ANTHROPOMETRIC DETERMINANTS OF ROWING ERGOMETER PERFORMANCE IN PHYSICALLY INACTIVE COLLEGIATE FEMALES

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ABSTRACT: The aim of the study was to evaluate anthropometric characteristics as determinants of 500 m rowing ergometer performance in physically inactive collegiate females. In this cross-sectional study, which included 196 collegiate females aged 19-23 years not participating in regular physical activities, body mass (BM), body height (BH), length of upper limbs (LA), length of lower limbs (LL), body mass index (BMI), slenderness index (SI), and the Choszcz-Podstawski index (CPI) were measured and a stepwise multiple regression analysis was performed. Participants performed 500 m maximal effort on a Concept II rowing ergometer. BM, BH, LA, LL, and the BMI, SI and CPI indices were found to be statistically significant determinants of 500 m performance. The best results (T) were achieved by females whose BH ranged from 170 to 180 cm, with LA and LL ranging from 75 to 80 cm and 85 to 90 cm, respectively. The best fitting statistical model was identified as: $T = 11.6793 \, L_R - 0.1130 \, L_R^2 - 0.0589 \, L_N^2 + 29.2157 \, CPI^2 + 0.1370 \, LR \cdot LN - 2.6926 \, LR \cdot CPI - 211.7796$. This study supports a need for additional studies focusing on understanding the importance of anthropometric differences in rowing ergometer performance, which could lead to establishing a better quality reference for evaluation of cardiorespiratory fitness tested using a rowing ergometer in collegiate females.

KEY WORDS: rowing, somatic variables, determinants, female, students, motor fitness

INTRODUCTION

The rowing ergometer has become a popular device in recent years, not only in specialized sports facilities but also in fitness clubs and even physical therapy clinics. The popularity of this kind of device stems directly from its vast array of possibilities of application in sports training as well as recreation and medical practice [1,2]. The continuously growing popularity of rowing ergometers has resulted in a relatively high number of scientific publications focused mainly on the possibility of using this device for improving sports performance. Research concerning the rowing ergometer is usually addressed at aerobic and anaerobic effort, with particular attention paid to competitive rowers taking part in sports competitions and training [3,4,5,6].

Results of maximal rowing ergometer performance are mainly determined by aerobic and anaerobic capacity as well as some somatic features [7]. It is believed that female collegiate rowers who have proportionally long limbs as well as higher body height also have a biomechanical advantage for sweep rowers [8]. Information about female collegiate rowers is limited to physiological characteristics. Still the best fitted allometric models are sought [7].

At competitive distances the 2000 m rowing ergometer test is recognized as the most valuable means of measuring rower performance. The standard error of the estimate of on-water 2000 m time predicted by 2000 m ergometer performance is 2.6% and 7.2% and is widely accepted by coaches and investigators [9]. The 500 m rowing ergometer trial can be used for assessment and for training purposes, to increase the level of endurance abilities among people who differ in terms of sports aspirations, and even among those who are partially physically impaired (e.g., overweight or obese). A device such as the rowing ergometer allows the practitioner to perform efforts of moderate intensity over a relatively long period of time, which has a positive effect on the level of his/her organism's endurance abilities, even when rowing a distance of 500 m just once a week [10]. Moreover, a rowing person performs physical effort in the sitting position, which relieves the lower limbs and neutralizes the negative impact of body mass on movement.

A number of papers concerning the relationships between physiological [11,12] and anthropometric parameters and motor fitness on the rowing ergometer at various distances have also been pub-

lished [13,14,15]. Moreover, the above-mentioned studies involved mainly physically active professional athletes and applied the rowing device during training or to assess their level of motor fitness, in an effort to improve preparatory training and maximize results achieved in sports competitions. Studies aimed at determining anthropometric determinants of rowing in collegiate females are limited. Results of such a study could yield valuable information that could subsequently be used for general rowing performance modelling, selection purposes and adjusting the motor fitness assessments.

The aim of the study was to evaluate anthropometric characteristics as determinants of 500 m rowing ergometer performance in physically inactive collegiate females.

MATERIALS AND METHODS

Subjects. A group of 196 female students attending the University of Warmia & Mazury in Olsztyn (Poland) was recruited for this study. The participants attended only the mandatory physical education classes (90 minutes per week) and did not participate in any other physical activities.

The volunteers willingly agreed to participate in the study, after being informed about the aims and design of the experiment. The research was carried out in compliance with the Declaration of Helsinki, with prior consent from the Bioethical Committee and governing bodies of the University of Warmia & Mazury in Olsztyn. The study group is characterized by Table 1.

Measurements

The following anthropometric parameters were measured and adopted as independent variables to determine their influence on the time needed to cover the simulated distance:
- body mass (M) and body height (H) of female students,
- length of upper limbs (L_A) and length of lower limbs (L_L).

Height/mass indices, such as BMI, slenderness index (SI), and the Choszcz-Podstawski index (CPI) constituted additional variables.

In order to assess the uniformity of the research group, a further independent variable – the year of studies – was included in the research. The individual years of studies were a direct reflection of the students' age (students enrolled in years 1, 2, 3, 4, and 5 were respectively 19, 20, 21, 22, and 23 years old). Due to the small number of female students enrolled in their 4th and 5th year, they were combined into one group. The time required to cover a simulated distance of 500 m on the rowing ergometer was accepted as the dependent variable.

Procedures

The participants covered the simulated distance of 500 m for the first time at the maximum pre-set resistance of movement (10 on a 1–10 scale), and were instructed to perform the trial to the maximum of their physical ability. All participants taking part in the research were instructed how to row and given opportunities to practice proper technique during P.E. lessons preceding the experiment. Anthropometric parameters and the time needed to cover a distance of 500 m on a rowing ergometer were measured with appropriate and adequately scaled study tools. These included a set for measuring body mass, height, and upper and lower limb length, as well as a *Concept II model C* rowing ergometer. Prior to performing the trial, all participants were instructed on the proper rowing technique when using this type of device. Each participant also took part in a 20 minute warm up preceding the commencement of the experiment.

Statistical analyses

The data were analysed statistically by means of the Statistica PL program package (StatSoft Inc., Tulsa, OK, USA). Statistical calculations were carried out at the significance level of $\alpha = 0.05$. Prior to

TABLE I. STATISTICAL PARAMETERS FOR THE ACCEPTED INDEPENDENT VARIABLES ACCORDING TO THE YEAR OF STUDIES.

Year of studies	I	II	III	IV+V
Number of subjects	56	58	58	24
Body mass [kg]	63.98 ± 10.21 (47÷96) 15.96	62.22 ± 8.88 (49÷97) 14.27	62.36 ± 8.80 (49÷94) 14.11	62.63 ± 5.41 (52÷72) 8.63
Body height [cm]	171.2 ± 7.67 (157÷192) 4.48	168.8± 7.44 (155÷191) 4.41	168.7 ± 7.73 (156÷190) 4.58	169.0 ± 7.20 (154÷182) 4.26
BMI [kg·m⁻²]	21.7 ± 2.16 (17.9÷27.2) 9.96	21.9 ± 1.59 (18.7÷26.6) 7.26	21.9 ± 2.07 (17.7÷28.7) 9.45	22.0 ± 2.59 (18.4÷30,4) 11.77
SI [cm·kg⁻⁰·³³]	32.6 ± 1.89 (28.6÷37.0) 5.79	32.4 ± 1.43 (29.6÷36.8) 4.41	32.2 ± 1.79 (29.1÷38.0) 5.56	32.2 ± 2.43 (26.6÷37.1) 7.55
CPI [cm·kg⁻¹]	2.7 ± 0.33 (2.0÷3.4) 12.22	2.7 ± 0.26 (2.0÷3.2) 9.63	2.7 ± 0.28 (1.9÷3.4) 10.37	2.7 ± 0.25 (2.1÷3.2) 9.26
Upper limbs length [cm]	71.3 ± 4.13 (62÷78) 5.79	71.6 ± 3.67 (63÷81) 5.13	71.6 ± 3.92 (64÷82) 5.47	71.8 ± 3.18 (65÷78) 4.43
Lower limbs [cm]	85.7 ± 5.52 (73÷98) 6.44	84.0 ± 6.50 (71÷103) 7.74	83.7 ± 7.03 (72÷103) 8.40	81.1± 4.27 (72÷91) 5.27

Note: values represent mean ± standard deviation in upper row and the coefficient of variation in lower row for each variable, range of values are in brackets, SI - slenderness index, CPI - Choszcz-Podstawski index

the verification of key hypotheses, the recorded results were checked for the presence of gross errors [16]. The research hypotheses were verified sequentially, assuming that the average time taken to complete the simulated distance of 500 m on a rowing ergometer depends on the students' year of studies, body height and mass, and upper and lower limb length. It was also tested whether the number of participants included in the research was sufficient for the group to be considered representative by applying the following formula (1):

$$n = \frac{\mu_\alpha^2 \cdot \hat{s}^2}{d^2},$$

For the accepted level of significance $\alpha = 0.05$, it was presumed that the error of estimating the average does not exceed 1.5% [16].

Due to the fact that the tested phenomenon can be described equally effectively by a few significantly different models, the following forms of functions were tested in the study:

$$y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 \tag{2}$$

$$y = a_0 + a_1 x_1^2 + a_2 x_2^2 + a_3 x_3^2 + a_4 x_1 + ... + a_7 x_1 x_2 + ... + a_9 x_2 x_3 \tag{3}$$

$$y = a_0 x_1^{b_1} x_2^{b_2} x_3^{b_3} \tag{4}$$

The choice of the correct function form was determined by the following criteria: it should be as simple and contain as much information as possible [17].

Upon deriving regression equations (multiple, second degree polynomial, and exponential), stepwise regression with the *a posteriori* procedure of eliminating insignificant variables and stepwise selection were carried out. The calculations were performed by means of Winstat and Statistica PL. The following criteria were assumed for assessing the suitability of a model for the given set of empirical data: the calculated value of F-Snedecor statistics, the probability of exceeding the value of F-Snedecor statistics, the multiple correlation coefficient, the percentage of explained variance, residual standard deviation, and the random variation coefficient.

Research hypotheses regarding the engagement of different areas of the body during the rowing ergometer trial were also subjected to verification. Variance analysis was applied for this purpose.

RESULTS

Table 2 presents the variance analysis of results regarding the influence of the year of studies the students were enrolled in on the average time needed to cover a simulated distance of 500 m.

TABLE 2. VARIANCE ANALYSIS OF THE AVERAGE TIME TAKEN TO COMPLETE THE TRIAL ACCORDING TO THE YEAR OF ACADEMIC STUDIES.

Year of studies	Number [n]	Time T [s] mean ± stand. dev. (range)	CV [%]
I	56	147.5 ± 10.28 (131.5÷181.7)	6.97
II	58	144.4 ± 9.24 (124.6÷170.5)	6.40
III	58	145.3 ± 10.92 (129.7÷198,3)	7.52
IV+V	24	145.4 ± 10.61 (133.3÷177.5)	7.30
Total	196	145.7 ± 10.22 (124.6÷198.3)	7.01

Note: Calculated value of (F) F = 0.9236, probability of exceeding the calculated (F) statistics p(F) = 0.4304, CV - the coefficient of variation index

TABLE 3. RESULTS OF MULTIVARIATE REGRESSION ANALYSIS

Feature	Mean ± stand. dev. (range)	CV [%]
Time [s]	147.5 ± 10.22 (124.6 ÷198.3)	7.01
Mass [kg]	62.9 ± 8.89 (47.3 ÷ 97.6)	14.13
Height [cm]	169.5 ± 7.58 (154.8 ÷ 192.1)	4.47
BMI [kg·m^{-2}]	21.8 ± 2.02 (17.7 ÷ 30.4)	9.27
SI [cm·kg$^{-0.33}$]	32.4 ± 1.81 (26.6 ÷ 38.0)	5.59
CPI [cm·kg^{-1}]	2.7 ± 0.29 (1.9 ÷ 3.4)	10.74
Arm length L_A [cm]	71.6 ± 3.80 (62.1 ÷ 82.5)	5.31
Leg length L_L [cm]	84.1 ± 6.28 (71.3 ÷ 103.3)	7.47

	M, H, L_A, L_L	BMI, L_A, L_L	SI, BMI, L_A, L_L	CPI, L_A, L_L
Calculated value of (F)	F = 170.889	F = 115.00	F=41.54	F=208.41
Probability of exceeding the calculated (F) statistics	p(F) < 0.0001	p(F) < 0.0001	p(F) < 0.0189	p(F) < 0.0001
Accepted level of significance	α = 0.05	α = 0.05	α = 0.05	α = 0.05
Percent of explained variability	84.44	78.50	52.23	86.87
Multiple correlation index	0.9189	0.8860	0.7227	0.9320
Standard deviation of the tests	4.0845	4.8007	8.5060	3.7514
Random variation coefficient	2.77	3.25	5.77	2.54
Regression equation	(a)	(b)	(c)	(d)

T= 3.1565 H + 0.0346 BM^2 − 0.0493 L_A^2 − 0.0602 H×BM + 0.1004 H×L_A + 0.0015×L_A×L_L - 92.5637   (a)

T= - 31.1336 BMI - 0.0322 L_A^2 - 0.0105 L_L^2 + 0.3081 BMI^2 + 0.1866 L_A BMI + 0.0954 L_L×BMI + 451.1327   (b)

T= 8.7877 L_A- 17.9428 SI + 0.5973 SI^2 + 0.0101 L_A×L_L - 0.3228 L_A×BMI + 157.6971   (c)

T= 11.6793 L_A - 0.1130 L_A^2 − 0.0589 L_L^2 + 29.2157 CPI^2 + 0.1370 L_A×L_L - 2.6926 L_A×CPI - 211.7796   (d)

Note: SI - slenderness index, CPI - Choszcz-Podstawski index, H - height, LA - length of upper limbs, LL - length of lower limbs, BM - body mass

The biggest differences in the average time taken to cover the simulated distance were observed between female students in their 1st and 2nd year of studies; however, these were now shown to be statistically significant. This variable was therefore omitted in further calculations and all persons participating in the research were treated as one homogeneous group. The required number of participants calculated from formula (1) was 185 and thus smaller than the number of women included in the study (196). The study group was, therefore, determined to be a representative sample for the population of female students attending the University of Warmia & Mazury in Olsztyn.

In the case of the remaining variables, i.e., the body height (H) and mass (M) of female students (including derivative indices such as BMI, SI and CPI), as well as their upper (L_A) and lower limbs (L_L) length, hypotheses assuming the lack of influence of these factors on the dependent variable were rejected in favour of alternative hypotheses. The results of statistical calculations on the influence of each of the independent variables (M, H, BMI, SI, CPI, L_A and L_L) on the dependent variable (T) are summarized in Table 3.

The performed regression analysis allowed us to work out several important equations describing the influence of the independent variables on the time needed to complete the rowing ergometer trial. Among the calculated dependences, the regression equation (d), in which the significant independent variables were the CPI index of the female students under study and their upper (L_A) and lower (L_L) limb length, was shown to be the most suitable for the given set of empirical data. In the case of this equation, the percentage of explained variation was equal to almost 87%, with a very low random variation coefficient (approx. 2.5%). Equations (a) and (b) were also characterized by a relatively high suitability, with the percentage of explained variation equal to 84.5% and 78.5% respectively, and a relatively low random variation coefficient (approx. 3%).
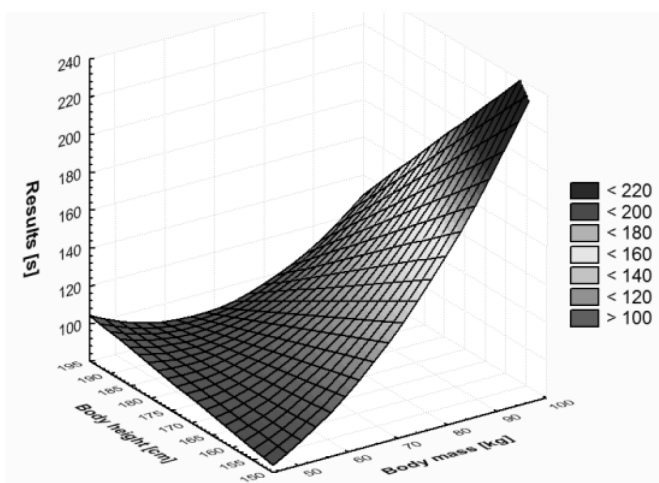

FIG. 1. RELATIONSHIP BETWEEN TIME TAKEN TO COMPLETE THE TRIAL AND BODY HEIGHT AND MASS OF STUDENTS
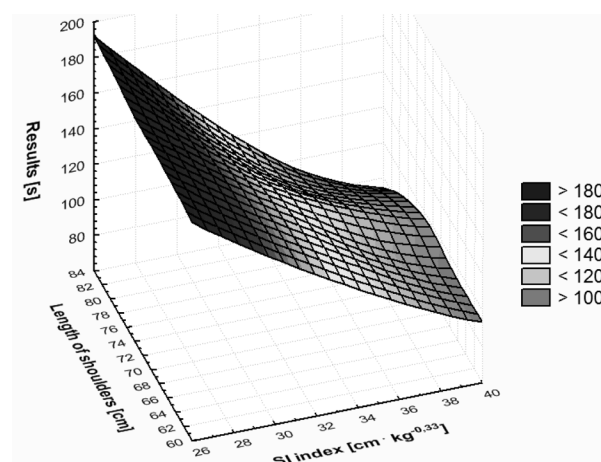

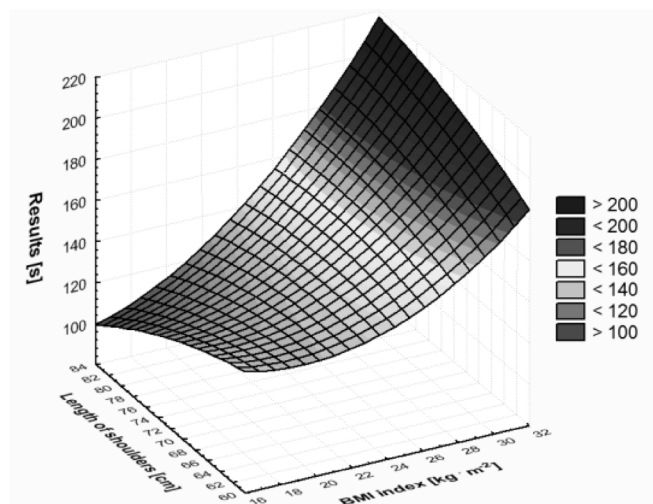**FIG. 3.** RELATIONSHIP BETWEEN TIME TAKEN TO COMPLETE THE TRIAL AND THE SI INDEX AND UPPER LIMB LENGTH

FIG. 2. RELATIONSHIP BETWEEN TIME TAKEN TO COMPLETE THE TRIAL AND THE BMI INDEX AND UPPER LIMB LENGTH
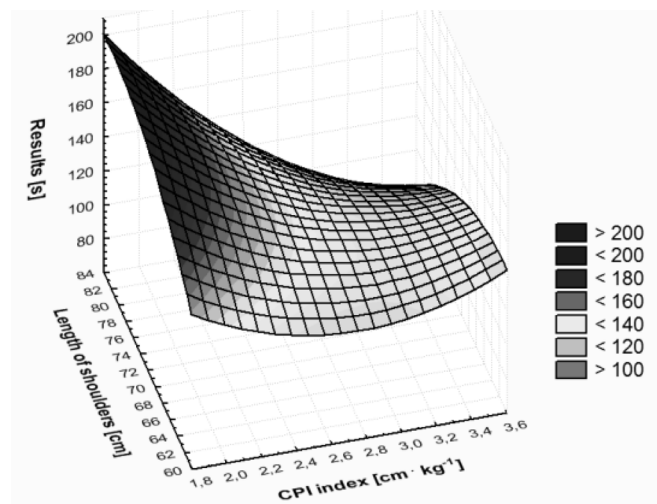

FIG. 4. RELATIONSHIP BETWEEN TIME TAKEN TO COMPLETE THE TRIAL AND THE CPI INDEX AND UPPER LIMB LENGTH

Based on the derived mathematical dependences (Table 3, regression equation – a) and analysis of the graph (Fig. 1), it was determined that the decision variables in this model were: the students' body mass (M) and height (H). Upper limbs length (L_A) also had a significant influence on the time (T), whereas lower limbs (L_L) was only shown to have an interactive effect (interactive effect of limbs length). The best results (below 120 s) were achieved by female students whose body mass and height ranged from 55 to 65 kg and 170 to 180 cm respectively, with an upper limb length of 75 to 80 cm and lower limb length of 85 to 90 cm.

From the models referred to in Table 3 as (b) and (d), upper and lower limb length were shown to have a significant influence, in addition to two of the analysed indicators (BMI and CPI). The usefulness of the equation presented in Table 3 as (c) is relatively low, as shown by values of indicators assessing the suitability of this model for the given set of empirical data. Due to the fact that lower limb length (L_L) had the smallest impact on the time (T) taken to row the distance of 500 m, the discussed dependences were presented with an average value of this factor.

Based on the analysis of graphical dependences (Fig. 2, 3 and 4), it can be concluded that the female students most predisposed to rowing are those whose upper and lower limb length ranges from 75 to 80 cm and 85 to 90 cm respectively, and who are characterized by the following values of selected indicators (derived from body mass and height): BMI (18–22 $kg \cdot m^{-2}$), SI (36–39 $cm \cdot kg^{-0.33}$), and CPI (3.0–3.3 $cm \cdot kg^{-1}$).

DISCUSSION

The present study is a continuation of observations concerning the possibility of applying the 500 m rowing ergometer trial in mass studies, as an accurate and reliable means of measuring short-term endurance [18]. As a follow-up to preliminary findings, the accuracy and reliability of this trial were determined [10] and next, the number of anthropometric parameters (gold standards) was expanded to enable more thorough assessment of the trial.

It was established that the main factors affecting the final result (measured time – T) are body mass (M), height (H) and upper limbs length (L_A) as well as indices derived from body mass and height, i.e., BMI, SI and CPI, as confirmed by mathematical models (Table 3). The significant influence of lower limbs length (L_L) had an interactive nature (together with upper limbs length) in the majority of components of individual equations. These anthropometric features may be considered a derivative of body build, which is generally characterized by body mass and height.

Research has revealed that anthropometric characteristics may have some influence on rowing performance. The best rowers are generally taller and heavier than other athletes competing in endurance sports [19]. This is most likely due to the fact that rowing is performed in the sitting position and the rowers' body mass is supported by the boat (rowing ergometer). This in turn means that these athletes can afford to be heavier without a detrimental effect on their performance [20]. A study focused on well-trained male and female rowers showed significant correlations between performance and body mass and dimensions [8,21,22]. Also it was shown that relative shank to thigh length is associated with different mechanisms of power production during elite male ergometer rowing [23]. It should however be noted that studies concerning such relationships were conducted mainly on 2000 m and less frequently on 1000 m rowing stretches. The authors proved that rowers presenting a high level of sports performance are characterized by higher values of anthropometric parameters and leaner body mass in comparison to average persons [13,24].

Well-trained rowers' organisms also achieve high values of VO_2max [14,25]. Research has consistently confirmed maximal oxygen uptake (in $L \cdot min^{-1}$) to be the strongest, and often the sole predictor of rowing ergometer performance of all tested anthropometric and physiological parameters. Nevertheless, body mass and lean body mass are also often indicated as important anthropometric predictors [6,24,26].

Research conducted on 23 of the best female rowers in the world revealed their average body height to be 179.4 cm in the HWT (heavy weight) and 167.8 cm in the LWT (light weight) category. The average body mass for HWT and LWT rowers was 75.7 kg and 59.5 kg respectively [7]. The results of our study indicate that the best results were obtained by female students whose body height ranged from 170 to 180 cm, which is similar to the results in the above-mentioned research. However, our results also revealed that students characterized by a lower body mass (from 55 to 65 kg) than indicated by research conducted on professional female rowers performed better in the trial.

This would mean that values of basic anthropometric parameters (body mass and height) and height/mass related indices should be interpreted differently in groups of trained and untrained individuals. The body mass of trained rowers predominantly consists of lean body mass [27], whereas people who lead a sedentary lifestyle, such as the students who participated in our research, have a higher percentage of adipose tissue than muscle, which significantly reduces their endurance abilities [6,14,28,29]. This most likely explains why students with a lower body mass performed better in our studies as compared to research on professional athletes.

The positive influence of possessing longer limbs is justified by the biomechanics of human movement during rowing. Rowers characterized by higher values of these parameters are able to use a longer levering effect (i.e., to perform longer strokes). The drive phase of the rowing stroke, as well as knee extensions, is increased by longer lower extremities, thus providing a biomechanical advantage [6,8,24,27]. As a result of the above, elite rowers possess a shorter sitting height (relative to stature) but longer extremities, and are more muscular than the average persons in the same age categories [12,13,30]. It appears that despite the various levels of training (in both well-trained and untrained individuals), certain similarities in limbs length predispose people to rowing.

As hypothesized, the age of physically inactive female students does not significantly influence the time needed to cover a simulated distance of 500 m on a rowing ergometer. Contrary to this, Battista et al. found that female collegiate rowers differ to some extent in physical and performance characteristics by level and age (experience) [8].

CONCLUSIONS

Anthropometric parameters such as body mass and height, upper and lower limbs length (interactive with upper limbs), as well as BMI, SI and CPI indices (derivates of body mass and height), have a significant influence on the dependent variable. Among the tested forms of mathematical models, the second degree multiple polynomial was found to be best suited for describing the phenomenon. The CPI index (ratio of height to mass), upper limbs length (L_A), and lower limbs length (L_L) of female students were found to be the main

variables determining its character. The 500 m trial on a rowing ergometer was completed the fastest (under 120 s) by female students who were characterized by CPI ranging from 3.0 to 3.3 cm kg^{-1}, with the length of upper and lower limbs ranging from 75 to 80 cm and 85 to 90 cm, respectively. The results of this study support a need for additional studies focusing on understanding the importance of anthropometric differences in rowing ergometer performance, which could lead to establishing a better quality reference for evaluation of cardiorespiratory fitness tested using a rowing ergometer in collegiate females.

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