S. Mandic
H. A. Quinney
G. J. Bell

Modification of the Wingate Anaerobic Power Test for Rowing: Optimization of the Resistance Setting

Abstract

The purpose of the study was to determine the resistance factor that would elicit the highest peak 5 s and mean 30 s power output (PO) during a maximal 30 s anaerobic power test on a rowing ergometer. Thirty-one rowers (17 male and 14 female) were recruited based on the light-weight (LW) (6 male; age 23 ± 6 yrs and 6 female; age 19 ± 2 yrs) and heavy-weight (HW) (11 male; age 24 ± 4 yrs and 8 female; age 27 ± 8 yrs) rowing categories. Each group completed 5 randomized series of maximal 30 s sprints equivalent to the following forces: 58.9, 63.8, 68.7, 73.7 and 78.6 N for LW males; 83.5, 88.4, 93.4, 98.2 and 103.1 N for HW males; 29.4, 34.3, 39.2, 44.1 and 49.1 N for LW females; and 44.1, 49.1, 54.0, 58.6 and 63.8 N for HW females. The tests were performed on a Gjessing rowing ergometer modified to accommodate greater resistance settings and computer linked to obtain the necessary data. The peak 5 s and mean 30 s PO (W) were determined for each test. A relative load factor (RLF) for determining the amount of resistance to be applied was calculated based on body mass (BM). The RLF settings that elicited the highest peak 5 s PO were 0.109 and 0.102 $kg \cdot kg^{-1}$ BM for LW and HW male rowers and 0.111 $kg \cdot kg^{-1}$ BM and 0.076 $kg \cdot kg^{-1}$ BM for LW and HW female rowers, respectively. The RLF settings for eliciting the highest mean 30 s PO were 0.102 and 0.095 $kg \cdot kg^{-1}$ BM for LW and HW male rowers and 0.103 $kg \cdot kg^{-1}$ BM and 0.068 $kg \cdot kg^{-1}$ BM for LW and HW female rowers, respectively. A 30 second anaerobic test was also performed on a Concept II rowing machine for comparison and it was found to elicit a significantly lower peak 5 s but not 30 s PO in both male and female rowers. Our findings provide RLFs for assessing anaerobic power using a 30 s test in male and female rowers. As well, peak 5 s but not mean 30 s PO is underestimated using the Concept II rowing machine.

Key words
Force · power output · fatigue · sprint · ergometry

Introduction

The Wingate anaerobic test (WAnT) is arguably the most widely used test of anaerobic fitness and has been established as a valid and reliable measure of anaerobic power output during maximal short term cycling and arm cranking exercise [1]. The intensity (all out) and duration (30 s) of this test allows the evaluation of the metabolic support underlying the rate and capacity of the high-energy phosphagens (adenosine triphosphate and phosphocreatine) and the rate of glycolytic energy contribution (glycolysis/glycogenolysis) to power generation [7]. Thus, the power output generated during the first 5 seconds of the test is considered to be indicative of the rate of energy supply from the high-energy phosphagens and produces a significantly higher power output than the power output that is averaged over the entire 30 seconds of the test; this latter value is thought to estimate energy contribution from the glycolytic system [1,7]. Since the test was originally designed for cycling and arm cranking exercise [1],

Affiliation
E424 Van Vliet Center Faculty of Physical Education and Recreation, University of Alberta, Edmonton, Alberta, Canada

Correspondence
Gordon Bell, Ph.D. · Faculty of Physical Education and Recreation · University of Alberta · E424 Van Vliet Center · Edmonton, Alberta, T6G 2H9 · Canada · Phone: + 78 04 92 20 18 · Fax: + 78 04 92 23 64 · E-mail: Gordon.bell@ualberta.ca

Accepted after revision: September 20, 2003

Bibliography
Int J Sports Med 2004; 25: 409 – 414 © Georg Thieme Verlag KG · Stuttgart · New York · DOI 10.1055/s-2004-815849 · Published online May 18, 2004 · ISSN 0172-4622

modifications were necessary to accommodate specific demands of different sports [8–10] and comparisons have been made to other anaerobic activities such as actual sprinting [12,14]. These results of sport-specific anaerobic fitness testing can more precisely predict performance and/or indicate the potential for improvement in a particular sport or athletic event [12].

In order to be a valid indicator of anaerobic fitness, the testing protocol must consider the resistance at which force is produced to achieve a maximal power output regardless of the mode of exercise [7]. Several studies have focused on determining a relative load factor to optimize the resistance setting for the original WAnT protocol on the cycle ergometer to maximize both peak 5 s and mean 30 s power output in various samples of athletes from different sport backgrounds [4,5,10]. For example, body mass, anthropometric measurements, anaerobic fitness level, metabolic energy system under evaluation and type of exercise apparatus have been considered as important factors in determining the appropriate relative load factor to optimize resistance [1,4]. Although resistance selection based on lean body mass is probably more precise, use of the total body mass is more practical and has been widely accepted [7].

There are few anaerobic tests available which are specifically designed to assess anaerobic power in rowers [2]. Furthermore, alternate unilateral movement with only the lower limbs or upper limbs does not correspond well to the coordinated bilateral movements of both upper and lower limbs in rowing, which stresses the importance of using sport-specific ergometers for an anaerobic power assessment of rowers. Little research [2,8] has been done in assessing anaerobic capabilities in rowers using rowing exercise and no reports of optimizing resistance setting for assessing anaerobic power using a modification of the WanT have been made to the best of our knowledge. Therefore, the purpose of this study was to modify the WAnT for assessing maximal PO during rowing exercise and to determine the optimal resistance settings for determining peak 5 second and mean 30 second power output in light and heavy rowers of both genders. In addition, anaerobic power output was compared between a rowing ergometer (Gjessing) and a popular rowing machine (Concept II) that is commonly used for indoor training and fitness assessment of rowers.

Methods

Subjects

Seventeen male and 14 female rowers volunteered to participate in this study. The subjects were recruited from two local rowing clubs. The subjects were further subdivided into a light-weight (LW) (6 male and 6 female) and heavy-weight (HW) category (11 male and 8 female) according to body mass (BM). These weight categories are based on the regulations outlined by the International Rowing Federation (FISA): LW male must be < 72.5 kg and LW females must be < 59 kg. The physical and physiological characteristics for each subgroup are presented in Table **1.** Note that since this study was conducted during the off-season, some of the LW rowers were not precisely within their competitive weight category. The subjects were required to be actively training and involved in competitive on-water rowing for a minimum of 1 year and therefore ranged in experience from one to several years. All subjects were currently training using a combination of rowing machines and on-water rowing as well as strength training. The subjects were requested not to train for 24 hours prior to each testing session and were provided with guidelines to ensure that adequate carbohydrate intake, hydration and sleep was consistent and similar during all testing. Every attempt was made to test each subject at the same time of day for each trial. The subjects were familiarized with the testing protocol and possible risks and signed an informed consent. A University Research Ethics Committee approved this study.

Study design

All subjects performed 5 randomized trials of a 30-second, all out sprint on a Gjessing rowing ergometer (Ergorow, Bergen, Norway) on separate days over a 2 week period. The Gjessing rowing ergometer has a friction belt and flywheel mechanism to provide resistance to the handle and an adjustable weight on a scaled lever arm to provide various resistance settings. We modified this ergometer to accommodate greater resistance settings by adding weight to the original resistance setting device on the ergometer and calibrating the resistance setting scale for these greater loads using calibration weights. A commercially available potentiometer was directly fixed to the flywheel and interfaced to a computer and a custom-designed software program was used to obtain flywheel revolutions from the ergometer during the test. PO (watts) was calculated as the product of resistance and flywheel revolutions every second and mean PO was deter-

Table **1** Subject characteristics. Values are means ± SD

	Male		*Female*	
	LW	*HW*	*LW*	*HW*
Age (yr)	23 ± 6	24 ± 4	19 ± 2	27 ± 8*
Height (cm)	181 ± 5	189 ± 6	166 ± 6	173 ± 5
Weight (kg)	68.7 ± 5.4	89.7 ± 5.9	58.8 ± 5.1	73.0 ± 5.3
VO_{2max} $(l \cdot min^{-1})$	4.12 ± 0.39	4.71 ± 0.45**	2.43 ± 1.25	3.12 ± 0.27**
VO_{2max} $(ml \cdot kg^{-1} \cdot min^{-1})$	59.4 ± 2.5	52.3 ± 5.4**	41.2 ± 2.07	42.7 ± 2.63

LW = light weight; HW = heavy weight. * = significantly different from LW women, $p < 0.05$. ** = significantly different from LW category, $p < 0.05$

mined from the first 5 s (peak 5 s PO) and for the whole 30 s of the test (mean 30 s PO) by the computer software.

Test protocols

The body mass of each subject dressed in socks, shorts and t-shirt but without shoes was measured using a calibrated scale to the nearest 0.1 kg. Standing height to the nearest cm was measured using an anthropometric tape measure from the floor to the top of the head by placing a right angle plane on the head and having each subject stand straight with their shoes removed against a designated wall. A peak VO_2 test was performed on a Concept II rowing machine (Morrisville, VT, USA). The protocol was an incremental exercise test to volitional exhaustion at the same time that expiratory air was collected and analyzed using a calibrated Horizon metabolic measurement system (Sensor Medics, CA, USA). This protocol is routinely performed in our laboratory and is identical to that previously reported by Gillies and Bell [6].

A randomized order of all resistance settings on the Gjessing rowing ergometer was pre-determined for each subject. These resistance settings were equivalent to a force of 58.9, 63.8, 68.7, 73.7 and 78.6 Newtons (N) for LW males; 83.5, 88.4, 93.4, 98.2 and 103.1 N for HW males; 29.4, 34.3, 39.2, 44.1 and 49.1 N for LW females; and 44.1, 49.1, 54.0, 58.6 and 63.8 N for HW female rowers. To establish that these range of forces would in fact elicit a peak and mean power output within the chosen resistance settings in our sample of rowers, preliminary research was conducted in a group of male and female light and heavy weight rowers that involved a series of 10-second sprints using a variety of resistance settings on the Gjessing ergometer. This allowed the investigators to establish a range of resistance settings that would encompass the maximal PO for the majority of our subjects in each rowing weight category and for each gender. For each subject and for each trial, the resistance setting (kg) was divided by BM (kg) to determine a relative load factor (RLF): RLF = resistance setting/BM. The optimal RLF was considered to be the resistance setting that elicited the highest peak 5 s and mean 30 s PO when performing at a maximal stroke rate for each subject in each weight category.

Each test began with a standardized warm-up consisting of rowing on the ergometer for 10 minutes at a PO of approximately 100 w in addition to 3 – 5 s high intensity sprints separated by 1 minute of rowing during the last 5 minutes of the warm-up [7]. After the warm-up, 5 minutes of general static stretching was performed. The test began with approximately 1 minute of submaximal rowing (~ 100 w) immediately followed by a verbal command of, “start rowing faster” (pause), “faster” (pause), “go all-out”. This required approximately 3 to 4 s and allowed each subject to overcome the inertia and frictional resistance of the flywheel to achieve a maximum stroke rate on the rowing ergometer. During this first part of the test, an investigator was manually holding the loaded lever arm to be applied during the test. After the last portion of the command of “go all out” and when the investigator judged the subject was at a maximal stroke rate, the full resistance was applied at the catch phase of the rowing stroke by lowering the load that maximally engaged the friction belt on the flywheel. A second investigator started the computer software program on verbal command that was simultaneous with the release of the full load on the ergometer flywheel. Each subject was then consistently, verbally encouraged to maintain as high a stroke rate as possible in 30 seconds. Thus, maximum (all-out) stroke rate was dependent on each subject’s ability. No visual or verbal feedback regarding the time to complete the 30 s test was provided. A cool-down consisting of continuous rowing for 10 minutes (~ 100 w) followed by static stretching was performed by all subjects after each test. The test-retest reliability of peak 5 second and mean 30 second PO of our protocol was Pearson’s r = 0.985 and r = 0.975, respectively, established on a group of 11 male rowers on two different days. Coggan and Costill [3] have reported a mean coefficient of variation (CV) of 5.4% for a 30 second cycle anaerobic power protocol. Day to day variability of anaerobic power testing must be considered a limitation in our experimental design.

In addition, a 30 second maximal sprint was performed on a Concept II rowing machine on a separate day. The force which each subject must row against on this type of machine is based on air resistance to a bladed flywheel enclosed in a cover that has setting mechanism of 1 to 10, with 10 being the greatest resistance available. This was the setting used for this study for all subjects and it was apparent that this resistance was less than would be achievable on the Gjessing rowing ergometer. However, the Concept II does not allow for an extra external load to be attached to its flywheel mechanism. PO on the Concept II is calculated using an algorithm generated by the manufacturer. The reason we chose to use this rowing machine as a part of our study is that it is widely used by the international rowing community for physiological testing and training. More recently, a world indoor 2000 m rowing event was initiated specifically using the Concept II rowing machine. The general test protocol, warm-up and cool-down for the Concept II testing was identical to the previous description for the Gjessing ergometer. The Concept II computer display was reset at the start of the test and the display was set to provide power output feedback to the investigator. Mean PO after the first 5 s (peak 5 s) and after the entire 30 s test (mean 30 s) was manually recorded from the display and used for comparison with the results from the Gjessing rowing ergometer.

Data and statistical analysis

The mean and standard deviations are reported for all data. A two-way analysis of variance (ANOVA) was used to compare weight category (LW and HW) and gender for all physical and physiological characteristics. The RLF was calculated as described previously and separate one-way ANOVAs for repeated measures were used to compare the power output at each of the trials for the different weight category and gender. A Newman Keuls procedure was used for all multiple comparisons where significant F-ratios were observed. A dependent *t*-test was used to compare the peak 5 s and mean 30 s PO between the Gjessing ergometer (using the optimal RLF) and the Concept II rowing machine. The level of significance was set a priori at $p < 0.05$.

Results

The mean physical and physiological characteristics of the subjects are presented in Table **1**. It is important to point out that the LW women were younger than the HW women. This was likely due to the nature of the female membership in the rowing

Table **2** Mean (± SD) relative load factors (RLF) that elicited the highest peak 5 s and mean 30 s power output (PO) on the Gjessing rowing ergometer for light weight (LW) and heavy weight (HW) male and female rowers

	Male		*Female*	
	LW	*HW*	*LW*	*HW*
Peak 5 s	0.109 ± 0.006	0.102 ± 0.009	0.111 ± 0.010	0.076 ± 0.006
Mean 30 s	0.093 ± 0.006	0.095 ± 0.010	0.103 ± 0.009	0.068 ± 0.005

Relative load factor is expressed as kg · kg^{-1} BM

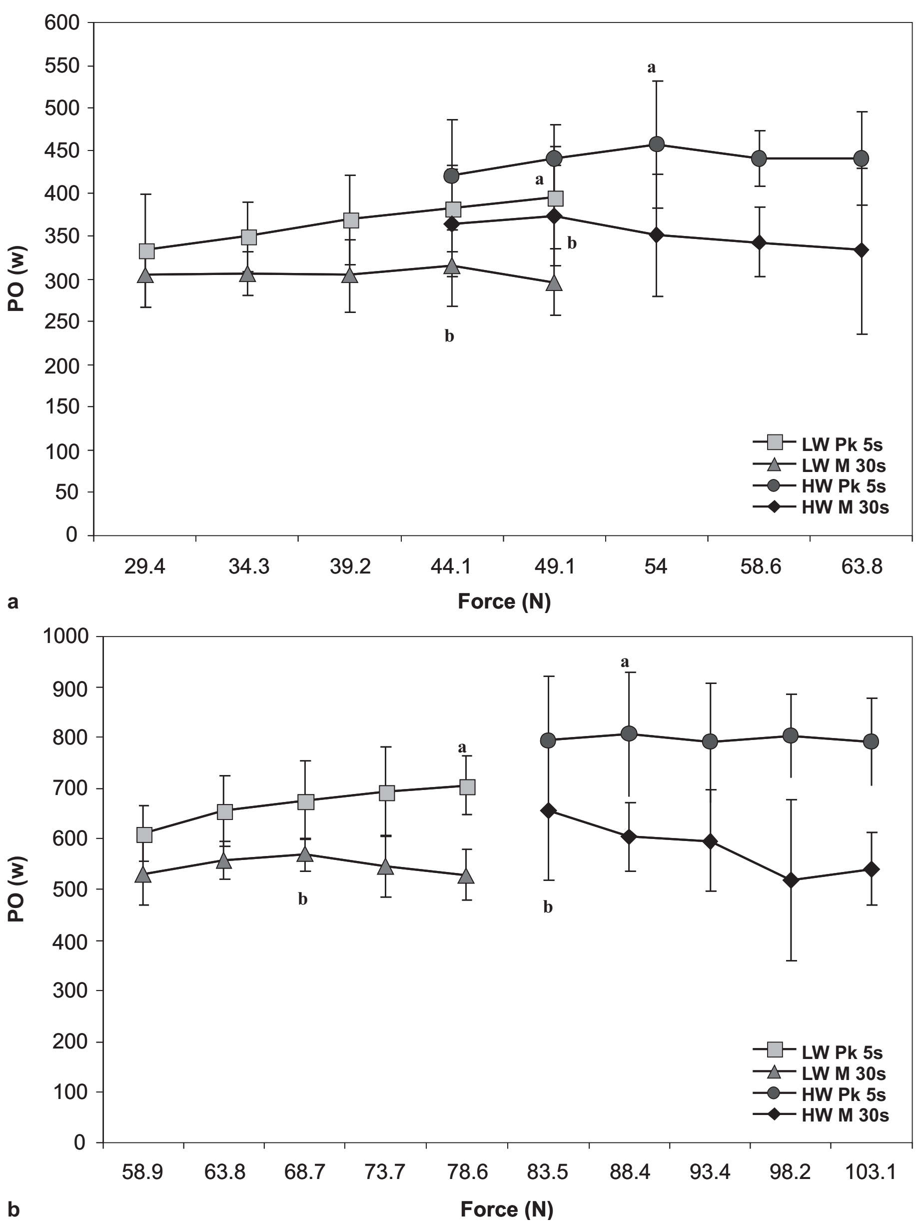

Fig. **1 a** and **b** Graphical representation of power output (PO) versus force (F) for each modified Wingate anaerobic power test for rowing. **a** Females. **b** Males. Values are means ± SD. LW = lightweight; HW = heavy weight; Pk = peak; M = mean; s = second. "a" indicates the highest peak 5 second power output, $p < 0.05$. "b" indicates the highest mean 30 second power output, $p < 0.05$.

clubs used for subject recruitment at the time of this study. Peak VO_2 was higher in absolute values (l · min^{-1}) for the HW men and women compared to the LW category that reflects the physically larger rower in the HW category. Relative peak VO_2 (ml · kg^{-1} · min^{-1}) was higher in the LW men compared to the HW men primarily due to the lower BM in the LW males. Relative peak VO_2 was similar between the LW and HW women which could be due to a combination of differences in body composition and aerobic fitness.

Mean RLF for peak 5 s and mean 30 s PO during the five trials with different resistance settings on the Gjessing ergometer are expressed as kg per kg of BM (kg · kg^{-1} BM) and reported in Table **2**. The peak 5 s and the mean 30 s PO at the optimal RLF was sig-

Table **3** Peak 5 s and mean 30 s power output (PO) on the Concept II rowing machine and the Gjessing rowing ergometer. Values are means ± SD

	Male[a]		*Female*[a]	
	LW[b]	*HW*[b]	*LW*[b]	*HW*[b]
Concept II				
– *Peak 5 s*	590.1 ± 60.7 [c]	694.1 ± 110.9 [c]	329.9 ± 51.8 [c]	384.4 ± 54.5 [c]
– *Mean 30 s*	569.4 ± 68.9	644.3 ± 48.1	311.8 ± 44.4	347.7 ± 57.3
Gjessing				
– *Peak 5 s*	704.5 ± 57.6	807.3 ± 121.8	394.9 ± 60.2	456.9 ± 74.6
– *Mean 30 s*	568.0 ± 34.4	654.0 ± 135.4	315.5 ± 47.2	374.2 ± 59.2

LW = light weight; HW = heavy weight. Relative load factor is expressed as $kg \cdot kg^{-1}$ BM. a = Peak 5 s and mean 30 s PO was significantly different between genders on the Gjessing rowing ergometer, $p < 0.05$. b = Peak 5 s and mean 30 s PO for males was significantly different between LW and HW rowers on the Gjessing rowing ergometer, $p < 0.05$. c = peak 5 s PO for the Concept II rowing machine is significantly different from peak 5 s PO on the Gjessing ergometer; $p < 0.05$

nificantly greater than all other power outputs at the different RLFs for both LW and HW men and women. Also, the peak 5 s and mean 30 s PO was significantly higher for men compared to women and higher for the HW versus LW categories. Fig. **1** displays the power outputs achieved at each of the selected forces for LW and HW men and women.

Table **3** shows the comparison of the peak 5 s and mean 30 s PO for the Gjessing rowing ergometer and the Concept II rowing machine. A significant difference was found for peak 5 s PO determined on the different ergometers for both men and women LW and HW but not for mean 30 s PO.

Discussion

This study established appropriate RLF settings to elicit peak 5 second and mean 30 second anaerobic power output during a WAnT modified for rowing. To the best of our knowledge, there are no reports of a modified WAnT anaerobic testing protocol using a rowing ergometer despite anaerobic power being an important fitness parameter in rowing performance. Our findings showed that the optimal RLF was different for light and heavy weight rowers and between male and female rowers. Since it is not practical to utilize 2 different resistance settings to determine peak 5 s and mean 30 s power output as this would require 2 different tests to be performed by the same athlete, our results would therefore recommend a relative load factor of 0.100 and 0.090 $kg \cdot kg^{-1}$ body mass for light and heavy weight male and female rowers as an appropriate and practical resistance prescription for WAnT anaerobic power testing. This is similar to the relative load factor of 0.086 $kg \cdot kg^{-1}$ body mass for women using the WAnT protocol on a cycle ergometer [4] and the relative load factor of 0.095 $kg \cdot kg^{-1}$ body mass recommended for men also using the WAnT protocol on a cycle ergometer [5] despite the differences in exercise mode.

Specific coordinated bilateral movements of both the lower and upper body in rowing exercise emphasize the importance of using a rowing ergometer for assessing any type of specific fitness parameter in this population. The rowing stroke can be separated into two general phases, the drive and the recovery. These phases of rowing exercise present a challenge when addressing the most appropriate resistance setting to use for anaerobic power testing. If the rower is required to row against too great a force on the rowing ergometer, the resistance provided by the friction belt causes the flywheel to decelerate quickly during the recovery phase of the rowing stroke. This in turn requires the rower to overcome much inertia at the start of each power stroke (the drive) that can greatly reduce flywheel revolutions and stroke rate which ultimately reduces the rate of power that can be achieved if resistance is too great. This makes the selection of an appropriate resistance setting critical to maximize anaerobic power output during rowing exercise. For this reason and since anaerobic fitness is important in rowing competition [2,13], it was important to develop a sport specific testing protocol with an optimal loading method to achieve maximal anaerobic power output.

Previous research has found that performance on the Wingate anaerobic power test was correlated to body mass [12] and therefore, selection of the appropriate resistance could be made using a relative load factor based on body mass [10]. Although total body mass does not take into account the active muscle mass [15] and may be also influenced by body composition, this approach seems reasonable from a practical prospective [7]. In addition, rowing exercise utilizes both upper and lower body muscle groups, which further supports the use of a loading factor based on total body mass. We selected a range of resistance settings that attempted to allow for a maximal power output to be achieved. This enabled us to establish the optimal resistance setting that would elicit the highest peak 5 second and mean 30 second power output for light and heavy weight male and female rowers.

It was also prudent to examine whether the Concept II rowing machine could be used to assess anaerobic power in the present study since it is widely used for other types of exercise testing and for indoor training. A comparison of the peak 5 s and mean 30 s power output showed that a significantly higher peak 5 s power output was achieved on the Gjessing rowing ergometer. This finding suggests that the Concept II rowing machine underestimates peak 5 s anaerobic power output in rowers. The reason for this is probably due to the design of the Concept II rowing machine which uses air resistance on a bladed type flywheel system and cannot provide enough force through this type of air resistive design for maximal peak 5 s anaerobic power to be achieved nor can it be easily modified (larger flywheel blades for example) to do so. The Gjessing rowing ergometer can be effectively loaded with greater weight and the scale of resistance setting can be calibrated to verify and quantify this modification. However, mean 30 s anaerobic power output is similar between the Gjessing rowing ergometer and the Concept II rowing machine, suggesting either apparatus would be suitable to assess this aspect of anaerobic fitness in rowers.

Conclusion

The present study is the first to report the modification of the WAnT protocol for rowing exercise testing on a Gjessing rowing ergometer. Based on the present results, the recommended resistance setting (RLF) to maximize both peak 5 s and mean 30 s power output is $0.100\,kg \cdot kg^{-1}$ body mass for light and heavy weight male rowers, and $0.090\,kg \cdot kg^{-1}$ body mass for light and heavy weight female rowers, respectively. The Concept II rowing machine underestimates peak 5 s anaerobic power output in rowers but can elicit a similar mean 30 s anaerobic power output to the Gjessing rowing ergometer. Further research is necessary with a larger sample and with more highly trained rowers to further establish the validity and reliability of this suggested protocol.

References

1 Bar-Or O. The Wingate anaerobic test. An update on methodology, reliability and validity. Sports Med 1987; 4: 381 – 394

2 Bell GJ, Petersen SR, Quinney HA, Wenger HA. The effect of velocity-specific strength training on peak torque and anaerobic rowing power. J Sports Sci 1989; 7: 205 – 214

3 Coggan AR, Costill DL. Biological and technological variability of three anaerobic ergometer tests. Int J Sports Med 1984; 5: 142 – 145

4 Dotan R, Bar-Or O. Load optimalization for the Wingate anaerobic test. Eur J Appl Physiol 1983; 51: 409 – 417

5 Evans JA, Quinney HA. Determination of resistance settings for anaerobic power testing. Can J Appl Spt Sci 1981; 6: 53 – 56

6 Gillies EM, Bell GJ. The relationship of physical and physiological parameters to 2000 m simulated rowing performance. Sports Med Training Rehab 2000; 9: 277 – 288

7 Inbar O, Bar-Or O, Skinner JS. The Wingate Anaerobic Test. Champaign, IL: Human Kinetics, 1996

8 Koutedakis Y, Sharp NC. A modified Wingate test for measuring anaerobic work of the upper body in junior rowers. Brit J Sports Med 1986; 20: 153 – 156

9 Manning JM, Dooly-Manning C, Perrin DH. Factor analysis of various anaerobic power tests. J Sports Med Phys Fitness 1988; 28: 138 – 144

10 Patton JF, Murphy MM, Frederick FA. Maximal power outputs during the Wingate anaerobic test. Int J Sports Med 1985; 6: 82 – 85

11 Pripstein LP, Rhodes EC, McKenzie DC. Aerobic and anaerobic energy during a 2-km race simulation in female rowers. Eur J Appl Physiol 1999; 79: 491 – 494

12 Reilly T, Bayley K. The relation between short-term power output and sprint performance of young female swimmers. J Human Movement Studies 1988; 14: 19 – 29

13 Secher NH. Physiological and biomechanical aspects of rowing. Sports Med 1993; 15: 24 – 42

14 Tharp GD, Newhouse RK, Uffelman L, Thorland WG, Johnson GO. Comparison of sprint and running times with performance on the Wingate anaerobic test. Res Q 1985; 56: 73 – 76

15 Vandewalle H, Peres G, Monod H. Standard anaerobic exercise tests. Sports Med 1987; 4: 268 – 289