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Relationship between 2000-m rowing ergometer performance times and World Rowing Championships rankings in elite-standard rowers

PAVLE MIKULIĆ[1], TOMISLAV SMOLJANOVIĆ[2,3], IVAN BOJANIĆ[2,3], JO A. HANNAFIN[4], & BRANKA R. MATKOVIĆ[1]

[1]*School of Kinesiology and* [2]*School of Medicine, University of Zagreb, Zagreb, Croatia,* [3]*Department of Orthopaedic Surgery, Clinical Hospital Centre, Zagreb, Croatia, and* [4]*Weill Medical College of Cornell University, New York, USA*

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Abstract

In this study, we evaluated the extent to which 2000-m rowing ergometer performance times predicted final rankings at the World Rowing Championships in a sample of 638 rowers of both sexes and body-mass classifications (i.e. open-category and lightweight rowers). Rowing ergometer performance times were examined using a questionnaire, and in 17 of 23 events they were positively correlated ($P \leq 0.049$) with the final rankings at the Championships. The highest correlations were for the ergometer performance times achieved by rowers in lightweight men's single sculls ($r = 0.78$; $P = 0.005$), women's single sculls ($r = 0.75$; $P = 0.002$), men's single sculls ($r = 0.72$; $P = 0.004$), and lightweight men's double sculls ($r = 0.72$; $P < 0.001$). We used linear regression to establish regression equations to predict final rankings based on 2000-m rowing ergometer performance times for each event in which there was a correlation greater than $r = 0.50$. Although correlations in 12 events met this criterion, the large standard errors of the estimate hindered ranking predictions in all of the studied events. Regression equations could be used to determine the most probable 2000-m ergometer performance time for a rower to achieve specific rankings at the World Rowing Championships.

Keywords: *Boat categories, elite rowing, performance prediction, open-category rowers, lightweight rowers*

Introduction

Rowing ergometers are designed to simulate movements performed during on-water rowing and are widely considered to be a valuable tool for rowing training, the evaluation of a rower's sport-specific performance, and the detection of changes in performance (Mäestu, Jürimäe, & Jürimäe, 2005). Tests to determine the shortest time needed to cover 2000 m on a rowing ergometer are frequently used to evaluate a rower's ability (Hahn, Bourdon, & Tanner, 2000; Mäestu et al., 2005), since the distance used for Olympic rowing events is 2000 m. Although ergometer rowing differs somewhat from on-water rowing in terms of the skills required (Russell, Le Rossignol, & Sparrow, 1998), the biomechanical and metabolic demands of on-water rowing are simulated closely (Lamb, 1989). However, the importance of rowing technique is less evident for ergometer rowing than for on-water rowing. On-water rowing requires balance, economy, and boat speed maintenance during the recovery phase, none of which is important for ergometer rowing. Furthermore, on-water performance is also affected by the impact of environmental conditions, including wind and waves (Secher, 1992).

Correlates for 2000-m rowing ergometer performance have been established, as have correlates for on-water single sculls rowing (for a review, see Mäestu et al., 2005). Jürimäe and colleagues (Jürimäe, Mäestu, Jürimäe, & Pihl, 2002) compared ergometer rowing with on-water rowing and found that, while almost every anthropometric and body composition variable was correlated to 2000-m ergometer times, only lean muscle mass was correlated to 2000-m single-sculls times. The authors concluded that care should be taken when interpreting rowing ergometer results to predict on-water performance because "the influence exerted by anthropometric variables upon the result obtained on the rowing ergometer might be too great". McNeely (2004) also compared the two types of rowing and found no correlation between 2000-m ergometer performance times and 2000-m on-water

Correspondence: P. Mikulić, Department of Sport, School of Kinesiology, University of Zagreb, Horvaćanski zavoj 15, 10 000 Zagreb, Croatia. E-mail: pavle.mikulic@kif.hr

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performance times. It should be noted that both of these studies (Jürimäe et al., 2002; McNeely, 2004) were conducted using small sample sizes ($n \leq 10$).

In a previous study (Mikulić, Smoljanović, Bojanić, Hannafin, & Pedišić, 2009), we examined the relationship between 2000-m rowing ergometer performance and on-water performance in elite junior rowers ($n = 398$). We also examined the accuracy of 2000-m rowing ergometer performance times as a predictor of 2000-m on-water performance. The present study aims to extend the findings of our earlier study on elite junior rowers to elite senior rowers both in the lightweight and open categories. Lightweight rowing is a special category of rowing where limits are placed on the maximum body mass of competitors. More precisely, the crew mean in men's lightweight events should be 70 kg or less with no rower over 72.5 kg. Equivalent values for women's lightweight events are a crew mean of 57 kg or less with no rower over 59 kg. In open-category rowing, no such limits apply.

Hence, the aims of this study were to investigate the relationship between 2000-m rowing ergometer performance times and on-water performance in elite senior rowers, and examine the extent to which it is possible to predict on-water rowing performance as measured using the final rankings achieved at the World Rowing Championships. We opted to use final rankings at the Championships rather than finishing times at the event as a criterion for on-water performance because rankings at the most important competition in a rowing season are ultimate arbiters of performance and so serve as the definitive yardstick by which a crew and its coach are evaluated at the end of the season. The predictions are based on 2000-m rowing ergometer performance times in a sample of 634 male and female rowers competing in 23 events at the 2007 World Rowing Championships.

Methods

Participants

We invited 1099 male and female rowers from 65 countries who competed in the open-category and lightweight divisions at the 2007 World Rowing Championships (Munich, Germany) to take part in the study. In total, 634 rowers from 59 countries completed and returned their questionnaires. Of these 634 competitors, 209 (33%) were female and 425 (67%) were male; 403 (64%) competed in open-category events and 226 (36%) competed in lightweight events. Five participants (1%) were reserves. Rowers from six countries chose not to participate in the study (7% of all competitors), and coxswains were excluded. The sample eventually comprised 58% of all competitors at the Championships, including 51% of all "A" finalists and 40% of all medallists. The participants' age, stature, and body mass, which were all determined using a questionnaire, are presented in Table I.

Study design

We used a retrospective survey based on the completion of a rowing-specific questionnaire. Copies of the questionnaire were distributed to team managers attending a mandatory regatta meeting under the auspices of FISA (Fédération Internationale des Sociétés d'Aviron), the world governing body for rowing, before the start of the World Rowing Championships. The aim and the methods were explained to the team managers, who were then asked to distribute the questionnaire to their national team rowers. The rowers were informed that participation was voluntary and were assured that any information provided could not be traced back to the individual or the team. The rowers were also told where they could ask any further questions and where they could submit the questionnaire. To facilitate participation, it was presented in 24 languages (Bulgarian, Chinese, Croatian, Czech, Danish, Dutch, English, Estonian, Finnish, French, German, Greek, Hebrew, Hungarian, Italian, Japanese, Norwegian, Polish, Portuguese, Russian, Serbian, Spanish, Swedish, and Turkish) with the additional possibility of either modern or traditional Chinese characters. Additional communication with non-English-speaking rowers was accomplished by the participants' team managers or team physicians.

The questionnaire consisted of general and rowing-specific sections. The general section characterized the participating rowers by country, age, sex, stature, body mass, rowing experience, and previous rowing achievements. The rowing section was intended to obtain information about the crew and the event in which each participating rower was competing together with his or her best 2000-m rowing ergometer performance time, achieved on a stationary Concept II rowing ergometer during a training session or at any official competition held in 2007. The study was approved by the local ethics committee and by the FISA Sports Medicine Commission.

Table I. Participants' age, stature, and body mass (mean $\pm$ *s*).

	n	Age (years)	Stature (m)	Body mass (kg)
Open-category men	246	25 ± 4	1.93 ± 0.05	93 ± 6
Open-category women	157	25 ± 4	1.81 ± 0.05	75 ± 5
Lightweight men	176	25 ± 4	1.83 ± 0.05	71 ± 2
Lightweight women	50	26 ± 5	1.70 ± 0.05	57 ± 2

Statistical analysis

We used SPSS for Windows 11.5 (Chicago, IL, USA) to process and report the data. Before they were processed, data were inspected using skewness and kurtosis coefficients. Furthermore, the Shapiro-Wilk test was used to test the assumption of normality. This indicated that the distributions in 21 of 23 variables were normal. Descriptive statistics were calculated for each of the 23 events in which the participants competed at the World Rowing Championships. Pearson correlation coefficients (*r*) were used to examine relationships between 2000-m rowing ergometer performance times and the final World Rowing Championships rankings. Using linear regression analyses, regression equations based on 2000-m rowing ergometer performance times were established for each event in which rowing ergometer performance times and final rankings had a correlation greater than $r = 0.50$. Coefficients of determination (R^2) and standard errors of the estimate (SEE) were calculated for the regression equations.

Results

Five reserve rowers who had completed the questionnaire but did not compete at the World Rowing Championships were excluded from the analyses. In addition, 67 rowers were also excluded from the analyses because of one or more of the following: (a) they had not completed the 2000-m ergometer test in 2007, (b) they failed to answer all the questions on the questionnaire, or (c) they had no evident final rankings because they had not started their final race or had been disqualified. The final number of participants included in the analysis was 562; 385 (69%) men and 177 (31%) women, with 365 (65%) competing in open-category events and 197 (35%) competing in lightweight events. Two female open-category rowers competed in two events, while all other competitors competed in one event at the World Rowing Championships.

Table II. Descriptive statistics and Pearson correlation coefficients (*r*) for competitors' 2000-m rowing ergometer performance times: Men's events.

Event	*n*	2000-m ergometer time (s) (mean $\pm s$)	Correlation with the final WRC rankings	Probability
Single sculls (M)	16	364 ± 12	0.72	0.004
Double sculls (M)	17	363 ± 13	0.55	0.023
Quadruple sculls (M)	49	363 ± 8	0.39	0.006
Coxless pair (M)	20	368 ± 12	0.44	0.048
Coxed pair (M)	10	367 ± 10	−0.68	0.032
Coxless four (M)	43	366 ± 11	0.58	<0.001
Coxed four (M)	8	362 ± 4	0.26	0.540
Eight (M)	67	363 ± 7	0.47	<0.001
Single sculls (LM)	11	388 ± 8	0.78	0.005
Double sculls (LM)	32	381 ± 11	0.72	<0.001
Quadruple sculls (LM)	21	382 ± 7	0.50	0.021
Coxless pair (LM)	9	382 ± 3	−0.72	0.028
Coxless four (LM)	56	384 ± 8	0.60	<0.001
Eight (LM)	27	381 ± 6	0.21	0.297

Note: M = open-category men; LM = lightweight men; WRC = World Rowing Championships.

Table III. Descriptive statistics and Pearson correlation coefficients (*r*) for competitors' 2000-m rowing ergometer performance times: Women's events.

Event	*n*	2000-m ergometer time (s) (mean $\pm s$)	Correlation with the final WRC rankings	Probability
Single sculls (W)	14	418 ± 16	0.75	0.002
Double sculls (W)	18	420 ± 15	0.51	0.031
Quadruple sculls (W)	38	417 ± 12	0.02	0.887
Coxless pair (W)	13	413 ± 7	0.55	0.049
Coxless four (W)	13	418 ± 8	0.63	0.020
Eight (W)	41	411 ± 6	0.33	0.035
Single sculls (LW)	14	440 ± 13	0.68	0.008
Double sculls (LW)	19	433 ± 10	0.69	0.001
Quadruple sculls (LW)	8	440 ± 8	0.19	0.651

Note: W = open-category women; LW = lightweight women; WRC = World Rowing Championships.

Descriptive statistics and correlations

The 2000-m rowing ergometer performance times and their correlations with final World Rowing Championships rankings are displayed in Tables II and III. Rowing ergometer performance times correlated ($P \leq 0.049$) with final rankings in 19 of 23 events. Note, however, that in two events (i.e. the men's coxed pair and lightweight men's coxless pair), ergometer performance times were inversely related to the final rankings at the Championships. In four events (i.e. men's coxed four, lightweight men's eight, women's quadruple sculls, and lightweight women's quadruple sculls), no correlations were observed.

To help clarify the strength of the relationship between 2000-m rowing ergometer performance times and the final on-water rankings, scatterplot graphs with linear regression lines are presented for the men's events (Figure 1: lightweight men's single sculls, lightweight men's double sculls, and men's single sculls) and for women's events (Figure 2: women's single sculls, lightweight women's double

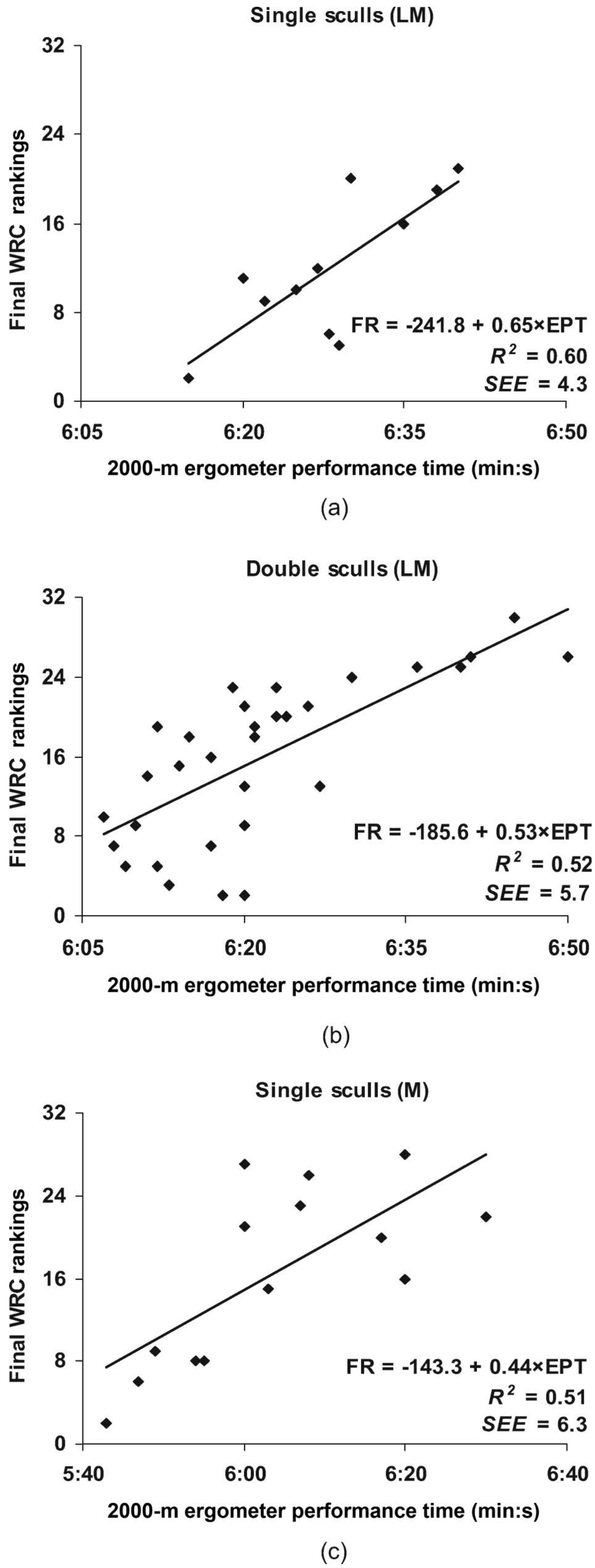

Figure 1. Relationships for three men's events (M = open-category men; LM = lightweight men) in which the strongest correlations between 2000-m rowing ergometer performance times and final rankings at the World Rowing Championships (WRC) were observed. FR = final rankings; EPT = ergometer performance time; SEE = standard error of the estimate of rank.

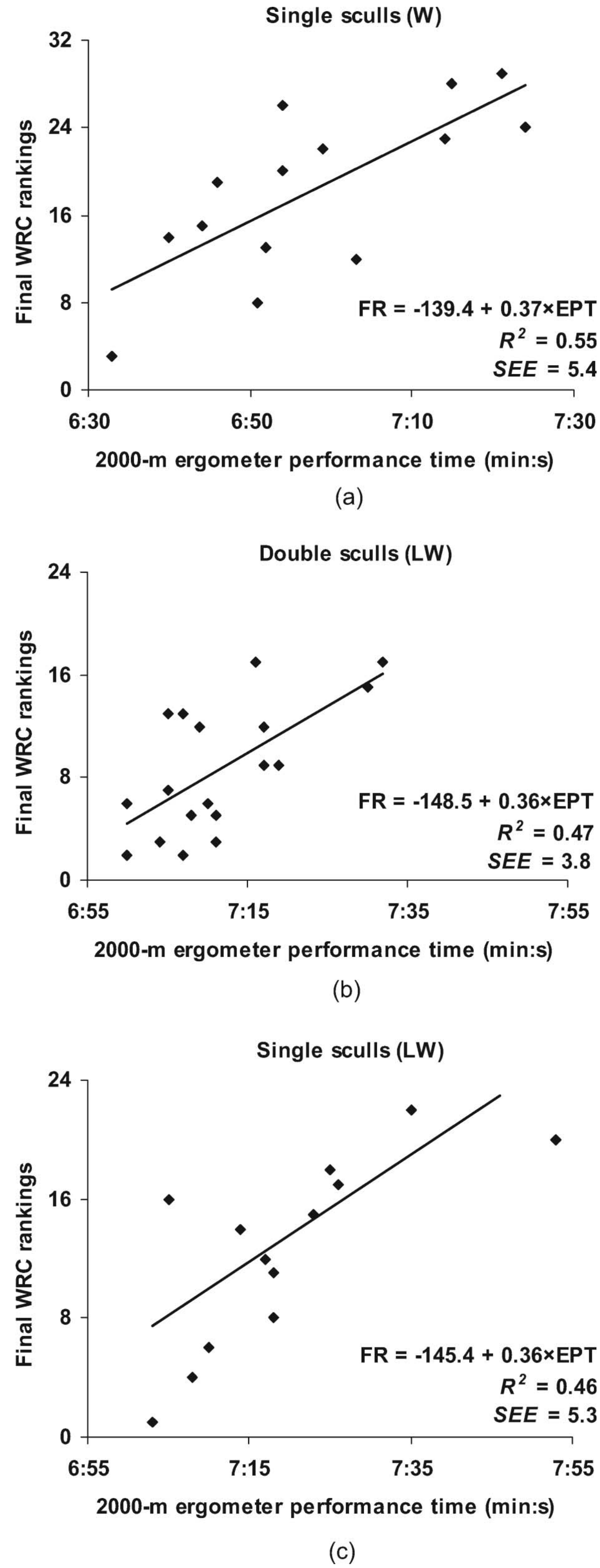

Figure 2. Relationships for three women's events (W = open-category women; LW = lightweight women) in which the strongest correlations between 2000-m rowing ergometer performance times and final rankings at the World Rowing Championships (WRC) were observed. FR = final rankings; EPT = ergometer performance time; SEE = standard error of the estimate of rank.

sculls, and lightweight women's single sculls). The graphs represent 2000-m ergometer performance times for competitors in the events in which the strongest correlations were observed.

Regression models

Using linear regression analysis, regression models were established for the events in which there was a correlation greater than $r = 0.50$ between 2000-m rowing ergometer performance times and participants' final rankings (Table IV). The most sensitive predictions were in lightweight men's single sculls ($R^2 = 0.60$, SEE = 4.3) and women's single sculls ($R^2 = 0.55$, SEE = 5.4).

Discussion

In this study, we examined the relationship between 2000-m rowing ergometer performance and 2000-m on-water performance in a large sample of elite rowers of both sexes and body-mass categories (i.e. open-category and lightweight). The main finding is that the 2000-m rowing ergometer performance times of competitors in 17 of 23 events correlated positively ($P \leq 0.049$) with their final World Rowing Championships rankings. The highest correlations were observed for lightweight men's single sculls ($r = 0.78$; $P = 0.005$), followed by women's single sculls ($r = 0.75$; $P = 0.002$), men's single sculls ($r = 0.72$; $P = 0.004$), lightweight men's double sculls ($r = 0.72$; $P < 0.001$), and lightweight women's double sculls ($r = 0.69$; $P = 0.001$). No correlations were observed in four events, while in two events final rankings were inversely related to 2000-m ergometer performance times (Tables II and III). These unanticipated findings could be attributed to the low number of surveyed participants ($n \leq 10$) in the relevant events (men's coxed four, men's coxed pair, lightweight men's coxless pair, and lightweight women's quadruple sculls) and/or to the low number of final rankings (lightweight men's eight). However, we have not been able to interpret the absence of correlations between 2000-m ergometer performance times and final rankings in women's quadruple sculls (Table III).

The observed correlations are higher for smaller boats, such as singles, doubles, and pairs ($r = 0.44$–0.78; $P \leq 0.048$), than for larger boats, such as quads, fours, and eights ($r = 0.33$–0.63; $P \leq 0.035$). This finding is observed both in men's and women's boat categories and is consistent with the findings of our earlier study (Mikulić et al., 2009) on elite junior rowers. It should be noted that the single ergometer simulates on-water racing conditions better for single sculls than, for example, for an eight. In larger boats, rowers have to coordinate and synchronize their individual motor performances, and these factors cannot be assessed on a rowing ergometer where overall performance is based solely on an individual rower's performance. When the observed correlations are interpreted, it should be remembered that the variability of results, which directly affects the correlation coefficient (r), is reduced in larger boats because of the lower number of entries (and, consequently, the lower number of final rankings) and also the wide spread of ability at each ranking. This could be a statistical artifact and statistical limitations should therefore also be taken into account when the results are interpreted.

Linear regression analyses were used to establish the regression equations based on 2000-m ergometer performance times for each event displaying a correlation greater than $r = 0.50$ (Table IV). Although the correlations in 12 events are greater

Table IV. Regression equations predicting the final World Rowing Championships rankings based on 2000-m rowing ergometer performance times (for events displaying a correlation greater than $r = 0.50$).

Event	Regression equation	R^2	SEE
Single sculls (M)	FR = −143.3 + 0.44 × (ergometer time)	0.51	6.3
Double sculls (M)	FR = −96.7 + 0.31 × (ergometer time)	0.30	6.3
Coxless four (M)	FR = −123.3 + 0.38 × (ergometer time)	0.33	5.8
Single sculls (LM)	FR = −241.8 + 0.65 × (ergometer time)	0.60	4.3
Double sculls (LM)	FR = −185.6 + 0.53 × (ergometer time)	0.52	5.7
Coxless four (LM)	FR = −199.1 + 0.56 × (ergometer time)	0.37	6.1
Single sculls (W)	FR = −139.4 + 0.37 × (ergometer time)	0.55	5.4
Double sculls (W)	FR = −56.2 + 0.16 × (ergometer time)	0.26	4.0
Coxless pair (W)	FR = −94.6 + 0.24 × (ergometer time)	0.30	2.9
Coxless four (W)	FR = −65.1 + 0.17 × (ergometer time)	0.40	1.6
Single sculls (LW)	FR = −145.4 + 0.36 × (ergometer time)	0.46	5.3
Double sculls (LW)	FR = −148.5 + 0.36 × (ergometer time)	0.47	3.8

Note: M = open-category men; W = open-category women; LM = lightweight men; LW = lightweight women; FR = final rankings; SEE = standard error of the estimate of rank.

than $r = 0.50$, the standard errors of the estimate of rank (SEE) could be considered too large to establish an accurate ranking prediction in any of the observed events. The regression equations used for the present study could, alternatively, be used to determine how fast a rower must perform during a 2000-m rowing ergometer time-trial if he or she hopes to achieve a specific ranking at the World Rowing Championships. Using regression equations (Table IV), we calculated the most probable 2000-m ergometer performance times for the first-place finishers: 328 s for men's single sculls, 379 s for women's single sculls, 374 s for lightweight men's single sculls, and 407 s for lightweight women's single sculls. These results appear to overestimate the winners' probable performance times, as they are 8–9 s (2%) better than the world record 2000-m ergometer performance times in those events. The exception is the winner's most probable 2000-m performance time in lightweight men's single sculls, which is 11 s (3%) longer than the world record time. The most probable 2000-m ergometer performance times for competitors in other boat categories can be calculated accordingly.

Mean 2000-m ergometer performance time in the present study is 364 s for men open-category rowers and 416 s for women open-category rowers. This 13% sex-based difference in ergometer performance times is identical to the difference we observed in elite junior rowers (Mikulić et al., 2009), and is consistent with differences in world record 2000-m ergometer performance times. In particular, the 2000-m ergometer performance time for the women open-category rowers is 13% longer than for the men. The sex-based difference for lightweight rowers in the present study is 12% (383 s for men lightweight rowers vs. 437 s for women lightweight rowers). For on-water rowing, Secher (2000) and Ingham and colleagues (Ingham, Whyte, Jones, & Nevill, 2002) observed that the rowing performance times for women are approximately 10–11% longer than for men. This gap in athletic performance between women and men is also observed in other sports, yet it appears to be decreasing as the number of women competitors increases (Wilmore & Costill, 1999). The 2000-m ergometer performance times of open-category rowers were 5% shorter than those of lightweights (364 s vs. 383 s; *t*-test: $P < 0.001$). There was an identical 5% difference between open-category women rowers and lightweights (416 s vs. 437 s; *t*-test: $P < 0.001$).

For men and, to some extent, women open-category rowers, athletes with better 2000-m ergometer performance times (Tables II and III) usually compete in larger boats, such as quads, fours, and eights. Men open-category rowers with the best 2000-m ergometer performance times were more likely to be members of the coxed four (mean $\pm$ *s*: 362 $\pm$ 4 s), eight (363 $\pm$ 7 s), and quadruple sculls (363 $\pm$ 8 s), whereas in women's open-category events, this was for eight (411 $\pm$ 6 s), coxless pair (413 $\pm$ 7 s), and quadruple sculls (417 $\pm$ 12 s). This is consistent with our earlier study on elite junior rowers (Mikulić et al., 2009) and might be explained by the use of larger boats, which exhibit more pronounced on-water stability than smaller boats and are less demanding on balance-related technical skills. Therefore, unlike smaller boats they are less likely to be affected by a lack of technical finesse. With a more stable boat, the emphasis is placed not on proficiency of balance-related technical skills, but rather on rowers' physical fitness, which a rowing ergometer is designed to assess. Notably, no such pattern of selecting the fastest 2000-m ergometer rowers for larger boats is evident in lightweight events, either for men or women.

Two limitations of this study must be acknowledged and addressed. The first limitation is that several months might elapse between the 2000-m ergometer test and the World Rowing Championships. Rowing ergometers are used as a training and testing aid primarily during the winter months when, in most countries in the northern hemisphere, on-water training is limited by bad weather and low temperatures (Mäestu et al., 2005). The World Rowing Championships, however, are traditionally held during the late summer months in the northern hemisphere. There is probably no practical way to shorten this interval as rowing ergometer training and testing are gradually replaced by on-water training and testing as warmer weather approaches. The second limitation is that, although the collected ergometer data were achieved on a stationary Concept II rowing ergometer (see "Study design"), it would be reasonable to assume that differences could stem from variations in the particular models (i.e. model B, C, D, or E) of the Concept II ergometer used. Furthermore, final 2000-m performance times could also have been affected by unavoidable possible mechanical differences between individual ergometers.

In conclusion, in 12 of 23 events the correlation coefficients between 2000-m ergometer performance times and 2000-m on-water performance in elite rowers are positive and greater than $r = 0.50$ (range: 0.51–0.78). This finding suggests a moderate-to-strong relationship between the two types of rowing both in men and women rowers, as well as the ability of 2000-m ergometer performance to predict on-water rowing performance. However, the standard error of the estimate obtained in the present study could be too large to predict rankings accurately in any of the studied events. The practical applications of the present study include the possibility for rowing coaches and rowing athletes to place their 2000-m ergometer performance times into a broader perspective and interpret these performance times in the context of rankings achieved at the World Rowing Championships. Specifically, the regression equations obtained in the present study could be used to determine the most probable 2000-m ergometer performance time that a rower would need to achieve to predict a specific ranking at the World Rowing Championships. Using these equations, the most probable rowing ergometer performance times required for a particular ranking in a given rowing event might easily be calculated.

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