have proportionally better rowing performance (Cosgrove et al., 1999; Mikulić, 2008; Yoshiga & Higuchi, 2003), and in a previous study, body height (BH) and body surface area average (BSA) were the strongest predictors. These results also indicate that more successful rowers tend to be taller and heavier than less successful rowers (Bourgois et al., 2000), in contrast to several previous studies that have identified lean body mass as the anthropometrical characteristic most associated with performance (Cosgrove,1999; Yoshiga, 2000; Mikulic,2009).

CONCLUSIONS

Internationally top-ranked rowers typically have better technique and sense of rhythm, faster pulling speed, higher average power and VO_{2max} than their less successful counterparts (Lawton et al., 2011). In the future, it would be ideal to compare the later results of the study participants with each other and with the results of the given age group in order to optimize the talent identification process. However, it seems clear that in order to achieve high levels of rowing performance, rowers' programmes should include the development of power (most notably dynamic leg power) and endurance to achieve a sufficiently low body fat percentage and high muscle mass in addition to optimal cardiorespiratory characteristics (Durkalec-Michalski et al, 2019). Nevertheless, favourable anthropometric profiles should be considered an important aspect from a very young age, and our study shows that their association with performance is already evident in adolescence.

AUTHOR CONTRIBUTIONS

The study was designed by SL and IF; data were collected and analysed by FB and IF; data interpretation and manuscript preparation were undertaken by SL, and BI. All authors approved the final version of the paper.

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DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

REFERENCES

Adhikari, A. (2015). Anthropometric Characteristic, Somatotype and Body Composition of Canadian Female Rowers. Am. J. Sports Sci., 3(3), 61. https://doi.org/10.11648/j.ajss.20150303.15

Akça, F. (2014). Prediction of Rowing Ergometer Performance from Functional Anaerobic Power, Strength and Anthropometric Components. J. Hum. Kinetics, 41(1), 133-142. https://doi.org/10.2478/hukin-2014-0041

Alföldi, Z., Borysławski, K., Ihász, F., Soos, I., & Podstawski, R. (2021). Differences in the Anthropometric and Physiological Profiles of Hungarian Male Rowers of Various Age Categories, Rankings and Career Lengths: Selection Problems. Front. Physiol., 12, 747781. https://doi.org/10.3389/fphys.2021.747781

Bourdin, M., Lacour, J. R., Imbert, C., & Messonnier, L. A. (2017). Factors of Rowing Ergometer Performance in High-Level Female Rowers. Int. J. Sports Med , 38(13), 1023-1028. https://doi.org/10.1055/s-0043-118849

Bourgois, J. (2000). Anthropometric characteristics of elite male junior rowers. Br. J. Sports. Med., 34(3), 213-216. https://doi.org/10.1136/bjsm.34.3.213

Cerasola, D., Bellafiore, M., Cataldo, A., Zangla, D., Bianco, A., Proia, P., . . . Capranica, L. (2020). Predicting the 2000-m Rowing Ergometer Performance from Anthropometric, Maximal Oxygen Uptake and 60-s Mean Power Variables in National Level Young Rowers. J. Hum. Kinet., 75(1), 77-83. https://doi.org/10.2478/hukin-2020-0038

Cosgrove, M. J., Wilson, J., Watt, D., & Grant, S. F. (1999). The relationship between selected physiological variables of rowers and rowing performance as determined by a 2000 m ergometer test. J. Sports Sci., 17(11), 845-852. https://doi.org/10.1080/026404199365407

Durkalec-Michalski, K., Nowaczyk, P. M., Podgórski, T., Kusy, K., Osiński, W., & Jeszka, J. (2019). Relationship between body composition and the level of aerobic and anaerobic capacity in highly trained male rowers. J. sports med. phys. fitness, 59(9), 1526-1535. https://doi.org/10.23736/S0022-4707.19.08951-5

Forjasz, J. (2011). Anthropometric Typology of Male and Female Rowers Using K-Means Clustering. J. Hum. Kinet., 28(2011), 155-164. https://doi.org/10.2478/v10078-011-0032-y

Huang, C.-J., Nesser, T., & Edwards, J. (2007). Strength and Power Determinants of Rowing Performance. J. Exerc. Physiol. Online, 10, 43-50.

Ingham, S. A., Carter, H., Whyte, G. P., & Doust, J. H. (2008). Physiological and Performance Effects of Low- versus Mixed-Intensity Rowing Training. Med. Sci. Sports Exerc., 40(3). https://doi.org/10.1249/MSS.0b013e31815ecc6a

Kleshnev, V. (2002b). Segments contribution to the stroke length and rower power. Higher percentage of the trunk power helps to achieve higher boat speed. Rowing Biomech. Newsletters, 2(2).

Lawton, T. W., Cronin, J. B., & Mcguigan, M. R. (2011). Strength Testing and Training of Rowers. Sports Med., 41(5), 413-432. https://doi.org/10.2165/11588540-000000000-00000

Maciejewski, H., Rahmani, A., Chorin, F., Lardy, J., Samozino, P., & Ratel, S. (2019). Methodological Considerations on the Relationship Between the 1,500-m Rowing Ergometer Performance and Vertical Jump in National-Level Adolescent Rowers. J. Strength Cond. Res., 33(11). https://doi.org/10.1519/JSC.0000000000002406

Maestu, J., Jürimae, J., & Jürimae, T. (2005). Monitoring of Performance and Training in Rowing. Sports Med., 35(7), 597-617. https://doi.org/10.2165/00007256-200535070-00005

Majumdar, P., Das, A., & Mandal, M. (2017). Physical and strength variables as a predictor of 2000 m rowing ergometer performance in elite rowers J Phys Educ Sport, 17(4), 2502-2507. https://doi.org/10.7752/jpes.2017.04281

Mikulić, P. (2008). Anthropometric and physiological profiles of rowers of varying ages and ranks. Kinesiology, 40, 80-88.

Mikulic, P. (2009). Anthropometric and Metabolic Determinants of 6,000-m Rowing Ergometer Performance in Internationally Competitive Rowers. J. Strength Cond. Res., 23(6). https://doi.org/10.1519/JSC.0b013e3181b3dc7e

Mikulić, P., & Ružić, L. (2008). Predicting the 1000m rowing ergometer performance in 12-13-year- old rowers: The basis for selection process? J. Sci. Med. Sport, 11(2), 218-226. https://doi.org/10.1016/j.jsams.2007.01.008

Nevill, A. M., Beech, C., Holder, R. L., & Wyon, M. (2010). Scaling concept II rowing ergometer performance for differences in body mass to better reflect rowing in water. Scand. J. Med. Sci. Sports, 20(1), 122-127. https://doi.org/10.1111/j.1600-0838.2008.00874.x

Penichet-Tomás, A., Pueo, B., & Jiménez-Olmedo, J. M. (2019). Physical performance indicators in traditional rowing championships. J. Sports Med. Phys. Fitness, 59, 767-773. https://doi.org/10.23736/S0022-4707.18.08524-9

Secher, N. (1993). Physiological and Biomechanical Aspects of Rowing. Sports Med. (Auckland, N.Z.), 15, 24-42. https://doi.org/10.2165/00007256-199315010-00004

Smith, T. B., & Hopkins, W. G. (2011). Variability and predictability of finals times of elite rowers. Med. Sci. Sports Exerc., 43(11), 2155-2160. https://doi.org/10.1249/MSS.0b013e31821d3f8e

Tittel, K., & Wurtscherk, H. (1992). Anatomical and anthopometric fundamentals of endurance. In R. J. Shepard & P. O. Åstrand (Eds.), Endurance in sport (pp. 35-45). Hoboken: Blackwell Scientifc Publications.

Volianitis, S., & Secher, N. (2009). Rowing, the ultimate challenge to the human body - Implications for physiological variables. Clin. Physiol. Funct. Imaging, 29, 241-244. https://doi.org/10.1111/j.1475-097X.2009.00867.x

Volianitis, S., Yoshiga, C. C., & Secher, N. H. (2020). The physiology of rowing with perspective on training and health. Eur. J. Appl. Physiol., 120(9), 1943-1963. https://doi.org/10.1007/s00421-020-04429-y

Weiner, J. E. S. S., & Lourie, J. A. (1969). Human biology: a guide to field methods. Oxford; Edinburgh: Published for the International Biological Programme by Blackwell Scientific.

Yoshiga, C. C., & Higuchi, M. (2003). Rowing performance of female and male rowers. Scand. J. Med. Sci. Sports, 13(5), 317-321. https://doi.org/10.1034/j.1600-0838.2003.00321.x

Yoshiga, C., Kawakami, Y., Fukunaga, T., Okamura, K., & Higuchi, M. (2000). (Originals) Anthropometric and Physiological Factors Predicting 2000 m Rowing Ergometer Performance Time. Adv. Exerc. Sports Physiol., 6.

Yusof, A. A. M., Harun, M. N., Nasruddin, F. A., & Syahrom, A. (2020). Rowing Biomechanics, Physiology and Hydrodynamic: A Systematic Review. https://doi.org/10.1055/a-1231-5268