Endurance Test on the Rowing Machine

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ABSTRACT

Several laboratory and field tests are used to assess the endurance level. The aim of the study was to determine the significance of differences between men and women 12-minute Rowing Test (12MRoT) and the relationship between the anthropometric and performance variables for both genders separately. A literature review of aerobic capacity indicators and endurance fitness tests on the C2 rowing machine was prepared. The result of extensive research is the design for a simple test with a set duration, when the tested person should try to cover the greatest possible distance (i.e. maximum effort). A total of 323 students of the University of Defence were males (n = 270; age = 20.9 ± 1.88) and females (n = 53; age = 20.6 ± 1.47) who participated in 12MRoT. The basic anthropometric characteristics were measured (height, weight). The endurance fitness indicators were the distance covered (DC, meters), average power (AP, watts), and average heart rate (HR, beats per minute). Statistical analysis of differences between mean values (t-test, effect size index d) and relationships between variables (Pearson or Spearman correlation coefficient r or rs, effect size index r) demonstrated significant differences between males and females were observed for the indicator DC ($p < .05$; $d = 1.79$) and for the AP ($p < .05$; $d = 1.94$). A small correlation between HR and DC ($p < .05$; ES small), HR and AP ($p < .05$; ES small) was found in males. A medium correlation between DC ($p < .05$; ES medium), AP ($p < .05$; ES medium), and HR was found in females. A statistically significant correlation was demonstrated between height ($p < .05$; ES medium), weight ($p < .05$; ES medium), and DC and also between height ($p < .05$; ES medium), weight ($p < .05$; ES medium) and AP in men. On the other hand, in women, there was no statistically significant correlation between height ($p > .05$; ES small), weight ($p > .05$; ES small), and DC and also between height ($p > .05$; ES small), weight ($p > .05$; ES small) and AP. The results of our study demonstrate the applicability of the 12MRoT on Concept II under the required conditions. The results of the study provided initial reference values for individual assessment of aerobic fitness. This study should be followed up by further research where it seems appropriate to compare performance on the 12-minute Cooper test and the 12MRoT.

Keywords: diagnostics, fitness test, Cooper´s test, 12-min rowing test, military, Concept2

INTRODUCTION

All students of the University of Defense in Brno must complete physical tests, as one of the conditions for fulfilling the credit from physical training. They have to overcome the high level of endurance they demonstrate by completing Cooper's 12-minute run. At the Physical Training and Sports Centre of the University of Defence, we encountered the following problem: How to test the endurance abilities of people who cannot undertake the running test? Therefore, we will try to define the physiological factors of running endurance and thus facilitate the selection of a substitute test for a 12-minute run.

Indicators of aerobic capacity:

A well-proven physiological indicator of aerobic capacity is the maximum minute oxygen uptake (VO_2max), especially when calculated per 1 kg of human weight ($VO_2max.kg-1$). An indicator of aerobic capacity is also the so-called anaerobic threshold. It is the load intensity in the transition zone between predominantly aerobic and predominantly anaerobic energy acquisition for muscle work. It is expressed by the highest power at the beginning of the steep onset of the indicators of anaerobic energy acquisition (during the graded load). Ventilatory-respiratory anaerobic thresholds can be established, based on the detection of a sudden increase in ventilation and CO_2 output: "V-slope", balanced ratio of CO_2 output and O_2 uptake (RER=1), the first ventilation threshold (VT1) at the beginning of the increase in the ventilation equivalent for O_2, the second ventilation threshold (VT2) at the beginning of the increase in the ventilation equivalent for CO_2. Another indicator of aerobic capacity is the so-called oxygen half-life. It is the time it takes for VO2 to reach half of its peak value (under constant load). It is not used in common practice. All these indicators can be monitored through spiroergometry, using a respiratory gas analyzer (Kenney et al., 2012; McArdle et al., 2007; Powers et al., 2007). The so-called Conconi's circulatory threshold was determined by the deflection of the minute heart rate (HR) from its linear course (under graded load). The corresponding load intensity was supposed to be an indicator of the level of the so-called anaerobic threshold. However, its validity and reliability have been fundamentally questioned (Bourgois & Vrijens, 1998; Cook, 2011; Ignjatović et al., 2008). In sports coaching practice, lactate thresholds are still used as indicators of the "anaerobic threshold". However, the methodology of their determination and implementation in practice is questionable. Different authors have different approaches to them: The first and second lactate thresholds (LT1 and LT2), the lactate turn-point (LTP), the onset of blood lactate accumulation (OBLA), and balanced lactate steady state (BLSS) are known. Currently, the dynamics of muscle oxygen saturation (SmO2) during muscle work is starting to be promoted as an indicator of aerobic capacity. The so-called hyposaturation threshold can be determined, i.e. the power, at which the saturation, under graded load, starts to decrease. A significant advantage is that it is a piece of information directly from the muscle. We decided to use the rowing machine test as a suitable alternative to the running test. Finding rowing tests of endurance fitness on the C2 rowing machine will be arranged chronologically.

The first, the Rowing Beep Test with increasing load intensity on the C2 rowing machine – the Incremental Rowing Test (IRT): Metcalfe et al. (2013) conducted a study of 25 males and 16 females aged 21.0 ± 5.1 years. Air resistance was set to level 10 in all participants. The initial stroke rate per minute was 28 in females and 30 in males; every other minute it increased by 1 stroke per minute until exhaustion. The clue was an audio signal that the person tested had in the mobile phone headphones. A treadmill test was performed to compare the aerobic response: with a 1 % slope, the initial speed was 8 km/h and increased by another 1 km/h every next 2 minutes. VO_2max, maximal ventilation, and maximal HR were significantly higher on the treadmill than during the IRT. There was no significant difference between the two tests in the values of the CO_2 and O_2 respiratory exchange ratio (RER) and lactate concentrations. There was a significant correlation between VO_2max on the treadmill and during IRT, similarly in HRmax. The average load time during IRT was 566.3 + 79.3 s. It correlated significantly with VO_2max during IRT, but rather loosely (r=0.32). Equations for constructing nomograms for predicting VO_2max on a rowing ergometer were obtained by regression analysis. An illustrative video and a mobile app are available on the website.

Second, in their research, Mello et al. (2014) used graded load to the maximum. On the C2 ergometer, an initial load of 150 W was increased by an additional 50 W every 30 seconds. They measured cardiorespiratory response (HR, VO_2, etc.) and lactate to determine the lactate threshold.

The third, Haraldsdottir et al. (2018) performed a maximal test on female rowers with the measurement of spiroergometric parameters on the C2 rowing machine, model E: When testing the rowers, they set the initial load to 70 W, then increased it every 3 minutes by another 70 W until exhaustion. It is not stated, how they did this setup.

The fourth, the possibility of gently increasing the load (ramp test) on the C2 rowing machine was developed by Treff et al. (2018). It is a special system, however, not readily available.

The fifth, a C2 rowing machine test with HR and VO_2 measurements was performed by Treff et al. (2022): Healthy, untrained people were supposed to maintain "submaximal" exercise intensity by themselves, lasting for 5 to 10 minutes. They found that uneven rowing is the main reason for C2 distance reading increased inaccuracy. Hence, rowers should row as even as possible and prefer higher stroke rates to minimize underestimation of their performance.

The sixth, was an aerobic fitness test in rowing with a set distance of 2 km on the C2 rowing machine: Sebastia-Amat et al. (2020) investigated the relationship of anthropometric and strength parameters to the power during a rowing test. In their test, they set a distance of 2 km and a "drag factor" to 130 in males and 110 in females. They monitored the total time, power, and stroke frequency.

The seventh, Benson and Connolly (2020) describe their test as follows: The person tested tries to cover a distance of 2 km in the shortest possible time (with maximum effort). The distance of 2 km is associated with a sufficiently long time when the work is carried out in a predominantly aerobic mode of energy metabolism. The predicted VO_2max can be calculated according to the Hagerman formula, in which data on the weight of the person tested and the time to cover the 2 km distance are entered: VO_2max = (t * 1000) / weight (kg) where t is time t (minutes). (A calculator is available at https://www.concept2.com/indoor-rowers/training/calculators/vo2max-calculator.)

The eighth, Holmes et al. (2020) tested 31 young females on the C2 training machine during two tests with a rest period of 72 hours between them: Tests to overcome distances of 6 km and 2 km, with a resistance adjusted to level "3–4". They found a close relationship of peak oxygen uptake (VO_2peak) to the total time at both 2-km and 6-km loads. There was no significant difference between VO_2peak in these two tests.

The ninth, the possibility of SmO2 monitoring with a rowing load was verified by Klusiewicz et al. (2021). They fixed the sensor in the area of the skin above the vastus lateralis muscle. They proved a decrease in SmO2 with an increasing load. Determining the hyposaturation threshold, however, requires a graded load intensity, which is complicated on this training machine.

Finally, the rowing 6-minute test on the C2 (6MRT) training machine Funch et al. (2021): It is a test of aerobic capacity, which is evaluated according to the distance covered (DC) in 6 minutes. The load is set to the 5th stage of the air brake. During the verification of this test, VO_2max was determined based on the highest VO_2 value in a 30-second interval. The VO_2max/kg values obtained from this 6MRT were not significantly different from the VO_2max/kg from the Cooper 12-minute Run Test (CRT), which was also performed. This proved the comparability of the results of both aerobic tests. The authors demonstrated a statistically close relationship between VO_2max and the DC during the CRT. In the 6MRT on a rowing machine, the researchers found a close relationship between VO_2max and the mean power output (MPO). This study also found a close relationship between the weight of the person tested and the MPO (higher power output at greater weight). The authors recommend the 6MRT as an alternative test of aerobic fitness, with the fact that the weight of the person tested must be taken into account when evaluating the result. The mean and peak heart rates were significantly higher in the CRT than in the 6MRT. A certain weak spot of this study is that these tests evaluated the results of males and females together. According to Jensen et al. (2021), the test on the rowing machine uses a close relationship of VO_2max to dynamometric indicators from two tests - to the average power when covering 2 km (W2k) and to the "maximum power output" (MPO) during the 7x2 minute test with increasing load intensity. With it, the initial load was 40 % W2k, and further load stages increase by another 25 %. On the C2 training machine, the degree of resistance of the air brake (damper) is set on a scale of 1–10. However, this is not the final setting of the load intensity. This is determined only by the strength, speed, and frequency of strokes during the work of the person tested. The so-called drag factor, which is based on measuring the speed of the flywheel deceleration, gives some information about the actual force of the strokes. As for this training machine, it is not possible to simply set the power in advance like on a bicycle ergometer or the speed like on a treadmill. It is not possible to increase the load accurately and reliably over time. Only the power after each stroke is continuously calculated and shown on the display as well as the mean power output (MPO) from the entire time of the work performed (Concept2, 2022). It is possible to set the distance (m) or time (sec) in advance. After the test, the average speed (m/s) can be calculated from the distance and time. The manner of generating resistance on the C2 training machine is created by air damping which means that the targeted mechanical performance is unstable. The mechanical performance we observe is influenced by the rower's effort. The high variability of power is especially at the beginning of the load during the first strokes. The authors provided a critical summary of findings on the application of C2 for testing physiological abilities for short-term performances. With the number of strokes performed, the flywheel apparently wears out and changes its properties.

The aim of the study was to find out in groups of men and women 1) the significance of differences between endurance characteristics in the 12-minute Rowing Test (12MRoT), 2) the relationship between anthropometric and endurance variables, 3) to compile percentile intervals allowing individual assessment of endurance fitness.

METHODS

Participants

A total of 323 males (n = 270; age = 20.9 ± 1.88 years; height = 181.2 ± 7.25; weight = 79.6 ± 10.48) and females (n = 53; age = 20.6 ± 1.47 years; height = 169.1 ± 5.58; weight = 63.9 ± 7.10) students of the University of Defence took the test. All the tested students were members of the first year of the military college and had passed both the University of Defence and Czech Army entrance physical tests, which are compiled of strength and endurance disciplines. Indisposed subjects were excluded from the study. The empirical part of the study was approved by the Ethic board of the University of Defence and all participants provided written informed consent. We followed the methods of the principles of the Declaration of Helsinki (World Medical Association, 2013).

Protocol

The 12-minute Rowing Test (12MRoT) was executed on Concept2 rowing ergometer model E (Concept2, Inc., 105 Industrial Park Drive, Morrisville, VT 05661, USA). Before the test, participants set the ergometer to fit their individual needs by adjusting the height of the foot stretchers and the height of the monitor. After a 5-minute warm-up on the training machine at any frequency at light resistance, there was a break of 2 minutes followed up by the test rowing for 12 minutes with damper setting 5. Execution of the load by a person tested was to cover the greatest possible distance with maximum effort in 12 minutes. The participants of the test were measured in their height and their weight before testing. Evaluation of the test was the endurance fitness indicators that are the distance covered (DC, meters) and the average power (AP, watts), which are measured by the display on the Concept2 rowing ergometer and were read after the end of the test. The heart rate (HR, beats per minute) was recorded throughout the HR monitor (Polar Sport Tester H7; Kempele, Finland) and read from the Concept2 rowing ergometer also after the end of the test. It was the average figure of all figures of the heart rate during the test.

Movement on the rowing machine, C2 properties:

The person tested rotates the flywheel (braked by an air brake) by repeated strokes using the part of the handle from front to back, over the chain. He has stationary leg support foot stretchers and slides backward using a movable "seat cushion". The basic movements are as follows: the catch-flexion of the hips, knees, and back, dorsiflexion of the legs and extension of the shoulders and elbows (without the resistance of the training machine); the drive and the finish, in which the back, hip, and knee extension, shoulder and elbow flexion, and foot plantar flexion take place against resistance (Figure 1).

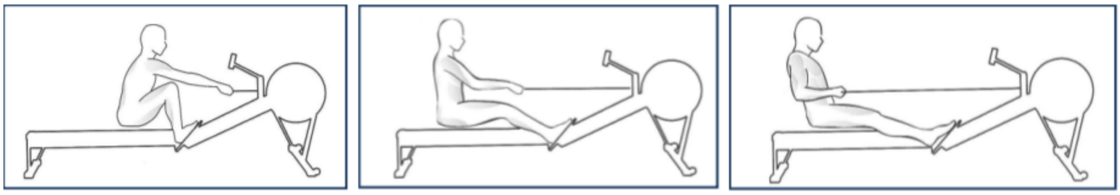

Figure 1. Three stages of work on a rowing machine, from left to right: catch, drive, and finish (Concept2, 2022)

Statistical Analysis

Distribution of values with an assessment of their normality (Shapiro-Wilk test). The basic anthropometric characteristics were measured (height, weight). The other characteristics of the observed parameters distance covered (DC, meters), average power (AP, watts), and heart rate (HR, beats per minute) in males and females were calculated (mean and standard deviations, coefficient of variation). Parametric tests (t-test, Pearson or Spearman correlation coefficient r or r_s) were used to analyze differences and relationships between variables with a normal distribution of values. The level of significance was set at $p < 0.05$. We evaluated the effect size (ES) of the distance covered (DC) and the achieved performance (AP) and average heart rate (HR) between men and women using Cohen's d. The evaluation of ES index d was interpreted as small (d = .20), medium (d = .50), or large (d = .80), and ES index r and r_s was interpreted as small (d = .10), medium (d = .30), or large (d = .50) (Cohen, 1988). The results were processed and statistically evaluated in Statistica 14 (IBM SPSS Statistics software version 14.0, SPSS INC., Chicago, IL USA) and MS Excel.

RESULTS

A study to validate the test

Based on the Shapiro-Wilk test (W), we note that the average power (AP) has a normal distribution in males (AP: W = 0.99, p = 0.89), however the distance covered (DC) and heart rate (HR) in male does not (DC: W = 0.91, p = 0.00; HR: W = 0.86, p = 0.00) it has an asymmetrical distribution. Height (W = 0.99, p = 0.67) and weight (W = 0.99, p = 0.28) in men also have a normal distribution. In females, both parameters have a normal distribution (AP: W = 0.98, p = 0.36; DC: W = 0.99, p = 0.97). Height (W = 0.98, p = 0.51) and weight (W = 0.98, p = 0.27) in women also have a normal distribution, but the average heart rate (HR) (W = 0.92, p = 0.003) in women has an asymmetrical distribution as well. Table 1 presents the basic statistical characteristics of the results and the comparison of males and females in the 12MRoT. The differences between males and females for DC are significant. We evaluated the effect size (ES) of the DC (m) between men and women using Cohen's d = 1.79 (large) and the effect size (ES) of the AP (W) between men and women is Cohen's d = 1.94 (large).

Table 1. Basic statistical characteristics of the distances covered and average power comparison of males and females in the test 12MRoT

Sample/ Variables	Distance covered (DC, m)				Average power (AP, W)			
	M ± SD	CV (%)	t-test	ES (*d*)	M ± SD	CV (%)	t-test	ES (*d*)
Males (n = 270)	2869.42 ± 230.91	8.07%	p < 0.0001	1.79	180.61 ± 31.64	17.54%	p < 0.0001	1.94
Female (n = 53)	2492.92 ± 187.32	7.51%			120.92 ± 30.00	24.82%		

Note: DC = distance covered; m = meters; AP = average power; W = watts; M = mean, SD = standard deviation, CV = coefficient of variation; ES = effect size; *d* = Cohen´s coefficient; statistically significant ($p < .05$)

Correlation analysis (Table 2) showed statistically significant correlations between both DC and HR (ES small) and between AP and HR (ES small) in men. Among women, statistically significant correlations were also demonstrated between both DC and HR (ES medium) and between AP and HR (ES medium) Thus, the relationships between variables are stronger than in men.

Table 2. Correlation between the distance covered, average power, and average heart rate (p < .05)

Coefficients of correlation (*r*)	DC vs HR			AP vs HR		
	r_s	*p*	ES	r_s	*p*	ES
Males (n = 270)	0.25	<.05	small	0.29	<.05	small
Females (n = 53)	0.43	<.05	medium	0.41	<.05	medium

Note: DC = distance covered (meters); HR = average heart rate (beats per minute); AP = average power (watts); ES = effect size; *r* = ES index; r_s = Spearman´s correlation coefficient; statistically significant ($p < .05$)

Correlation analysis (Table 3) showed statistically significant correlations between body height, weight, and DC (ES medium) and also between body height, weight, and AP (ES medium). Among women, no statistically significant correlations were found between body height, weight, and DC (ES small) and also between body height, weight, and AP (ES small).

Table 3. Correlation of body height and weight with a distance covered and average power in men, and women (p < .05)

Males (n = 270)	**DC**	***p***	**ES**	**AP**	***P***	**ES**
Height (r_s, r)	0.40	<.05	medium	0.42	<.05	medium
Weight (r_s, *r*)	0.34	<.05	medium	0.39	<.05	medium
Females (n = 53)	DC	*p*	ES	AP	*P*	ES
Height (*r*)	0.17	> .05	small	0.14	> .05	small
Weight (*r*)	0.20	> .05	small	0.16	> .05	small

Note: DC = distance covered (meters); AP = average power (watts); ES = effect size; *r* = ES index; *r* = Pearson´s correlation coefficient; r_s = Spearman´s correlation coefficient; statistically significant ($p < .05$)

Statistical analysis of endurance variables allowed the construction of percentile intervals that provide the possibility of individual assessment of the endurance fitness of each individual. The students' results were divided into five intervals of 20 percentiles each (Table 4).

Table 4. Percentile intervals of the distances covered and average power with a verbal assessment of endurance fitness.

	Percentiles (*p*)	**< 20.**	**21. – 40.**	**41. – 60.**	**61. – 80.**	**> 81**
	Fitness assessment	**very bad**	**bad**	**average**	**good**	**very good**
Males	DC (m)	< 2 720	2 721–2 843	2 844–2 927	2 928–3 040	3 041
	AP (W)	< 153	154–174	175–190	191–211	212
Females	DC (m)	< 2 329	2 330–2 465	2 466–2 544	2 545–2 650	2 651
	AP (W)	< 95	96–112	113–124	125–146	147

DISCUSSION

In the study we present, the differences between men and women are significant. We hereby correct the approach of Funch et al. (2021), who did not respect the differences between males and females in the statistical evaluation. A statistically significant relationship was found between distance covered (DC), average power (AP), and heart rate (HR) in both men (ES always small) and women (ES always medium). The statistical power of detecting an effect is therefore only small in men. Given the individual genetic dispositions of both men and women, it cannot be argued that a higher average heart rate means both higher distance covered and higher average power. In the male cohort, there was a statistically significant relationship between height, weight, and DC ($p < .05$; ES medium) and between height, weight, and AP ($p < .05$; ES medium). In the female cohort, there was no statistically significant relationship between height, weight, and DC ($p > .05$; ES small), as well as between height, weight, and AP ($p > .05$; ES small). The statistical power of detecting an effect is therefore only small in women. This suggests that height and weight have a greater effect on overall performance in males than in females. In men, taller stature with longer limbs may be a definite advantage for this test. Also, greater weight in males may mean a greater amount of muscle and therefore gain a definite advantage. However, it cannot be concluded that the higher the weight the better the performance. For these reasons, it makes no sense to overestimate the influence of height and weight and we recommend that these anthropometric variables be taken only as supplementary indicators. The level of aerobic fitness has a decisive influence on the level of performance in the 12MRoT in both men and women, and the rowing technique also plays a role. Our goal was not to create a maximum test into the exhausting like other authors (Haraldsdottir et al., 2018; Mello et al., 2014; Metcalfe et al., 2013). In contrast, the studies by Treff et al. (2022) and Funch et al. (2021) are more similar to ours in terms of loading. After considering the above-mentioned literary review findings, we used a simple test with a set duration, when the tested person should try to achieve the greatest possible distance (i.e. maximum effort). Such a test was largely validated and published by Funch et al. (2021) as a 6-minute rowing test (6MRT), where the main indicators of endurance fitness are the distance covered and average power, which are correlated with VO_2max. It was prepared by the authors for the Danish Armed Forces. However, the 6MRT does not meet the requirements for the test to be comparable to the Cooper 12-minute Run Test (CRT); therefore, we recommend setting the test length to 12 minutes so that similar energy coverage and mental load demands for both the CRT and the 12-minute rowing test (12MRoT) may be achieved. To achieve the comparability of the physical and psychological demands of the CRT, a new 12MRoT was created. For the above-mentioned reasons, the new 12MRoT should closely match the CRT. Evaluation of the test was the endurance fitness indicators which are the distance covered (meters) and the average power (watts), which are measured by the display on the Concept2 rowing ergometer. Volianitis et al. (2022) reported that there was relatively limited data on the validity and accuracy of the tests on the C2 training machine. The study that verified the technical accuracy of the C2 training machine functions (Treff, et al., 2022) brought positive findings: The nominal accuracy of the machine depends on the total number of strokes. No significant differences were found in the structure of strokes at frequencies of 22–28 per minute. The participants of the University of Defence achieved a significantly lower average power than the group of people in the study by Funch et al. (2021). We explain it by half-duration of the maximum performance of their people (6 minutes). It also logically corresponds to the fact that the distances they covered (1,507 m) exceeded half the distance of our students. Statistically significant relationships between height, weight, and distance covered (DC) with average power (AP) in men correspond to similar results of the study by Funch et al. (2021). Low correlations between these fitness indicators to body weight and height in females do not support the need to use relative fitness indicators (per kg of weight). The results of the study provided initial reference values for individual assessment of aerobic fitness. Interestingly, the scaling of distance traveled for both men and women roughly matches the scaling at the University of Defense for the 12-minute run. 2.850 m for men (2.450 for women) is an average performance in both running and rowing tests. Those findings suggest that running and rowing 12-minute tests might be legitimately substitutable and even comparable, even though further research is necessary to confirm this statement.

CONCLUSION

The results of the study demonstrated that significant differences in performance variables were found between men and women in the proposed alternative 12-minute Rowing Test (12MRoT), both in terms of statistical significance and level of effect size. This confirms the importance of evaluating the results for each gender separately. The relationships found between performance variables (distance covered and average power) and heart rate were statistically significant between men and women although the level of effect size was small in men and medium in women. Furthermore, statistically significant relationships were demonstrated between anthropometric (height and weight) and performance indicators (distance traveled and average performance) and mean ES level in men, while not in women. The results of our study demonstrate the applicability of the 12MRoT on Concept II under the required conditions. The results of the study provided initial reference values for individual assessment of aerobic fitness. This study should be followed up by further research where it seems appropriate to compare performance on Cooper´s 12-minute run test and the 12MRoT.

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