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THE DEVELOPMENT OF AN ANAEROBIC SPRINT RUNNING TEST UTILIZING
A NONMOTORIZED TREADMILL

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science – Human Performance

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Human Performance

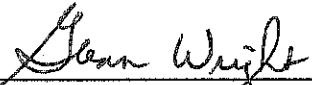
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By Trisha A. VanDusseldorp

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science – Human Performance.

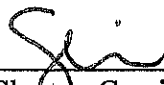
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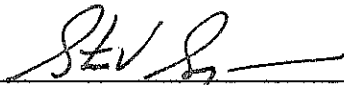


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ABSTRACT

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The purpose of this study was to determine the test-retest reliability of a newly developed anaerobic sprint running test on a nonmotorized treadmill (NMT). Twenty-six collegiate male athletes (20.2 ± 2.1 yr; 181.3 ± 6.5 cm; 79.04 ± 9.3 kg) completed three trials of a 25-second maximal effort sprint on a NMT against a workload set to 18% of their individual body mass. Anaerobic power was determined by relative peak power output (PP) and anaerobic capacity was determined by relative mean power output (MP) during the test. Blood lactate response (Δ La) and fatigue index (FI) were also determined. Test-retest reliability was assessed by intraclass correlation coefficient (ICC) and coefficient of variation (CV%). Results indicate no significant differences between the three trials for PP ($T_1 = 29.95 \pm 6.51$ W/Kg, $T_2 = 28.57 \pm 5.55$ W/Kg, $T_3 = 29.47 \pm 5.94$ W/Kg), MP ($T_1 = 20.97 \pm 3.64$ W/Kg, $T_2 = 20.50 \pm 3.46$ W/Kg, $T_3 = 21.17 \pm 3.79$ W/Kg), and FI (T_1 : $55\% \pm 8\%$, T_2 : $51\% \pm 8\%$, T_3 : $52\% \pm 9\%$). Reliability between the three trials for PP (ICC: $r = 0.96$, CV: 7%) and MP (ICC: $r = 0.97$, CV: 6%) were considered strong. Reliability for FI exhibited an ICC of $r = 0.83$ (CV: 8%). Lactate responses were not significantly different (T_2 : Δ La = 11.61 ± 1.8 mmol/L, T_3 : Δ La = 11.0 ± 2.5 mmol/L). The results of the study indicate the ASRT is reliable for assessing PP and MP in highly motivated subjects.

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INTRODUCTION

There are many different types of anaerobic tests which incorporate different modes of exercise or movement patterns and vary in duration. Examples include the Margaria step-running test (Margaria, Aghemo, & Rovelli, 1966), vertical jump tests (Komi & Bosco, 1978), treadmill tests (Medbo, Mohn, Tabata, Bahr, Vaage, & Sejersted, 1988), cycle ergometer tests (Ayalon, Inbar, & Bar-Or, 1974; Bar-or, 1987), and isokinetic tests (Vandewalle, Pérès, & Monod, 1987). Specifically, since the development and introduction of the Wingate Anaerobic Test (WAnT) on a cycle ergometer in the 1970s, anaerobic testing has received considerable attention. Currently, the WAnT is the most utilized and most reported laboratory anaerobic performance test, commonly used to evaluate anaerobic power and capacity (Bar-Or, 1987; Inbar, Bar-Or, & Skinner, 1996).

The reliability indices of these anaerobic tests are quite acceptable, with coefficients ranging for the power tests from $r=0.85$ to $r=0.98$ (Vandewalle et al., 1987), while the constant load anaerobic tests tend to hover around $r=0.77$ (Vandewalle et al., 1987), and typically strong correlations for the WAnT are reported between $r=0.89$ to $r=0.99$ (majority above 0.94) (Dotan & Bar-Or, 1983; Inbar, Bar-Or, Skinner, 1996; Patton, Murphy, & Frederick, 1985). Moreover, when appropriate equipment and proper testing procedures are utilized, the WAnT can provide reliable results concerning cycling peak power (PP), mean power (MP), as well as fatigue index (FI) (Falk et al., 1996), regardless of climate or subject population (Inbar et al., 1996). Still, the main drawback

of these anaerobic tests lies in the very nature of anaerobic power, specifically the recruited muscles and the recruitment pattern (Falk et al., 1996). Thus, the cycle ergometer-based WAnT may be an admirable cycling-specific test, but does not satisfy the need for a running-specific anaerobic test. Running anaerobic performance tests have exhibited reliable results, such as the Margaria step-running tests (Margaria et al., 1966) and the Maximal Anaerobic Running Test (MART) (Nummela, Alberts, Rijntjes, Luhtanen, & Rusko, 2007), but no tests have provided the extent of information derived from the WAnT. Additionally, researchers attempting to assess anaerobic power output during sprinting have been limited by motorized treadmills (MT). Although speed and grade may be confidently manipulated using a MT, actual power output produced by the subject can only be estimated, making power output assessment from a MT challenging (Falk et al., 1996). For example, the MART, which utilizes a MT, estimates running power via oxygen equivalents and the American College of Sports Medicine's formula for inclined treadmill running, and assumes that, although the formula only applies to submaximal intensities, a linear extrapolation to higher intensities occurs (Nummela et al., 2007).

Originally described by Lakomy (Lakomy, 1984), the nonmotorized treadmill (NMT) offers a potentially suitable tool for the assessment of all-out sprint running performance in a controlled laboratory setting. When utilized, the NMT offers the potential to measure performance indices such as time to peak running speed, distance covered, PP, MP, and FI, all of which may be of interest for researchers, athletes, and coaches.

Since sprint running and field sports (i.e. track and field, football, soccer) are more common than cycling, the need for a running-specific anaerobic test that produces reliable results is crucial, and remains mostly unsatisfied. Therefore, the purpose of the present study was to develop an anaerobic sprint running test (ASRT) utilizing a NMT and assess its test-retest reliability on skilled sprinting and middle distance athletes.

MATERIALS AND METHODS

Experimental Approach to the Problem

The study was conducted in 3 phases in order to develop and assess the test-retest reliability of the ASRT. All sprint testing was performed on the Woodway Force 2.0 (Woodway, Waukesha, WI) NMT. The purpose of the first two phases was to develop an ASRT on a NMT. Phase I was designed to define the relative (% body weight) load for the ASRT. Phase II was designed to determine the duration of the ASRT. The primary study (Phase III) implemented the optimal load and duration determined from Phase I and Phase II and assessed the test-retest reliability of the ASRT over three trials.

Subjects

In total, 58 healthy males participated in the study. All subjects were recruited from the university student population and included trained Division III collegiate athletes. Before the commencement of the study, ethical approval was obtained from the University of Wisconsin- La Crosse IRB committee. All subjects were informed of the possible risks and provided written informed consent prior to participating in any phase of the study.

Subjects were asked to refrain from lower body strength training and intense sprinting at least 24 hours (hr) prior to each testing session. Caffeine and preworkout supplementations were also prohibited 12 hr prior to testing. Subjects maintained a similar testing schedule (same time of day) and at least 48 hr separated all sessions. All

subjects completed a food recall prior to testing and were verbally asked about activities (exercise, sleep, etc.) in the last 24 hr prior to each testing session. Subjects were encouraged to eat a nutritious meal (high in carbohydrates) 3-5 hr prior to testing and avoid eating immediately (1 hr) prior to testing.

Testing and Procedures

Phase I

The purpose of Phase I was to determine the optimal load for the ASRT. Fifteen physically active men with prior experience in sprint related sports participated in Phase I. Their age, height, and body mass (BM) (21.3 ± 2.4 years (yr), 177.7 ± 6.4 centimeters (cm), 82.6 ± 7.3 kilograms (kg), respectively) were determined during the first visit to the laboratory. Subjects visited the laboratory on four different occasions. Subjects were asked to sprint maximally for 10 seconds (sec) against five different loads (12, 14, 16, 18, and 20% of their individual BM) in a randomized order. The first visit, subjects were familiarized with sprinting on the NMT. The next two visits had the subjects sprinting on the NMT against two of the relative loads with greater than 20 minutes (min) between 10 sec sprints. The last remaining relative load was utilized on the fourth visit. A standardized warm-up was used for all three phases of this study prior to all sprints on the NMT. The warm-up consisted of a 5 min warm-up on a MT, including 3 min of walking and 2 min of low intensity jogging. Following the treadmill warm-up, subjects performed a predetermined dynamic warm-up (12 exercises) that lasted approximately 5 min and two practice starts on the NMT lasting 2-3 sec each. Upon completion of the two practice starts, subjects underwent 4 min of passive recovery. Following recovery from the warm-up, subjects completed a 10 sec all out sprint on the NMT at the designated load.

All sprints started from a crouched, split-stance, standing position. Subjects were informed to accelerate to maximal sprint speed as fast as possible without pacing, and continue to run as fast as possible for the entire duration of the test. Immediately following the sprint, subjects underwent active and passive recovery, consisting of 10 min of walking at 4.02 kilometers per hour (Km/h) on a MT and 10 min of passive recovery, respectively. Following passive recovery, subjects repeated two practice starts at a different load of either 12, 14, 16, 18, or 20% BM, followed by 4 min of passive recovery. Subjects were then asked to complete a second 10 sec sprint during the same visit at a different load. Peak power values were determined from each testing session utilizing Pacer Performance Software (Innervations, Sydney, Australia). Power values were collected at 200 Hz. MATLAB (Mathworks, Natick, MA) software was utilized to determine the average sprint power per sec from the PP of each sprint running stride. The optimal load was determined as the load that produced the greatest 1 sec power measure in the 10 sec all out sprints.

Phase II

The purpose of Phase II was to determine the optimal duration (25, 30, or 35 sec) for the ASRT. Seventeen university football players with prior sprint experience participated in Phase II. Their age, height, and BM were 18.6 ± 0.6 yr, 175.6 ± 3.8 cm, and 81.90 ± 5.8 kg, respectively. Following a familiarization session, subjects completed three separate testing sessions sprinting for 25, 30, or 35 sec at the load determined to produce the greatest PP in Phase I. Prior to each sprint, subjects underwent the same standardized warm-up and practice starts utilized in Phase I. Upon completion of the two practice starts on the NMT, subjects underwent 4 min of passive recovery. Subjects completed

the all-out sprint for the designated duration with the same instructions as in the Phase I. The order of test duration was randomized for all subjects. Immediately following the sprint on the NMT, subjects were guided to a MT in which they walked at a pace of 4.02 Km/h for an active recovery. Peak power, MP, and FI were calculated from each testing session. Peak power was determined by the same methods as in Phase I. Mean power (MP) was determined as the average power per sec over the entire duration of the test. The duration with the greatest post sprint blood lactate concentration was determined as the optimal duration for the ASRT.

Phase III

The purpose of the final phase was to determine the reliability of the newly developed ASRT utilizing the results of Phase I and II of this study. Twenty-six collegiate male athletes [sprinters (n=15), 400-meter (m) specialists (n=6), and/or 800 m runners (n=5)] participated in this phase. Each subject's BM, age, and height were collected prior to the first trial. Their age, height, and weight were 21.2 ± 2.1 yr, 181.3 ± 6.5 cm, 79.0 ± 9.3 kg, respectively. All subjects completed three ASRT testing sessions. Prior to each test, subjects underwent the standardized warm-up protocol utilized in Phase I and Phase II. Upon completion of the 2 practice starts on the NMT, subjects underwent 4 min of passive recovery. Subjects then completed the 25 sec ASRT against a load of 18% of their individual BM. The rationale for choosing 25 sec and 18% BM will be discussed later in the discussion. Each subject's load and duration was consistent for all 3 trials. Similar to Phase II, immediately following the ASRT on the NMT, subjects were guided to a nearby MT in which they walked at 4.02 Km/h. Peak power, MP, and FI were calculated from each testing session as described in Phase I and II.

Blood Analysis

In Phase II and III, fingertip capillary blood samples were taken 1 min prior to the start of the sprint test and 5 min following the sprint. If feeling nauseous or light-headed during the recovery, subjects were permitted to lay down in the supine position with their legs elevated and the post-sprint blood sample was taken while the subject rested in the supine position. The sample was analyzed for blood lactate by a Lactate Plus Lactate Analyzer (Lactate Plus, USA). Delta lactate (ΔLa) was calculated as post-sprint blood lactate minus pre-sprint blood lactate concentration.

STATISTICAL METHODS

Results were evaluated using SPSS version 21.0 software (SPSS Inc., Chicago, IL). Commonly used statistical methods including mean and standard deviation were used in the study. Test-retest reliability of the ASRT was analyzed using intraclass correlations (ICC) and coefficient of variation (CV). The CV was calculated ($CV = SD / \text{mean} \times 100$) for each individual and then the mean CV was determined for the entire sample. Data collected (PP, MP, and FI) from each trial of the ASRT was compared via repeated measures analysis of variance (ANOVA). A paired sample t-test was utilized to determine differences in pre and post blood lactate values. Significance was accepted for all analyses at the alpha <0.05 level.

RESULTS

Phase I

The purpose of Phase I was to determine the load of the ASRT. Peak power was calculated from each of the different loads. While the numerically greatest PP was seen at 18% BM load, no significant difference ($p>0.05$) was observed in PP between loads of 12, 14, 16, 18, and 20% relative BM (Table 1).

Table 1. Peak Power (PP) output during 10 sec trials (n=15).

Trial (%BM)	PP (W)
12	2,275±477
14	2,232±485
16	2,183±465
18	2,312±460
20	2,240±458

Values (mean ± standard deviation), W=watts, BM=bodyweight

Phase II

The purpose of Part II was to determine the duration of the ASRT. Peak power, MP, and Δ La were determined for each testing session (Table 2). There were no significant differences in PP ($p>0.05$) or MP ($p>0.05$) between trials of 25, 30, and 35 sec. There were no significant differences for Δ LA between trials ($p>0.05$).

Table 2. Peak power (PP), mean power (MP), and lactate response (Δ La) for sprints of varying durations of 25, 30, and 35 seconds (n= 17).

Trial (Sec)	PP (W)	MP (W)	LA (Δ)
25	2,081±244	1,532±210	11.0±2.9
30	2,034±370	1,445±206	12.0±2.6
35	2,018±341	1,375±185	12.2±2.4

Values (mean ± standard deviation), PP= Peak Power, MP=Mean Power, W=Watts, Δ LA=Change in blood lactate, Sec=Seconds

Phase III

The purpose of Phase III was to assess the test-retest reliability of the newly developed ASRT using a NMT. The performance data produced during the three trials of the ASRT are listed in Table 3. No significant differences among the three trials for PP, MP, or FI were identified. Reliability between the three trials for PP ($r=0.96$) and MP ($r=0.97$) were considered strong (Table 3). Power behavior during the ASRT for a representative subject is shown in Figure 1. Reliability for FI between the trials was moderately strong ($r=0.83$).

Delta scores for blood lactate were analyzed since within subject preprint blood lactate values were not different from each other ($p>0.05$). Changes in blood lactate responses were not significantly different between trial 2 (11.6 ± 1.8 mmol/L) and trial 3 (11.0 ± 2.5 mmol/L) ($p>0.05$).

Table 3. Performance indices of peak power (PP), mean power (MP), and fatigue index (FI) for ASRT performed on 3 different days. Test-retest reliability for PP, MP, and FI ($n= 26$).

	PP (W)	Relative PP (W)	MP (W)	Relative MP (W)	FI%
T ₁	2,360±547	29.9±6.5	1,648±294	20.9±3.6	55±8
T ₂	2,250±462	28.6±5.6	1,612±286	20.5±3.5	51±8
r	0.96	0.96	0.97	0.97	0.83
CV%	7.0	7.0	6.0	6.0	6.0

Values (mean ± standard deviation); T₁, T₂, T₃=Trial; r=reliability coefficient; CV= Coefficient of variation

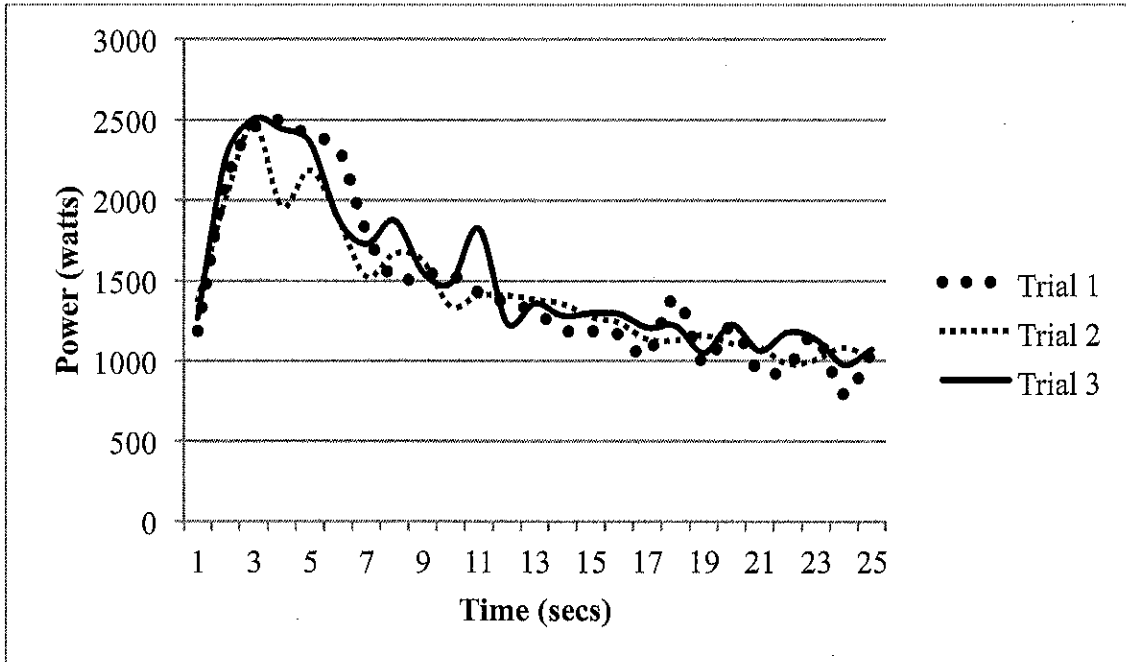


Figure 1. Trials 1, 2, and 3 of one participant's averaged power values over 1 second segments during the ASRT utilizing a load of 18% body mass during Part III.

DISCUSSION

Similar values of PP and MP recorded during the ASRT indicate that the 25 sec tethered maximal sprint test utilizing a NMT may represent an acceptable and reliable assessment of anaerobic power and capacity. Hamar & Zemková (2004) found that analysis of power during short-term bouts of cycling and tethered running showed that sprinters performed significantly better on the treadmill than on the cycle ergometer and cyclists achieved higher “all-out” power during cycling, rather than during tethered running. Thus, for individuals training and performing in a bipedal manner, assessment utilizing tethered running on a treadmill may be considered as a more specific method and hence, a more suitable means for the assessment of anaerobic power and capacity (Hamar & Zemková, 2004). This finding is in agreement with previous research by several authors (Cheetham, Boobis, & Brooks, 1986; Cheetham & Williams, 1985; Falk et al., 1996; Jaskólski, Veenstra, & Goosens, 1996; Lakomy, 1985; Lakomy, 1994; Nevill, Boobis, & Brooks, 1989). Despite the high reliability of previously developed anaerobic running tests, the tests have not been utilized for varying reasons, some which include tests developed employing altered equipment only available to those researchers and lack of specific details regarding test loads and protocols (Cheetham, Williams, & Lakomy, 1985; Falk et al., 1996; Lima et al., 2011). For these reasons, the purpose of the present study was to develop and implement a more specific test of anaerobic power and

capacity utilizing a widely available treadmill (Woodway Force 2.0, Waukesha, WI) capable of assessing power output.

Load

The first aim of this study was to determine the most effective test load and duration in order to develop an ASRT utilizing a NMT treadmill, followed by the primary aim of examining the test-retest reliability of the newly developed anaerobic performance test utilizing a NMT. Regarding our aim to determine the most effective test load, we determined that the ideal load of those tested (12, 14, 16, 18, & 20%) was 18% BM for physically active males with previous sprint experience. Although 18% of BM was not significantly different than loads of 12, 14, 16, and 20% BM, it was the numerically highest attained PP of all loads and the majority of subjects (9 of 15 subjects) recorded their highest PP at 18% BM. This is in agreement with a number of other studies that found that 18% BM is an optimal load for assessing power output during running or similar bipedal modes of locomotion. For example, Lima et al. (2011) developed a semi-tethered test for power assessment (on a synthetic track) utilizing a specific apparatus developed in their laboratory in which subjects performed a maximal 120 meter (m) run against 18% BM resistance. The load of 18% BM was chosen from pilot tests; however, no detail was given concerning other loads piloted. A recent study by Ozkaya, Colakoglu, Kuzucu, & Yildiztepe (2012) found that a load of 18% BM was the most effective load for reaching maximum anaerobic output for whole body tests on a modified mechanically braked elliptical test used to measure maximum anaerobic performance for the whole body. A load of 18% BM is considerably larger than the widely accepted workload for traditional cycle ergometer testing, the WAnT in particular,

with customarily accepted loads of 7-10%. Cycle ergometers mainly involve the activation of either the lower body (legs) or upper body (arms), while the movement pattern of sprinting on the NMT requires activation of both the upper body and lower body. This may explain why the most favorable workload for the ASRT utilizing a NMT was higher than the typical workloads used for cycle ergometer testing.

Duration

The purpose of Phase II was to determine the most effective duration (25, 30, or 35 sec) for the ASRT. Prior to testing it was decided that the criteria to determine duration used would be the one to produce the greatest blood lactate response. Although subjects recorded a higher average Δ La during the 35 sec trial, no significant differences were found for Δ La between the 25, 30, and 35 sec trials. Furthermore, there were no significant differences in PP or MP between trials of 25, 30, and 35 sec. Similar findings regarding PP indicate that, regardless of the test duration, subjects did not pace themselves. This is a critical finding since during the development of the WAnT on the cycle ergometer, it was found that subjects began to start at a less than "all-out" speed when durations of 45 and 60 sec were piloted, as compared to 30 sec (Inbar, Bar-Or, & Skinner, 1996). Subjects not giving an all-out effort from the beginning of the test through the entire duration, whether it be the WAnT, the ASRT, or any short duration anaerobic test, will decrease the reliability of the variables tested.

Another consideration for the duration of the test is subject safety. After developing a 30 sec laboratory anaerobic sprint test utilizing a commercially available treadmill (BRL 1800, Gymrol, France), Falk et al. (1996) found that many subjects had to quit the running test earlier or their performance become very irregular and running

technique deteriorated badly during the final sec of testing. We also noticed that during the longer durations of Phase II, some subjects had issues with their running technique and stumbled during the last few sec as a result of fatigue. This also influenced our decision to set the duration of the test to 25 sec.

To use an anaerobic power test for research or the assessment of athletes, subject motivation must be considered to return for follow-up testing. We considered this also to determine the most effective duration for the ASRT. The consideration of subject retention with longer duration tests was also considered when determining the optimal duration for the WAnT. During the development of the WAnT, researchers found that as test durations increased, subjects were less willing to repeat the test (Inbar et al., 1996). Importantly, Vandewalle, Peres, and Monod (1987) found that the correlation coefficient between total work done at 20 sec and that done at 30 sec of an all-out cycling test was $r=0.99$. Moreover, Vandewalle et al. (1987) suggest that anaerobic tests need to only last 15-20 sec due to the similarity in work output, as well as they are, "easier to perform than tests lasting 30-40 sec" (Inbar et al., 1996, 23).

An important "side effect" of the high intensity of many anaerobic capacity tests is that many subjects, upon completion of the test, feel nauseous, syncope, and at times, vomit. This has been observed during WAnT testing since its inception (Inbar et al., 1996). Research by Thoren (1979) found that in times of physiological conditions of hypoxia or mechanical distortion of the left ventricle from vigorous contractions (i.e. high intensity exercise may cause this) around a reduced diastolic volume has the potential to trigger the Bezold-Jarish reflex, and therefore, a nauseous or vomiting response. Interestingly, during Phase II testing, we observed that as the duration of the test

increased, so did the incidence and severity of nausea and vomiting. Therefore, due to the maximal nature of the ASRT and the previously mentioned reasons, as well as the indifferent values for ΔLA between 25, 30, and 35 sec, we decided 25 sec is optimal for subject retention, completion of testing, and importantly, suitable to tax the anaerobic system.

Reliability

The main purpose of this study was to examine the test-retest reliability of the newly developed ASRT utilizing a NMT. Common statistical procedures of test-retest reliability are the intraclass correlation coefficient (ICC) for relative reliability and the coefficient of variation (CV) for absolute reliability. The $ICC > 0.9$ and a $CV < 10\%$ typically is interpreted as highly reliable (Atkinson and Nevill, 1998). Therefore, performance of the ASRT would be considered highly reliable for both PP ($r=0.96$) and MP ($r=0.97$), whereas the relative reliability of the FI would fall a little below these standards at $r=0.83$, but the absolute reliability of the FI would still be considered high ($CV= 6.0\%$).

Similar to the results of our study, research into the reliability of power output data during single bouts of maximal cycling lasting ≤ 30 sec suggests that the reliability of MP output data is superior to PP output data (Glaister, Stone, Stewart, Hughes, & Moir, 2003; Hopkins, Schabort, & Hawley, 2001). Moreover, under standardized environmental conditions, correlation coefficients for the WAnT, the “gold standard” in anaerobic testing (Inbar et al., 1996), have ranged between $r=0.89$ and $r=0.99$ and typically have been found to be higher than $r=0.94$, which is considered very strong.

Studies analyzing the reliability of sprint running tests have reported high values of reliability as well. High reliability of tethered running is supported by Zemková & Hamar (2004) who reported high test-retest correlation coefficients of $r=0.85$ for PP and $r=0.92$ for MP when examining 30 sec of all out tethered running. More recent research investigating reliability of sprint performance utilizing a NMT has been quite strong. Although they did not examine power output, Highton, Lamb, Twist, and Nicholas (2012) found that sprint performance variables of peak and mean running velocities (affecting power output), on a NMT are reliable when examining 20 and 30 m sprint times. Additionally, Cheatham et al. (1986) found a high correlation of $r=0.93$ when examining recreational runners ($n=14$) whom performed a 30 sec sprint test on a NMT on two separate occasions. However, like Highton et al. (2012) the examination of reliability was based on speed outputs, rather than power output.

As the results of our study demonstrate, less support for the reliability of decline in power output (FI) has also been reported (Bouchard et al., 1990). Reliability for the FI was slightly more variable than PP and MP among trials of the ASRT ($r=0.83$). As compared to the WAnT, the FI for the ASRT is slightly higher, with typical correlation coefficients for FI of the WAnT ranging between $r=0.43-0.74$ (Vandewall, Pérès, & Monod, 1987). In the study by Tirosh, Bar-Or, and Rosenbaum (1990), test-retest correlation coefficients of leg and arm WAnT, FI values were $r=0.76$ and $r=0.48$, respectively.

Furthermore, the reliability of FI for the ASRT is similar to those values reported in previously developed anaerobic sprint running tests. Cheatham et al. reported a lower reliability ($r=0.73$) of FI using the percentage drop-off in speed between test 1 (24%) and

test 2 (22%) for subjects completing a 30 sec all out maximal sprint on a NMT. Furthermore, Zemková and Hamar (2004) reported a slightly higher FI ($r=0.88$) reliability while examining the FI test-retest reliability of tethered running, as compared to the ASRT.

Lactate

In the present study, mean post-sprint blood lactate obtained 5 min post ASRT (data not shown), was 15.1 ± 2.1 mM with one individual recording a value of 20.9 mM. These findings suggest that the 25 sec ASRT is dependent on a large contribution from fast glycolysis, likely leading to a high level of acidosis. Cheatham, Williams, & Lakomy (1985) recorded similar values of 17.9 ± 1.1 mM in rugby players and 14.5 ± 1.8 mM in cross-country skiers when analyzing blood lactate 5 min after a 30 sec maximal sprint utilizing a NMT treadmill. The increase in blood lactate concentrations following the 25 sec ASRT is greater than blood lactate levels recorded following 30 sec of maximal cycling exercise (MacDonald, Wootton, Munoz, Fentem, & Williams, 1983). This is likely an effect of the increased muscle mass utilized during sprinting compared to cycling.

Moreover, the reliability of ΔLa data in our study was low ($r=0.52$). Though, the pre-sprint blood lactate values between trials were not different from each other, nor were the blood lactate values taken 5 min following the ASRT. Nummela, Alberts, Rijntjes, Luhtanen, & Rusko (1996) also found low reliability ($r=0.60$) of peak lactate measurements between two trials of the MART. The coefficient of variation of the ΔLa in their study was moderately high (12%), suggesting that reproducibility of ΔLa measurements was not extremely high. Possible explanations for the low reproducibility

of ΔLa in our study, and other anaerobic capacity tests include subject motivation, as well as diet and nutrition of subjects. In our study, subjects were asked to eat similar, as well as carbohydrate rich meals the day prior to testing, and if testing during the morning hours, subjects were encouraged to have an appropriate, nutritious breakfast; however, these variables are difficult to control.

Familiarization/Mode

Knowledge of the familiarization process and within-subject variation associated with any measure of human performance is essential for the evaluation of performance tests. Given the high test-retest reliability results of the ASRT over 3 trials, it appears that it is unnecessary to perform a familiarization trial prior to testing. However, previous research on the effect of familiarization on anaerobic performance tests completed on a cycle ergometer has suggested that subjects unfamiliar with test of all-out cycling should complete a minimum of 2 familiarization trials in order to establish a high degree of reliability in measures of power output (Capriotti, Sherman, & Lamb, 1999; Glaister et al., 2003; Martin, Diedrich, & Coyle, 2000). Moreover, Barfield, Sells, Rowe, and Hannigan-Downs (2002) recommended that, due to the occurrence of a practice effect, at least one full practice WAnT should be given prior to documenting baseline data for performance purposes.

Documented changes in PP and MP output following an initial administration have ranged from a 1% to 15% increase (Green, McLester, Smith, & Mansfield, 2001; Hebestreit, Dunstheimer, Staschen, & Strabburg, 1993; Patton, Murphy, & Frederick, 1985; Kaczowski, Montgomery, Taylor, & Klisouras, 1983; Nicklin, O'Bryant, Zehnbauehm & Collins, 1990). Interestingly, our study indicated a slight drop off in PP

and MP during the second trial of the ASRT; however, no significant difference in these performance measures between trial 1 and 2 was observed. Furthermore, a reliability of $r=0.94$ for PP and $r=0.97$ for MP between trials 1 and 2 does not suggest a familiarization trial is needed as well.

Although our results do not suggest a familiarization trial is needed, we would still recommend at least one prior to data collection. While tethered running tests have emerged as alternatives to the WAnT, for evaluating athletes training and performing in running-based sports, as well as athletes' utilization of sprinting parachutes and/or towing sleds has become more common, running maximally while attached to a fixed point is not particularly common for subjects or athletes. Similarly, the fear of falling may curb performance due to unfamiliarity with NMTs, therefore a familiarization should be performed not only for performance outcome purposes, but for safety purposes.

Conclusions

The results of this study indicate that with proper familiarization, anaerobic performance testing utilizing a 25 sec ASRT with a load of 18% on a NMT seems to be a suitable method which may provide useful information concerning the ability to exert peak anaerobic power (PP) and anaerobic capacity (mean 25 sec power and FI), namely, for athletes whom train and perform weight bearing activities that include sprinting/running. However, further studies are needed to validate this method on large samples of specific sports, as well as different age groups and populations.

Practical Applications

Anaerobic testing using the ASRT may be a more sport-specific test to assess anaerobic performance for many coaches and athletes. In addition to the high reliability

of the ASRT, it is more specific to the mode in which many athletes train and perform, compared to cycle ergometer based anaerobic tests. The ASRT is potentially simple to perform and could fill the present gap in the available collection of laboratory and field tests of anaerobic power.

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APPENDIX A
INFORMED CONSENT

Informed Consent Form

Title of Study: The Development of an Anaerobic Sprint Running Test utilizing a Nonmotorized Treadmill

Researchers: Trisha VanDusseldorp (UWL Graduate Student); Cell: 641-295-2699
Email: vandusse.tris@uwlax.edu

Dr. Glenn Wright (Associate Professor, Advisor); Phone: 608-785-8689
Email: wright.glen@uwlax.edu

Emergency Contact: Trisha VanDusseldorp
Cell: 641-295-2799

Purpose and Procedure

- The purpose of this study is to develop an anaerobic sprint running test that will elicit reliable anaerobic power and anaerobic work capacity values.
- My participation will involve participating in 1 of the 3 testing phases on a nonmotorized treadmill.
- The total time requirement is approximately 2.0-2.5 hours.

Please read the appropriate phase section that applies to you:

- ***Participants taking part in Phase I:*** I will be required to attend 4 testing sessions (a minimum of 72 hours apart) and sprint maximally for approximately 10-15 seconds on a non-motorized treadmill (NMT) against five different loads, 12%, 14%, 16%, 18%, and 20% of my individual body weight (1-2 loads/sprints per session). I will be required to warm up, which consists of 5 minutes of brisk walking or slow jogging pace on a motorized treadmill, followed by two starts of approximately 2-3 seconds on the NMT treadmill. A fitted harness that tethers me to the back of the treadmill will wrap around my chest and shoulders while sprinting on the NMT. Peak power will be analyzed following the sprint.
- ***Participants taking part in Phase II:*** I will be required to sprint maximally against the optimal load that was determined during Phase I for a duration of 25, 30, and 35 seconds, in order to determine the optimal duration for the actual testing sessions. I will be required to participate in 4 test sessions with at least 72

hours in between each session. I will be required to warm up, which consists up 5 minutes of brisk walking or slow jogging pace on a motorized treadmill, followed by two starts of approximately 2-3 seconds on a non-motorized treadmill (NMT). A fitted harness that tethers me to the back of the treadmill will wrap around my chest and shoulders while sprinting on the NMT. Fingertip blood samples will be taken to measure blood lactate before and after I sprint. Peak power, mean power, and fatigue index will also be analyzed following the sprint.

- ***Participants taking part in Phase III:*** I will be required to sprint maximally on a non-motorized treadmill (NMT) against an optimal load (either 12%, 14%, 16%, 18%, or 20% of my body weight) and duration (either 25, 30, or 35 seconds) that has been determined from pilot testing. I will be required to participate in at least 3 test sessions with at least 72 hours in between each session. A fitted harness that tethers me to the back of the treadmill will wrap around my chest and shoulders while sprinting on the NMT. Fingertip blood samples will be taken to measure blood lactate before and after I sprint. Peak power, mean power, and fatigue index will also be analyzed following the sprint.

Potential Risks

- Very low risk is anticipated to me, but possible side effects of sprinting include shortness of breath, dizziness, nausea, fatigue, sweating, and muscle soreness during or after the test.
- Minimal finger soreness may occur during or immediately after the blood sample from your fingertip is taken.
- In the unlikely event that any injury or illness occurs as a result of this research, the Board of Regents of the University of Wisconsin System, and the University of Wisconsin-La Crosse, their officers, agents, and employees, do not automatically provide reimbursement for medical care or other compensation. I have been informed that payment for treatment of any injury or illness must be provided by me or my third-party payor, such as my health insurer or Medicare. If any injury or illness occurs in the course of research, or for more information, I will notify the investigator in charge. I have been informed that I am not waiving

any rights that I may have for injury resulting from negligence of any person or other institution.

- For information about policies, the conduct of the study, or the rights of research subjects, please contact the University of Wisconsin-La Crosse Institutional Review Board (IRB) for the Protection of Human Subjects (608-785-6892; irb@uwlax.edu). The IRB is a group of people who review the research to protect the rights of research participants.

Rights and Confidentiality

- My participation in this study is voluntary.
- I can withdraw from the study at anytime for any reason without penalty and prejudice.
- All information pertaining to this study will be kept confidential through the use of codes. My data will not be linked with personally identifiable information.
- Information pertaining to this study may be published or presented at professional meetings, such as for educational purposes. However, my name and other identifying information will not be used without my written permission. Any personal demographic data or information collected will be kept confidential.
- Only the primary investigator and the faculty advisors will have access to the individual data collected during testing sessions.

Possible Benefits

- Participation in this study does not guarantee any physiological benefits to me, but will tell me information regarding my current anaerobic physiological capacity.
- The information gathered from this study will help develop and determine the reliability of an anaerobic running specific non-motorized treadmill test that could be implemented in labs across the country in the future.

Who can answer my questions?

- I may contact the primary investigator (Trisha VanDusseldorp) on her cell phone (641-295-2799) with any questions. However, contacting Trisha by email is a much better method (vandusse.tris@uwlax.edu).
- I may also contact the faculty advisor, Dr. Glenn Wright, at 608-785-8689, or preferably by email, gwright@uwlax.edu. The address 137 Mitchell Hall, UW-L, La Crosse, WI 54601 will direct you to the faculty advisor.
- Questions regarding the protection of human subjects may be answered by the UW-La Crosse Institutional Review Board for the Protection of Human subjects (irb@uwlax.edu).

I HAVE READ ALL THE ABOVE, ASKED QUESTIONS, RECEIVED MY ANSWERS CONCERNING MY QUESTIONS, AND I WILLINGLY GIVE MY CONSENT TO PARTICIPATE IN THIS STUDY. UPON SIGNING THIS FORM, I WILL RECIVED A COPY.

PARTICIPANT: _____
DATE: _____

RESEARCHER: _____
DATE: _____

APPENDIX B
LITERATURE REVIEW

REVIEW OF LITERATURE

Overview of Metabolic Processes

When assessing different metabolic processes in the human body, it is essential to discuss energy and the various energy production systems. Energy is defined as the ability to do work or cause motion (Marieb, 1988). All forms of human movement, including athletic or rehabilitation movements, can be described as energetic events, with the release and harnessing of energy central to performance (Brooks, Fahey, & Baldwin, 2005). Interestingly, energy is able to take on different forms such as heat, electrical energy, mechanical energy, and chemical energy. Specifically, metabolic processes in the human body use chemical energy. Human metabolic processes, muscular contractions in particular, use chemical energy that is converted into mechanical energy. Adenosine Triphosphate (ATP), the most prevalent high-energy phosphate in the body, is the main source of energy utilized for muscle contractions and other forms of cell work (Bouchard, Taylor, Simoneau, & Dulac, 1990). The cells, tissues, and organ systems of the human body are designed to maintain cellular ATP homeostasis, regardless of the rate of ATP utilization.

It is commonly accepted that depending on the duration, as well as the recovery time and intensity of an event, there are three different types of metabolic processes involved in ATP regeneration (Bouchard et al., 1990; Brooks et al., 2005; Goktepe, 2007). The three different metabolic processes or “energy systems” are referred to as the

immediate energy system (ATP-PC system), anaerobic glycolysis (fast glycolysis or short-term system), and aerobic metabolism (oxidative or long-term system) (Bouchard et al., 1990; Brooks et al., 2005; Goktepe, 2007; Turner & Stewart, 2013). Each system has its own advantages, such as speed of response exploited by the ATP-PC system, and disadvantages, such as duration of response, an unfavorable aspect of the ATP-PC system. Together, under different exercise or activity conditions, these systems work to maintain ATP homeostasis.

Integration of Energy Delivery of Metabolic Processes

It must be recognized that although each energy system is described independently, the replenishment of ATP is never achieved exclusively through only one energy delivery system, but is rather the result of a coordinated metabolic response in which all energy systems contribute to different degrees (Bouchard et al., 1990). Moreover, whether the activity is predominantly explosive and powerful, utilizing primarily the immediate and short-term energy systems, or endurance oriented, utilizing primarily the long-term energy system, the degradation of ATP supplies the chemical energy to power the activity (Brooks et al., 2005).

Immediate Energy System (ATP-PC)

The immediate energy system is made up of three components, each contributing to ATP production in its own unique way. The first fuel for muscle contraction is stored ATP. Gaitanos, Williams, Boobis, and Brooks (1993) and Goktepe (2007) have indicated that the human body has approximately 20-25 millimolar/kilogram (mmol/kg) dry muscle (dm) of stored ATP in muscle. This is typically enough to fuel 1-2 seconds of maximal work (Boobis, Williams, & Wooton, 1982; Dawson et al., 1997; Gaitanos, Williams,

Boobis, & Brooks, 1993; Goktepe, 2007; Parolin et al. 1999). The stored ATP is degraded by the enzyme myosin ATPase, in a hydrolysis reaction involving water. The chemical products of ATP hydrolysis are adenosine diphosphate (ADP) and inorganic phosphate (P_i). During a muscle contraction and recovery from a contraction, ATP is continually being hydrolyzed to ADP, followed by phosphorylation of ADP to resynthesize ATP through different metabolic energy systems.

Another source of immediate energy in muscle is stored phosphocreatine (PCr). Creatine is an amine, and can either be produced by the body, or ingested via food or supplements. Phosphocreatine is considered a high-energy phosphorylated compound and according to Jackson (2002), intramuscular PCr stores exist in five to six times greater concentrations, 100 to 140 mmol/kg dm than resting, stored ATP. The role of PCr is to provide a “reserve” of phosphate energy that regenerates ATP quickly. The enzyme creatine kinase (CK) is responsible for the catabolic interaction of PCr and ADP to produce a viable ATP. The reaction does not depend on oxygen, and therefore is considered to be “anaerobic” (Dunford & Doyle, 2008). Peak rate for the synthesis of ATP from the degradation of PCr is in the range of approximately 9 mmol ATP/kg dm per second (Hultman & Sjoholm, 1983) and within 10 seconds of intense activities, such as sprinting or maximal work, stores of PCr are significantly reduced (Glaister, 2005; Turner & Stewart, 2013). Boobis, Williams, and Wooten (1982) reported that PCr is 60-80% depleted immediately following a 30 second sprint. Interestingly, in 2.5 seconds of electrical muscle stimulation Hultman and Sjoholm (1983) found a PCr depletion of 26%, while PCr was depleted 40-70% and 30-55% during 10 second and 6 second cycling sprints, respectively (Boobis et al., 1982; Jones et al., 1985). Specifically during sprint

running, Hirvonen, Rehunen, Rusko, and Harkonen (1987) investigated the diminution of ATP and PCr levels. Well-trained sprinters underwent maximal sprinting activity of varying distances comprising 20, 40, 60, 80, and 100 meters (m). Via analysis of muscular ATP and PCr prior to and after the sprints, it was found that the levels of PCr declined substantially throughout the high-intensity exercise, particularly within the first 5 seconds (i.e. ~40 m sprint), but were never completely depleted (Hirvonen, Rehunen, Rusko, & Harkonen, 1987).

Phosphocreatine, after degradation, is rephosphorylated via the aerobic system at an average rate of approximately 1.3 mmol/kg dm per second (Gaitanos et al., 1993). Although, PCr can regenerate ATP at very high rates, approximately 9 mmol ATP/kg/dm per second (Turner & Stewart, 2013), the recovery of power output may be determined by the time course of PCr resynthesis, approximately 2-3 minutes or as long as 9-25 minutes, and therefore may likely be a major factor governing the rate of fatigue (Bogdanis, Nevill, Boobis, Lakomy, & Nevill, 1995; Chandler & Brown, 2008; Harris et al., 1976; Sahlin & Ren, 1989; Sargeant & Dolan, 1987). In addition to the rate of PCr recovery, it is also important to consider the nature of the recovery process. Research on PCr resynthesis points toward a biphasic recovery pattern, especially following intense bouts of muscular contraction (Atkinson, 1977; McMahon & Jenkins, 2002). It appears that there is an initial fast phase immediately after intense exercise, limited by oxygen availability, followed by a slower secondary recovery phase, limited by the hydrogen ion (H^+) transport out of the muscle (Sahlin, Harris, & Hultman, 1979).

Lastly, the third immediate energy source in muscles involves the enzyme adenylate kinase, which in muscle is referred to as myokinase (MK). The contribution of

the MK reaction is the generation of one ATP from two ADPs. Importantly, in the process, MK creates an adenosine monophosphate (AMP), a signaling “element” for activating mechanisms of ADP restoration to ATP (Brooks et al., 2005). In a corresponding reaction, the enzyme AMP deaminase irreversibly deaminates the base adenine of AMP, producing ammonia, which is toxic to the cell. Ammonia formed via AMP deaminase reactions can leave the muscle cell and travel into the blood where it is further metabolized in the kidneys and liver.

Fast Glycolysis

Fast glycolysis, or the short-term energy system, utilizes the breakdown of stored glycogen in the muscle (glycogenolysis), or glucose from the blood, to produce ATP. The maximal ATP turnover rate of fast glycolysis is between 5-9 mmol/kg dm per second (Gaitanos et al., 1993; Hultman & Sjoholom, 1983; Jones et al., 1985; Parolin et al., 1999). Quantitatively, the energy available through fast glycolytic metabolism is significantly greater than that available through immediate energy sources (Brooks et al., 2005). On the other hand, fast glycolysis involves multiple enzymatic reactions and is therefore “slower” than the ATP-PC system. This short-term system may be slower, but is still rapid, with evidence of high muscle lactate values (i.e. Jones et al. (1985) reported 29.0 ± 3.98 and 31.0 ± 4.31 mmol/kg wet muscle after 10 seconds of cycling at 140 rpms) within 10 seconds of maximal activity (Boobis et al., 1982; Jones et al., 1985). When fast glycolysis is utilized, the concentrations of glycogen decrease, while the concentration of muscle lactate increase (Dunford & Doyle, 2008). It has been reported that in humans, intramuscular glycogen stores range around 80-150 mmol/kg per dm (Hawley, Schabort, Noakes, & Dennis, 1997; Ivy, Katz, Cutler, Sherman, & Coyle, 1988; Jensen, Ruge, Lai,

Svensson, & Eriksson, 2011), although values as high as 300 mmol/kg per dm have been reported (Gaitanos et al., 1993). This is important because, during brief, intense exercise in particular, it is not likely that glycogen availability causes a decrease in ATP production during fast glycolysis, but rather progressive changes in the metabolic environment is what ultimately cause a reduction in ATP.

Fast glycolysis is associated with the intracellular accumulation of metabolic by-products, such as lactate and H^+ . Lactate, a metabolic by-product of the short-term energy system, is one of the major substrates produced by the muscle, during both active and resting conditions. Lactate formation was recognized as early as 1807, when Berzelius identified lactate in the muscles of hunted stags (Needman, 1971). In the 1900s, the intensive search began in order to understand the role of lactate and its involvement during muscular contractions.

Ole Bang (1936) was the first to notice that blood lactate levels increased with exercise, but decreased again after 10-20 minutes of continuous exercise. Extreme blood lactate values have been recorded, reaching levels as high as 15–25 mmols/liter (L), typically observed 3–8 minutes after “all-out” maximal exertion of 30–120 seconds (van Hall, 2010; Withers et al., 1991).

Upon exercise initiation, the demand of ATP for muscular contraction is instantaneously increased (Bangsbo, Krstrup, Gonzale-Alonso, Boushel, & Saltin, 2000; Grassi, 2005; Krstrup, Hellsten, & Bangsbo, 2004). Muscular ATP levels are virtually unchanged, suggesting that ATP hydrolysis is matched by resynthesis via the “fast” systems of ATP-PC and glycogenolysis/glycolysis. Thus, lactate formation is caused by a

mass action of high pyruvate and NADH (nicotinamide adenine dinucleotide with a H^+) concentrations from fast glycolysis.

Robergs, Ghiasvana, & Parker (2004) advocate that lactate formation is essential to the maintenance of a high glycolytic rate. They point out that lactate formation allows the recycling of NAD^+ (nicotinamide adenine dinucleotide without a H^+), as the lactate dehydrogenase reaction utilizes the protons (H^+) from NADH to produce lactate from pyruvate. The accumulation of H^+ in muscle is identified as one of the major limiting factors affecting anaerobic performance. It has been suggested that the build-up of H^+ decreases intracellular pH which inhibits glycolytic enzymes and the binding of calcium to troponin, thus muscle excitation-contraction coupling is impaired. When excitation-contraction is impaired, this causes fatigue and a decrease in muscle performance (Turner & Stewart, 2013). Therefore it may be concluded that the binding of H^+ to pyruvate producing lactate delays, not worsens acidosis (Robergs, 2001) and therefore improves energy production through fast glycolysis and ultimately, muscle performance.

Aerobic Metabolism

In contrast to the ATP-PC system and fast glycolysis, aerobic metabolism takes more time to provide substantial contributions to energy production. Nonetheless, overall aerobic metabolic reactions provide for the greatest portion of energy transfer out of all of the energy systems (McArdle, Katch, & Katch, 2006). The immediate and fast glycolytic systems do not require oxygen for their operation; however, aerobic metabolism does. Energy transduction in this system is dependent on the presence of oxygen (Brooks et al., 2005).

For the purposes of this review, the process of aerobic metabolism will not be discussed in detail, rather its contribution and integration with the ATP-PC and fast glycolysis systems will be discussed. Notably, aerobic metabolism contributes to ATP provision sooner than commonly understood; however, the aerobic system will not be functioning at a maximal level and oxidation contributions less to the energy needs, as compared to anaerobic energy contribution. Research by Parolin et al. (1999) found that during a 30 second maximal sprint an aerobic ATP turnover rate of 1.3 mmol ATP/kg dm per second contributed approximately 10% of the total energy produced. It has been estimated that the total aerobic energy contribution during a 30 second all-out cycling test is between 18% and 28% of the total energy production (Bahr, 1992; Bangsbo, Gollnick, Graham, & Saltin, 1991).

The contribution of aerobic metabolism to high intensity exercise bouts may be heavily influenced by the duration of the sprints, as well as the amount of recovery between sprints, if sprints are repeated. Balsom, Seger, Sjodin, & Ekblom (1992) found that aerobic system contributed significantly more during 30 and 40 m sprint trials, compared with 15 m sprint trials. Additionally, Balsom et al. (1992) explored the effect of recovery time on aerobic contribution to repeat sprinting and found that VO_2 measured during the rest periods was elevated in the shorter recovery trials. An important study by Gaitanos et al. (1993) studied repeat sprints and during the last sprint (10th sprint) there was no change in muscle lactate as compared to the 5th sprint, despite the fact that mean power output had been reduced 73% of that recorded during the initial sprint. Gaitanos et al. (1993) suggests that a greater contribution from aerobic metabolism partly counteracted the reduction in fast glycogenolysis likely caused by decreases in pH during

the repeated sprint trials, although the aerobic contribution was still small. Therefore, variables such as sprint duration, sprint number, and recovery duration clearly influence the energy system contribution, specifically aerobic contribution, during short bouts of intense exercise (Spencer, Bishop, Dawson, & Goodman, 2005).

Anaerobic Performance

In anaerobic metabolism literature, *anaerobic power* and *anaerobic capacity* are two terms that have been used to reference the two anaerobic energy systems, ATP-PC and fast glycolysis, respectively (Garret & Kirkhendell, 2000). In the Wingate Anaerobic Test (WAnT), a well-known 30 second anaerobic performance test, anaerobic power is defined as the maximal or peak power (PP) generated (in the first 5-10 seconds), whereas anaerobic capacity is defined as the mean power (MP) or total work calculated over the entire 30 second test. However, not all literature agrees with these statements, and as a result, there are often discussions about the terminology and whether it adequately describes what is being measured (Inbar, Bar-Or, & Skinner, 1996). A study by Jacobs, Tesch, Bar-Or, Karlsson, & Dotan (1983) revealed that muscle lactate climbs to extremely high levels in as early as 10 seconds during high intensity activities. Therefore, anaerobic power, often indicated by PP, is unlikely to reflect only the ATP-PC system. Nonetheless, even though it has been shown that the initiation of glycolysis occurs early in the transition from rest to high intensity exercise, Gollnick & Hermansen (1973) found that blood lactate increased only 3 mmol/L after 10 seconds of maximal exercise. Therefore, PP still may reflect the ability to produce a large portion of ATP from the ATP-PC system during the first 10 seconds of maximal exercise. Peak power is

commonly measured in watts (W) and can be expressed in both absolute and relative (to body weight) units.

Moreover, in the literature, anaerobic capacity is typically indicated by MP output, although this has not been substantiated (Bar-Or, 1987). Anaerobic capacity has been defined as the maximum amount of ATP that can be resynthesized via anaerobic metabolism (both ATP-PC and anaerobic glycolysis) during maximal exercise (Gastin, 1994; Noordhof, Koning, & Foster, 2010). Mean power is commonly measured in W and can be expressed in both absolute and relative (to body weight) units. Relative power is commonly used to control for dissimilarities in body mass (BM) between subjects, especially if there are variations in gender, whom commonly vary in BM. Mean power is the average power sustained throughout the duration of the test, 30 seconds if considering the WAnT. Numerous anaerobic capacity tests exist and will be discussed next in this review.

ANAEROBIC PERFORMANCE TESTS

Tests of anaerobic ability involve very high-intensity exercise lasting between a fraction of a second and a few minutes (Skinner & Morgan, 1985). It has been generally accepted that the majority of anaerobic tests are reliable in motivated subjects and that they correlate highly with each other. However, there has been a great deal of disagreement as to what “specifically” each anaerobic test measures. Therefore, it is common for anaerobic performance tests to be classified by their variations in performance time.

Very Brief Tests or Short-Term Tests

In this review, very brief tests are defined as anaerobic performance tests lasting

10 seconds or less. These tests are designed to evaluate primarily the ATP-PC system. There are numerous examples of anaerobic power tests lasting approximately 1 to 10 seconds. Tests vary from sprinting up stairs to jumping tasks. Popular "very brief" tests from shortest duration to longest duration include the vertical jump test (Davies, 1971; Fox & Mathews, 1974), lasting less than 1 second, and the Margaria step running test (Margaria, Aghemo, & Rovelli, 1966), lasting typically around 1 second. Very brief tests lasting 3-10 seconds include short sprint tests, either in a running or cycling manner (Bar-Or, 1983; Crielaard & Pirnay, 1981; Fox & Mathews, 1974).

Intermediate Tests

In this review, intermediate tests are defined as anaerobic performance tests lasting 20-50 seconds. These tests are designed primarily to assess the peak anaerobic power, as well as anaerobic capacity. The majority of the brief tests utilize either treadmills or cycle ergometers and are considered laboratory assessments of anaerobic performance. Brief anaerobic performance tests have been used to compute total work output, PP, MP, and power output at exhaustion or during the last few seconds of a given test. Intermediate tests also commonly evaluate a subject's ability to resist fatigue or sustain power output (Bouchard et al., 1990). Popular intermediate test include the 30 second WAnT, as well as modified 45 second WAnT (Ayalon, Inbar, & Bar-Or, 1974).

Long-Term Tests

Long-term anaerobic tests can be defined as tests lasting from around 60-120 seconds. The central purpose of these anaerobic tests is to evaluate the total anaerobic capacity and the ability to maintain a high power output when a large anaerobic energy component is present (Bouchard et al., 1990). It is critical to recall that the aerobic

component becomes progressively more involved as the time periods of a given test increases. Popular long-term anaerobic tests include the 60 second vertical jump test (Bosco, Luhtanen, & Komi, 1983), the Quebec 90 second tests (Simoneau et al., 1983), the 90 second WAnT (Ayalon et al., 1974), and the Cunningham and Faulkner treadmill test (Cunningham & Faulkner, 1969).

The “Gold Standard” of Anaerobic Testing

The WAnT has been considered the “gold standard” in laboratory assessments of anaerobic performance testing. Since it was first developed in 1974, the 30 second WAnT has been used more than any other anaerobic performance test to assess the characteristics of anaerobic performance (Inbar et al., 1996). Numerous research studies have confirmed its very high reliability ($r=0.89-0.99$) as well as its validity ($r\geq 0.75$) as a test that can yield information on peak mechanical power and on local muscle endurance (Inbar et al., 1996).

When first developed, the WAnT was designed as a leg performance test, but was adapted to test the anaerobic performance of the upper body. A WAnT performed using the legs, utilizes a cycle ergometer (i.e. Monark) and requires pedaling maximally for 30 seconds against a constant force. Prior to the performing the WAnT, a warm-up of 2-4 minutes of “easy” pedaling is interspersed with two or three “all out sprints” against the predetermined test load. Each sprint lasts 4-8 seconds so that the subjects can get a feel for the actual test. After completion of the warm-up and a passive recovery of 3-5 minutes, subjects are asked to begin pedaling as fast as possible progressing to maximal revolutions per minute (RPMs) within 2-5 seconds. Once max RPMs are reached a “start” command is given and the addition of the load or resistance is applied to the flywheel to

begin the 30 second test. It is highly suggested that verbal encouragement be given throughout the test, especially during the last 10-15 seconds when discomfort is greatest for the subject. In order to get the best results, it is important that the researcher emphasize the need to pedal as fast as possible from the beginning and to maintain, to the subject's best ability, a maximal RPM throughout the entire 30 second period. Additionally, it is standard that the subject stays seated on the cycle ergometer seat during the entire duration of the test. In order to maximize results, nothing less than a maximal effort should be accepted from subjects (Bouchard et al., 1990; Inbar et al., 1996).

Duration Variations of the Wingate Anaerobic Test (WAnT)

When first employed, the WAnT was structured as a 30 second cycling test. Based on results from pilot studies using treadmill runs until exhaustion of 30, 45, and 60 seconds and a supramaximal treadmill tests by Margaria, Oliva, Di Prampero, and Cerretelli (1969), 30 seconds was suitable for taxing the fast glycolytic system and therefore was chosen as the optimal duration for testing (Inbar et al., 1996). Considerations such as subject retention with longer duration tests were also considered when determining the optimal duration. It was found that as test durations increased, subjects were less willing to repeat the test. Moreover, it was reported that subjects repeatedly tried to start at less than all-out pedaling speed during the longer tests, due to their uncertainty about finishing the entire test (Inbar et al., 1996).

More support came for the shorter duration anaerobic tests when Vandewalle, Peres, and Monod (1987) suggested that there is an ever-increasing aerobic system contribution with longer test duration and tests longer than 60 seconds are not needed.

This was supported by Katch, Weltman, Martin, and Gray (1977) whom found a correlation coefficient of $r=0.95$ between total work output in a 40 second test and a 120 second test. Interestingly, evidence for tests shorter than 30 seconds has been suggested as well. Raveneau, in an unpublished work, found that the correlation coefficient between total work done at 20 seconds and that done at 30 seconds was $r=0.99$ (Inbar et al., 1996). This suggests that anaerobic tests may only need to last 20 seconds (Vandewalle, Peres, & Monod, 1987). Due to the vast amount of data that has been generated using the 30 second WAnT, it has been recommended that 30 seconds be used for literature comparative purposes (Inbar et al., 1996).

Load Variations of the Wingate Anaerobic Test

When determining the optimal load for the WAnT, researchers were looking for a load that would elicit the highest possible PP and MP for each subject. However, the “optimal” load is a somewhat unresolved challenge and demands much research attention and subject compliance. When the WAnT was first developed the suggested load was 0.075 kiloponds (kp) per kg BM (Inbar et al., 1996). However, this load was determined using a small group of untrained subjects and has appeared to be too low for most adults as more research has been conducted and reported on the issue. A follow-up study by Evan and Quinny (1981) studied male physical education students and found that a load of 0.098 kp per kg of BM yielded the highest MP. Evan and Quinny (1981) developed and recommended an equation in order to calculate load based on individual BM and leg volume; however, when used to determine the load in a study by Patton, Murphy, and Frederick (1985) it was found that the equation was unreliable. Lavoie, Dallaire, Barrett, and Brayne (1984) found that when the equation was applied for implementing a load, PP

was found to be higher and MP was similar to tests utilizing a load of 0.075 kp per kg BM. As research on different load variations has continued, it has been concluded that the load needed to yield the highest MP is some 20% to 30% higher than the original load of 0.075 kp per kg BM. Generally, it has also been found that the load needed to elicit the highest PP is higher than that needed for the highest MP.

Moreover, subject training status, gender, and previous experience in power-related activities also effects optimal load and it has been suggested by the original researchers that optimal load settings should eventually be conducted on an individual basis (i.e. previous experience and/or fat-free mass may be a better alternative than BM). Nonetheless, for practical purposes, selecting a load that is somewhat off the actual optimal load introduces only a small underestimate of the true MP (Dotan & Bar-or, 1993; Patton, Murphy, and Fredrick, 1985). More research needs to be conducted on the effect of different loads on PP and MP output.

Reliability and Validity of the Wingate Anaerobic Test

The WAnT appears to have been studied the most relative to its reliability and validity. Additionally, researchers have strived to establish norms for various ages and groups, such as athletes or men compared to women. It is generally perceived that the 30 second WAnT is a reliable instrument, especially when considering PP and MP. However, less support for the reliability of decline in power output (fatigue index) has been reported (Bouchard et al., 1990).

Under standardized environmental conditions, correlation coefficients for the WAnT (PP and MP) have ranged between $r=0.89$ and 0.99 and typically have been found to be higher than $r=0.94$, which is considered very strong. A pattern of higher correlations

for MP, than for PP, has commonly been found. Strong reliability indices have not only been found in able-body, young adults, but also in children, the elderly, and the diseased. Research by Tirosh, Bar-Or, and Rosenbaum (1990) found a reliability coefficient of $r=0.94$ for PP and $r=0.98$ for MP in 58 children with spastic cerebral palsy, athetotic cerebral palsy, muscular dystrophy, and muscular atrophy upon completion of the 30 second arm crank WAnT. Thirty-eight of these subjects also completed the cycling WAnT, and a $r=0.96$ reliability coefficient was reported for both PP and MP (Tirosh, Bar-or, & Rosenbaum, 1990).

Furthermore, research has been conducted on whether the WAnT is reliable if conducted on the same day or different days (i.e. a week apart). Hebestreit, Mimura, and Bar-Or (1993) found reliable results with only 20 minutes of rest between WAnT trials. This has been considered a major strength of the WAnT and recently, much research has been conducted utilizing repeat WAnTs in various laboratories around the world (Greer, McLean, & Graham, 1998; MacDougall et al., 1998).

Historically, validity has been difficult to relay due to the lack of another “gold standard” anaerobic test that measured both PP and local muscle endurance of the lower and upper limbs. Comparisons of the anaerobic indices of the WAnT to both field based anaerobic tests and laboratory based anaerobic tests has been reported. Regarding field based tests, the highest correlation coefficients (≥ 0.75) were reported with an anaerobic 25 m swim test (Inbar & Bar-Or, 1977) and the weakest association with the Sergeant Anaerobic Skating test ($r=0.32$) (Watson & Sergeant, 1986). It was concluded that a greater skill set might be required for ice-skating, which may explain the weak association. Overall, literature has revealed that the relationship between the WAnT

power indices and field based anaerobic tests is quite high, but not high enough to use results from a WAnT as a predictor of success in specific field-based events or athletics (Inbar et al., 1996).

Comparisons of the WAnT with other laboratory based anaerobic tests have been reported, especially the relationship between the Margaria step running test and the WAnT. Two studies reported that PP from the WAnT and the reported power from the Margaria step running test were closely associated (Ayalon et al., 1974; Jacobs, 1979). Reports on the comparisons of the WAnT to the laboratory based 30 second test developed by Thorstensson and Karlsson (1976) reveal significant correlation coefficients (Inbar, Kaiser, & Tesch, 1981). Overall, correlation coefficients between the WAnT and other laboratory-based anaerobic tests are high, even when performance in both tests is expressed relatively (Inbar et al., 1996).

Typical Outcomes for the Wingate- Sport Specificity Studies

In order to understand a new test, it is often useful to show some typical values found from research with varying subject groups. As previously mentioned, performance on the WAnT typically varies significantly between gender groups, as well as between different age groups. Additional research has been gathered on the WAnT performance indices of athletes specializing in different sports. Tharp, Johnson, and Thorland (1984) tested 21 females and 18 males, age 10 to 17, who were members of an elite track club. After WAnT testing, it was apparent that there was a significant difference in PP output between the male sprinters, $10.90 \text{ W}\cdot\text{kg}^{-1}$, compared to $9.94 \text{ W}\cdot\text{kg}^{-1}$ of the long-distance runners. A similar trend was shown in the female group (sprinters $9.04 \text{ W}\cdot\text{kg}^{-1}$ vs. long-distance runners $8.45 \text{ W}\cdot\text{kg}^{-1}$). Research on the MP of male runners from the Burmese

national track team indicated that as the distance of the events increased, the lower the MP WAnT score (Bar-Or, 1987). Interestingly, the 10-kilometer (km) runners and the marathon runners recorded a lower average MP, as compared to a similar aged sedentary group of Burmese males (Bar-Or, 1987). Taunton, Maron, and Wilkinson (1981) compared WAnT performance in young adult middle-distance and long-distance runners. Results indicated that the PP of the middle distance runners was significantly higher, but there was no difference in MP between groups. Moreover, even when corrected for BM, athletes, such as power lifters, recorded a significantly higher PP than a group of 10-km runners and ultramarathoners. Scores for gymnasts and wrestlers fell between the two groups (Skinner & O'Conner, 1987). Again, there were no significant differences in MP among the 10-km /ultramarathoners, gymnasts, wrestlers, or powerlifters (8.8 to 9.3 $W \cdot kg^{-1}$). In terms of fatigue index (FI), Skinner & O'Conner (1987) reported that the 10-km and ultramarathoners had significantly lower rates of fatigue (26-33%) than the other three groups (43-47%). A more recent study by Coppin, Heath, Bressel, and Wagner (2012) tested WAnT values (load: 0.085 kp/kg BM) for NCAA Division I American football players and track and field athletes (i.e. power athletes). Overall, absolute mean values for PP and MP were 1084.2 ± 137.0 and 777.1 ± 80.9 W, respectively, whereas values normalized to BM were 12.9 ± 1.5 and 9.3 ± 0.9 W/kg BM, respectively. Mean FI values were $49.1\% \pm 8.4\%$. It is apparent from the above studies that typically, athletes specializing in power training or events produce a higher PP output, but MP values vary between groups and MP is occasionally very similar between athletes of all types.

FACTORS INFLUENCING ANAEROBIC PERFORMANCE

The factors influencing human anaerobic performance are varied and complex and include, but are not limited to, the following human characteristics: heredity, age and sex, muscle characteristics, and training status. Additional issues include warm-up, circadian rhythm, hydration status, motivation, fatigue, and familiarization.

Human Characteristics: Heredity

Like other individual human characteristics, human physical performance is dependent on interactions between genes and the environment (Brutsaert & Parra, 2009). Various studies suggest a significant effect of genetics on physical performance, anaerobic athletic performance in particular, even when adjusted for the manifest effect of environmental factors (Lucia, Moran, Zihong, & Ruiz, 2010). Literature suggests that the genetic contribution to short-duration and long-duration anaerobic tasks is quite significant. Simoneau et al. (1986) investigated the anaerobic capacity of 328 monozygotic and dizygotic twins using a cycle ergometer. Results indicated that individuals sharing half of the genome and who were living together performed significantly better on an anaerobic task compared to those who only lived together and did not share any genes. A more recent study by Wolanski, Tomonori, and Klissouras (2004) reported high heritability estimates for several phenotypes, such as handgrip strength and sprint performance in 20, 30, and 60 m sprints. Calvo et al. (2002) found a statistical relationship (heritability index (HI)= 0.74; $p < 0.05$) when measuring the heritability of explosive power at 5 seconds using a WAnT. The heritability index is calculated via a genetic statistical relationship (Rodas et al., 1998), based on a 0.00-1.00 scale, with larger scores attributed to higher genetic influence.

Some studies also suggest the significant role of genetics in the distribution of muscle fiber types, a noteworthy factor in a person's ability to perform certain physical tasks such as a 100 km race, compared to a 60 m sprint. Research published by Komi, Rusko, Vos, & Vihko (1977) reported a HI ($p < 0.05$) for the proportion of type I fibers: 0.99 in men and 0.93 in women. Although, a study by Bouchard et al. (1986) found no significant genetic effect for muscle fiber type I, IIa, and IIb distribution and fiber areas.

Human Characteristic: Aging, Age, and Sex

It is well known that the capacity of the anaerobic and aerobic systems declines with aging (Fitzgerald, Tanaka, Tran, & Seals, 1997; Reaburn & Dascombe, 2009; Wilson & Tanaka, 2000). From a performance perspective the energy systems are critical in performance outcomes and if not trained and maintained, performance may decrease. Although one may train, aging is inevitable and previous works have found declines of anaerobic power and capacity of approximately 6-8% per decade of aging in subjects between the ages of 29 and 72 (Reaburn & Dascombe, 2009). A recent longitudinal study by Gent & Norton (2012) found a similar (~ 8%) decline per decade in anaerobic power and anaerobic capacity when exploring 173 male and female cyclists between the ages of 35 and 64. There appears to be similar patterns of age-related declines in anaerobic power and capacity, which cluster around the 6-8% range across numerous heterogeneous studies (Perusse et al., 2003). In addition, Marsh, Paterson, Govindasamy, and Cunningham (1999) found that average power during a WAnT declined by 6.3% per decade between two groups of active men with mean ages of 30 and 69 years.

Sparse information has been published on age-related anaerobic performances. According to Di Prampero (1981), a 60 year old person has a PP that is 60% of the value

for one who is 20 years old. Moreover, the first ever study on age-related PP was conducted using the Margaria step running anaerobic test. Conducted in 1966 by Margaria, Aghemo, and Rovelli, results indicated that children reached distinctly lower PP than the adolescents and young adults. This difference was apparent regardless if PP was expressed in absolute or relative manner. Specifically, relative PP in 9 year olds was only 60% of that found in the 20 year olds. Similarly, Margaria et al. (1969) found that children performed considerably worse than the adolescents or young adults, both in absolute and relative power units. Cross sectional data (Inbar & Bar, 1986) was collected using the WAnT on 306 males, age 8 to 45. Results indicated that PP and MP of both the legs and arms increased consistently from age 10 to adulthood and seemed to peak at the end of the third decade for the legs and at the end of the second decade for the arms.

It has been suggested that age-related differences in anaerobic power and capacity are best explained by qualitative characteristics of the muscle. The total amount of ATP in resting muscle and its utilization during intense exercise seems to be similar in preadolescent boys and older males, but PCr concentration is somewhat lower at rest in preadolescent boys. However, it seems that the biochemical difference in anaerobic characteristics between children and adults is associated more with the anaerobic glycolysis, and less with the ATP-PC system. It has been noted that the main age- or maturation-related differences is in the concentration and rate of utilization of muscle glycogen, which is much lower in preadolescent children (Eriksson, 1980; Karlsson, 1971). This notion has been supported with evidence of lower concentrations of the enzymes phosphofructokinase (PFK), a rate-limiting enzyme in anaerobic glycolysis, as well as decrease levels of lactate dehydrogenase (LDH), resulting in lower maximal

blood lactate concentrations (Eriksson, Karlsson, & Saltin, 1971).

It is clear that large gender differences exist in anaerobic power when comparing test scores on an “absolute” basis. Several theories have been advocated to explain the differences in power and strength between men and women (Inbar et al., 1996).

According to Di Prampero (1981) the average man produces a 15-30% higher PP output than the average women. It has been suggested that these differences lie in BM, inefficient skeletal configuration, active muscle mass, lower peak lactate levels after all-out performances, and fat free BM or percentage of adipose (Inbar et al., 1996; McArdle et al., 2006). Moreover, the male populations greater relative muscle area and metabolic capacity of fast-twitch muscle fibers, as well as the larger catecholamine response to exercise may also aid in better performance on different anaerobic tests (McArdle et al., 2006).

Human Characteristic: Muscle Characteristics

Muscles exert forces and thus are the major contributor to human movement. Muscles and muscle groups are arranged so that they contribute individually (rare) or collectively to produce a very small, fine movement, or a very large, powerful movement. It is likely that the architecture of the muscle plays a substantial role in the power and work output that can be generated by that muscle during anaerobic performance (Edgerton, Roy, Gregor, & Rugg, 1986). A muscle's structure includes different sarcomere arrangements and lengths, different muscle cross-sectional areas, varying angles of pennation, varying muscle fiber lengths and types, and total muscle mass. The different components making up a muscle's structure absolutely contribute to the ability of a muscle to perform under anaerobic settings, especially in terms of power and total

work output (Edgerton et al., 1986; Bouchard et al., 1990).

Research has been conducted on muscle fiber type, and how different muscle fiber type compositions relate to anaerobic performance. Although the relationship between specific types of muscle fibers and anaerobic performance is not a simple one, research by Burke, Levine, and Zajac (1971) and Thorstensson and Karlsson (1976) have reported high correlations between fiber-type distribution and anaerobic performance. Both studies (Burke, Levine, & Zajac, 1971 and Thorstensson & Karlsson, 1976) concluded that a higher proportion of fast twitch (FT) fibers are advantageous for short-term, anaerobic power and capacity. Fast twitch fibers typically generate higher mechanical tension and fatigue earlier than slow twitch (ST) fibers. Therefore, it may be concluded that high FT fiber ratios or increased FT muscle fiber area appears to be beneficial, primarily under conditions of maximal instantaneous power and short-term anaerobic work output (Bar-Or et al., 1980; Bosco, Komi, Tihanyi, Fekete, & Apor, 1983; Inbar et al., 1981; Jacobs & Tesch, 1981; Kaczkowski, Montgomery, Taylor, & Klissouras, 1982; Kommie, Rusko, Vos, & Vihko, 1977).

Specifically, authors such as Bar-Or et al. (1980) explored fiber type composition based on WAnT performances of 19 male physical education students, sprinters, and long distance runners. It was concluded that PP, MP, and FI were significantly correlated (positively) with the ratios of FT /ST area, indicating a strong relationship. Inbar et al. (1981) found similar results when exploring how fiber-type distribution relates to performance on a 30 second isokinetic test (Thorstensson Test). In general, research has indicated that correlations between fiber type and power output are stronger in males than in females, stronger in trained than in sedentary subjects, and stronger with PP output and

short-term anaerobic work output than with MP output and intermediate and longer-term work output (30 seconds or more). In other words, the trend is that the more FT fibers or the larger percentage FT fiber area, the greater the ability to produce high amounts of power but at the same time, the lower a person's ability to sustain high power output over time.

Training

Training brings about transformations that are typically known as training *adaptations*. The purpose of physical training is to stress the body systematically so that it improves its capacity to exercise or perform in a certain manner (Brooks et al., 2005). Physical training is beneficial, as it forces the body to adapt to the stress of physical effort. An abundant amount of research has been conducted on countless exercise devices and training programs and their effects on performance indices. For the purposes of this review, only the characteristics and effects of anaerobic training programs will be discussed in detail.

The influence of strength training and sprint training programs on anaerobic performance has been well documented. After a period of sprint training, Nevil, Boobis, Brooks, and Williams (1989) found an increase in PP (12%) and MP (6%) during a 30 second maximal sprint utilizing a nonmotorized treadmill (NMT). No details regarding a resistive load were given for the 30 second sprint test utilizing the NMT. Weltman, Moffatt, and Stamford (1978) using a training period that included bouts of 40 second sprints resulting in improvements in both anaerobic PP and MP. Regarding strength training, a 6 week mesocycle of general fitness training resulted in significant increase in maximum anaerobic power and anaerobic capacity in handball players as measured by

the 30 second WAnT (Boraczynski & Urniaz, 2008). This agrees with research by Komi (1992), Thorstensson and Karlsson (1976), and Zajac, Pilis, and Waskiewicz (1999) whom all showed that strength training increased anaerobic power significantly.

Warm-up

Warming up is common practice, especially prior to research testing or sporting events involving physical performance and has been considered essential to facilitate optimal performance, as well as to reduce the incidence of sports-related musculoskeletal injuries (Bishop, 2003a; Bishop, 2003b; Van Mechelen, Hlobil, Kemper, Voorn, & de Jongh 1993). Over the years the concept of warming up has been divided into two main categories: the active warm-up and the passive warm-up. Passive warm-ups typically require a heat source to raise muscle or core temperature without depleting energy substrates, while active warm-ups utilize muscle activity, and are likely to induce greater metabolic and cardiovascular changes (Bishop, 2003a; Bishop, 2003b).

It has been proposed that the majority of the effects of warm-up are attributed to separate temperature related and non-temperature related physiological mechanisms. Suggested non-temperature related mechanisms include increased blood flow and related oxygen delivery leading to speeded VO_2 kinetics, elevation of baseline VO_2 , and increased postactivation potentiation (Bishop, 2003a; Bishop, 2003b; McCutcheon, Geor, & Hinchcliff, 1999). Proposed temperature-related mechanisms include decreased joint stiffness, augmented nerve conduction velocity (Karvonen, 1992), altered force-velocity relationship, and increased anaerobic energy provisions (Bishop, 2003a; Bishop, 2003b). de Vries (1959), Dolan, Greig, and Sargeant (1985), and Thompson (1985) reported an increase in muscle temperature following an active warm-up improved short-term

performance. On the other hand, studies by Margaria et al. (1971) and Sargeant and Dolan (1987) reported a significant decrease in short-term performance following an active warm-up. However, it was reported that the warm-up in these studies were either too intense, or subjects were given insufficient recovery between the active warm-up and subsequent task. Therefore, it may be concluded that prior to anaerobic performance testing, an appropriate low intensity warm-up should be highly considered.

Circadian Rhythm

The concept of circadian rhythms (CR) in physical performance has been extensively researched (Atkinson & Reilly, 1996; Drust, Waterhouse, Atkinson, Edwards, & Reilly, 2005; Redlin & Mrosovsky, 1997; Reilly, 1990). Circadian rhythms refer to cyclical changes that occur in the body over a period of time, usually 24 hours. Many physiological functions associated with athletic performance have also been shown to follow a specific CR (Winget, DeRoshia, & Holley, 1985). For example, previous research has documented that within the human body many variables, such as resting blood pressure (Cabri, De Witte, Clarys, Reilly, & Strass, 1988; Reilly, Westgate, Fitzgerald, 2007), are closely associated with the CR of body temperature (Reilly, 1987), which may influence physical performance (Atkinson, Todd, Reilly, & Waterhouse, 2005).

The effect of CR has been widely reported with regard to anaerobic performance or short-term maximal exercise lasting 1 minute or less (Lericollais, Gauthier, Bessot, Sesboüé, & Davenne, 2009; Nicolas, Gauthier, Trouillet, & Davenne, 2005; Racinais, Blanc, Jonville, & Hue, 2005a; Souissi, Gauthier, Sesboue, Larue, & Devanne, 2004). Hill and Smith (1991) and Melhim (1993) reported a “time of day” effect that

demonstrated daily variations in peak anaerobic power observed during WAnT testing. This supports research by Reilly and Baxter (1983), whom found performance during the evening was superior compared to that of morning, particularly when large muscle mass was activated during sustained, high-intensity exercise. Nonetheless, research by Reilly and Down (1992) and Racinais, Blonc, and Hue (2005b) suggested that CR effects on anaerobic performance have been misinterpreted for changes in motivational levels of subjects. Racinais et al. (2005b) found that prior to an evening anaerobic performance test, subjects reported greater motivation and higher energy levels, which could be related to higher power output performances. However, a plethora of support for higher anaerobic performance values of PP and MP outcomes tend to occur during afternoon or early evening testing hours, compared to early morning testing hours (Giacomoni, Billaut, & Falgairette, 2006; Hill & Smith, 1991; Racinais et al., 2005a; Souissi et al., 2004). An explanation for such findings may be found in the variation of body temperature, with a higher body temperature associated within the afternoon or early evening hours, and with enhancing metabolic reactions, nerve conduction velocity (Ferrario, Tredici, & Crespi, 1980; Shephard, 1984), and joint mobility (Fathallah, Marras, & Wright, 1995), all of which may effect power output and performance outcomes. It has been suggested that an increase of at least 1 degree Celsius ($^{\circ}\text{C}$) is needed to influence any of the functions mentioned previously (Reilly et al., 1997). Bergh (1980) showed that maximal anaerobic exercise was impaired by approximately 5% for each 1 degree $^{\circ}\text{C}$ decrease in core temperature.

Nonetheless, the evidence that temperature affects anaerobic performance indices provides more support to perform a warm-up, in order to raise body temperature and reap

the positive effects of increased body temperature. In addition, the effect of CRs should be considered important when scheduling anaerobic performance testing times, especially when multiple sessions are involved.

Hydration Status

Sufficient quantities of research have found that dehydration has profound negative effects on endurance performance (Cheuvront, Carter, & Sawka, 2003; Folgelholm, 1994; Saltin, 1964; Sawka, Lutzka, Matott, & Montain, 2007; Yoshida, Takanishi, Nakai, Yorimoto, & Morimoto, 2002). Conversely, research studying the impact of hydration status on anaerobic performance is limited. One issue deterring suitable research on hydration status effects on anaerobic performance (i.e. dehydration, hypohydration) is variations in anaerobic exercise testing modes. Tests of anaerobic performance range from vertical jump tests to 30 second cycling sprints; although, each of the different anaerobic exercise tests are dominated primarily by anaerobic pathways. Research indicates that the influence of hypohydration on anaerobic performance indices of MP and PP may depend at least in part on interaction effects between method of dehydration, level of dehydration, mode of exercise, and length of anaerobic performance (Kraft et al., 2013). Jacobs et al. (1980) reported no significant difference in MP or PP during a 30 second WAnT at levels of dehydration as high as 4%. Conversely, others have demonstrated hypohydration mediated reductions in anaerobic performances using the WAnT or similar tests (Nielsen et al., 1981; Yoshida et al., 2002); however, with confounding factors such as evaluating the affects of hypohydration on anaerobic performance during or following (Nielsen et al., 1981; Yoshida et al., 2002) vigorous exercise accompanied by moderate or large increases in body temperature. With the

knowledge of the effect of hydration on performance indices, and the fact that training status may affect how each individual handles different levels of dehydration (Kraft et al., 2013), it is important to note prior activity and hydration status to ensure quality anaerobic testing for subjects.

Motivation

It is commonly accepted that motivation may play a key role in the outcome of performance of any all-out task. The effect of motivation on performance tasks differs considerably. The inverted U hypothesis, related to arousal state for a given person, has received considerable acceptance into the research world (Carron, 1978; Yerkes & Dodson, 1908). The inverted U hypothesis is a well-accepted principle in literature that states increases in arousal (assuming that arousal is initially at a low level) are accompanied by increases in performance, but only to a point, with performance usually peaking at some intermediate level of arousal. If arousal continues to increase beyond the intermediate level, a person's performance begins to decrease (Schmid & Wrisberg, 2008). Zanders (1974) and Alderman (1978) stress that the type of motivation employed largely influences how one responds. It is known that competitive situations and achievement motivation can affect performance, either in a positive or negative manner (Carron, 1978; Myers, 1971), as well as performance in a group or individual setting (Cottrell, 1968).

Little research has been conducted concerning motivation and its effect on anaerobic performance. Geron and Inbar (1980) explored the effect of motivation on anaerobic performance. Geron and Inbar divided 204 males into ten groups (8 experimental, 2 control) and asked them to perform the 30 second WAnT twice. Each

group was assigned a different “type” of motivation, which was implemented during the second performance. The 2 control groups performed the WAnT twice, without any motivation. The experimental groups included 8 separate groups, each with a separate type of motivation: intrinsic motivation, extrinsic motivation (i.e. verbal motivation), the audience effect, competition, punishment, the reward, group belonging, and social responsibility. Each individual’s MP, PP, and FI were analyzed during the WAnT trials. The overall findings of the study found that motivation does affect anaerobic performance. More specifically, motivations based on reward, punishment, and competition significantly improved performances, with social motivation, such as audiences and social responsibilities were introduced to subjects, causing the greatest improvements in performance. On the other hand, motivational stimuli based on cognitive information (i.e. past behaviors/performances) had little or no effect on WAnT performance. Based on the above study and the limited amount of research performed on motivation and anaerobic performance, it may be concluded that until further research is conducted with groups, environmental conditions that may affect a subject’s motivation should be consistent throughout all trials (Geron & Inbar, 1980).

Fatigue

Muscle fatigue is frequently defined as a temporary loss in force or torque generating ability, due to recent, repetitive muscular contraction (Bigland-Ritchie & Woods, 1984). Many properties of muscle change during fatigue including the action potential, extracellular and intracellular ions, and many intracellular metabolites. A range of mechanisms has been identified, that conceivably contribute to a decline of performance (Allen, Lamb, & Westerblad, 2008).

As discussed previously, the build up of H^+ decreases intracellular pH which inhibits glycolytic enzymes and the binding of calcium to troponin, thus muscle excitation-contraction coupling is impaired. When excitation-contraction is impaired, this causes fatigue and impairs performance of working muscles (Turner & Stewart, 2013). Moreover, the chain reaction caused by H^+ is not the sole cause of fatigue (Brooks et al., 2005). The increased concentration of P_i from the breakdown of PCr and the CK reaction has been related to fatigue. It has been implicated that P_i decreases force production observed with fatigue presumably through its effect on cross-bridge cycling; specifically P_i may interfere with calcium release from and reuptake to the sarcoplasmic reticulum (McLester, 1997; Stephenson, Lamb, & Stephenson, 1998; Westerblad, Allen, & Burton, 1998).

During the transition into intense exercise, it has been reported that energy consumption of the skeletal muscle may increase up to 100-fold, with the largest fraction of ATP (energy) provided by anaerobic metabolism (Westerblad, Allen, & Lannergren, 2006). The breakdown of glycogen via anaerobic metabolism leads to an intracellular accumulation of H^+ . The accumulation or increase in H^+ (decreased pH or acidosis) has been related to a decrease in muscular contraction (Westerblad et al., 2006), negatively affecting performance.

Familiarization

The issue of familiarization to maximal testing, whether it is jumping, sprinting, or a cycling test, is fundamental when looking to properly collect valid and accurate results. Past research has found that insufficient practice or familiarization of certain anaerobic tests may lead to inflated performance changes. Barfield, Sells, Rowe, and

Hannigan-Downs (2002) explored familiarization or the “practice effect” on WAnT performances of 25 college males. Barfield et al. (2002) found a significant increase in PP (14%) and MP (5%) during the second trial compared to the first trial completed by subjects. Based on the results of the study, they recommended that at least 1 full practice WAnT should be given prior to recording baseline data. Other literature indicates changes in PP and MP outputs between the first and second trials, with increases of 8-15% (Green, McLester, Smith, & Mansfield, 2001; Herbestreit, Dunstheimer, Staschen, & Strabburg, 1999). Therefore, inadequate practice prior to baseline testing may produce less than reliable results, especially in anaerobic performance tests involving PP.

Nausea

Brief maximal exercise to exhaustion has been associated with a persistent sensation of weakness; employing sensations of nausea and light-headedness, and in severe cases, vomiting (Shwartz et al., 1978). The immediate increase in heart rate at the onset of exercise is caused by vagal withdrawal by the vagus nerve, and therefore, it may be expected that the vagus nerve does not play a role during exercise (Thorén, 1979). However, intense, vigorous exercise requires forceful heart contractions and therefore the demand to meet an increased heart rate via high sympathetic drive. The heart, specifically the left ventricle, has been shown to possess C-fibers, receptors with unmyelinated vagal afferents, which are responsible for eliciting the Bezold-Jarish depressor reflex. It was discovered by Widdicombe and Sleight, as well as Coleridge and his colleagues that these “C-fibers” were more specifically, mechanoreceptors. These mechanoreceptors are excited during systole, especially by vigorous contractions caused by epinephrine. It was found that these mechanoreceptors would signal for intramyocardial tensions, and that the

Bezold-Jarish reflex serves to match the force of contractions of the left ventricle to the peripheral resistances. Thus at times when cardiac output rises, for example during exercise, ventricular emptying is facilitated by the drop in resistance (Sleight, 1981). Abrahamsson and Thoren (1973) made the important observation that stimulation of these ventricular mechanoreceptors also led to reflex gastric dilation and eventual vomiting. Moreover, research by Thoren (1979) found that in times of physiological conditions of hypoxia or mechanical distortion of the left ventricle from vigorous contractions (i.e. high-intensity exercise may cause this), around a reduced diastolic volume via blood pooling in the active muscles, may trigger the Bezold-Jarish reflex, and therefore, a nauseous or vomiting response.

Sleight (1981) suggested that at the end of fully-body heavy exercise, sympathetic drive is high, but the heart is empty because of the abrupt cessation of venous return from now, “less active” leg muscles. The same circumstances (empty heart and reflex tachycardia and sympathetic drive from baroreceptor reflexes) may occur with peripheral venous pooling when standing in hot weather, triggering a fainting or vasovagal reaction.

SPECIFICITY AND NEW RESEARCH

Since the development of the WAnT, several studies have suggested that the WAnT test may not be the most appropriate test for analyzing anaerobic power in all athletes (Falk et al., 1996; Lima et al., 2011; Ozkaya et al., 2009a; Ozkaya, Colakoglu, Fowler, Kuzucu, & Colakoglu, 2009b; Rusko, Nummela, & Mero, 1992). A major concern of many of the following studies focuses on the applicability of the WAnT for assessing anaerobic power in athletes whom perform primarily sprint running activities. The lack of activity pattern specificity of the WAnT on a cycle ergometer for athletes that

train and perform using sprint running has led to the development of more specific tests to measure anaerobic performance.

Semi-Tethered Tests

Falk et al. (1996) set out to develop and test the reliability of a running specific laboratory test in which sprint running power output could be precisely determined. A novel type of commercially available treadmill (BRL 1800 Gymrol, France), equipped with a torque motor to neutralize the frictional resistance of the treadmill belt, and a hip-belt harness connected to a horizontal rod was used. The test protocol included a several minute warm-up of moderate aerobic running on a motorized treadmill, followed by the several short “sprints” on the BRL 1800, followed by a short (1-3 min) rest. Subjects then underwent a 30 second maximal sprint on the BRL 1800; however, many subjects had to quit early due to volitional fatigue or their performance became very irregular and deteriorated badly during the final seconds of testing due to fatigue. Test-retest coefficients for PP ($r=0.80$) and MP ($r=0.81$) were found between the second and third trials. The relationship between the first and second trials was found to be less reliable than between the second and third trials, and therefore the authors concluded that there is likely a learning curve for producing reliable data during a 30 second maximal sprint using the BRL 1800 treadmill.

Lima et al. (2011) analyzed the usefulness of a semi-tethered field running test (STR) and the relationships between indices of anaerobic power, anaerobic capacity, and running performance as compared to the WAnT. Semi-tethered running involved an all-out 120 m run on a synthetic-surfaced 400 m running track, with subjects attached to an apparatus that enabled power calculation from force and velocity measurements. For the

STR, athletes performed a maximal sprint for 120 m against a load of 18% BM resistance, chosen from pilot tests in order to allow efforts between 25-30 seconds. Since time to cover 120 m during the STR ranged from 25 to 30 seconds, Lima et al. (2011) analyzed MP from 0-25 seconds for all subjects. Results of the study indicated a significant difference ($p < 0.01$) between PP-STR and PP-WAnT (1720 ± 221 vs. 808 ± 130 W) and MP-STR and MP-WAnT (1391 ± 201 vs. 603 ± 87 W). However, significant relationships were found between STR and WAnT for peak and mean power expressed in absolute units (PP: $r = 0.82$, MP: $r = 0.82$; $p < 0.01$), but not relative to BM (PP: $r = 0.60$, MP: $r = 0.15$; $p < 0.05$). It was concluded that that a field based STR provides a useful alternative method for specific power assessment of running for athletes, coaches, and researchers whom need to evaluate such characteristics.

Motorized Anaerobic Treadmill Tests

Rusko, Nummela, and Mero (1992) developed a maximal anaerobic running power (MART) test. The test consists of repeated 20 second runs on a treadmill with 100 seconds of recovery between runs. During the first run, the treadmill was set at $3.97 \text{ m} \cdot \text{s}^{-1}$. Speed of the treadmill was increased by $0.35 \text{ m} \cdot \text{s}^{-1}$ for each consecutive run until the subject reached failure. It was concluded that this method allows for the evaluation of several determinants of maximal anaerobic performance. In 1996, Nummella, Alberts, Rijntjes, Luhtanen, and Rusko (2007) explored the reliability and validity of the MART. It was found that, indeed the MART is reliable (P_{max} : $r = 0.92$, $p < 0.001$). On the other hand, correlations between the corresponding variables of the MART and WAnT were not significant. Therefore, it was concluded that the MART and WAnT measure slightly different anaerobic qualities.

Nonmotorized Anaerobic Treadmill Tests

Cheetham, Williams, and Lakomy (1985) devised a laboratory running test to examine the performance characteristics and metabolic responses of individuals whom maximally sprinted for 30 seconds on a NMT. Subjects completing the study were familiarized with the treadmill running on a day prior to testing and following an overnight fast, completed the all-out, 30 second sprint on the NMT. Subjects completing the test were asked to sprint maximally against an unspecified load (no additional load, only belt resistance/friction) while tethered to a flat cross-bar positioned at the rear of the treadmill during the 30 second test; however, individuals self-selected a running speed and accelerated or slowed down at will as in the case during free running. Pre and postcapillary blood samples were collected at 4 min after the warm-up and 1 and 5 min following the 30 second sprint. At the conclusion of each sprint, the averaged 1 second values of treadmill speed were calculated. Results of the study indicated that the treadmill sprint test was highly reproducible as reflected by the results of peak running speeds (T_1 5.49 ± 0.60 m.s⁻¹ and T_2 5.43 ± 0.65 m.s⁻¹; $r=0.93$) and the mean values for the distance covered (T_1 144.43 ± 13.26 m and T_2 144.12 ± 15.04 m). However, the percentage fall in speed was more variable (T_1 23.81 ± 7.76 % and T_2 21.84 ± 7.62 %) with a correlation coefficient of $r=0.73$. Blood lactate values showed significant increases at both 1 minute and 5 minutes (Pre-sprint: Rugby Players (RB), 1.37 ± 0.80 mM; Cross Country Ski (CCS), 1.48 ± 0.50 mM; Post-sprint (1 min): RB, 10.05 ± 2.97 mM; CCS, 7.78 ± 1.51 mM; Post-sprint (5 min): RB, 17.89 ± 1.12 mM; CCS, 14.49 ± 1.79 mM). It was concluded that a 30 second maximal sprint on a NMT proved reliable for the examination of the performance and metabolic responses of athletes to sprint running in a laboratory.

Elliptical Wingate

Ozkaya et al. (2009a) set out to modify an elliptical trainer and determine a suitable workload in order to conduct Wingate anaerobic testing (WAnTet). The study was conducted in four stages: (a) the integration of a computer interface and software was implemented onto an *electromagnetically braked* elliptical trainer, (b) a pilot study of 5 subjects was conducted on the modified elliptical trainer to determine electrical signaling errors and to estimate a convenient range of test loads for WAnTet (0.5 to 1.3 W/kg), (c) optimal WAnTet loads were examined in order to determine the most suitable load via logical error analyses, and (d) test-retest study was performed using the most suitable (1.0 watt/kg) WAnTet load on subsequent days at the same time of day. Measures of PP, MP, FI, and change in blood lactate (Δ La) were analyzed. The WAnTet included a warm-up, acceleration bursts, a short unloaded period just before the test applications, and verbal motivation. The warm-up for the WAnTet was performed at 20% of the actual test load. In contrast to the WAnT cycling protocol, subjects were standing while they performed the WAnTet exercises.

Test and retest results of the PP (1477 ± 258 and 1484 ± 271 W), MP (1134 ± 209 and 1120 ± 208 W), FI (49 ± 10 and 49 ± 10 %) and Δ La (12.6 ± 1.7 and 12.4 ± 2.1 mmol/L) ($r=0.94, 0.94, 0.80,$ and 0.74 respectively; $p < 0.001$) were highly correlated, demonstrating a high test-retest reliability for the WAnTet. Ozkaya and colleagues (2009a) concluded that the WAnTet may be used to measure anaerobic power and anaerobic capacity of athletes and may be substituted for the usual Wingate anaerobic test.

Ozkaya, Colakglu, Fowler, Kuzucu, & Colakoglu (2009b) followed up with a

study to evaluate and compare PP, MP, FI, and Δ La between WAnTet and WAnT (cycling) in male university athletes. Results of the study found that PP and MP for the WAnTet were higher compared to the WAnT (1463 ± 238 vs. 879 ± 162 W and 1127 ± 191 vs. 649 ± 82 W, respectively; $p < 0.001$). Fatigue index of WAnTet and WAnT were similar (49.8 ± 10.3 and 46.9 ± 8.3 , respectively; $p = 0.054$), but Δ La values were higher for WAnTet than for WAnT (12.9 ± 1.7 mM vs. 9.2 ± 1.5 mM, respectively; $p < 0.001$). It was concluded from the study, that higher anaerobic power and capacity was measured in male athletes performing the WAnTet, compared to similar testing on the WAnT. It was suggested that greater power outputs may be expected when measured on the elliptical trainer because more leg, hip, trunk, and upper extremity muscles are recruited than during the cycling WAnT.

Ozkaya, Colakoglu, Kuzucu, and Yildiztepe (2012) recently modified an elliptical trainer using a *simple mechanical brake system*, instead of the electromagnetically braked modification, in order to develop a Mechanically Braked Elliptical Wingate Test (EWT). The study consisted of 3 phases: (a) an engineering study to design and modify the elliptical trainer, (b) a pilot study to determine the load for the primary study, and (c) a primary study to determine a proper test load (i.e. to reveal the most efficient anaerobic test outcomes) and to evaluate the test-retest reliability of the selected load using the EWT.

Once the elliptical was modified, a pilot study was conducted on a range of loads (12-24% BM) to determine a proper load range for the primary study. It was determined that loads of 16-20% were optimal for primary testing. Importantly, in the optimal workload range, it was determined that 18% of BM was the most effective load for

reaching maximum anaerobic output for whole-body tests on the EWT. During primary EWT testing, all loads were randomly tested. A warm-up prior to testing was implemented consisting of (a) 5 min of elliptical at 80-90 RPMs at a load of 20% of the day's randomly assigned workload, (b) three acceleration bursts during the 3rd, 4th, and 5th min, lasting 2-3 seconds each with verbal cues, and (c) a dynamic warm-up period, which included relevant muscle groups. Following the dynamic warm-up, subjects performed the EWT, consisting of a 30 second all-out test duration at the day's randomly selected load with verbal motivation to facilitate maximum anaerobic power and capacity results. A retest study was performed using the same standards on subsequent days at the same time of the day. Values of PP, MP, minimum power, power drop, FI, and ΔLa were evaluated after testing for each load. It was found that test-retest analyses of the EWT was reliable especially of power outcomes for 18% BM, which was the highest correlated of the optimal workloads.

Conclusion

It has been generally accepted that the majority of anaerobic tests are reliable in motivated subjects and that they correlate highly with each other. Considering variables such as human subject classification (i.e. sprinter vs. distance runner), age, sex, subject training status, motivation, warm-up, the "time of day" effect, hydration status, and test familiarization is imperative for optimal performance during anaerobic testing. The WAnT has been the traditional and most commonly used method for estimating anaerobic power and capacity (Bar-Or, 1987). However, the use of the WAnT for evaluation of individuals partaking in activities other than cycling has been criticized due to the WAnT's nonspecific nature (Chia & Lim, 2008; Falk et al., 1996). Therefore, the

purpose of this study was to determine the test-retest reliability of a newly developed anaerobic sprint running test (ASRT) on a NMT that assesses anaerobic power and anaerobic capacity.

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