**ABSTRACT**

**Purpose.** The aim of the study was to develop a mathematical model to determine correlations between selected somatic traits and indoor rowing test results over a distance of 500 m as well as differences in the level of motor fitness of students of the University of Warmia and Mazury in Olsztyn. **Material and methods.** The research was carried out on a group of 274 full-time UWM students with the aid of Concept II Indoor Rower. The analysis concerned the effects of students' body weight and body height, year of study and the time required to cover the distance of 500 m during an indoor rowing test. **Results.** Analysis of variance and regression analysis with stepwise elimination of the polynomial degree and form were used. Only 15 subjects (5.5% of the sample) achieved the highest level of motor fitness, i.e. covered the distance under 92.7 s. A mathematical model describing the effects of decisive variables on the dependent variable was a model of regression of multiple variables of the 2nd degree. The exogenous variables were subjects' body height and body weight. **Conclusions.** The proposed mathematical model of regression of multiple variables of the 2nd degree can be useful for selection of individuals with predispositions to practice rowing at the academic and recreational levels. The proposed method of mathematical model development should be regarded as an algorithm for other, more versatile models involving additional variables.

**Key words:** motor fitness, ergometer, body height, body weight, students, mathematical model

**Introduction**

The diversity of morphological predispositions [1] is a decisive factor affecting the process of selection for particular sports [2–4]. It has been subject to numerous research studies focusing on athletes’ body build and sports results [5–8]. Body height is often taken into consideration in selection for such sports as basketball, jumping events, judo, canoeing, air sports or rowing. Long arms and legs as well as big feet and hands are equally important. Limb length proportions and the body height/body weight ratio are significant factors affecting achievement of results in the vast majority of sports [9].

One of methods of assessment of motor fitness is the measurement of time required to cover a simulated distance with the aid of a rowing ergometer. Ergometer tests on large, representative samples can be carried out, for example, during various sports competitions held at the academic level [10, 11]. The measurements of students’ motor fitness have been, first of all related to their health, as they have been commonly regarded as a determinant of good health and capacity to successfully perform different motor tasks [12]. In this context motor fitness can determine the body’s adaptability to the motor challenges of the surrounding environment.

In 2004 the 1st 500 m Indoor Rowing Championships of the University of Warmia and Mazury were held by the University Study Center for Physical Education and Sport. The results of the ergometer tests became the basis of the following analysis.

The following research hypothesis was formulated: the mean time required to cover a simulated distance of 500 m on a rowing ergometer is correlated with the students’ year of study, body height and body weight. The research also aimed to determine the impact of selected factors (independent variables) on the dependent varia-
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Table 1. Number and percentage of students participating in ergometer fitness tests with regard to their year of study

| Year of study | Male students |
|---------------|---------------|
|               | Number | %     |
| I             | 119    | 43.43 |
| II            | 93     | 33.94 |
| III           | 50     | 18.25 |
| IV            | 12     | 4.38  |
| Total         | 274    | 100.00|

Material and methods

The sample consisted of full-time students of the UWM in Olsztyn, who attended their PE classes at the time of the indoor rowing championships and volunteered to take part in them. The sample included 274 male students who only attended the mandatory PE classes for two hours a week and did not practice any other sport. The sample was divided according to the participants’ years of study (Tab. 1).

The measurements carried out on a Concept II Indoor Rower are commonly used in studies of pro-oxidative/antioxidative balance disturbances in rowers [13]. The ergometer allows nearly an ideal re-creation of all phases of rowing action (Fig. 1):

Phase I (pulling the handle) – from the starting position (a), legs bent in knees, arms straight, the trunk leaning forward – the legs slowly straighten up (b), the handle is pulled towards the chest by bending the arms in elbows, the trunk is pushed backwards (c).

Phase II (releasing the handle) – from the position with straight legs, the trunk pushed backwards and handle pulled close to the chest (c) – the legs slowly bend in knees and the arms straighten up (d) returning to the starting position (a).

Each test was preceded by a 5 min warm-up with a load ensuring the heart rate of 140/min. The ergometer action phases on an ergometer

Figure 1. Rowing action phases on an ergometer
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The subjects performed the test (covering the simulated rowing distance of 500 m) twice at the maximum resistance force (level 10). The rowing time was displayed on the PM-2 screen. The better of the two scores (shorter time) was recorded. To ensure proper sample representativeness the following necessary sample size formula was used [14]:

\[ n_0 = \frac{u_\alpha^2 \cdot \sigma^2}{d^2} \]  

\( n_0 \) – necessary sample size,
\( \sigma^2 \) – sampling variance,
\( u_\alpha \) – normal variable value \( N(0.1) \) with a set confidence coefficient (for \( 1 - \alpha = 0.95 \Rightarrow u_\alpha = 1.96 \)),
\( d \) – admissible mean error, accepted as 1% of relative error.

When the size of the original sample \( n \) is greater than the necessary sample size, the former is taken as the proper sample. To confirm the sample representativeness, the sample should be taken from a population with the normal distribution.

To determine the subjects’ rowing predispositions a five-level score scale was used (poor, satisfactory, average, good, very good) based on the three-sigma rule \((m \pm 3\sigma)\).

The results obtained were analyzed statistically with the WINSTAT statistical software package [15–17]. The level of statistical significance was set at \( \alpha = 0.05 \). To verify the normal distribution of the time necessary to cover the distance of 500 m on an ergometer the test of goodness of fit \( \chi^2 \) was applied. The analysis of variance was used to examine the significance of the impact of studied parameters on the mean time of covering the set distance. To determine the effects of independent (exogenous) variables on the dependent (endogenous) variable a polynomial regression of the 5th degree and multivariable regression of the 2nd degree were used. Also a stepwise elimination of the polynomial degree and form was applied.

**Results**

The distribution of rowing time required to cover the distance of 500 m seems to confirm hypothesis \( H_0 \) pointing to a normal distribution \( M = 104.18 \) and standard deviation \( \sigma = 8.1649 \). The number of students participating in the indoor rowing test \( (n = 274) \) was higher than the necessary sample size \( n_0 = 235.96 \approx 236 \), thus the sample can be considered representative.

Tab. 2 presents the students’ ergometer results over the set distance using the three-sigma rule.

| Motor fitness level | Rowing time (s) | Number of subjects | % |
|---------------------|-----------------|--------------------|---|
| Very good           | under 92.7      | 15                 | 5.47 |
| Good                | 92.7 – 100.0    | 72                 | 26.28 |
| Average             | 100.1 – 107.3   | 107                | 39.05 |
| Satisfactory        | 107.4 – 114.6   | 59                 | 21.54 |
| Poor                | over 114.6      | 21                 | 7.66 |

Table 3. Analysis of variance of indoor rowing mean times achieved by students in regard to their year of study

| Year of study | Mean (s) | Standard deviation (s) | Coefficient of variation (%) |
|---------------|----------|------------------------|-------------------------------|
| 1. I          | 103.45   | 7.22                   | 6.98                          |
| 2. II         | 103.62   | 7.51                   | 7.25                          |
| 3. III        | 103.64   | 7.39                   | 7.13                          |
| 4. IV         | 105.30   | 7.06                   | 6.70                          |

statistical significance \( F = 0.2311 \); probability of crossing the level of statistical significance \( p(F) = 0.8747 \); statistical significance level \( \alpha = 0.0500 \); because \( p(F) > \alpha \) there is no ground for rejection of null hypothesis \( H_0 \).

The results of the analysis of variance verifying hypothesis \( H_0 \) are presented in Tab. 3.

The analysis of the mean time required to cover the ergometer distance of 500 m revealed no statistically significant differences in regard of the subjects’ year of study. A slightly worse time (1.5 s longer) was recorded in the 4th year students, which can most likely be explained by the fact that the seniors devoted generally less time to physical education.

With the accepted level of statistical significance \( (\alpha = 0.05) \) hypothesis \( H_0 \) (i.e. no significant differences between the achieved rowing time and the subjects’ year of study) was confirmed. In the case of the other variables, i.e. subjects’ body weight and body height, hypo-
thesis $H_0$ was rejected in favour of alternative hypothesis $H_1$ with the exogenous variable $w$, i.e. ratio between students’ body height and body weight.

The results of polynomial regression analysis are presented in Tab. 4. As the regression coefficients were significantly different from zero, a correlation was noted between the independent (exogenous) variable $w$ and the ergometer test time (2):

$$Y = 36928.95 \cdot w^5 - 431432.58 \cdot w^4 + 1998420.14 \cdot w^3 - 4581873.27 \cdot w^2 + 5190915.68 \cdot w - 2319297.28 \quad (2)$$

The stepwise regression failed to eliminate the polynomial degree and form. The mathematical model revealed no significant correlation between the 500 m rowing time and the $w$ index (body height/body weight). In the first, third and fifth power the increase of $w$ extended the time of the test performance; whereas in the second and fourth power the rowing time was reduced.

The statistical results show that only in 65.17% the endogenous variable is explained by the mathematical model. Moreover, with the coefficient of multiple correlation slightly above 0.8 and the probability of crossing the level of statistical significance 0.0493, it can be stated that the dependent variable ($Y'$) determined by the independent variables can only to some extent affect the tested rowing time (Fig. 2).

Generally, it can be noted that the increase of the index $w$ from about 2.36 to 2.42 significantly extends the time required to cover the ergometer distance. In the $w$ interval between 2.42 and 2.58 the time is relatively stable. Above the value of $w$ of 2.58 a significant reduction of the rowing time can be noted.

In order to fit the model to the empirical data, the students’ body height and body weight were taken as decisive variables (Tab. 5).

Since the coefficients of regression were significantly different from zero, a correlation was noted between

![Figure 2. Correlation between rowing time and the w index](Image)

**Table 4. Correlation between rowing time and index $w$ (body height/body weight)**

| Parameter                  | Mean (s) | Standard deviation (s) | Coefficient of variation (%) |
|----------------------------|----------|------------------------|-------------------------------|
| $w$ (body height/body weight) (cm/kg) | 2.49     | 0.0974                 | 3.91                          |
| Time – $Y$ (s)             | 104.72   | 12.8784                | 12.30                         |

Verification of hypothesis on the significance of regression coefficients

- hypothesis $H_0$ – coefficients of regression insignificantly different from zero; hypothesis $H_1$ – coefficients of regression significantly different from zero; statistical significance $F = 5.724$; probability of crossing the level of statistical significance $p(F) = 0.0493$; level of statistical significance $\alpha = 0.0500$; percent of verified variability 65.17; coefficient of multiple correlation – 0.8070; standard deviation of the remainder – 12.4110; because $p(F) < \alpha$ null hypothesis $H_0$ is rejected in favour of alternative hypothesis $H_1$.

**Table 5. Correlation between rowing time, body weight and body height**

| Parameter                  | Mean (s) | Standard deviation (s) | Coefficient of variation (%) |
|----------------------------|----------|------------------------|-------------------------------|
| Body weight – $X$ (kg)     | 72.67    | 3.1623                 | 4.35                          |
| Body height – $Z$ (cm)     | 180.33   | 1.7321                 | 0.96                          |
| Time – $Y$ (s)             | 104.72   | 12.8784                | 12.30                         |

Verification of hypothesis on the significance of regression coefficients

- hypothesis $H_0$ – coefficients of regression insignificantly different from zero; hypothesis $H_1$ – coefficients of regression significantly different from zero; statistical significance $F = 14.1142$; probability of crossing the level of statistical significance $F – p(F) = 0.0270$; level of statistical significance $\alpha = 0.0500$; percent of verified variability 95.92%; coefficient of multiple correlation – 0.9789; standard deviation of the remainder – 4.2465; because $p(F) < \alpha$ null hypothesis $H_0$ is rejected in favour of alternative hypothesis $H_1$.

The stepwise regression analysis did not eliminate the degree and form of the polynomial. On the basis of the

$$Y = -161.46 \cdot X - 1003.71 \cdot Z - 2.23 \cdot X^2 + 2.26 \cdot Z^2 + 2.69 \cdot XZ + 95724.62 \quad (3)$$
derived mathematical model (2) the value of the exogenous (dependent) variable was approximated (Fig. 3).

The mathematical model (2) and Fig. 3 show that an increase of body weight in the first and the second power reduces the time necessary to cover the set ergometer distance. A greater body height also reduces the rowing time, despite some equivocal effects (time reduction in the first power, time extension in the second power). There are also some interactive effects of the body weight and body height on the mean time required to cover the 500 m distance. The increased body weight and body height (or only one of these variables) extends the time of performing the test.

The use of exogenous variables of $X$ (subjects’ body weight) and $Z$ (subjects’ body height) greatly improves the fitting of the model to the empirical data. The percentage of verified variability exceeded 95.9%; the coefficient of correlation reached almost 0.98 and the standard deviation of the remainder decreased nearly three times as compared with the previous mathematical model.

The goodness of fit analysis proved the validity of the accepted model, which can be used for selection of individuals with potential predispositions for rowing at the academic and recreational levels.

**Discussion**

An ergometer test should be analysed in terms of its individual components: duration, resistance force, number of strokes per split. Such an analysis corresponds to the general view that exercise load in all sports is related to the temporal-spatial structure of movement, its intensity and training loads [18, 19].

The maximum rowing rate can be attained on an ergometer through maximization of positive forces and minimization of negative forces generated during the rowing strokes [20].

The standard ergometer distance of 500 m is often called the “anaerobic starting phase” of a 2000 m rowing run. It can be used to measure the local physical efficiency of participating muscles, providing the duration of this phase is between a few seconds and two minutes [21]. The analysis of the students’ mean time values (from 103.5 to 105.3 s) required to cover the distance of 500 m showed that they fell below the upper limit of the duration time. Following Janssen [18, p. 45], depending on physical exercise duration the efforts necessary to cover the ergometer distance of 500 m can be placed between anaerobic exercise (45–120 s) and aerobic–anaerobic exercise (120–140 s) with an emphasis on the anaerobic exercise. Apart from one’s ability to develop maximum force, the time in which it is sustained at a steady level and rowing technique are equally important.

It was observed that the motor predispositions essential in rowing included endurance skills in different combinations, i.e. complex predispositions [compare 22], for example, special endurance or strength endurance [18, 23]. It can be thus assumed that the rower’s exercise involves the basic motor skills with great emphasis on endurance skills [24].

The following rowing predispositions can therefore be identified:

- strength – overcoming the rowing resistance at the highest level on a ten-point scale;
- endurance – maintaining the exercise level between 131.7 and 132.1 s;
- speed – maintaining the proper rowing pace on a set distance;
- coordination – alternating movements of the arms and legs (bending the arms in elbows with simultaneous straightening of the legs in knees and leaning the trunk backwards).

Each predisposition features its own intensity; however, short time endurance plays here a decisive role. Short-time endurance is typical of exercise of submax-
nal intensity with the duration between 50 and 120 s. The most significant component of motor fitness is aerobic endurance [25]. Despite the fact that the 500 m rowing distance is commonly classified as a short endurance distance, the time required to cover this distance falls below the upper range of short-time endurance and close to the lower limit of middle-time endurance. It is most likely due to the necessity of greater effort to cover the ergometer distance with the highest load. Thus, the energy supplies during such an exercise may involve both anaerobic processes (up to 90 s) and aerobic processes (above 4 min) constituting a complex system (90 s – 4 min) [26].

A thorough factor analysis of rowing tests will be therefore necessary and should aim at an improvement of accuracy, reliability, objectivization and economy in a 500 m indoor rowing exercise [27, 28]. Detailed studies of metabolic processes as factors determining the physical fitness over the rowing distance mentioned are also important. As Zambroń-Lacny et al. [13] noted, the number of research studies concerning the prooxidative-antioxidative balance in rowers have been extremely scarce.

The ergometer 500 m tests can be extremely useful in future studies of motor fitness, as a measurement of the state of health of physically active young people. Obviously, certain aspects of the indoor rowing tests require further research, especially the endurance skills constituting one’s motor potential. Ergometer tests may constitute a significant contribution to studies of young people at different stages of their physical development. Their results presented in tables can be used for development of prospective standards and be applied in research of many other different populations.

Conclusions

1. There is a correlation between the two variables under study: subjects’ body weight and body height and the mean time of covering the distance of 500 m on a rowing ergometer.

2. No statistically significant correlations between the rowing time and the subjects’ year of study were found. This can be explained by the relatively broad age span of students participating in the study.

3. It can be stated that the indoor rowing time required to cover the distance of 500 m depends on the index w, i.e. ratio of a subject’s body height and body weight. An increase of the index w from about 2.36 to about 2.42 extends the rowing time. In the w range between 2.42 to about 2.58 the indoor rowing time is relatively stable; whereas with the index w between 2.58 to about 2.65 a distinct reduction of the rowing time can be observed.

4. The derived mathematical model of regression of multiple variables of the second degree can be applied in the process of selection of individuals with predispositions to practice rowing at recreational and academic levels.

5. Ergometer tests should continue and possibly incorporate additional variables which may significantly affect the final research results.

References

1. Szopa J, Mleczko E, Zak S. The rudiments of anthropometrics [in Polish]. PWN, Warszawa–Kraków 1996.

2. Chwała W, Mirek W, Mleczko E, Ruchlewicz T. The influence of an individual model of racewalker’s legs on the range of upper body movements [in Polish]. Antropomotoryka, 2005, 30, 31–38.

3. Litkowycz R, Zając A, Wasikiewicz Z. Ontogenetic variability of morphostructural predispositions of basketball players at various levels of sports training [in Polish]. Antropomotoryka, 2005, 30, 39–45.

4. Ziółkowska A. Body build of military air pilots [in Polish]. Wych Fiz i Sport, 1995, 3, 13–20.

5. Crielard J.M., Pirnay F., Anaerobic and aerobic power of top athletes. Eur J Appl Physiol, 1981, 47(3), 295–300. DOI: 10.1007/BF00422475.

6. Dotan R., Bar-Or O., Load optimization for the Wingate anaerobic test. Eur J Appl Physiol, 1983, 51(3), 409–417. DOI: 10.1007/BF00429077.

7. Nowacka-Chiari E., Morphological diversity of boys and girls training jumps [in Polish]. Wych Fiz i Sport, 1988, 2, 97–13.

8. Karolakiewicz J., Szczesiak L., Comparative analysis of reduced glutathione (GSH) in red blood cells and thiobarbituric acid reactive substances (TBARS) in blood plasma of rowers in four periods of the annual training cycle [in Polish]. Medicina Sportiva, 2001, 5(2), 79–88.

9. Wieczorek W, Witkowski M., Motor fitness and body build changes in young swimmers [in Polish]. Wych Fiz i Sport, 1990, 3, 17–26.

10. Wujciak A., Indoor rowing championships [in Polish]. Wiadomości Uniwersyteckie UWM, 2005, 2 (69), 27.

11. Podstawski R., Choszcz D., Wysocka-Welanc M., The impact of body height and body weight on the ergometer split [in Polish]. Antropomotoryka, 2006, 34, 69–76.

12. Przewęda R, Trzesniowski R., Physical fitness of Polish youth according to 1989 research studies [in Polish]. AWF, Warszawa 1996, 20–22.

13. Zambroń-Lacny A., Szyszka K., Disturbance of pro-oxidative/antioxidative balance during a 2000 m indoor rowing test [in Polish]. Medicina Sportiva, 2002, 6(2), 29.

14. Greli J., Mathematical statistics. Models and exercises [in Polish]. PWN, Warszawa 1974.

15. Mikolajczak J., Mathematical statistics with WinStat on CD [in Polish]. UWM, Olsztyn 2001.
HUMAN MOVEMENT
D. Choszcz, R. Podstawski, M. Wysocka-Welanc, Motor fitness of students

16. Stanisz A., Practical course in statistics with STATISTICA PL using examples from medicine. Volume II [in Polish]. StatSoft Polska, Kraków 2000.
17. Stanisz A., Practical course in statistics with STATISTICA PL using examples from medicine [in Polish]. StatSoft Polska, Kraków 2001.
18. Ronikier A., Physiology of sport [in Polish]. COS, Warszawa 2001, 39–40.
19. Szopa J., Structure of motor abilities: identification and measurement [in Polish]. Antropomotoryka, 1998, 18, 79–86.
20. Rowing: Rowing – FISA basic course (II). Physiological basics of rowing [in Polish]. Sport Wyczynowy, 1991, 11–12, 56–60.
21. Wojcieszak I., Burke E., Michael E., Puchow M., Physiological and mechanical aspects of anaerobic exercise of various duration [in Polish]. Wych Fiz i Sport, 1981, 24, 100–106.
22. Raczek J., Structuralization and classification of human motor function. In: Osiński W. (ed.), Human motor function: structure, variability, conditions [in Polish]. AWF, Poznań 1993, 310, 63–80.
23. Steinacker J.M., Secher N.H., Advances in physiology and biomechanics of rowing. Int J Sports Med, 1993, 14 (Suppl. 1), S1–S2.
24. Szopa J., Structure of human motor function: a revision [in Polish] Antropomotoryka, 1993, 10, 217–227.
25. Heyward V.H., Advanced fitness assessment exercise prescription. (3rd ed.). Human Kinetics, Champaign 1997.
26. Wuest D.A., Bucher C.A., Foundations of physical education and sport (11th ed.). Mosby Year Book Inc, St. Louis 1991.
27. Pilicz S., Measurement of general physical fitness [in Polish]. AWF, Warszawa 1997, 16.
28. Osiński W., Anthropomotorics [in Polish]. AWF, Poznań 2003, 162–163.

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