ROWING ERGOMETER PERFORMANCE AND ANAEROBIC CAPACITY IN COLLEGE ROWERS

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Abstract:

The aim of the study presented was to assess the relationships between the 6-minute "all-out" rowing ergometer test with physical performance indices in college rowers. Ten male rowers (21.60±4.20 yrs; 186.90±5.64 cm; 84.10±6.59 kg; %body fat: 9.62±2.81%) performed a 6-minute "all-out" rowing ergometer test on a rowing ergometer (Concept II, USA) at the first measurement session. In addition, a graded exercise test at the intensities of 150, 200 and 250 W (6-minutes each) and a maximal 5x1 minute interval test were performed at separate measurement sessions. The heart rate (HR) was recorded at the end of each load during a graded exercise test. The individual physical working capacity (PWC) of the rowers was calculated at the maximum of HR recorded during a 6-minute "all-out" test. Blood samples for lactate (LA) determination were obtained from the fingertip before and immediately after each bout of exercise. The anaerobic threshold (AT) indices were determined by interpolation from the relationships between the LA concentration and the respective variable at a LA concentration of 4.0 mmol/l. The LA concentration in the blood was also determined before, immediately after and after 3 minutes and 5 minutes of recovery of the maximal 5 x 1 minute interval test. Significant correlations ($p<0.05$) were observed between the AT (W) and power ($r=0.56$) and the covered distance ($r=0.55$) of a 6-minute "all-out" test. In addition, the power and distance covered of the 6-minute "all-out" test were significantly related to the covered distance and power of all five trials of the maximum interval test ($r=0.64$-0.77). The stepwise multiple interval test indicated that the power of a 6-minute "all-out" test was explained by the mean power of a maximal 5 x 1 minute interval test at 82.75% (R^2). In conclusion, the results of our study suggest that our proposed interval test has a high diagnostic value in the assessment of the anaerobic work capacity of rowers.

Key words: rowing performance, anaerobic capacity, rowers

ERFOLGE MITTELS RUDERERERGOMETER UND ANAEROBE LEISTUNGSMÖGLICHKEIT BEI DEN RUDERERN-STUDENTEN

Zusammenfassung:

Das Ziel dieser Untersuchung war, die Zusammenhänge zwischen 6-Minuten Leistungstest mittels eines Rudererergometers und Indexen der körperlichen Leistungsmöglichkeit von Ruderern-Studenten zu erstellen. Zehn männliche Ruderer (21.60+/-4.20 Jahre; 186,90+/-5,64cm; 84,10+/-6,59kg; 9,62+/-2,81% Fettgewebe) wurden dem 6-Minuten Leistungstest am Rudererergometer (Concept II, USA) in der ersten Messung unterzogen. Zusätzlich wurden der progressive Belastungstest mit den Werten 150, 200 und 250 W (je 6 Minuten) und der Intervall-Leistungstest in der Zeitspanne von 5x1 Minute in abgesonderten Messungen durchgeführt. Die Herzfrequenz (Heart Rate - HR) wurde in der Endphase jeder Belastung des Stufentestes gemessen. Persönliche körperliche Arbeitsleistung (PWC - engl. physical working capacity) der Ruderer wurde nach maximall gemessener Herzfrequenz in der Zeitspanne des 6-Minuten Leistungtestes errechnet. Aus der Fingerkuppe wurden vor und nach jeder Leistung die Blutproben zur Feststellung des Milchsäurespiegels (LA) entnommen. Die Indexe der anaeroben Schwelle (anaerobic threshold - AT) wurden nach der vorgenommenen Interpolation der Wechselbeziehung zwischen dem LA-Spiegel und der entsprechenden Variable mit der Konzentration von 4,0 mmol/l festgestellt. Der LA-Spiegel wurde im Blut vorher, anschliessend, 3 wie auch 5 Minuten nach dem Intervall-Leistungstest 5x1 gemessen. Es wurde eine bedeutende Wechselbeziehung ($p<0,05$) zwischen der anaeroben Schwelle (W) und dem Kraftaufwand ($r=0,56$) einerseits und der zurückgelegten Entfernung ($r=0,55$) in den Zeitspannen des Leistungtestes festgestellt. Der Kraftaufwand und die zurückgelegte Entfernung im Laufe des Leistungtestes hingen auch bedeutend von der zurückgelegten Entfernung und dem Kraftaufwand in allen fünf Zeitspannen des Intervall-Leistungtestes ($r=0,64$-$0,77$) ab. Der wiederholende Intervall-Test mit progressiver Belastung beweist, dass sich der 82,75% (R^2) Kraftaufwand, gemessen in 6-Minuten Leistungtest, über arithmetisches Mittel vom Kraftaufwand, gemessen im Leistungtest mit Intervallen von 5x1 Minute erklären lässt. Wir schlussfolgern, dass die Ergebnisse unserer Untersuchung darauf hinweisen, wie hoch der diagnostische Wert des vorgeschlagenen Intervall-Leistungtests bei der Einschätzung von Arbeitsleistung der Ruderer ist.

Schlüsselwörter: Rudern, Leistung, anaerobe Leistungsmöglichkeit, Ruderer

Introduction

During a rowing competition, anaerobic alactic and lactic as well as aerobic capacities are stressed to their maximum (Steinacker, 1993). A typical rowing competition lasts 6-7 minutes. The rowers are adapted to this effort by a large body muscle mass and high metabolic capacities (Hagerman, 1984; Steinacker, 1993). Research has shown that maximal oxygen consumption and anaerobic threshold (AT) are both well correlated with the rowing performance (Hagerman, 1984; Secher et al., 1982; Steinacker, 1993). It has been reported that aerobic capacity could explain approximately 80% of the performance in competition in trained rowers (Hagerman, 1984; Steinacker, 1993). During a rowing ergometer bout lasting 6 to 7 minutes, the mean power output requires a metabolic rate of approximately 96% to 98% of maximal oxygen consumption (Hagerman et al., 1978).

Thus, having an elevated aerobic capacity appears to be a necessary but not a sufficient condition to excel in rowing (Mesonnier, 1997). The elevated lactate (LA) concentrations (15-17 mmol·l^{-1}) in the blood after international competitions in rowers (Vaage, 1986) suggest that the anaerobic capacity plays an important role in the energy supply (Mesonnier, 1997). Under laboratory conditions, different tests on the rowing ergometer have been used to assess the anaerobic capacity of rowers (e.g., five maximally performed strokes, power of a 40 seconds test) (Steinacker, 1993).

The aim of this study was to examine the relationships between the 6-minute "all-out" rowing ergometer test with submaximal (AT) and maximal physical performance indices (physical working capacity [PWC], 5 x 1 minute interval test).

Materials and methods

Subjects

Ten college rowers volunteered to participate in this study. The subjects trained regularly and had been doing so for the last 4.40±2.61 years. None of the subjects had an unsatisfactory medical history or was taking any medications. The subjects were instructed to eat their usual meals and abstain from strenuous activity the day before the exercise test. Measurements were taken at the beginning of the preparatory period (i.e., in November). This study was approved by the Medical Ethics Committee of the University of Tartu. Each subject gave informed written consent to participate in the investigation and was submitted to three successive exercise sessions separated by at least three days. At the first exercise session, the subjects performed a 6-minute "all-out" rowing ergometer test. The second exercise session consisted of the determination of the PWC and AT of the rowers. At the third measurement session, the maximal 5 x 1 minute interval test was performed.

Anthropometrics

The height (Martin metal anthropometer) and body weight (medical balance scale) of the subjects were measured and the body mass index (BMI; kg·m^{-2}) was calculated. The percentage of body fat and lean body mass (LBM) were obtained using the bioelectrical impedance analysis method (Bodystat-500, UK).

Testing procedure

The first measurement session consisted of a 6-minute "all-out" test performed on a rowing ergometer (Concept II, USA) preceded by a warm-up lasting 8-10 minutes. The maximum power and distance covered were recorded during the test (Steinacker et al., 1993). The heart rate (HR) was measured continuously and stored at 15 second intervals (Sporttester Polar Vantage NV, Finland). Blood samples were obtained from the fingertip for the determination of LA concentrations before and immediately after the test. The whole blood LA was determined immediately enzymatically with a Lange (Germany) microanalyzer according to the procedure of Greiling and Gressner (Greiling and Gressner, 1987).

At the second measurement session, the PWC of the rowers was determined by a graded exercise test performed on a rowing ergometer (Concept II, USA) at the intensities of 150, 200 and 250 W. Each bout of exercise lasted 6 minutes separated by 1 minute of rest between the exercise bouts. The blood samples for the LA measurements were obtained from the fingertip before and immediately after each bout of exercise. The HR was recorded at the end of each exercise bout by the Sporttester Polar Vantage NV (Finland). The PWC at the individual maximum HR obtained during a 6-minute "all-out" test was calculated by extrapolation. The AT indices were determined by interpolation from the relationships between the LA concentration and the respective variable at a concentration of 4.0 mmol·l^{-1} LA (Mader et al., 1976).

At the third measurement session, the maximal 5 x 1 minute interval test was performed on a rowing ergometer (Concept II, USA) preceded by a warm-up lasting 8-10 minutes. The subjects rowed maximally for 1 minute followed by a 1 minute rest between the exercise bouts. The HR was recorded

Table 1. Anthropometric and physical performance characteristics of rowers ($\overline{X}\pm SD$)

Variable	$\overline{X}\pm SD$	Minimum	Maximum
Age (yrs)	21.60±4.20	18.00	32.00
Height (cm)	186.90±5.64	180.00	198.00
Weight (kg)	84.10±6.59	76.00	97.00
BMI (kg.m^{-2})	24.10±0.60	23.46	24.74
% body fat	9.62±2.81	6.70	16.60
LBM (kg)	75.89±4.70	68.70	81.20
6-minute "all-out" test			
Power (W)	342.34±26.71	304.20	375.20
Distance (m)	1785.70±47.03	1718.00	1842.00
LA_{before} (mmol.l^{-1})	2.02±0.41	1.37	2.73
LA_{after} (mmol.l^{-1})	18.46±3.30	14.00	24.70
Graded exercise test			
PWC (W)	250.80±19.44	221.00	293.00
PWC_{kg} (W.kg^{-1})	2.98±0.04	2.91	3.02
AT (W)	166.70±20.88	135.00	207.00
AT (HR, beats.min^{-1})	161.50±12.98	144.00	178.00

BMI, body mass index; LBM, lean body mass; PWC, physical working capacity; LA_{before}, lactate at rest; LA_{after}, lactate after the test.

continuously (Sporttester Polar Vantage NV, Finland). The fingertip blood samples were obtained before, immediately after and after 3 minutes and 5 minutes of recovery. The LA concentrations were determined using the Lange (Germany) microanalyzer (3).

Statistical methods

The descriptive statistics (mean±standard deviation [SD]) for each of the dependent variables were determined. The differences were estimated with a one-way analysis of variance (ANOVA) and the Scheffe post-hoc test with an error of estimate set to 0.05. The Pearson Product Moment Correlation coefficient was used to determine the relationships between dependent variables. The stepwise multiple regression analyses were used for presenting the role of anaerobic performance during the 6-minute "all-out" rowing ergometer test. Again an alpha level of 0.05 was used.

Results

The mean (±SD), minimum and maximum values for the anthropometric and physical performance characteristics of rowers are presented in Table 1. The relative values of power output at the AT (W) and PWC levels compared with power of a 6-minute "all-out" test were 48.7% and 73.3%, respectively.

Table 2 demonstrates the effects of the maximum 5 x 1 minute interval test results. The power and covered distance of the first trial were significantly higher in comparison with the other four trials ($p<0.05$). Similary, the power and distance covered of the second and third trials were significantly higher ($p<0.05$) than the following trials of the maximum 5 x 1 minute interval test. Only the fourth and the fifth trials were not significantly different from each other ($p>0.05$) (Table 2). The values of the LA concentrations before, immediately after, and after 3 minutes and 5 minutes recovery of the maximal interval test are presented in Table 3. The LA concentration was significantly increased after the test and remained significantly elevated after 5 minutes of the test.

The correlation analysis revealed a statistically significant relationship ($p<0.05$) between the power of the 6-minute "all-out" rowing ergometer test and weight ($r=0.55$), and the LBM ($r=0.71$) of rowers, while the HR value of

Table 2. Physical performance characteristics of maximal 5 x 1 minute inerval test in rowers ($\overline{X}\pm SD$).

Trials	Power (W)	Distance (m)
1	512.53±38.03	340.50±8.51
2	444.66±32.83*	326.80±7.47*
3	399.20±21.44*	313.40±5.80*
4	374.07±25.55*#f	306.60±7.01*#f
5	362.32±35.5*#f	303.30±10.18*#f

* Significantly different from trial 1; $p<0.05$.
# Significantly different from trial 2; $p<0.05$.
f Significantly different from trial 3; $p<0.05$.

the AT was significantly related to the PWC measure of the rowers (r=-0.58). In addition, significant correlations existed between the power at the level the AT and power (r=0.56), and the distance covered (r=0.55) of the 6-minute "all-out" test. All other correlations between the physical performance characteristics of the PWC and the 6-minute "all-out" tests were not significant (r<0.54). Significant correlations were observed between power at the AT and the various levels of power and the distances covered of the first, fourth and fifth trials of the maximum 5 x 1 minute interval test (r=0.56-0.75). While the power and the distance covered of the 6-minute "all-out" test were significantly related to the distance covered and power of all five trials of the maximum interval test (r=0.64-0.77). All other relationships between the measured PWC and the 6-minute "all-out" tests' parameters, and maximum 5 x 1 minute performance indices were not significant (p<0.54). The stepwise multiple regression analysis indicated that the power (W) of a 6-minute "all-out" rowing ergometer test was explained by the mean power (W) of a 5 x 1 minute interval test at 82.75% (R^2).

Discussion

The highest values of mean power were recorded in a 6-minute "all-out" test (Table 1). The mean power of our college rowers was similar to the recorded values of rowers of different countries as reported in other investigations (Hagerman et al., 1978; Hartman and Mader, 1993; Klusiewicz et al., 1997).

The mean AT (W) of the rowers was relatively low - only about 50% of the maximal power recorded during the 6-minute "all-out" test (Table 1). It has been reported to be about 20% higher in world class rowers (Klusiewicz et al., 1997). The PWC (W) value determined at the maximal individual HR was about 70% of power, which was recorded during the 6-minute "all-out" test. This is comparable with the results obtained from world class rowers (Klusiewicz et al., 1997). Similary to the Steinacker (Steinacker, 1988) study, the AT (W) correlated significantly with the mean power (W) of a 6-minute "all-out" rowing ergometer test (r=0.56) in our rowers. Thus, the AT (W) could be regarded as an index with a highly diagnostic value.

The aim of the 5 x 1 minute maximal interval test was to stress the glycolytic capacity of the rowers to the maximum. The mean LA concentration in the blood was increased to 23.24±3.63 mmol·l^{-1} immediately after the test (Table 3). In a review article, Billat (Billat, 1996) suggests that the increase in the blood LA level to 20-25 mmol·l^{-1} is often observed following the completion of maximal exercises for the duration of 1-2 minutes. Steinacker (Steinacker, 1993) argues that maximum LA decreases with higher AT due to the higher oxidative metabolic capacity. The AT, which does not depend on the rowers' motivation was relatively low (Table 1) in comparison with other studies (Faff et al., 1993; Klusiewicz et al., 1997).

In our study, the AT was relatively low (Table 1). On the other hand, the qualification of our rowers was not very high. It is possible that the relatively low AT of our rowers could be compensated to some degree by: (a) higher strength, (b) LA formation (see Table 1), (c) increased LA tolerance (Howald, 1988) and also (d) higher work efficiency (Roth, 1979). The maximum LA concentration in the blood

Table 3. Lactate concentration in blood before and after 5 x 1 minute maximal interval test in rowers ($\bar{X}\pm SD$)

Variable	$\bar{X}\pm SD$	Minimum	Maximum
LA_{before} (mmol·l^{-1})	2.37±0.51	1.24	2.98
LA_{after} (mmol·l^{-1})	23.24±3.63*	17.20	27.00
$LA_{3'}$ (mmol·l^{-1})	22.17±3.00*	17.50	25.70
$LA_{5'}$ (mmol·l^{-1})	21.09±2.97*	16.40	26.00

LA_{before}, lactate before the test; LA_{after}, lactate immediately after the test; $LA_{3'}$, lactate after 3 minutes of recovery; $LA_{5'}$, lactate after 5 minutes of recovery.
*Significantly different from LA_{before}; $p<0.05$.

decreases with a higher AT value due to the higher oxidative metabolic capacity (Steinacker, 1993). The LA concentration in the blood after the 6-minute "all-out" rowing ergometer test was quite high in our subjects (Table 1).

In our study, the correlation analysis revealed significant correlations between the performance indices of the 6-minute "all-out" ergometer test and the maximal 5 x 1 minute interval test indices. Additionally, the mean power (W) of the maximal 5 x 1 minute interval test explains 82.75% (R^2) of the mean power during a 6-minute "all-out" rowing ergometer test results. This suggests that our proposed interval test has a high diagnostic value in the assessment of the anaerobic work capacity of rowers.

In conclusion, the maximal 5 x 1 minute interval test can be recommended as a highly useful method for the assessment of rowers' physical performance. In addition, the AT (W) could be used as an index with a high diagnostic value.

References

1. Billat, L. V. (1996). Use of blood lactate measurements for prediction of exercise performance and for control of training. *Sports Med.*, 22:157-175.

2. Faff, J., A. Bienko, K. Burkhard-Jagodzinska, L. Borkowski (1993). Diagnostic value of indices derived from the critical power test in assessing the anaerobic work capacity of rowers. *Biol. Sport,* 10: 9-14.

3. Greiling, H., A. M. Gressner (1987). *Lehrbuch der Klinischen Chemie und Pathobiochemie.* Stuttgart: Schattauer., pp. 210-211

4. Hagerman, F. C., M. C. Connors, J. A. Gault, G. R. Hagerman, W. J. Polionski (1978). Energy expenditure during simulated rowing. *J. Appl. Physiol.*, 45:87-93.

5. Hagerman, F. C. (1984). Applied physiology of rowing. *Sports Med.*, 1: 303-326.

6. Hartman, U., A. Mader (1993). Modeling metabolic conditions in rowing through post-exercise simulation. *Coach*, 4: 2-15.

7. Howald, H. (1988). Leistungsphysiologische Grundlagen des Ruderns. In: Steinacker (Ed.) *Rudern*, str. 31-38. Berlin, Heidelberg: Springer.

8. Klusiewicz, A., J. Faff, R. Zdanowicz (1997). The usefulness of PWC170 in assessing the performance determined on a rowing ergometer. *Biol. Sport,* 14:127-133.

9. Mader, A., H. Liesen, H. Heck, H. Philippi, R. Rost, P. Schurch, W. Hollmann (1976). Zur Beurteilung der Sportartspezifischen Ausdauerleistungsfähigkeit im Labor. *Sportarzt Sportmed.*, 4: 80-112.

10. Mesonnier, L., H. Freund, M. Bourden, A. Belli, J.-R. Lacour (1997). Lactate exchange and removal abilities in rowing performance. *Med. Sci. Sports Exerc.*, 29: 396-401.

11. Roth, W. (1979). *Ergebnisse sportphysiologischer Studien zur Leistungsentwicklung ausgewählter Sportarten in den Jahren 1964-1978 und dem Profil leistungsbestimmender Merkmale sowie der muskelzellulären Grundlagen der spezifischen Leistungsfähigkeit in der Sportart Rudern.* (Dissertation B). Universität Greifswald.

12. Secher, N. H., O. Vaage, R. C. Jackson (1982). Rowing performance and maximal aerobic power of oarsmen. *Scand. J. Sports Sci.,* 4: 9-11.

13. Steinacker, J. M. (1988). Methoden für die Leistungsdiagnostik und Trainingssteuerung im Rudern und ihre Anwendung. In: Steinacker (Ed.) *Rudern,* str. 39-54. Berlin, Heidelberg: Springer.

14. Steinacker, J. M. (1993). Physiological aspects of rowing. *Int. J. Sports Med.*, 14: S3-S10

15. Steinacker, J. M., W. Laske, D. Hetzel, W. Lormes, Y. Liu, M. Stauch (1993). Metabolic and hormonal reactions during training in junior oarsmen. *Int. J. Sports Med.*, 14: S24-S28.

16. Vaage, O. (1986). Table 14-2. In: Åstrand i Rodahl (Ed.) *Textbook of Work Physiology.* New York: McCraw-Hill.