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Abstract

In this study, we assessed the extent to which 2000-m rowing ergometer performance predicted final rankings at the World Junior Rowing Championship in a sample of 398 junior rowers competing in 13 events. The rowers' ergometer performance times were examined using a questionnaire, and in all 13 events they correlated ($P \leq 0.039$) with the final rankings at the Championship. The strongest correlations were observed for ergometer performance times in junior women's single sculls ($r = 0.92$; $P < 0.001$), followed by junior men's single sculls ($r = 0.80$; $P < 0.001$) and junior women's double sculls ($r = 0.79$; $P < 0.001$). The observed correlations were higher for smaller boats - singles, doubles, and pairs ($r = 0.64$ - 0.92 ; $P \leq 0.025$) - than for larger boats - quads, fours, and eights ($r = 0.31$ - 0.70 ; $P \leq 0.039$). Linear regression analyses were used to construct regression equations to predict final rankings based on 2000-m rowing ergometer performance times for each event. Although correlations in 10 of the 13 events were above $r = 0.5$, the large standard errors of the estimate impaired the prediction of rankings in all of the studied events. Using these equations, the most probable rowing ergometer performance times required for a particular ranking in a given rowing event might easily be calculated.

Keywords: boat categories; elite rowing; performance prediction; regression analysis

Introduction

Rowing ergometers are designed to simulate on-water rowing and are widely considered to be valuable for rowing training, the evaluation of a rower's sport-specific performance and the detection of changes in a performer's capability (Mäestu, Jürimäe & Jürimäe, 2005). Time needed to cover a particular distance is likely to be the most relevant measure in the testing and evaluation of an athlete's capability. One of the most frequently used "all-out" ergometer tests to assess rowing-specific ability is a test performed over 2000-m (Hahn, Bourdon & Tanner, 2000; Mäestu *et al.*, 2005), which corresponds to the distance used for Olympic rowing events.

Correlates for 2000-m rowing ergometer performance have been established in many studies, and to a lesser degree, correlates have also been established for on-water single-sculls rowing (for a review, see Mäestu *et al.* 2005). Such studies reveal differences among the strongest correlates and among regression equations used to predict rowing performance. These differences are probably attributable to variations in sample groups such as sex, performance standard and classification of rower.

Jürimäe, Mäestu, Jürimäe & Pihl (2000) compared ergometer rowing with on-water rowing and found that, while almost every anthropometric and body composition variable was correlated to 2000-m ergometer time, only lean muscle mass was correlated to 2000-m single-sculls time. 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) examined the relationship between physiological variables measured on the ergometer and 2000-

m on-water performance and found that while the Pearson correlations showed that certain physiological variables were related to 2000-m ergometer performance, there was no correlation between any of the measured variables and 2000-m on-water performance. In addition, no correlation could be found between 2000-m ergometer performance times and 2000-m on-water performance times.

Although ergometer rowing differs from on-water rowing in terms of required skills (Russel, Le Rossignol & Sparrow, 1998), biomechanical and metabolic demands of on-water rowing are simulated closely (Lamb, 1989). As in sculling, trunk movement during ergometer rowing is straightforward, whereas rotation of the trunk that occurs in sweep rowing cannot be simulated on an ergometer. Because sweep rowers employ only one oar handle, as opposed to scullers, who must manipulate two oar handles, ergometer rowing is closer to sweep rowing. The importance of rowing technique is less evident for ergometer rowing than on-water rowing. Rowing is a complex task and comprises components such as balance, economy and boat-speed maintenance during the recovery phase, none of which can be measured on an ergometer (Mäestu *et al.*, 2005). Furthermore, on-water performance also depends on external factors, including environmental conditions.

The extent to which rowing ergometer performance and on-water performance are related, as well as the accuracy of rowing ergometer 2000-m performance time as a predictor of 2000-m on-water performance, has not been thoroughly investigated. Hence, the aim of this study was to predict on-water rowing performance as measured using the final rankings achieved at the World Rowing Junior Championships. The predictions are based on 2000-m ergometer performance times in a sample of 398 male and female junior rowers competing in all 13 events at the 2007 World Rowing Junior Championships.

Methods

Participants

Five hundred and ninety-six rowers from 49 countries, 362 (61%) males (mean age 17.9 years, $s=0.8$; body mass 83.2 kg, $s=2.0$; stature 188.4 cm, $s=6.0$) and 234 (39%) females (mean age 17.6 years, $s=0.7$; body mass 68.7 kg, $s=6.7$; stature 176.6 cm, $s=5.8$), competing in 13 rowing events at the 2007 World Rowing Junior Championships, were invited to take part in the study. Three hundred and ninety-eight rowers from 45 countries completed and returned their questionnaires. The sample comprised 66% of all competitors, including 53% of the "A" finalists and 40% of the medalists; 231 (58%) rowers were male and 167 (42%) female. Five participants (1%) were reserves. Coxswains were not included.

Study Design

Questionnaires were distributed to team managers from each of the 49 nations attending the team managers' meeting under the auspices of FISA (Fédération Internationale des Sociétés d'Aviron - World governing body for rowing) three days before the official start of the Championships. The aim of the study and the methods used to complete it were explained to the team managers, who relayed them, along with the questionnaires, to their rowers. In addition, the rowers were told where they could ask any questions about the study and where they could submit the questionnaires. To facilitate participation in the study, the questionnaire was available in 21 languages (Bulgarian, Chinese, Croatian, Czech, Dutch, English, Estonian, Finnish, French, German, Greek, Hebrew, Italian, Japanese, Norwegian, Portuguese, Russian, Serbian, Spanish, Swedish, and Turkish), translated from English by the national rowing team coaches and/or physicians. When the questionnaires were administered, interviews with non-English speaking rowers were conducted by their team managers, team physicians or translators (Beijing

Normal University students training to volunteer at the 2008 Olympic Games in Beijing).

The questionnaire included 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 used to elicit information about the crew and the event in which each participating rower was competing at the Championships along with his/her best 2000-m rowing ergometer performance time achieved on a stationary Concept II rowing ergometer either during a training session or at an official competition during 2007. The study was approved by the local ethics committee and by the FISA Sports Medicine Commission.

Statistical Analyses

Statistica for Windows 7.0 software (Tulsa, Oklahoma, USA) was used to process and report the data. Before processing, data was visually inspected and Shapiro-Wilk test was used in order to test the assumption of normality. Descriptive statistics were calculated for each of the 13 events in which the participants competed at the Championships. Independent-samples t-test was used to compare 2000-m rowing-ergometer performance times between scullers and sweep rowers. Pearson correlation coefficient (r) was used to determine the association between 2000-m rowing-ergometer performance time and the final rankings at the Championships. Using linear regression analyses, regression equations for each event were established based on 2000-m rowing-ergometer performance times. Coefficients of determination (R^2) and standard errors of the estimate (SEE) were also calculated.

Results

Five reserves who completed the questionnaire but did not compete at the Championships, as well as 11 rowers with invalid 2000-m ergometer performance times, were eliminated from the analysis because they had not completed the 2000-m ergometer test in 2007 or their ergometer tests included rowing over 2500-m. The final number of participants that were included in the analysis was 382; out of which 222 (58%) were male and 160 (42%) were female.

Descriptive statistics and correlations

The reported rowing-ergometer performance times and their correlations with final World Rowing Junior Championships rankings are displayed in Table 1. Rowing-ergometer performance times correlated ($P \leq 0.039$) with final rankings in each of 13 events. The observed correlations between rowing-ergometer and on-water performance both for junior men and junior women are higher for smaller boats, i.e. singles, doubles, and pairs ($r = 0.64-0.92$; $P \leq 0.025$) than for larger boats, i.e. quads, fours, and eights ($r = 0.31-0.70$; $P \leq 0.039$).

To provide a better understanding of the strength of the relationship between 2000-m rowing-ergometer performance times and the final on-water rankings, scatterplot graphs with regression lines representing 2000-m ergometer performance times for competitors in the events in which the strongest correlations were observed are presented for junior men's events (Figure 1 - Single sculls, Eight, and Coxless pair) and for junior women's events (Figure 2 - Single sculls, Double sculls, and Coxless pair).

****Table 1 near here****

****Figures 1 and 2 near here****

Regression models

Using linear regression analysis, regression models for each of 13 events were established (Table 2). The most accurate predictions were obtained with the model used to predict rankings in junior women's single sculls ($R^2=0.85$, $SEE=2.0$), followed by the model used to predict rankings in junior men's single sculls ($R^2=0.65$, $SEE=5.8$).

****Table 2 near here****

Discussion

This study examines the relationship between 2000-m rowing-ergometer performance and 2000-m on-water performance in a large sample of junior rowers of both sexes. The 2000-m rowing-ergometer performance times of competitors from all 13 events held during the 2007 World Rowing Junior Championships were correlated ($P \leq 0.039$) with their final rankings at the Championships. The highest correlations (Table 1) were observed for junior women's single sculls ($r=0.92$; $P < 0.001$) followed by junior men's single sculls ($r=0.80$; $P < 0.001$), junior women's double sculls ($r=0.79$; $P < 0.001$), and junior men's eight ($r=0.70$; $P < 0.001$). Higher observed correlations for smaller boats than for larger boats can probably be explained by the fact that considerably higher speeds can be reached in larger boats, so rowers need to coordinate and synchronize their individual performances. These factors cannot be assessed on a rowing ergometer, where overall performance is based solely on an individual rower's performance.

Interpretation of observed correlations for larger boats should consider two particular points. First, in large boats the final result depends on the performance of a group of athletes. This collective performance is likely to increase the variability of results. For example, in an eight, underperformance by only one of the crew is sufficient to lose the race for a crew whose other members possess the physical characteristics to win. Second, 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 to the wide spread of ability at each ranking. This could be considered a statistical artifact. Hence, technical background influences apparent relationships.

When the observed correlation coefficients between rowing ergometer performance times and on-water performance are compared according to sex, similar correlation coefficients are observed for each boat category (for example, junior men's single sculls vs. junior women's single sculls etc.). Junior women's events produced slightly higher correlation coefficients in all boat categories except in eights. Indeed, the ergometer times for the junior men's eight have a notably higher correlation coefficient with the final rankings than for the junior women's eight ($r=0.70$ vs. $r=0.45$).

Linear regression analyses were used to predict final rankings at the 2007 World Rowing Junior Championships (Table 2). The most accurate predictions were for final rankings in junior women's single sculls ($R^2=0.85$, $SEE=2.0$) followed by junior men's single sculls ($R^2=0.65$, $SEE=5.9$). Although correlations in 10 out of 13 events were greater than $r=0.5$, the large standard errors of the estimate impaired the ability of regression equations to predict rankings accurately in any of the studied events. The regression equations obtained in the present study could also be used to determine how fast a junior rower needs to perform on a 2000-m rowing ergometer time trial to achieve high rank at the World Rowing Junior Championships. Using these equations, we calculated the most probable 2000-m ergometer performance times for the first-place finishers: 357 s for junior men's single sculls and 414 s for junior women's single sculls. These results yield close estimates of the winners' probable 2000-m ergometer performance times, as they are 10 s (3%) and 20 s (5%) slower than the world record 2000-m rowing-ergometer performance times for junior men and junior women, respectively. The most probable 2000-m ergometer performance times for competitors in other boat categories could be calculated accordingly using the obtained regression equations.

Both for male and female junior rowers, the best 2000-m ergometer performers (Table 1) are likely to be selected for larger boats. In junior men's events, the best ergometer performers are likely to be selected for eights (mean \pm s: 378 ± 9 s), coxed fours (385 ± 10 s), and quadruple sculls (386 ± 10), while in junior women's events, the best ergometer performers are likely to be chosen for coxless fours (440 ± 10 s) quadruple sculls (441 ± 13 s), and eights (443 ± 11 s). This observation might be attributable to larger boats' improved on-water stability over smaller boats. Therefore, they are less apt than smaller boats to be affected by a lack of balance-related technical skills. With a more stable boat, the emphasis is placed not on balance-related technical proficiency, but instead on rowers' physical fitness, which a rowing ergometer is designed to measure. There were no differences between 2000-m ergometer performance times of scullers and sweep rowers competing at 2007 Championship, either for male (t-test: $P=0.947$) and female (t-test: $P=0.299$) junior rowers.

Mäestu *et al.* (2005) stated that the 2000-m rowing ergometer performance test is more suitable for rowers who compete in large boats, such as quads, fours and/or eights, to ensure a similar performance time. When rowers' performance in small boats is measured, a 2500-m ergometer distance appears to provide a more accurate reflection of the metabolic effort involved in on-water rowing for singles, doubles and pairs. Mean 2000-m ergometer performance time in the present study was 387 s for male junior rowers and 445 s for female junior rowers. This 13% difference in ergometer performance times is consistent with sex-based differences in world record times on the rowing ergometer for 2000-m. Ergometer performance time for the female junior rower is 12% longer than that of her male counterpart; furthermore, ergometer performance time for the female open category rower is 13% longer than that of her male counterpart. Secher (2000) and Ingham, Whyte, Jones & Nevill (2002) observed that for on-water rowing, rowing times for women

are about 10-11% longer than for men. This gap in athletic performance between females and males is also observed in other sports although appears to be decreasing as the number of female competitors increases (Wilmore & Costill, 1999).

This study examined the season's best 2000-m ergometer performance times achieved on a stationary Concept II rowing ergometer, the type of ergometer most commonly used for testing. It is generally assumed that a more specific approach to testing rowers' capabilities is provided by dynamic ergometers (i.e. Concept II ergometer on slides or RowPerfect ergometer) that are more "on-water specific". Some recent studies (Elliott, Lyttle & Birkett, 2002; Colloud, Bahuaud, Doriot, Champely & Chèze, 2006) that have evaluated the use of dynamic ergometers have found that they provide a closer match between the inertial forces and force-time curves recorded with those in a boat. Another benefit of dynamic ergometers is their ability to be combined and set up as a "sliding team boat," so the total effort of the crew could be evaluated even more precisely.

In conclusion, in 10 out of 13 events the obtained correlation coefficients between 2000-m rowing-ergometer performance time and 2000-m on-water performance in elite junior rowers is greater than $r=0.5$. This suggests a strong association between the two types of rowing, as well as the ability of 2000-m rowing ergometer performance time to predict on-water rowing performance. However, the large standard errors of the estimate impair the ability of regression equations 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 put 2000-m rowing-ergometer performance times into a broader perspective and to interpret these performance times within the

context of the World Rowing Junior Championships rankings. Specifically, the regression equations obtained in the present study could be used to determine how fast a junior rower needs to perform on a 2000-m rowing ergometer time trial to predict specific rankings at the World Rowing Junior 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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Tables

Table 1. Descriptive statistics and Pearson correlation coefficients (*r*) for competitors' 2000-m rowing-ergometer performance times

Event	N	Mean ± s (time in seconds)	Correlation with final WRJC rankings	Probability of correlation
Single sculls (JM)	24	386 ± 14	0.80	<0.001
Double sculls (JM)	30	390 ± 14	0.64	<0.001
Quadruple sculls (JM)	60	386 ± 10	0.31	0.002
Coxless pair (JM)	24	395 ± 15	0.67	<0.001
Coxless four (JM)	33	388 ± 12	0.54	0.001
Coxed four (JM)	16	385 ± 10	0.54	0.030
Eight (JM)	35	378 ± 9	0.70	<0.001
Single sculls (JW)	13	449 ± 18	0.92	<0.001
Double sculls (JW)	39	448 ± 15	0.79	<0.001
Quadruple sculls (JW)	40	441 ± 13	0.33	0.039
Coxless pair (JW)	11	446 ± 14	0.69	0.025
Coxless four (JW)	27	440 ± 10	0.66	<0.001
Eight (JW)	30	443 ± 11	0.45	0.013

Note: WRJC - World Rowing Junior Championships; JM – junior men; JW – junior women

Table 2. Regression analysis summary: predicting the final rankings at the World Rowing Junior Championships based on 2000-m rowing-ergometer performance time

Event	Regression equation formula	R^2	<i>SEE</i>
Single sculls (JM)	FR = -191.9 + 0.54×(erg time)	0.65	5.9
Double sculls (JM)	FR = -99.7 + 0.29×(erg time)	0.41	5.0
Quadruple sculls (JM)	FR = -52.0 + 0.17×(erg time)	0.10	5.4
Coxless pair (JM)	FR = -66.8 + 0.19×(erg time)	0.44	3.3
Coxless four (JM)	FR = -56.5 + 0.17×(erg time)	0.29	3.1
Coxed four (JM)	FR = -56.6 + 0.16×(erg time)	0.30	2.6
Eight (JM)	FR = -46.9 + 0.14×(erg time)	0.49	1.3
Single sculls (JW)	FR = -98.3 + 0.24×(erg time)	0.85	2.0
Double sculls (JW)	FR = -167.7 + 0.41×(erg time)	0.63	4.7
Quadruple sculls (JW)	FR = -30.6 + 0.09×(erg time)	0.11	3.2
Coxless pair (JW)	FR = -58.0 + 0.15×(erg time)	0.45	2.3
Coxless four (JW)	FR = -74.1 + 0.18×(erg time)	0.43	2.1
Eight (JW)	FR = -34.3 + 0.09×(erg time)	0.20	2.0

Note: FR - final rankings; *SEE* - standard error of the estimate of rank; JM – junior men; JW - junior women

Figure legends

Figure 1: Scatterplot graphs with regression lines for 3 junior men's (JM) events in which the strongest correlations between 2000-m rowing ergometer performance times and final rankings at the World Rowing Junior Championships (WRJC) were observed

Figure 2: Scatterplot graphs with regression lines for 3 junior women's (JW) events in which the strongest correlations between 2000-m rowing ergometer performance times and final rankings at the World Rowing Junior Championships (WRJC) were observed

Figure 1

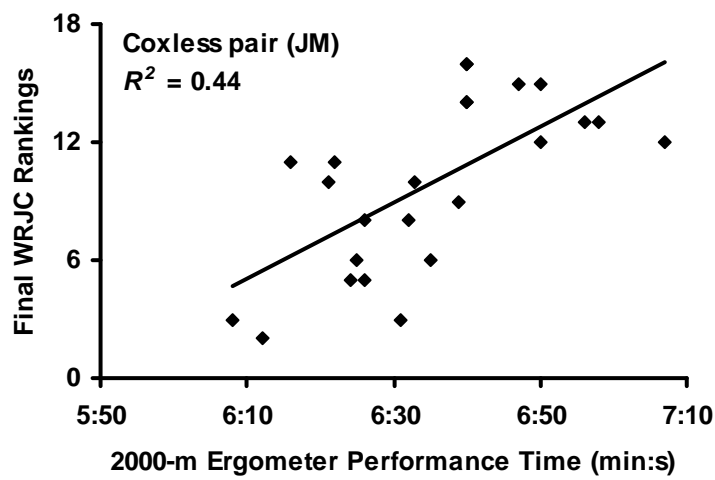
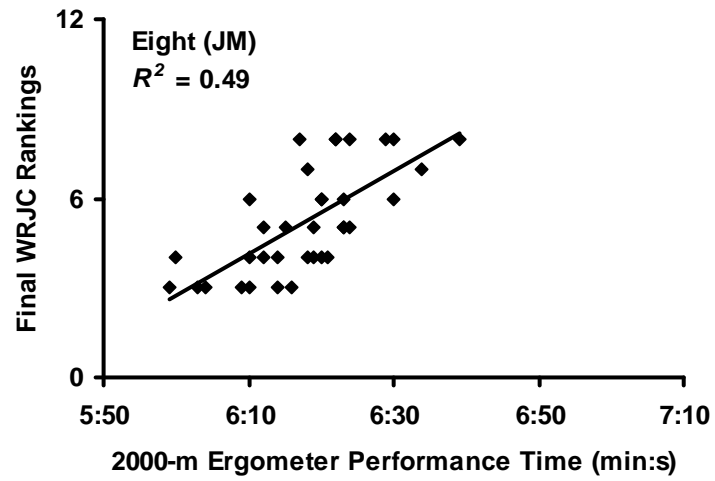
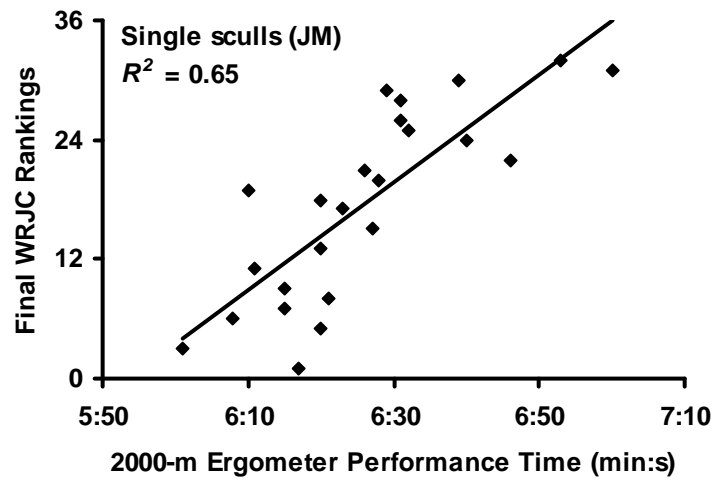


Figure 2

