ORIGINAL ARTICLE

Optimal loads for a 30-s maximal power cycle ergometer test using a stationary start

Nicole T. Vargas · Robert A. Robergs · Dawn M. Klopp

Abstract

Introduction A stationary start modification to the Wingate Anaerobic Test (WAnT) has become increasingly common. The aim of the present study was to determine whether the traditional 85 g kg^{-1} body weight (BW) load (TRAD), or an individualized optimal load (OPT), is more suitable for obtaining peak and mean power outputs (PPO and MPO, respectively) for a stationary start.

Methods Twelve recreationally active males and 10 females (mean age 30 ± 9.1 and 25 ± 5.5 years, respectively) completed three trials. The first determined the OPT load and included a familiarization of the 30-s stationary start test, followed by two randomized sessions testing the OPT and TRAD loads during the 30-s stationary start test on separate days. For each test, measures of power (watts), time, and cadence were collected to determine PPO, MPO, rate of power decline (rPD) and time to peak power (TtPP). All power data were corrected for flywheel moment of inertia.

Results Results revealed significant differences between OPT and TRAD load settings for males (95.1 ± 10.7 and 85.06 ± 0.40 g kg^{-1} BW; $p = 0.008$) but not for females (84.71 ± 8.72 and 85.2 ± 0.61 g kg^{-1} BW; $p = 0.813$). Relative PPO was not different for OPT or TRAD loads for males ($p = 0.485$) or females ($p = 0.488$).

Conclusion It is not necessary to use an OPT load setting to acquire maximal PO for a 30-s cycle test using a stationary start. Instead, the traditional 85 g kg^{-1} BW loading is suitable for both males and females.

Keywords Anaerobic test · Wingate · Peak power · Ergometry

Abbreviations

WAnT	Wingate anaerobic test
BW	Body weight
TRAD	Traditional load
OPT	Optimal load
PPO	Peak power output
MPO	Mean power output
FI	Fatigue index
W	Watts
TtPP	Time to peak power
PD	Power decline
rPD	Rate of power decline
I	Inertia

N. T. Vargas (✉) · R. A. Robergs · D. M. Klopp
School of Human Movement Studies, Charles Sturt University,
Allen House, Building N1, Office 2:23, Bathurst, NSW 2795,
Australia
e-mail: nvargas@csu.edu.au

Introduction

Many factors can be attributed to an accurate peak power output (PPO) or mean power output (MPO) measure obtained during a maximal sprint on a cycle ergometer. The literature is largely varied in regards to the methodology, equipment and correction factors that might apply when attempting to test an individual's power output. For instance, the traditional and widely used wingate anaerobic test (WAnT) has been the subject of criticism, primarily in regards to the model of cycle ergometer used (Micklewright et al. 2006), the appropriate application of inertial corrections (MacIntosh et al. 2001, Bassett et al. 1989, Reiser et al. 2000), the methodology used in performing

the test (MacIntosh et al. 2003), and the load that should be applied during the test (Ayalon et al. 1974; Bosco et al. 1983; Dotan and Bar-Or 1983; MacIntosh et al. 2001; Rodgers and Hermiston 2000; Ucock et al. 2005).

Traditionally, the WAnT involved a fly start in which an individual reached their maximal cadence (in ~5 s) prior to the application of a predetermined load. The subject was then required to sustain their highest possible cadence for 30 s (Dotan and Bar-Or 1983; Dotan 2006). These methods were developed to measure overall MPO; however, PPO and fatigue index (FI) were readily available through simple calculations, and thus, also became additional measurements of the test (Arsac et al. 1996; Dotan 2006; Ayalon et al. 1974). Today, software and electronic systems are used in place of lab technicians to calculate mechanical PO per crank revolution for time intervals <1 s (Arsac et al. 1996; Dotan 2006; Lakomy 1986). While electronic counting of pedal revolutions has increased the precision and temporal resolution of data acquired from the test, recent concerns have been raised regarding the validity of the fly start methodology still commonly used in labs around the world (Dotan 2006; MacIntosh et al. 2003). Moreover, there seems to be a lack of standardization that has developed over the past 40 years in test procedures, which leads to challenges when comparing results from different laboratories.

A couple of research groups have made queries with regards to the validity of the methodology of the WAnT and the fly start that is typically used (MacIntosh et al. 2003; Jastrzebski et al. 1995). Though not explicitly stated in literature, it seems that there may be unnecessary waste of energy ensuing in the fly start test as the participant attempts to reach maximal cadence prior to the load being applied. The preemptive muscular requirements are thought to compromise power measurements thereafter and hence render them invalid. For instance, MacIntosh et al. (2003) reported that, when using the traditional load (85 g kg^{-1} BW), the fly start methodology of the WAnT generated a significantly lower PPO than if the test is performed using a stationary start (833 W vs. 974 W, respectively). This might suggest that indeed there is some mechanism in which the power produced during the pre-load phase may compromise PPO measured after the load is applied. While EMG data supporting this hypothesis remain elusive, the lack of standardization of test methodology can be improved if these results can be reproduced through careful comparison of the fly and stationary start versions of the test.

Previous discussion aside, the main concern of the present study revolves around the appropriate load prescription necessary to attain maximal PPO. Additional concerns have been raised regarding the suitability of the current recommended load of 85 g kg^{-1} BW for the fly start version for both males and females. Numerous studies (Ayalon et al. 1974; Bradley and Ball 1992; Bosco et al. 1983; Dotan and Bar-Or 1983; MacIntosh et al. 2001; Rodgers and Hermiston 2000; Ucock et al. 2005) have tested the appropriate loading for the traditional fly start methodology, however, only two groups, MacIntosh et al. (2003) and Arsac et al. (1996), have done so using an optimal load for each participant. Furthermore, MacIntosh et al. (2003) remain the sole group to have compared the individually optimal load and traditional load using a stationary start. MacIntosh et al. (2003) used the load that gave the maximal PPO of five short sprints (4–7 s) and compared it to the recommended 85 g kg^{-1} BW (Bar-Or 1986) load during both a stationary start and traditional WAnT. Interestingly, they found a significant increase in load settings for the optimal load, but no significant difference in PPO (MacIntosh et al. 2003).

While it seems there is a movement to change the traditional WAnT to a stationary start version, standardization of the methods and prescribed load are an important factor to consider. Furthermore, while the study by MacIntosh et al. (2003) reported that there was not an increased performance despite a significant increase in resistance with the optimal load, it is necessary to provide further evidence that this is in fact the case. The results of their study were largely unexpected and thus, it is necessary to validate the results for use in future research and laboratories. The principle aim of the present study was to provide further evidence that, when using a stationary start methodology for the WAnT, the traditional recommended load is as effective as an individually optimized load. Furthermore, the study was designed to compare the difference between PPO, MPO, time to peak power (TtPP), power decline (PD–calculated the same as FI) and the rate of PD (rPD) in each load condition. It was hypothesized that there would be a significant difference in prescribed load between the individual optimal load and the traditional 85 g kg^{-1} BW load used for the 30-s test for both males and females. Likewise, it was anticipated that PPO, MPO, PD and rPD would be significantly increased for the optimal load trials for both males and females, but that TtPP would be decreased in the optimal load trials due to an increased resistance load.

Methods

Subjects

Twelve males and 10 females, all recreationally active (participated in aerobic or resistance type exercise at least 3 × per week for 60 min), ages 30.5 ± 9.2 (mean ± SD) and 25.2 ± 5.6, weighing 84.2 ± 8.7 and 61.4 ± 7.3, respectively, consented to participate in the study. The institution's ethics committee approved the study and participants were required to read and sign necessary

consent forms. Each participant completed an Adult Pre Exercise Screening Tool (APSS) and was screened for risk factors for sedentary lifestyle diseases that would exclude them from the study as recommended in current guidelines from Exercise and Sports Sciences Australia (ESSA). The subjects attended three sessions with a minimum of 48 h between each session. Subjects were required to refrain from intense exercise, alcohol and caffeine at least 24 h prior to testing, and were instructed to keep a food and activity log for this time period. They were required to wear comfortable exercise clothing and the same shoes for each session, which was performed during the same time of the day (within 30–60 min either side) to prevent diurnal variation, and were allowed to drink water ad libitum. At the beginning of each session, weight and height measurements were taken and the food/activity log was collected and compared to previous sessions to ensure similarity. Seat height was set at a level that allowed almost full knee extension at the bottom of the pedal stroke and each individual chose handle bar placement. Both settings were recorded for consistency in subsequent trials.

Familiarization session

The familiarization session was used to determine the optimal load setting for subjects, as well as familiarize them with the cycle ergometer (Monark model 834 E; Varberg, Sweden) and how to perform the 30-s maximal power cycle test. Optimal load was determined using methodology previously established by MacIntosh et al. (2003). In brief, following a 5 min warm up at 50 (W) and a 5 min recovery, each subject completed five short sprint tests from a stationary start at loads ranging between 65 and 125 g kg^{-1} BW, and were blinded to the load. The recovery method through all testing was optional and ranged from passive sitting down to light walking around the laboratory or unloaded pedaling on a different cycle ergometer for at least 3 min (Blonc et al. 1998). The first three loads were designated to be either 85, 95 or 100 g kg^{-1} BW and the final two loads were chosen based on power outputs from these three loads so that, when graphed, an inverted resistance–velocity power curve was produced, as detailed by MacIntosh et al. (2003). Each sprint lasted between 5 and 15 s to ensure that peak power was reached (Fig. 1). Finally at the end of the sprint session, the subjects were given 5 min of recovery before the 30-s familiarization trial. The subjects returned to the bike and were given a 3 s countdown before they began pedaling as hard and as fast as possible at the command, "Go!". There was no verbal encouragement given, but participants were told when 15 and 5 s remained to ensure consistency between
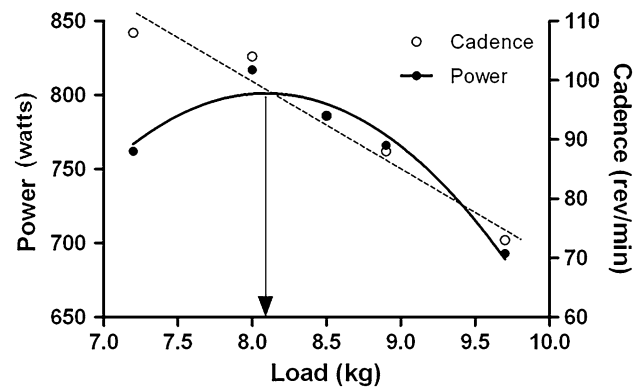

Fig. 1 Example of single subject power–force curve used to extrapolate optimal individual load, similar to the methods used by MacIntosh et al. (2003)

each trial. Upon completion of the test, subjects were instructed to cool down by pedaling against zero resistance until they felt well enough to both get off the cycle ergometer and leave the laboratory.

Data acquisition

Raw data for the sprint trials were collected at 250 Hz using custom software (LabVIEW, National Instruments, Austin, TX) from a voltage spike generated by a magnetic counter mounted on the flywheel and the bike frame. The signals were saved and then processed post data acquisition in another custom program (LabVIEW, National Instruments, Austin, TX) for conversion to cadence and calculations of mechanical power.

Peak and mean mechanical power output was calculated in the LabVIEW data acquisition program for both the short sprint trials and the successive 30-s maximal test, and were later transferred to an excel spread sheet (Microsoft, Seattle, WA, 2007). A separate LabVIEW program was used to apply an inertia coefficient factor to the PPO and MPO data. The technique used for determining the coefficient of inertia is described below. Data from the short sprints were used to find the resistance–velocity relationship by which each individual optimal load was extrapolated from the peak power of the power–load curve and recorded for use in the following trials.

Moment of inertia methodology

Flywheel moment of inertia was computed from the Lakomy (1986) method and as refined by MacIntosh et al. (2001). Four metal "L" shaped 15 mm wide obstructers were placed equally ($\pi/2$ rads) around the flywheel. An "L" shaped analog output photomicrosensor (EE-SX871 2 M, OMRON Corporation, Singapore) was then positioned on

a wooden extension bolted to the angled metal frame of the ergometer. The sensor and obstructers were positioned so that each obstructer moved through the two "L" shaped arms of the photomicrosensor, blocking the light source and causing a reduction in output voltage. A custom software program (LabVIEW™, National Instruments, Austin, TX) was developed to acquire signal voltage from the sensor at 1,000 Hz.

For data collection, a subject cycled on the ergometer to approximately 70 rev/min for nine different load conditions (0.5 kg increments from 1 to 5 kg). For each load condition, the software program was started once the targeted cadence was reached, and the subject ceased pedalling, allowing the flywheel to spin down to zero rotations. Data acquisition was then stopped and data were saved to a .txt file.

To compute flywheel inertia, three other programs were developed (LabVIEW™, National Instruments, Austin, TX). First, the acquired data for each condition were processed to detect a 0.05 volt change from stationary baseline. The time of each voltage change was captured and then the time difference between each signal and the corresponding flywheel angular velocity were computed. The onset of each spin down was then identified as the data point coinciding with the start of a consistent decrease in delta time and all data to follow were saved as a .txt file. An additional program was written to graph the decreased angular velocity over time, which was fitted with linear regression to obtain the slope (deceleration) for each load condition. The applied load and deceleration data were then processed as follows. Applied load was converted into torque by multiplying by the flywheel radius (0.26 m), and torque (y-axis) was graphed to deceleration (x-axis). Linear regression was completed to produce equation x.

$$T = I \cdot \alpha + T_r, \tag{1}$$

where T = torque (Nm); I = inertia; α = angular acceleration (rad· s^{-2}); T_r = residual torque (Nm) associated with the resistance provided by the mechanical bearings of the flywheel.

As such, the slope of the torque to deceleration regression is the flywheel moment of inertia (I). The application of the correction for flywheel moment of inertia was treated as an additional factor (INERTIA) with two levels; yes, no.

The two remaining trials were completed in the same manner as the first session, without the short sprints. The two trials consisted of load settings based on either the traditional 85 g kg^{-1} BW (Bar-Or et al. 1987) or the individual optimal load extrapolated from the repeated short sprints conducted in familiarization. Subjects completed a 5 min standardized warm up followed by 5 min of rest, during which time the ergometer load was prepared for

the subject and was covered to ensure blinding. The procedures of the tests were identical as those carried out during the familiarization session. The second trial was completed a minimum of 48 h later, within 30 to 60 min of the same time of day as the previous trial to eliminate diurnal variation.

Data processing and statistical analysis

Sample size was determined *apriori* using G*Power (Faul et al. 2009) and designated 8 males and 8 females to find statistical significance in the results at a value of $p < 0.05$ with a statistical power of 0.8. Added subjects were recruited and tested to account for potential subject dropout and to further improve statistical power. The calculated data were saved as text files per subject and then imported into a commercial spreadsheet program (Excel, Microsoft Corporation, Seattle, WA) for added identification and calculations of absolute and relative PPO, MPO, PD, rPD, and TtPP. Power variables were adjusted for flywheel moment of inertia using a custom software program (LabVIEW, National instruments, Austin, TX) based on the change in flywheel angular velocity resolved to each crank revolution.

Data were analyzed using a 2 × 2 × 2 mixed design (SEX × TRIAL × INERTIA) ANOVA for the dependent variables PPO, MPO, and Peak Cadence. A 2 × 2 (SEX × TRIAL) ANOVA was run for all other variables not effected by inertia including load settings, PD, rPD and TtPP. When there was a significant interaction, specific paired mean comparisons were completed using specific mean contrasts. All data are presented as mean ± SD and statistical significance was accepted at an alpha level of $p < 0.05$. All statistical analyses were completed using commercial software (SPSS, v17.0).
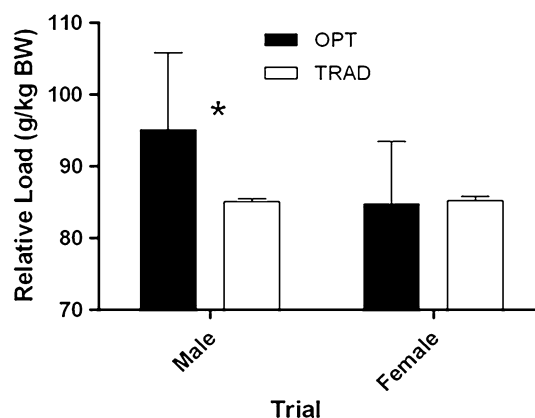

Fig. 2 Relative load settings (g kg^{-1} BW). There was a significant SEX × INERTIA interaction ($p = 0.024$) (*asterisk*), with significance occurring between loads for males only ($p < 0.05$)

Table 1 Results for data not presented in figures; presented in Mean ± SD

Variables	Males		Females	
	OPT	TRAD	OPT	TRAD
Load (kg)	8.0 ± 1.4*	7.2 ± 0.7	5.2 ± 0.7	5.2 ± 0.6
PPO (W)	949.25 ± 226.2 (*I*)	946.99 ± 183.05 (*I*)	518.08 ± 102.53 (*I*)	511.82 ± 99.48 (*I*)
	940.3 ± 225.3	922.1 ± 171.9	518.6 ± 102.6	511.0 ± 99.2
PPO (W kg^{-1})	11.18 ± 1.69 (*I*)	11.91 ± 1.26 (*I*)	8.41 ± 1.16 (*I*)	8.33 ± 1.24 (*I*)
	11.1 ± 1.7	10.9 ± 1.1	8.4 ± 1.2	8.3 ± 1.2
MPO (W)#	744.95 ± 147.56 (*I*)	749.23 ± 143.67 (*I*)	428.6 ± 65.0 (*I*)	425.0 ± 68.3 (*I*)
	742.92 ± 147.5	726.67 ± 143.67	430.3 ± 65.08	426.72 ± 68.46
MPO (W kg^{-1})#	8.81 ± 1.04 (*I*)	8.86 ± 0.97 (*I*)	7.01 ± 0.69 (*I*)	6.95 ± 0.75 (*I*)
	8.78 ± 1.0	8.61 ± 0.7	6.98 ± 0.69	6.92 ± 0.75
Tt PPO#	8.3 ± 1.9	8.4 ± 2.1	10.4 ± 1.5	9.9 ± 1.5
PD (%)#	47.6 ± 11.3	47.2 ± 9.3	37.3 ± 10.4	35.1 ± 9.6
Rate of PD (W s^{-1})#	−21.0 ± 9.0	−19.6 ± 7.3	−9.8 ± 3.4	−9.2 ± 4.0

PPO peak power output, *MPO* mean power output, *PD* power decline, *abs* absolute, *rel* relative, *Tt* time to, (*I*) Corrected for inertia

* Significant interaction (SEX × TRIAL × INERTIA) or (SEX × TRIAL) ($p < 0.05$)

Significant main effect for SEX, TRIAL or INERTIA ($p < 0.05$)

Results

Resistance loads

For both relative load (Fig. 2) and absolute load (Table 1), there was a significant TRIAL × SEX interaction ($p = 0.024$ and 0.013, respectively). This interaction occurred due to the significantly higher male load for the optimal trials ($p < 0.05$).

Peak power output

The flywheel moment of inertia was found to be 1.0384 kg m^2. For both relative and absolute PPO, there was only a trend towards a significant main effect for INERTIA ($p = 0.093$, for both).

Mean power output

For both relative and absolute MPO, there were no significant 2- or 3-way interactions. There was a significant main effect for INERTIA ($p = 0.027$) for the relative MPO (Table 1). There was also a significant main effect for INERTIA ($p = 0.041$) for the absolute MPO.

Peak cadence

For peak cadence, there was a significant interaction for SEX × TRIAL ($p = 0.042$) (Fig. 3), indicating a higher peak cadence for males than females ($p < 0.05$).

Time to peak power, power decline over time (PD) and rate of power decline (rPD)

Results for TtPP, PD and rPD were all similar. No significant interactions were found in any variables. There
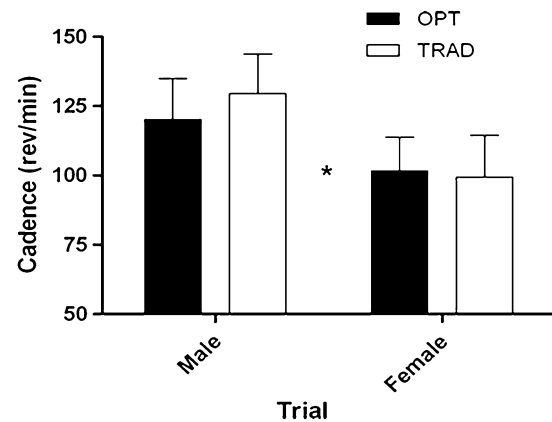
Fig. 3 Peak cadence (rev/min). There was a significant SEX × TRIAL interaction ($p = 0.042$) (*asterisk*), with males having a higher cadence than females ($p < 0.05$)

was only a significant SEX main effect found for each ($p < 0.015$) (Table 1).

Discussion

The present study aimed to determine if the resistance setting for a stationary start 30 s maximal intensity cycle ergometer test is different from the recommended resistance setting for the traditional WAnT. Two load settings were compared, the recommended 85 g kg^{-1} BW (TRAD) used for a traditional fly start and an optimal individualized load (OPT) determined by plotting a series of short sprint tests performed by each participant (Fig. 1). The methodology of the test was standardized and performed using a stationary start in which the load was applied prior to commencing the exercise test, followed by 30 s of immediate all-out sprint exertion.

The results of the present study found no significant difference in PPO, despite a significant (10.5 %, $p = 0.008$) greater load in OPT compared to TRAD conditions for males. A similar study by MacIntosh et al. (2003) found the optimal load was also significantly greater (46.7 % or 1.22 g kg^{-1} BW) compared to a traditional load, but they too failed to find significant differences in PPO. In our study, contrary to male subjects, there was no significant difference between OPT and TRAD resistance settings for females and as expected, there were no significant changes in PPO either. These findings confirm that it is not necessary to perform optimal load testing prior to a 30 s maximal cycle ergometer test.

There is substantial literature that suggests it is important to take flywheel moment of inertia into account when performing the WAnT; however, we determined that applying a moment of inertia correction to the PPO did not change the data outputs significantly and thus is not a necessary procedure to undertake when performing a stationary start version of the test for acquiring PPO. When the test commences, the impact of the flywheel moment of inertia is at its highest as the change in cadence per time interval of data collection is the highest. However, as the individual produces enough force to overcome the moment of inertia, and reaches peak power, their cadence does not readily change across each data collection time window, and therefore, the moment of inertia is less able to influence power output. We anticipated that there might be a significant difference in MPO when inertia was accounted for due to the acceleration and deceleration of the flywheel pre- and post-reaching PPO. While a significant interaction was not found, there was a significant main effect for inertia correction in both relative and absolute MPO. We believe this is due, in part, to the significantly decreased load used in the traditional vs. optimal tests for the males, coupled with no significant change in time to peak power, while the females had the same load setting for both conditions, but a significant increase in time to peak power for the optimal condition.

We propose that the insignificant PPO, despite significant increase in OPT load may be partly attributed to pacing strategies used in the 30-s maximal effort sprints compared to the shorter (10–15 s) maximal effort sprints. Pacing strategies in the traditional start WAnT test were studied by Ansley et al. (2004). Subjects were told they would be performing 6 Wingate tests, 4 of 30 s duration and 1 each of 33 and 36 s duration. In fact, they performed 2 of each duration. There was a decrease in MPO over the duration of the test for the 36-s deception trial compared to the 36-s informed trial (Ansley et al. 2004), but, there was no difference in PPO for any of the tests. Moreover, the PO dropped significantly in the last 3 s of the 36-s deception trial compared to the 36-s informed trial (Ansley et al. 2004). As such, we analyzed TtPP for the short sprints in the load nearest the OPT load used for the 30-s test for each male subject. There was a tendency to reach PPO earlier in the short sprint conditions compared to the full 30-s test, approaching statistical significance ($p = 0.074$). Both the findings by Ansley et al. (2004) and the present study may be indicative of a pacing strategy based on knowledge of the duration of the test (Ansley et al. 2004). For instance, Ansley et al. (2004) suggest, that the ability to produce significantly more power when informed of the duration compared to when deceived, may be due, in part, to subconscious feed forward neural inhibition that occurs in the central nervous system, simply through knowledge of the end point, though still likely combined with peripheral feedback that occurs and is typically profiled in the WAnT (Ansley et al. 2004). Similarly, in regards to the present study, perhaps with maximal efforts for short sprints lasting only 10–15 s, there are increases in motor unit recruitment that may initially be subconsciously inhibited in a 30-s (or longer) test to complete the longer effort with some reserve. This theory may offer limitations to the present study, as using short sprints to determine individual optimal load settings to use in a test of longer duration may not be applicable and should only be performed if PP is the only variable of interest. Clearly, further investigation of pacing strategies during maximal exercise of short duration is warranted. To support these assumptions, further research involving the use of electromyography with a similar exercise protocol is warranted and may provide further evidence of motor unit recruitment during these types of activities.

Further analysis of the differences between loads for males and females found no significant changes for MPO, TtPP, PD and rPD. In this study, we use the term rate of power decline (rPD) rather than fatigue index, as it is only a superficial measure of the change in power over time. Though calculated the same as the fatigue index, we feel this is a better description of the measure considering the lack of physiological evidence that shows true fatigue which would be measured by force output and EMG during the test. The technology used in the present study recorded continuous voltage (later calculated to power based on the load setting) two times per pedal revolution, which facilitated a PPO measurement for calculation of the PD. This PPO point provided a more valid power decrement measurement than previously calculated in earlier research, as discussed by Dotan (2006), which averaged PPO over 3–5 s and calculated it based on these averages.

The variables were all analyzed between groups to compare males vs. females. Significant main effects were found between sexes for PD, relative PPO, and TtPP. The percent change in PD was -47.56 % (OPT) and -47.23 % (TRAD) for males and -37.3 % (OPT) and -35.1 % (TRAD) for females. These findings are supported by

known physiological differences between males and females. It is documented that anaerobic capacity between males and females largely differ, with males reaching higher PO, but having increased fatigability of muscle fibers compared to females (Patton et al. 1985; Pincivero et al. 2003). When expressed relative to body weight, male PPO was at least 1.5 times greater than the female PPO for both OPT and TRAD conditions. Furthermore, there was a main effect for TtPP, with females taking ~1.5 s longer to reach PP ($p = 0.021$). All of these findings suggest an underlying difference in the anaerobic capacity between males and females, perhaps due to an increased relative area of fast twitch fibers, an increase in the metabolic capacity of these fibers, and a greater catecholamine response to exercise in males compared to females, respectively (Miller et al. 1993).

In summary, results from the present study suggest that it is not necessary to perform individual optimal load testing prior to completing a 30 s maximal cycle ergometer test from a stationary start for sex specific measurements of PPO, MPO, PD, rPD, and TtPP. Although the optimal resistance was higher than traditional recommended resistance for males, the subsequent power outputs were not significantly different. Thus, the recommended 85 g kg^{-1} BW is adequate to measure PPO for recreationally active males when performing the test using the stationary start method. Comparably, the traditional resistance setting of 85 g kg^{-1} BW is also appropriate for females. However, preceding suggestions regarding a pacing strategy in maximal exercise may advocate for further investigation into individualizing the resistance setting relative to the duration of the test. In such cases, determination of the load setting should be based primarily on the desired measurements and outcomes for performing the test in the first place. If the PPO is the only significant measurement required, then it may be that an individual load setting should be determined, using methods similar to those in the present study, with short 10-15 s sprints for every trial including the final one to determine actual PPO. On the other hand, if MPO and PD are desired, the test should be of longer duration, bearing in mind that, if an individual optimal load is necessary, the sprints used to determine the load should be of comparable length to the actual test that will be performed.

Due to the required physiological demands of such a high intensity test, we advocate that further investigation should be led into the stationary start version of the test and the muscle fiber recruitment patterns that are required in each of the traditional and stationary start versions. Such investigation will help to reveal the physiological and neurological demands necessary for the tests and will provide scientific evidence for the methodology that most accurately represent a true power output value.

References

Ansley L, Robson PJ, Gibson ASC, Noakes TD (2004) Anticipatory pacing strategies during supramaximal exercise lasting longer than 30 s. Med Sci Sports Exerc 36(2):309–314

Arsac LM, Belli A, Lacour JR (1996) Muscle function during brief maximal exercise: accurate measurements on a friction-loaded cycle ergometer. Eur J Appl Physiol Occup Physiol 74(1–2):100–106

Ayalon A, Inbar O, Bar-Or O (1974) Relationship among measurements of explosive strength and anaerobic power. Biomechanics IV International series on Sport Sciences. University Park Press, Baltimore, pp 527–537

Bar-Or O (1987) The Wingate Anaerobic Test. An update on methodology, reliability and validity. Sports Med 4(6):381–394

Bassett DR Jr (1989) Correcting the Wingate test for changes in kinetic energy of the ergometer flywheel. Int J Sports Med 10(06):446–449

Blonc S, Casas H, Duche P, Beaune B, Bedu M (1998) Effect of recovery duration on the force-velocity relationship. Int J Sports Med 19(04):272–276

Bosco C, Luhtanen P, Komi PV (1983) A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol 50(2):273–282

Bradley AL, Ball TE (1992) The Wingate Test: effect of load on power outputs of female athletes and nonathletes. J Appl Sport Sci Res 6(4):193–199

Dotan R (2006) The wingate anaerobic test's past and future and the compatibility of mechanically versus electro-magnetically braked cycle-ergometers. Eur J Appl Physiol 98(1):113–116

Dotan R, Bar-Or O (1983) Load optimization for the wingate anaerobic test. Eur J Appl Physiol 51(3):409–417

Faul F, Erdfelder E, Buchner A, Lang AG (2009) Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behavior Res Method 41(4):1149–1160

Jastrebski Z (1995) Selected aspects of the assessment of anaerobic capacity by applying th wingate test. Biol Sport 12(3):131–135

Lakomy H (1986) Measurement of work and power output using friction-loaded cycle ergometers. Ergonomics 29(4):509–517

MacIntosh BR, Rishaug P, Norris SR (2001) Evaluation of the monark wingate ergometer by direct measurement of resistance and velocity. Can J Appl Physiol 26(6):543–558

MacIntosh BR, Rishaug P, Svedahl K (2003) Assessment of peak power and short-term work capacity. Eur J Appl Physiol 88(6):572–579

Micklewright D, Alkhatib A, Beneke R (2006) Mechanically versus electro-magnetically braked cycle ergometer: performance and energy cost of the Wingate anaerobic test. Eur J Appl Physiol 96(6):748–751

Miller AEJ, MacDougall JD, Tarnopolsky MA, Sale DG (1993) Gender differences in strength and muscle fiber characteristics. Eur J Appl Physiol 66(3):254–262

Patton JF, Murphy MM, Frederick FA (1985) Maximal power outputs during the wingate anaerobic test. Int J Sports Med 6(2):82–85

Pincivero DM, Gandaio CMB, Ito Y (2003) Gender-specific knee extensor torque, flexor torque, and muscle fatigue responses during maximal effort contractions. Eur J Appl Physiol 89(2):134–141

Reiser RF, Jeffrey PB, Peterson ML (2000) Inertial effects on mechanically braked Wingate power calculations. Med Sci Sports Exerc 32(9):1660–1664

Rodgers CD, Hermiston RT (2000) A velocity-related means of determining resistance load for the wingate test of anaerobic power. J Strength Cond Res 14(1):92–96

Ucock K, Gokbel H, Okudan N (2005) The load for the wingate test: according to the body weight or lean body mass. Eur J Gen Med 2(1):10–13