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VALIDITY AND RELIABILITY OF THE HAWAI'I ANAEROBIC  
RUN TEST

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## **PART I**

### **INTRODUCTION**

Energy required for the performance of exercise is produced via aerobic and anaerobic biochemical processes that collectively determine metabolic cost. Metabolic cost is assessed directly for the aerobic system (e.g.  $\text{VO}_2$  max, ventilation, blood lactate, etc.), but is assessed indirectly for the anaerobic system (e.g. work, fatigue, etc.), since the substrata needed for direct quantification are located inside the muscle cell. These direct measurements require complex and invasive techniques such as muscle biopsy sampling and magnetic resonance procedures (Heck, Schultz, & Bartmus, 2003), which provide limited information specific to the muscle tissue sampled (Scott, Roby, Lohman, & Bunt, 1991). Consequently, a variety of anaerobic tests have been developed to indirectly quantify different components of the anaerobic metabolic processes, (PC-ATP and glycolytic contributions). Tests include laboratory tests (bicycle ergometer and treadmill tests), shuttle runs, and field tests.

Currently the most frequently used and accepted anaerobic test is the Wingate Anaerobic Test (WAnT), which is designed to assess anaerobic capacity while cycling (Bulbulian, Jeong, & Murphy, 1996; Vandewalle, Peres, & Monod, 1987). The WAnT protocol involves 30 seconds of maximal exercise that results in second by second calculations of peak power, mean power, and percent power decrease. Wingate post exercise maximal blood lactate concentrations have been reported to correlate with total work output (Tamayo, Sucec, Philips, Bicono, & Laubach, 1984). Additionally, WAnT peak power has been identified as the defining variable between anaerobically and

aerobically trained males (Tharp, Johnson, & Thorland, 1984; Taunton, Maron, & Wilkinson, 1981). While the muscle specificity of the WAnT makes it an acceptable test of the anaerobic power of cyclists, it may not be accurate in predicting the anaerobic power of runners (Baker & Davies, 2002; Tharp, Newhouse, Uffelman, Thorland, & Johnson, 1985; Falk et al., 1996).

Assessments of anaerobic capacity designed more specifically for runners include laboratory treadmill tests, shuttle run tests, and field sprint tests. Treadmill test accuracy is questionable for the following reasons, (1) inability to run at maximum speed, (2) difficulty finding an optimal stride, and (3) a decreased energy requirement (Schnabel, & Kindermann, 1983; Frishberg 1983). Shuttle run test accuracy is also questionable, since they are designed to assess agility and recovery capabilities. Sprint field test assessments include the use of maximal post-exercise blood lactate concentrations for varying distances, and sprint components such as total time, peak and mean velocity. Blood lactate is an accurate and reliable measure of lactic capacity as long as criteria such as recovery mode and sampling site are controlled (di Prampero, Peeters, & Margaria, 1973). Thus, a direct correlation between blood lactate levels and running performances at different distances exists (Lacour, Bouvat, & Barthelemy, 1990; Ohkuwa, Kats, Katsumata, Nakao, & Miyamura, 1984; Borsetto, et al., 1989). Peak blood lactate concentrations have also correlated significantly with velocity over the last 165 meters of a 200-meter sprint (Hautier et al., 1994). However, blood lactate concentrations should be used in conjunction with other data such as peak velocity, mean velocity, and deceleration to assess anaerobic potential. Maximal attained running speed (peak velocity) is described as the best predictor of performance in 100 and 150-meter sprints

of men (Berthoin, Dupont, Mary, & Gerbeaux, 2001; Volkov & Lapin, 1979) and can distinguish between trained sprinters and novice runners (Volkov & Lapin, 1979).

Therefore, an anaerobic assessment test designed specifically for runners should be developed. The optimal duration of this anaerobic run test should be 20-30 seconds to allow a sufficient amount of time to stress the phosphagen and anaerobic glycolytic systems (Thompson, 1981; Green & Dawson, 1993). A two hundred meter sprint would approximate the 20-30 second duration as female sprinters complete this distance in approximately 22 seconds. Consequently, the “average” female and male should complete this distance in 25-35 seconds. As such, a 200-meter sprint would simulate the duration of the WAnT (30 seconds), which has been proven to be a reliable test of anaerobic capacity (Bar-Or, 1987). Additionally, since blood lactate concentration has been commonly used for a marker of anaerobic energy production, as it is an end product of anaerobic glycolysis, it should be used along with other variables (e.g. velocity, fatigue) to assess the anaerobic capacity of runners.

The purpose this research study was to determine the validity and reliability of the Hawaii Anaerobic Run Test (HART). The following hypotheses were made: 1) there will be no difference in lactate concentrations between the WAnT and the HART; 2) there will be no difference in lactate concentrations, time, or velocity between two trials of the HART; and 3) correlation for lactate concentrations, time, and velocity, will be high between two trials of the HART.

## **METHODOLOGY**

### **Subjects**

Thirteen well conditioned National Collegiate Athletic Association (NCAA) Division I female track and field athletes participated in this study. Consent forms approved by the University of Hawaii Human Subjects Committee were signed by all subjects.

### **Research Design**

Anaerobic potential was assessed via two test modes: the HART and the WAnT. Validity was assessed via comparison of the blood lactate HART and WAnT. Reliability was assessed via intraclass correlation coefficients for two trials of the HART. Correlations between the HART and the WAnT were also made for the following variables: peak power and velocity, mean power and velocity, and percent decrease.

**Hawaii Anaerobic Run Test.** The HART trials were performed on a Mondo track (Mondo USA, Lynnwood, WA). Testing protocol included a 5-minute warm up, followed by the HART. Subjects were instructed to sprint as hard and as fast as possible throughout the entire 200-meter distance. The HART protocol involved a standard track gun start (standing start). Sprint times were recorded using Speedtrap II (Brower Timing Systems, Draper, UT) photoelectric timing cells placed at 25, 50, 100, 150, 175, and 200 meters to measure the sprint variables of peak velocity, mean velocity, and percent decrease in velocity. Timing was initiated automatically as the cells were triggered by

the starting gun and split times were collected as subjects disrupted the infrared signal between timing cells. A Skymate wind meter (Speedtech, Great Falls, VA) was also used to factor out wind assistance ( $<2.0$  mph). Subjects participated in two trials of the HART, separated by a 20-minute rest period. Track competition footwear (e.g. spikes) were worn by all subjects during the HART.

**Wingate Anaerobic Test.** The Wingate 30-second Anaerobic Tests were administered on a Monark cycle ergometer (Monark, Stockholm, Sweden) 72 hours following administration of the HART. Testing protocol involved a 5-minute warm against 1 kp resistance on a similar Monark cycle ergometer. Ergometer seat height was adjusted for each subject and the feet were firmly strapped to the pedals via toe clips. Resistance for the WAnT was set at 0.075 percent of the subjects' body mass. Subjects were instructed to begin pedaling as hard and as fast as possible (approximately 100 rpm) upon hearing the command "On your mark, set, go." Upon reaching a maximal pedaling rate, the resistance was applied to the flywheel, and the test time began. Verbal encouragement and instructions to maintain maximal pedaling rates were given throughout the 30-second test. Peak power, mean power, and percent decrease in power data were collected from second by second intervals.

**Blood Lactate Sampling.** Blood lactate concentration analysis involved a collection of blood from a free flowing digit puncture of a warmed hand after an active (walking) recovery 7 minutes after completion of each test. Blood lactate samples (25  $\mu$ l aliquots) were analyzed with a YSI 1500 Sport Lactate Analyzer (Yellow Springs Instrument Co., Inc., Yellow Springs, OH) performed in duplicate and the mean value was used in the statistical analyses.

### **Statistical Analysis**

Descriptive statistics and correlations were generated using SPSS v12.0.

Intraclass correlation coefficients (ICC [1, 1]) were used to test reliability of the HART.

Standard errors of measurement (SEMs) for test-retest reliability were also determined.

Paired *t*-test analysis was used to determine differences in lactate concentrations between

the HART and the WAnT as well as between the two HART trials. Pearson product

correlations were used to examine all HART and WAnT data. The alpha level was set at

0.05.

## RESULTS

Subjects' mean age and body mass were  $20.2 \pm 1.2$  years and  $65.2 \pm 14.9$  kilograms respectively. The peak power, peak power  $\cdot \text{kg}^{-1}$ , mean power, mean power  $\cdot \text{kg}^{-1}$ , percent decrease, maximal post exercise blood lactate concentration data from the WAnT and HART, and the corresponding *t*-test are presented in Table 1.

**Table 1.** Wingate Anaerobic Test Data (mean  $\pm$  StD).

Variables	WAnT	HART	<i>t</i> -test	P value
Lactate (mmol)	$8.8 \pm 2.2$	$10.0 \pm 2.30$	2.813	<0.01
Peak Power (W)	$1318.8 \pm 346.1$			
Peak Power ( $\text{W} \cdot \text{kg}^{-1}$ )	$20.7 \pm 1.5$			
Mean Power (W)	$1107.0 \pm 287.0$			
Mean Power ( $\text{W} \cdot \text{kg}^{-1}$ )	$17.4 \pm 1.0$			
Percent Decrease	$32.3 \pm 5.7$			

No significant correlations were found among WAnT variables or between 200-meter sprinting time and any WAnT variable. Paired *t*-test analysis showed a statistically significant difference in blood lactate concentrations between tests. However, a significant correlation ( $r= 0.78$ ,  $P<0.01$ ) was found between HART and WAnT maximal post exercise blood lactate concentrations (see figure 1). HART mean time, peak velocity, mean velocity, and post exercise blood lactate concentrations, standard deviations, reliability coefficients, and paired *t*-test results for trials one and two are listed in Table 2.

**Table 2.** HART trial-to-trial means, standard deviations, reliability coefficients, and paired t-test values.

Variables	Trial 1	Trial 2	<i>t</i> -test	P value	ICC (SEM)
Lactate (mmol)	10.00 ± 2.30	10.83 ± 3.22	-1.809	0.10	0.89 (1.32)
Time (s)	29.26 ± 2.61	29.35 ± 2.65	-0.331	0.75	0.97 (0.63)
Peak Velocity (m·s <sup>-1</sup> )	7.83 ± 0.72	7.73 ± 0.76	1.290	0.22	0.97 (0.19)
Mean Velocity (m·s <sup>-1</sup> )	6.86 ± 0.59	6.83 ± 0.62	1.043	0.32	0.98 (0.12)
Percent Decrease	16.99 ± 3.99	15.30 ± 3.89			

\*ICC = intraclass correlation coefficient; SEM = standard error of measurement

Test-retest results for peak velocity, mean velocity, and maximal post exercise blood lactate concentrations were analyzed using intraclass correlation coefficients (ICC [1, 1]) to determine reliability of the test (n= 13). The intraclass correlation coefficients indicate that 97%, 98%, and 89% of the variance between trials was reliable, and associated SEM values were low (<1.32). Paired t-tests showed no differences in blood lactate, time, peak velocity, or mean velocity between the two HART trials. Correlations between trials were  $r = 0.94$ ,  $0.96$ , and  $0.88$  for peak velocity, mean velocity, and lactate concentrations respectively (see figures 2-4). The HART was therefore considered to be a reliable measure of anaerobic performance for Division I-A female track and field athletes. A significant correlation between peak velocities with running time ( $r = -0.952$ ,  $P < 0.01$ ) was found; however, no other significant correlations among HART variables were identified.

## DISCUSSION

The most significant finding of this study was that the HART, designed to more specifically assess the anaerobic capacity of runners, was found to be a valid and reliable test. A significant correlation ( $r = 0.78$ ,  $P < 0.01$ ) was found between HART and WAnT blood lactate concentrations indicating that both tests, which are of similar duration, are also anaerobic in nature. Interestingly, the results revealed that maximal post exercise blood lactate concentrations were higher in female track and field athletes following the HART ( $10.0 \text{ Mmol} \pm 2.3$ ) than in the WAnT ( $8.8 \text{ Mmol} \pm 2.2$ ). HART and WAnT were examined via a paired *t*-test that revealed significant differences in blood lactate concentrations. Since higher levels of blood lactate may be one contributing factor to anaerobic performance capacity (Fujitsuka, Yamamoto, Ohkuwa, Saito, & Miyamura, 1982), our findings indicate that the HART may have afforded these runners a more specific anaerobic effort than the WAnT. However, more research is needed to corroborate these findings. Additionally, since anaerobic contributions to maximal effort exercise lasting 10-seconds to 1-minute range from 65-85% of the total energy output (Astrand, & Rodahl, 1986), and since the HART is a maximal exertion test lasting approximately 30-seconds, face validity can be assumed.

Results of the present study revealed a high correlation between peak velocity and 200-meter sprint time ( $r = -0.95$ ) (see figure 5) and indicated that peak velocity was attained between 4.23 - 8.86 seconds, corresponding to a distance of 25-50 meters (see figure 6). Similar findings were documented by Volkov & Lapin (1979), and Berthoin et al. (2001) who found correlations of  $r = -0.855$  and  $r = -0.90$ , respectively between peak

velocity and 100 meter sprint performance (total time) of sprinters. These authors also found that peak velocity was attained within 4-5.6 seconds, corresponding to a distance of 30-50 meters. Peak velocity appears to be a more sensitive indicator of sprint time as distance increases from 100 to 200 meters.

The results of the present study showed no significant relationship between maximal post exercise blood lactate concentrations and any variable from the HART. Significant correlations between maximal post exercise blood lactate concentrations and 400 meter mean velocity in long distance runners and untrained subjects ( $r = 0.71$  and  $0.76$ ) have been reported. However, correlations failed to reach significance for sprinters ( $r = 0.38$ ,  $P > 0.05$ ) (Ohkuwa et al., 1984). A similar non-significant correlation between mean velocity over 200 meters and blood lactate concentration was found in our study ( $r = 0.37$ ,  $P > 0.05$ ). This non-significant correlation may be due to the fact that the subject pool in our study consisted of field athletes, heptathletes, long distance runners, and sprinters. Thus, no conclusions can be made concerning correlations as they pertain to specific groups within this study. Correlations between run times to various distances and maximal post exercise blood lactate concentrations have been dichotomous. Significant correlations of  $r = -0.65$ ,  $-0.78$ , and  $-0.79$  between run times to 100, 200, and 400 meters and blood lactate concentrations have been reported (Fujitsuka et al., 2001), while non-significant correlations between 100 and 200 meter run times and blood lactate concentrations have also been shown (Hautier et al., 1994). Findings of our study indicated a moderate correlation  $r = -0.50$  between 200 meter run time and blood lactate concentration.

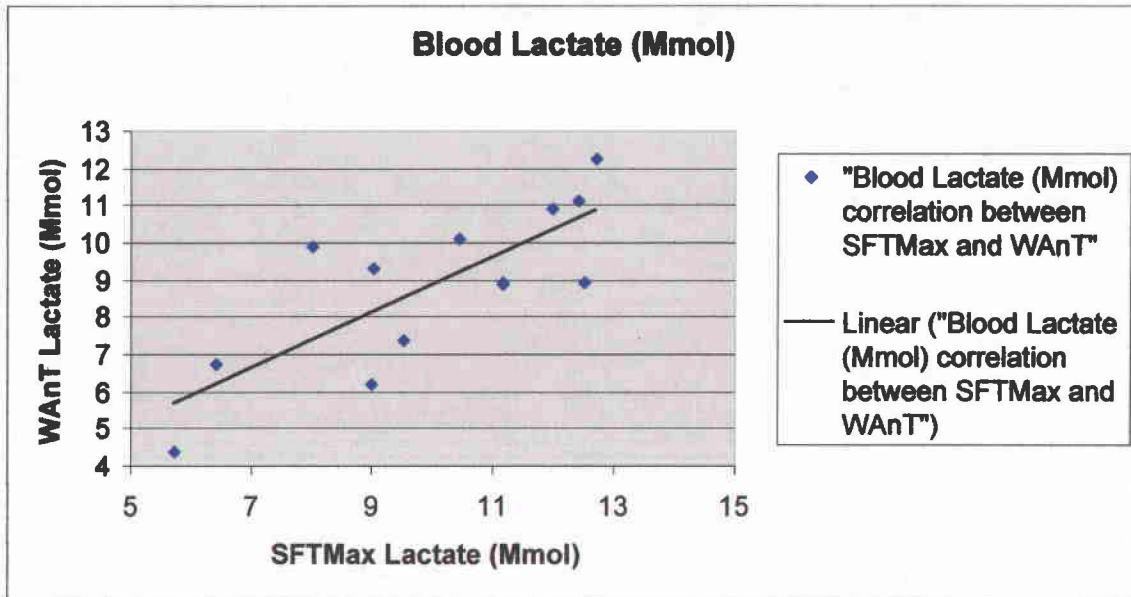
No significant relationships were revealed between 200-meter sprint time and any variable from the WAnT in the present study. Previous findings indicated both significant and non-significant relationships between run times to various distances and WAnT peak and mean power. Significant correlations of  $r = -0.886$  and  $-0.824$  were reported between 100 meter run times and WAnT peak and mean power for female 100 meter sprinters, respectively (Meckel, Atterbom, Grodjinovski, Ben-Siera, & Rotstein, 1994). Likewise, a significant correlation of  $r = -0.82$  was also revealed between 200 meter run times and WAnT mean power (Patton, & Duggan, 1987). Conversely, no significant relationships were reported between 50 and 600-yard sprint and run times and WAnT mean power ( $r = -0.26$  and  $-0.53$ ), respectively (Tharp et al., 1985). The lack of significant correlations between 200 meter run times and WAnT peak ( $r = 0.39$ ) and mean power ( $r = 0.26$ ) revealed in our study suggests that cycle ergometry is not an effective indicator of 200 meter sprint performance in female track and field athletes.

A high percentage of the variance between test-retest trials was found to be reliable when assessed via intraclass correlation coefficients. The SEMs for the HART were low, with SEMs of 0.63 seconds in sprint time, 0.19 m/s in peak velocity, 0.12 m/s in mean velocity, and 1.32 mmols in post exercise blood lactate concentrations. The SEM is a representation of the range in which the true score of each subject can be calculated to a 95% confidence interval by adding and subtracting the product of 1.96 and the SEM value ( $\text{score} \pm 1.96[\text{SEM}]$ ) from the subjects score. Values that fall outside this calculated range are then representative of a true change. Paired *t*-test values showed no significant differences between HART trials. Figures 2-4 present the high correlations of peak velocity, mean velocity, and lactate concentrations between the two HART trials.

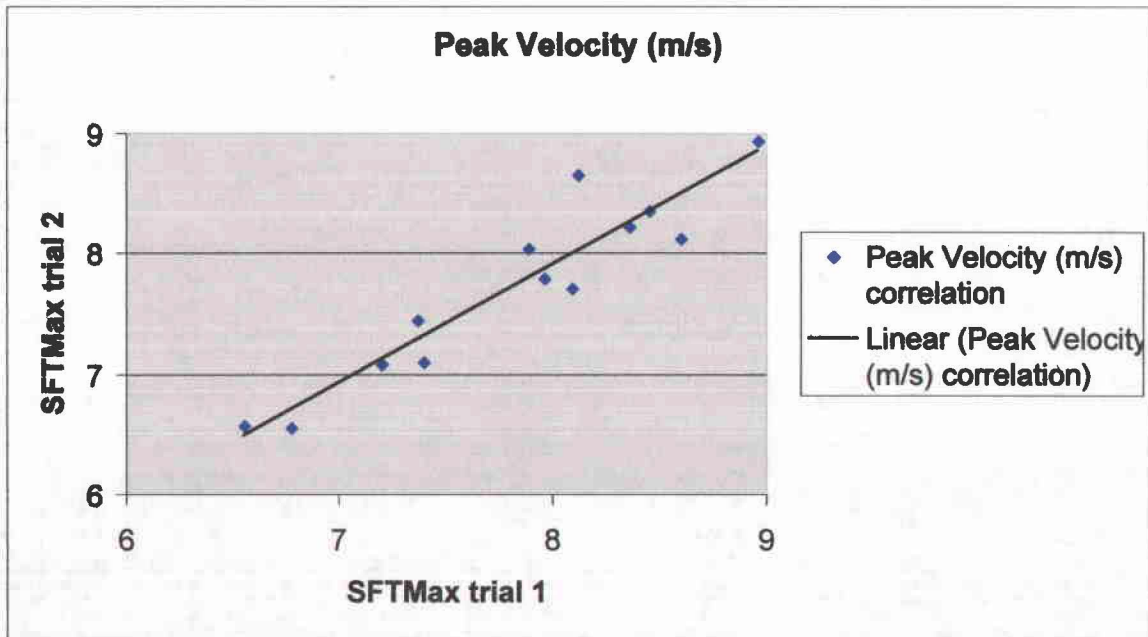
In summary, high ICCs and low SEMs show that the HART is a reliable test. Blood lactate responses suggest a high anaerobic contribution to energy production. Correlations with WAnT scores support the validity of the HART as a test of anaerobic power. The lactate results also suggest that the HART is more specific for runners than the WAnT. Face validity can also be assumed. It was concluded that the HART was a reliable and valid test for determining anaerobic power of runners.

Based on the statistical analyses, null hypothesis 1 was rejected and null hypothesis 2 was not rejected. Additionally, high correlations were revealed for all dependent variables tested between two trials of the HART.

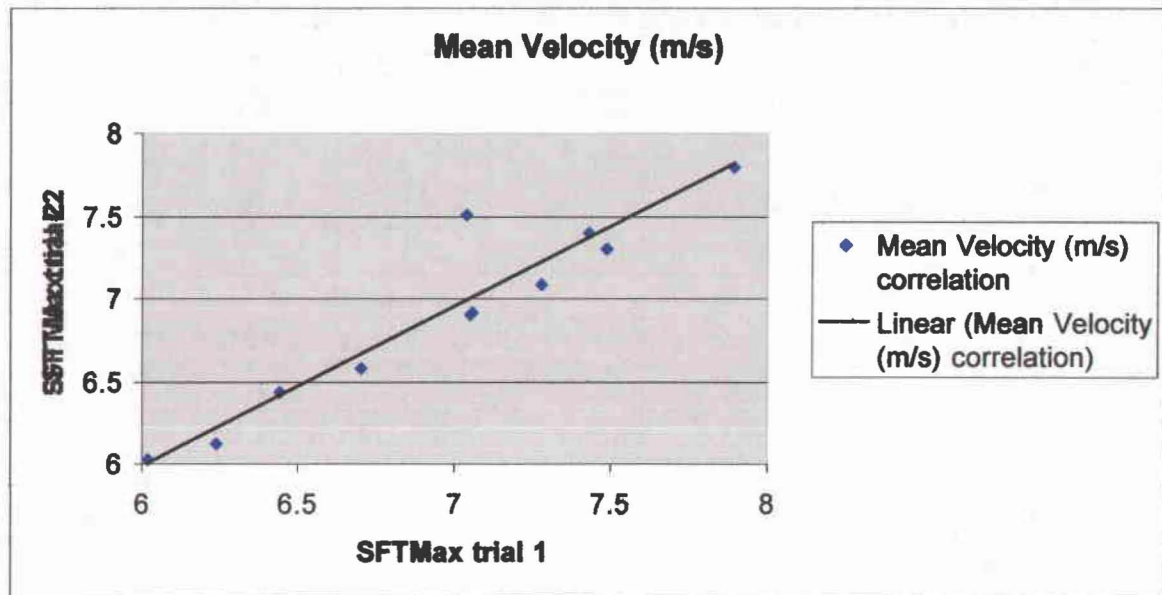
**Figure 1. Blood Lactate Correlation Between HART and WAnT.**



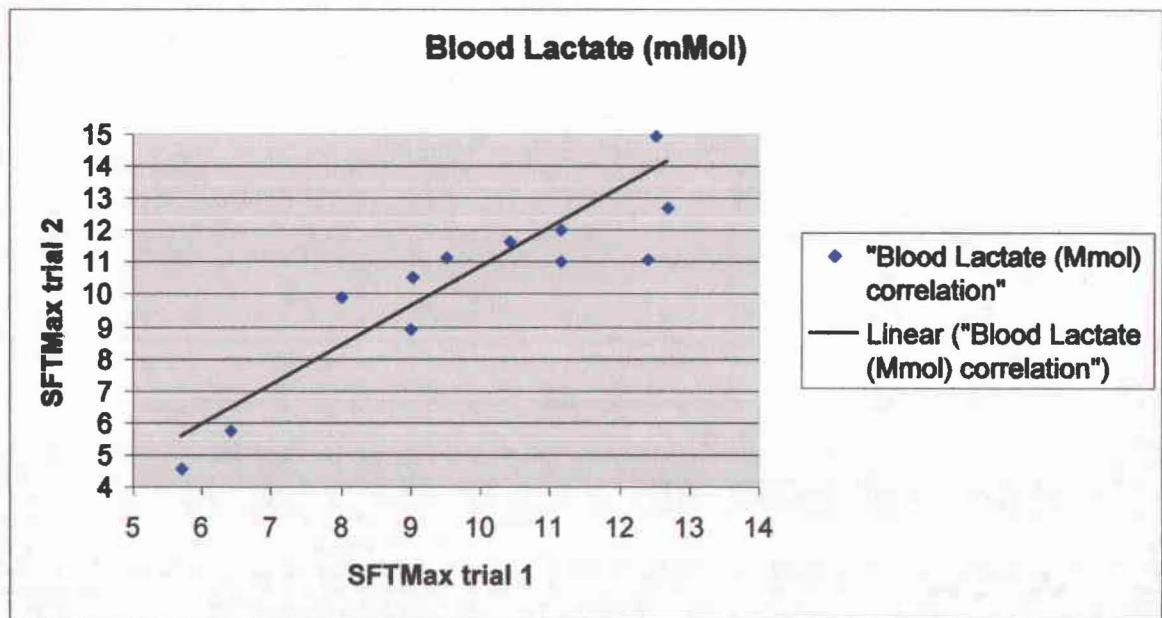
**Figure 2. Peak Velocity Correlation Between HART Trials.**



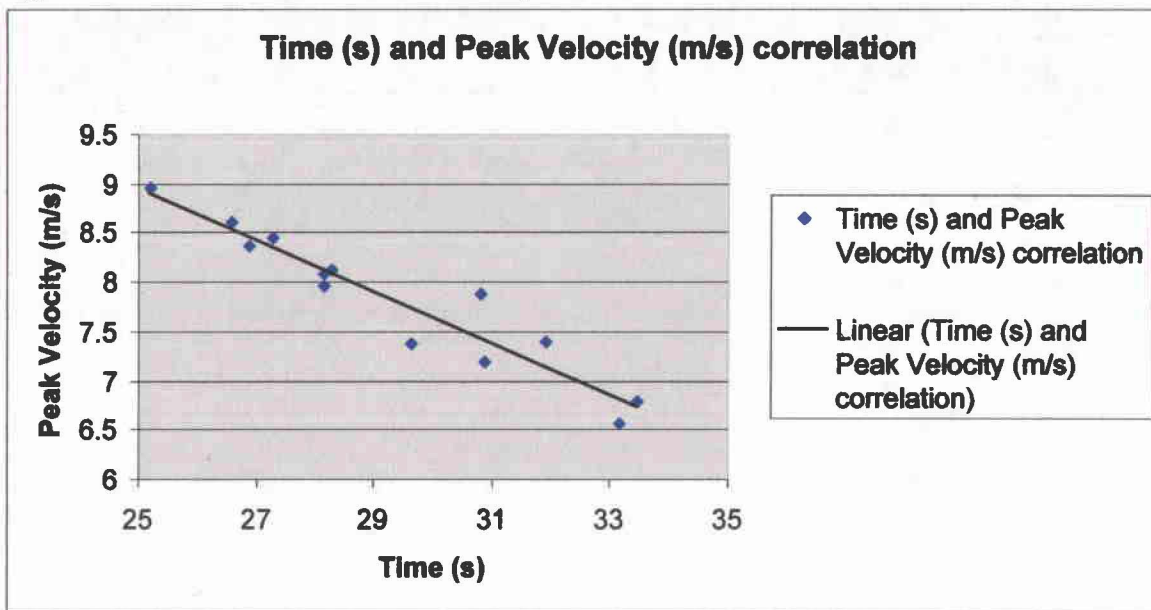
**Figure 3. Mean Velocity Correlation Between HART Trials.**



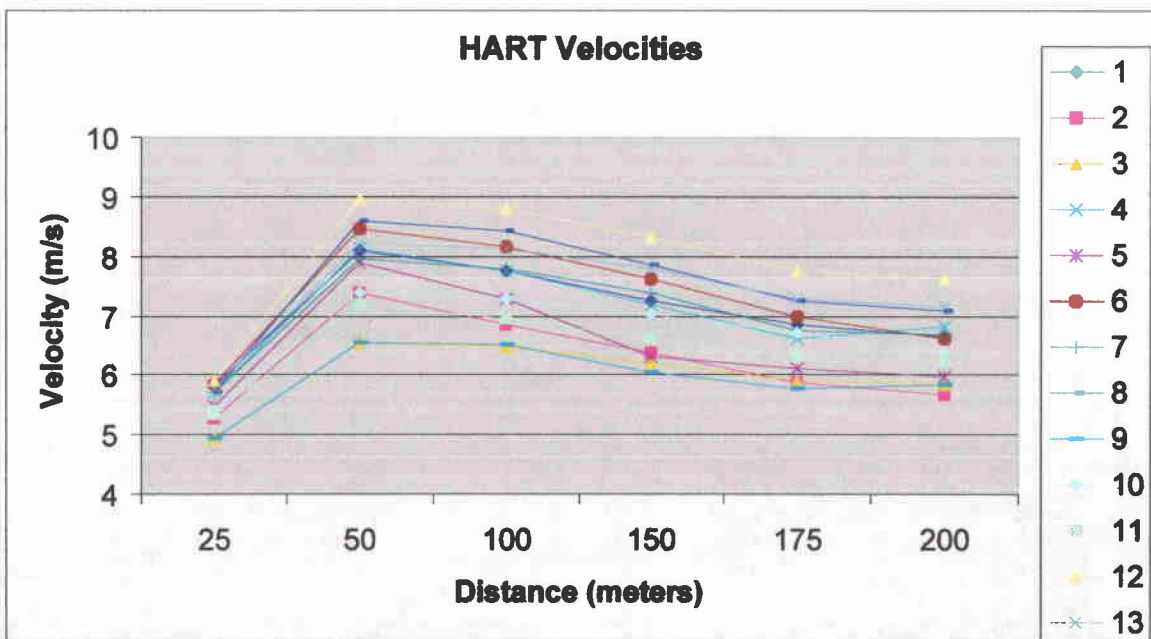
**Figure 4. Blood Lactate Correlation Between HART Trials.**



**Figure 5. HART Time and Peak Velocity Correlation.**



**Figure 6. HART Velocities Over Distance**



## PART II

### REVIEW OF LITERATURE

#### Anaerobic Performance Assessment Overview

Anaerobic power (recruitment of the phosphagen system) and capacity (recruitment of the glycolytic system) are important contributors of the energy required for athletic performance. Anaerobic power and capacity have long been investigated and many tests and techniques have been developed in efforts to determine the anaerobic potential in runners. These include treadmill tests, ergometer tests, and sprint field tests, all of which many times employ blood lactate sampling in order to assess the involvement of anaerobic metabolism during exercise.

#### Blood Lactate Concentrations Following Maximal Exercise

Fujitsuka, Yamamoto, Ohkuwa, Saito, and Miyamura (1982) conducted a study to determine  $[La]_{pk}$  following maximal treadmill running. Nineteen male subjects participated in this study and completed an exhaustive treadmill sprint lasting approximately one minute. Blood was drawn at varying intervals during 70 minutes of recovery after the run in order to ascertain  $[La]_{pk}$ . Validity of  $[La]_{pk}$  as a determinant of anaerobic performance was assessed via fifteen subjects who completed 100, 200, and 400-meter maximal sprints on a separate day.

Student's *t*-test indicate that  $[La]_{pk}$  was reached 6.44-9.95 minutes after maximal exercise of approximately one minute, and that the mean time value was 7.65 minutes. Blood lactate concentrations at 7.65 minutes of the fifteen subjects were plotted against

their 100, 200, and 400-meter run times, and correlations of  $r = -0.65$ ,  $r = -0.78$ , and  $r = -0.79$  were found, respectively. The investigators concluded that the ability to accumulate higher blood lactate concentration levels may be attributed to anaerobic performance capacity and a valid indicator of anaerobic work capacity in man.

Ohkuwa, Kato, Katsumata, Nakao, and Miyamura (1984) conducted a study to investigate peak blood lactate concentrations ( $[La]_{pk}$ ) as an indicator of anaerobic capacity in sprinters and long distance runners after 400-meter and 3,000-meter runs. Eight sprinter, eight long distance runners, and seven untrained subjects participated in a 400-meter and 3,000-meter maximal run, immediately after which  $[La]_{pk}$  samples were drawn.

Results showed that  $[La]_{pk}$  significantly correlated with mean velocity for the 400-meter run in the untrained and long distance runners ( $r = 0.76$ ,  $p < 0.05$ ;  $r = 0.71$ ,  $p < 0.05$ ), but failed to reach statistical significance in the sprinters ( $r = 0.38$ ,  $p > 0.05$ ). Student's *t*-test results revealed significantly higher  $[La]_{pk}$  in the sprinters than in the other two groups after the 400-meter run.

Hirvonen, Rehunen, Rusko, and Harkonen (1987) investigated the breakdown of ATP and CP during short-term maximal sprinting. Seven male sprinters were instructed to sprint maximally over distances of 40, 60, 80, and 100-meters. Running speeds were calculated using photoelectric cells placed at ten-meter intervals. Blood lactate concentrations were taken immediately after the sprints, and at 2, 4, 6, 8, and 10 minutes following completion of the test in order to identify  $[La]_{pk}$ . Peak running speed was calculated between 40 and 60 meters. Results also indicated that  $[La]_{pk}$  appeared at approximately 6 after the 100-meter sprint.

Nummela and Rusko (1995) investigated the time course of anaerobic and aerobic energy expenditure during short-term exhaustive exercise in sprint and endurance athletes. Eight male 400-meter runners and six endurance athletes completed a maximal run of 400-meters to exhaustion upon a motorized treadmill. Blood lactate concentrations were taken at rest and at 0, 3, 6, 9, 12, and 15 minutes following completion of the test. Results indicated that the sprint group had significantly higher  $[La]_{pk}$  than the endurance group (16.6 versus 13.8 mmol/kg). Blood lactate levels were highest approximately 7.5 minutes following exercise in the sprint-trained athletes.

Weinstein, Bediz, Dotan, and Falk (1998) examined the reliability of  $[La]_{pk}$ , heart rate, and plasma volume following the WAnT. Fifteen males and 14 females performed two trials of the WAnT with identical resistance loads 3-7 days apart. Blood lactate samples were drawn from the fingertip of a prewarmed hand on six occasions: before warm-up, immediately before the test, and at 3,5,7, and 9 minutes following the warm-up. Differences in  $[La]_{pk}$  were analyzed with repeated measures ANOVA and assessed for test-retest reliability via intraclass correlation coefficients. Pearson correlation coefficients were also calculated.

No significant differences were found in  $[La]_{pk}$  between two trials of the WAnT. High intraclass correlation coefficients ( $r = 0.926$ ;  $P < 0.001$ ) and Pearson correlation coefficients ( $r = 0.86$ ) indicated that  $[La]_{pk}$  following the WAnT was reliable. The authors concluded that measures of  $[La]_{pk}$  following the WAnT are reliable and can be used for comparisons between subjects and treatments and as characteristics of the response to WAnT.

**Summary.** Peak blood lactate concentrations have been significantly correlated with mean velocity during a 400-meter sprint in untrained and long distance runners, and has been shown to reach significantly higher levels in sprinters as compared to untrained and long distance runners (Ohkuwa et al., 1984). Research results also indicate that  $[La]_{pk}$  is recorded at approximately 6-7.65 minutes following maximal exercise of different durations (Hirvonen et al., 1987; Nummela et al., 1995; Fujitsuka et al., 1982). In addition,  $[La]_{pk}$  has been shown to correlate with 100, 200, and 400-meter run times (Fujitsuka et al., 1982), and was revealed as a reliable measure of anaerobic capacity following performance of the Wingate Anaerobic Test (Weinstein et al., 1998).

### **Cycle Ergometry Tests on Runners**

Taunton, Maron, and Wilkinson (1981) conducted a study to compare the WAnT and the Margaria Power Test. Subjects were seven long distance runners (LD) and eight middle distance runners (MD). The WAnT consists of a thirty second all out exercise from which "Total Anaerobic Output," (An30), and anaerobic output from the first five seconds (An5) were calculated. Blood samples were drawn five minutes after completion of the tests in order to record blood lactate concentration levels. Subjects also completed a Margaria Power Test, which consisted of a maximum stair run.

No differences were revealed between mean blood lactate concentration levels for MD (8.6 mM) and LD (8.0mM) groups. In addition, no differences in power output were revealed during the Margaria Power Test between the two groups (MD = 109.6; LD = 109.5 kgm/sec). However, significant differences were found in the mean An5 of the

MD (61.4 kpm/min/kg) and LD (56.9 kpm/min/kg) groups. No differences were found in An30 between the two groups.

Tharp and Thorland (1984) conducted a study to determine the anaerobic power and capacity of elite sprinters' and runners' on the WAnT. Twenty-one female and 18 male track athletes, ages 10-15, participated in the WAnT and were divided into female and male sprinter and distance runner groups. Student's *t*-tests results indicated that males demonstrated significantly higher anaerobic power and capacity levels than females. In addition, male sprinters revealed greater anaerobic power and capacity than did the male distance runners. No significant differences in either anaerobic power or capacity were found between female sprinters and distance runners. The authors concluded that the WAnT can distinguish between sprint and distance running ability in males.

Tharp, Newhouse, Uffelman, Thorland, and Johnson (1985) conducted a study to compare sprint, run, and WAnT performances. Anaerobic capacity of fifty-six 10-15 year old males during a 50-yard sprint, a 600-yard run, and the WAnT was determined. Correlations among tests indicated that the WAnT was not a strong predictor of sprint and run times ( $r = -.26$  to  $-.53$ ) in this population. Results also indicated that the WAnT was a stronger predictor of sprint and run times when adjusted for body weight.

Patton and Duggan (1987) compared WAnT data to those from the isokinetic endurance, Margaria stair-climb, and 50 and 200-meter sprint field tests in 14 Army soldiers. During week one subjects performed the WAnT and the isokinetic endurance tests on separate days. During week two subjects performed the 50 and 200-meter sprints as well as the Margaria stair-climb test.

Correlation coefficients were calculated to assess the degree of association between these tests of anaerobic power. Indices of power output collected from the WAnT correlated significantly with sprinting ability. The correlation between mean power (W/kg) from the WAnT ( $r = -0.82$ , SEE 0.98) and 200-meter sprint test indicated that the WAnT could be used to predict 200-meter run performance to one second. The authors concluded that the single best index of anaerobic power was mean power from the WAnT, relative to body weight, since it showed the highest correlations with peak torque indices from the isokinetic tests ( $r = 0.761$ ) as well as from the sprint tests.

Granier, Mercier, Mercier, Anselme, and Prefaut (1995) conducted a study to investigate the aerobic and anaerobic contributions of WAnT performance in middle distance runners (MD) and sprinters (S). Seven subjects were ascribed to each group and underwent three exercise tests: a force-velocity test, the WAnT, and an incremental aerobic test. Breath by breath gas exchange was recorded during the WAnT, and blood lactate concentrations were recorded during 20 minutes of recovery from the WAnT.

Two-way ANOVA results indicated that MD had significantly higher oxygen uptake than S (4367 vs. 3481 ml/min). Conversely, venous plasma lactate values and peak and mean power outputs on the WAnT were higher in S (924 W and 662 W) than in MD (842 W and 578 W). The authors concluded that energy supply used for the WAnT was group specific and that the higher blood lactate concentrations in S resulted from their enhanced potential to derive energy from the glycolytic process.

Baker and Davies (2002) conducted a study to compare high intensity cycle ergometry and other high intensity field tests. Twelve members of a sprint squad

underwent a series of anaerobic tests including a 30 second all out cycle ergometry test, a 30-meter sprint, a 40-meter shuttle run, and vertical and horizontal jump tests.

Only moderate correlations were found between peak power from the cycle ergometer test and all other performance tests ( $r=0.51$ ,  $P>0.05$ ). Significant correlations were found among all performance tests excluding the cycle ergometer test. The investigators concluded that cycle ergometry results did not correlate well with the field tests because different components of high intensity exercise were compared and thus may not be indicative of sprint performance.

**Summary.** The above research results indicate that the WAnT is not a strong predictor of sprint and run performance over distances of 30 or 600-yards (Tharp et al., 1985), although it can be used to distinguish between male sprinters and distance runners (Tharp et al., 1984). Likewise, only moderate correlations were found between WAnT peak power and 30-meter sprint performance (Baker & Davies, 2002). Conversely, significant correlations have been found between mean power from the WAnT and 200-meter sprinting performance (Patton & Duggan, 1987). Male sprinters have shown to produce higher values of anaerobic power and capacity than male long and middle distance runners; however, this relationship has not been shown to be true in females (Tharp et al., 1984, Granier et al., 1994). Finally, higher anaerobic power and capacity values have been obtained in male than in female sprint and distance runners (Tharp et al., 1984).

## Cycle Ergometry Tests and Gender

Murphy, Patton, and Frederick (1986) conducted a study to compare anaerobic power between men and women. Nineteen male and 18 female physically active subjects performed the WAnT, from which peak power (PP), mean power (MP) and power decrease (PD) were computed. All three indices were also expressed relative to kilograms body weight and kilograms lean body mass.

Student's T-test results indicated that all values were significantly higher for men than women, except power decrease relative to kilograms lean body mass. Men demonstrated significantly higher peak power values (770 W, 10 W/kg) than women (503 W, 8.5 W/kg). Likewise, men demonstrated significantly higher mean power values (555 W, 7.3 W/kg) than women (334 W, 5.7 W/kg). The investigators concluded that significant physiological differences existed between men and women in the production of anaerobic power and capacity.

Meckel, Atterbom, Grodjinovsky, Ben-Sira, and Rotstein (1995) conducted a study to identify physiological differences among 30 female 100-meter sprinters. Subjects were divided into three groups according to their 100-meter sprint times. The ten fastest 100-meter sprinters were classified as the "fast" group, the next 10 fastest sprinters were classified as "average," and the slowest sprinters were placed in the "slow" group. The following data were collected for each subject: peak oxygen consumption, WAnT performance, body fat, strength, reaction time, flexibility and sprint skill, and correlated to 100-meter sprint time.

One-way ANOVA results indicated significant differences in WAnT peak power among the three groups (fast = 11.6 W/kg, average = 10.1 W/kg, slow = 8.1 W/kg).

Likewise, significant differences in WAnT mean power among the three groups was revealed (fast = 8.6 W/kg, average = 7.6 W/kg, slow = 6.8 W/kg). A significant correlation was found between 100-meter running time and WAnT peak power ( $r=-0.886$ ,  $p<0.001$ ) and mean power ( $r=-0.824$ ,  $p<0.001$ ) for all subjects. The authors concluded that the main difference among female 100-meter sprinters of different performance levels is their ability to produce muscular power and strength.

Bulbulian, Jeong, and Murphy (1996) investigated the relationship between the anaerobic components of the WAnT and the Critical Power Test, as well as differences in anaerobic capacity reserve between males and females. Thirteen males and 16 females performed three exercise tests: the WAnT, the Critical Power Test, and an aerobic power test. Results indicated significant differences in WAnT power output between males and females (694.2 W vs. 427.2 W). Aerobic estimates of females were significantly lower than males (35.4 ml/kg/min vs. 41.7 ml/kg/min).

Sands et al. (2004) compared peak and average power from the WAnT with the Bosco Anaerobic Tests. Peak blood lactate concentration levels were also compared to determine if the tests induced similar anaerobic energy demands. Nine female field event jumpers and throwers, and eleven male sprinters and middle distance runners participated in both the WAnT and the Bosco jumping tests.

Analysis of Variance results indicated that WAnT average power was statistically different by sex, in that men demonstrated significantly higher values than women (690 W vs. 531 W). Additionally, men demonstrated significantly higher WAnT peak power values than women (984 W vs. 746 W). Wingate Anaerobic Test  $[La]_{pk}$  was statistically higher in men (~15 mmol) than women (~12 mmol).

**Summary.** Males have been shown to produce higher peak and mean power values on cycle ergometry tests (Sands et al., 2004, Bulbulian et al., 1996, Murphy et al., 1986), as well as higher peak blood lactate concentrations following maximal cycle ergometry testing (Sands et al., 2004). Significant differences have been found in WAnT peak and mean power among female sprinters of different performance levels, in that faster sprinters have demonstrated higher power values. In addition, significant correlations between female 100-meter sprint times and WAnT peak and mean power has been demonstrated (Meckel et al., 1995).

### **Sprint Field Tests**

Shaver (1975) conducted a study to investigate whether data from 100, 220, 440, 880-yards, and 1, 2, and 3-mile runs could be used to predict anaerobic work capacity and maximum aerobic power. Performance data of 30 untrained males aged 18 to 26 who performed all 7 runs were correlated with maximum oxygen intake, measured via a treadmill protocol, and anaerobic capacity, measured via administration of the Margaria Test of Anaerobic Power.

Results indicated that running performances of 100, 220, and 440-yards significantly correlated to anaerobic capacity ( $r = -.85, -.82, \text{ and } -.79$  respectively), while performance data on the other four distances significantly correlated with maximum oxygen uptake ( $r = -.35, -.43, -.76, \text{ and } -.82$ ). The investigator concluded that run distances of 100, 220, and 440-yards could be used to predict anaerobic capacity, whereas run distances of 880-yards, 1, 2, and 3 miles should be used to predict maximum oxygen uptake.

Volkov and Lapin (1979) examined the velocity curve in sprint running over a distance of 150 meters. Subjects were classified into two groups: 17 physical education students specializing in short-distance running (sprinters) and 23 beginning sprinters (beginners) who were instructed to sprint maximally for 150-meters. A speedograph was used to record changes in running speed over the 150-meter distance.

Results indicated significant differences between the sprinters' and beginners' maximal attainable speed, while no difference was found between acceleration rate or the maintenance of maximal speed. Maximal attainable speed was significantly higher in sprinters (9.0 m/sec) than beginners (7.6 m/s). Maximal velocity was significantly correlated to 100-meter sprint performance for sprinters ( $r = -.855$ ) and beginners ( $r = -.716$ ) and was shown to be attained 4-5 seconds after the start. This corresponds to a distance of approximately 40 meters. The authors concluded that sprinters and beginners mainly differed in the maximal running speed that could be attained, while no differences were found in acceleration or in the ability to resist fatigue when running at maximal speed.

Thompson (1981) developed a sprint test to predict anaerobic capacity. Fourteen male subjects were instructed to sprint maximally over a distance of 400 meters while split times were recorded via stopwatches at distances of 183, 220, 256, 293, and 366 meters. Run times at specified distances and running speeds between distances were correlated to the subjects' anaerobic capacity, which was pre-determined using a laboratory protocol. Multiple regression analysis revealed that the greatest reduction in variance was accounted for when time to 256 meters ( $r = 0.74$ ) and speed between 256 and 329 meters ( $r = 0.82$ ) were correlated with anaerobic capacity.

Borsetto et al.(1989) conducted a study to develop a field sprint test to measure the speed generated by anaerobic glycolysis. Thirty-nine male athletes were classified into three groups: marathon runners, 5000-10000-m runners, 400-800-m runners, and sprinters. Subjects were instructed to progressively increase speed over 1000-m until their speed of deflection (the speed at which the relationship between heart rate (HR) and running speed (RS) was no longer linear, as determined in a previous test) was reached. Subjects then ran an additional 200-m at maximal speed. Venous blood samples were drawn 5 minutes after completion of the test. The HR-RS line was extrapolated to estimate the maximum speed attained at maximum HR. This value was used to determine anaerobic speed by subtracting actual maximal RS.

Results indicated that anaerobic speed and blood lactate concentrations were highest for the sprinters and decreased significantly for each of the other groups. Unpaired Student's *t*-tests were used to evaluate differences between mean values. The anaerobic speed attained by the sprint group (14.04 km/h) was three times higher than that of the marathon runners (4.15 km/h). Likewise, the blood lactate values were three times higher in the sprint group (14.8 mmol/l) than were measured in the marathon group (5.2 mmol/l). The authors concluded that the aforementioned test can be used to effectively determine the power output generated by anaerobic glycolysis.

Hautier et al. (1994) examined the relationships between anaerobic glycolysis and average velocity sustained during sprint running over 100 and 200-meters. Subjects were 12 national level male sprinters. Blood lactate concentrations were measured within 3 minutes of completion of both sprints, and related to running performance and velocity.

Results indicated no correlation between 100 or 200-meter running performance and  $[La]_{pk}$ ; however, a correlation was found between  $[La]_{pk}$  and the velocity sustained over the last 165 meters of a 200-meter sprint ( $r = 0.65, P < 0.05$ ). The authors concluded that this data indicates the important contribution of anaerobic glycolysis to 200-meter running performance.

Berthoin, Dupont, Mary, and Gerbeaux (2001) compared kinematic characteristics of sprint running (acceleration, maximal running, and deceleration) with anaerobic tests. Twenty-two physically active male subjects performed a 100-meter sprint, vertical jump test, force-velocity test, and the WAnT. Velocity was measured during the sprint tests via four photoelectric cells positioned at 0, 20, 50, and 100 meters. Spearman coefficient of correlations were used to examine the relations between data. Results indicated that maximum velocity was attained at approximately 5.6 seconds, or between 30 and 50 meters. Maximal running velocity was significantly correlated to 100-meter sprint performance and maximal running velocity was the best predictor of performance of the sprint run ( $r = -0.90, p < 0.001$ ).

**Summary.** The above research results indicate that measurements of velocity play a significant role in the prediction of sprint performance. Maximal running velocity is highly correlated to sprinting performance over 100 meters and is attained between 30 and 50 meters (Berthoin et al., 2001, Volkov & Lapin, 1979). Blood lactate concentrations following sprint tests correlate significantly with running velocity over the last 165-m of a 200 meter sprint (Hautier et al., 1994), and also reach significantly higher levels in sprinters than in middle or long distant runners (Borsetto et al., 1989).

## APPENDIX A

### INFORMED CONSENT To Participate in a Research Study

#### I. INVESTIGATORS

**Principal Investigators:**

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#### II. TITLE

##### **Determination of Anaerobic Performance Via a Maximal Sprint Field Test**

#### III. INTRODUCTION

This study is part of two master's degree theses by University of Hawai'i graduate students. Because you are in good physical condition and participate regularly in some form of physical activity, you are being asked to take part in this research study. The purpose of this study is to examine a sprint field test (SFT<sub>Max</sub>) of 200 meters and the Wingate anaerobic test (WAnT) to assess your anaerobic performance (a type of physical ability which enables one to perform high-intensity exercise in a relatively short period of time). During the SFT<sub>Max</sub> test you will be video-recorded with high speed cameras for biomechanical analyses.

The reason for giving you the following information is to help you decide if you would like to participate in this study. This consent form may contain words that are unfamiliar to you. Please discuss any questions you have about this study with the research staff members. Your participation in this research is voluntary, and you will not be paid. Be assured that all information collected about you will be kept confidential. You and the researchers will be the only ones to know the individual results of your tests.

#### IV. DESCRIPTION OF PROCEDURES

You will be asked to report to the University of Hawai'i at Manoa Human Performance Laboratory to engage in standard measurements of height, body mass and lower limb lengths (hip-knee length, lower leg length, and foot length). You will also be asked to refrain from exercising, eating or drinking (except water) 4 hours prior to reporting to the laboratory so that you are well rested and well hydrated upon arrival.

### Test Schedule

You will be asked to perform three different tests, which will be randomly ordered at least one week apart for a total of 2-3 weeks. Your scheduled may appear like that depicted in the table below.

	Exercise Bicycle Test	Sprint Field Tests (SFT <sub>Max</sub> )	
	WAnT	200 meter sprint	300 meter sprint
Week 1	30 sec (1 trial)	<input type="checkbox"/>	<input type="checkbox"/>
Week 2	<input type="checkbox"/>	25-35 sec (2 trials)	<input type="checkbox"/>
Week 3	<input type="checkbox"/>	<input type="checkbox"/>	45-55 sec (2 trials)

### Wingate Anaerobic Test

A maximum bicycle sprint will be performed using the cycle ergometer (exercise bicycle). You will start with a 5-15 minute warm up on the cycle ergometer, a 15-second mock familiarization trial of the WAnT, followed by a 5-minute resting and stretching period. You will then participate in the 30-second WAnT protocol. A blood sample will be drawn from your fingertip using a sterile lancet during a passive recovery 7 minutes after completion of the test. Your blood sample will be labeled using your identification number in order to ensure confidentiality. These samples will be used to measure accumulated blood lactate, which is a byproduct of high intensity activity. The capacity for high intensity activity can then be assessed using these measurements. The total time of the test will be approximately 15-25 minutes.

### Maximal 200 meter Sprint Field Test

The SFT<sub>Max</sub> test will be performed at the University of Hawai'i Cooke Field track. You are asked to wear proper running shoes for the test. Before the tests, you will participate in a 5-15 minute warm up period, followed by a 5-minute resting and stretching period. You will then participate in the SFT<sub>Max</sub> test. Sprint times will be recorded using photoelectric cells and will be used to measure velocity and acceleration. You will also be video-recorded with high speed cameras for biomechanical analyses. Blood samples will then be drawn during recovery 7 minutes after completion of the test. This procedure will be the same as previously described in the Wingate anaerobic test. This test will be performed twice, separated by a twenty-minute recovery period. The total time of the test will be approximately 20 to 30 minutes.

## V. RISKS

Due to the high intensity of the activity involved (maximal anaerobic performance), you may feel distress, nausea, fatigue, muscle pain, soreness, or discomfort. A very remote possibility of cardiac arrest exists. Temporary pain or discomfort may be felt during blood drawing. Excessive bleeding or infection from blood drawing may occur, and ecchymosis or bruising at the site is a common side effect. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. First Aid/CPR and a referral to a medical emergency room will be provided. The investigators are First Aid/CPR certified and trained to use the portable

automated external defibrillator (AED) on site. You should understand that if you are injured in the course of this research procedure that you alone may be responsible for the costs of treating your injuries.

**VI. BENEFITS**

You may not directly benefit from this study although you will gain the experience of being part of a scientific experiment. You will obtain information concerning your anaerobic fitness levels and sprint running abilities. This study will provide an assessment of anaerobic performance (capacity for high-intensity exercise) without using invasive techniques.

**VII. CONFIDENTIALITY**

Your research records will be confidential to the extent permitted by law. You will not be personally identified in any publication about this study. A code, which will be known only to study personnel and you, will be used instead of your name on laboratory records of this study. Personal information about your test results will not be given to anyone without your written permission. In addition, all data (including video recordings) and subject (identity) information will be kept under lock and key in the Department of Kinesiology and Leisure Science Human Performance Laboratory. These materials and the video recordings will be permanently disposed of in a period not longer than 5 years.

**VIII. CERTIFICATION**

I certify that I have read and that I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning the project procedures and other matters and that I have been advised that I am free to withdraw my consent and to discontinue participation in the project or activity at any time without prejudice.

I herewith give my consent to participate in this project with the understanding that such consent does not waive any of my legal rights, nor does it release the principal investigator or institution or any employee or agent thereof from liability for negligence.

If you have any questions related to this research study, please contact principal investigators, Joseph Smith and Tomoki Kanaoka at 956-3804 or you may contact Iris F. Kimura at 956-3800 at any time.

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Signature of individual participant

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Date

If you cannot obtain satisfactory answers to your questions, or have complaints about your treatment in this study, please contact: Committee on Human Subjects, University of Hawaii at Manoa, 2540 Maile Way, Honolulu, Hawaii 96822, Phone (808) 956-5007.

## APPENDIX B

### **Instructions to Participants (HART)**

Hello and thank you for agreeing to participate in this research study. At this time you will be participating in a 200-meter maximal sprint test. We ask that at this time you begin your five minute warm-up session in which you should undergo five sprints around 40 meters in length to adequately prepare yourself for this test. You will then be asked to stand with one foot on the starting line and assume a standing start position. Following the countdown, "Runner take your mark, set," you will hear the starting gun and begin running as **hard and as fast** as you can. We ask that you continue to run as **hard and as fast** as you can without pacing yourself until you have completed the 200 meters or are unable to continue. After completing the sprint you will be handed a stopwatch and we ask that you walk slowly and report to Dr. Hetzler under the tent to have your blood lactate sample taken when the time on your stopwatch reads **6 minutes**. After your blood sample has been collected you will be given 15 minutes to rest and will then be instructed to begin your five minute warm-up in preparation for your second trial run. Thank you again for your participation.

### **Instructions to Participants (WAnT)**

Hello and thank you for agreeing to participate in this research study. At this time you will be participating in a Wingate Anaerobic Test on a cycle ergometer. We ask that at this time you begin your five minute warm-up session in which you should undergo five sprints around 5-6 seconds in length to adequately prepare yourself for this test. You will then be asked to assume your starting position and begin pedaling. Following the countdown, "Three, two, one, " you should be pedaling at maximum speed, while the weight basket is dropped upon the flywheel. We ask that you pedal as **hard and as fast** as you can without pacing yourself until you have completed the 30 second test or are unable to continue. After completing the test you will be handed a stopwatch and we ask that you pedal slowly and report to Dr. Hetzler to have your blood lactate sample taken when the time on your stopwatch reads **6 minutes**.

## REFERENCES

Astrand, P., & Rodahl, K. (1986). Textbook of Work Physiology: Physiological Bases of Exercise (3<sup>rd</sup> ed.). New York: McGraw-Hill.

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

Baker, J.S., & Davies, B. (2002). High intensity exercise assessment: Relationships between laboratory and field measures of performance. *Journal of Science and Medicine in Sport*, 5, 341-347.

Berthoin, S., Dupont, G., Mary, P., & Gerbeaux, M. (2001). Predicting sprint kinematic parameters from anaerobic field tests in physical education students. *Journal of Strength and Conditioning Research*, 15, 75-80.

Borsetto, C., Ballarin, E., Casoni, I., Cellini, M., Vitiello, P., & Conconi, F. (1989). A field test for determining the speed obtained through anaerobic glycolysis in runners. *International Journal of Sports Medicine*, 10, 339-345.

Bulbulian, R., Jeong, J.W., & Murphy, M. (1996). Comparison of anaerobic components of the Wingate and Critical Power tests in male and females. *Medicine and Science in Sports and Exercise*, 28, 1336-1341.

di Prampero, P.E., Peeters L., & Margaria, R. (1973). Alactacid O<sub>2</sub> debt and lactic acid production after exhausting exercise in man. *Journal of Applied Physiology*, 34, 628-632.

Falk, B., Weinstein, Y., Dotan, R., Abramson, D.A., Mann-Segal, D., & Hoffman, J.R. (1996). A treadmill test of sprint running. *Scandinavian Journal of Medicine and Science in Sports*, 6, 259-264.

Frishberg, B.A. (1983). An analysis of overground and treadmill sprinting. *Medicine and Science in Sports and Exercise*, 15, 478-485.

Fujitsuka, N., Yamamoto, T., Ohkuwa, T., Saito, M., & Miyamura, M. (1982). Peak blood lactate after short periods of maximal treadmill running. *European Journal of Applied Physiology*, 48, 289-296.

Granier, P., Mercier, B., Mercier, J., Anselme, F., & Prefaut, C. (1995). Aerobic and anaerobic contribution to Wingate test performance in sprint and middle-distance runners. *European Journal of Applied Physiology*, 70, 58-65.

- Green, S., & Dawson, B. (1993). Measurement of anaerobic capacities in humans. *Sports Medicine*, 15, 312-327.
- Hautier, C.A., Wouassi, D., Arsac, L., Bitanga, E., Thiriet, P., & Lacour, J. (1994). Relationship between postcompetition blood lactate concentration and average running velocity over 100-m and 200-m races. *European Journal of Applied Physiology*, 68, 508-513.
- Heck, H., Schulz, H., & Bartmus, U. (2003). Diagnostics of anaerobic power and capacity. *European Journal of Sport Science*, 3, 1-23.
- Hirvonen, J., Rehunen, S., Rusko, H., & Harkonen, M. (1987). Breakdown of high-energy phosphate compounds and lactate accumulation during short supramaximal exercise. *European Journal of Applied Physiology*, 56, 253-259.
- Lacour, J.R., Bouvat, E., & Barthelemy, J.C. (1990). Post-competition blood lactate concentrations as indicators of energy expenditure during 400-m and 800-m races. *European Journal of Applied Pysiology*, 61, 172-176.
- Meckel, Y., Atterbom, H., Grodjinovsky, A., Ben-Sira, D., & Rotstein, A. (1995). Physiological characteristics of female 100 metre sprinters of different performance levels. *Journal of Sports Medicine and Physical Fitness* 35, 169-75.
- Murphy, M.M., Patton, J.F., & Frederick, F.A. (1986). Comparative anaerobic power of men and women. *Aviation in Space and Environmental Medicine*, 57, 636-641.
- Nummela, A., & Rusko, H. (1995). Time course of anaerobic and aerobic energy expenditure during short-term exhaustive running in athletes. *International Journal of Sports Medicine*, 16, 522-527.
- Okhuwa, T., Kats, Y., Katsumata, K., Nakao, T., & Miyamura, M. (1984). Blood lactate and glycerol after 400m and 3000m runs in sprint and long distance runners. *European Journal Applied Physiology*, 53, 213-218.
- Patton, J.F., & Duggan, A. (1987). An evaluation of tests of anaerobic power. *Aviation in Space and Environmental Medicine*, 58, 237-42.
- Sands, W.A., McNeal, J.R., Ochi, M.T., Urbanek, T.L., Jemni, N., & Stone, M.H. (2004). Comparison of the Wingate and Bosco anaerobic tests. *Journal of Strength and Conditioning Research*, 18, 810-815.
- Schnabel, A. & Kindermann, W. (1983). Assessment of anaerobic capacity in runners. *European Journal of Applied Physiology*, 52, 42-46.

Scott, C.B., Roby, F.B., Lohman, T.G., & Bunt, J.C. (1991). The maximally accumulated oxygen deficit as an indicator of anaerobic capacity. *Medicine and Science in Sports and Exercise*, 23, 618-624.

Shaver, L.G. (1975). Maximum aerobic power and anaerobic work capacity prediction from various running performances of untrained college men. *Journal of Sports Medicine*, 15, 147-150.

Tamayo, M., Sucec, A., Phillips, W., Bicono, M., & Laubach L. (1984). The Wingate anaerobic test, peak blood lactate and maximal oxygen debt in volleyball players. Abstract. *Medicine and Science in Sports and Exercise*, 16, 126.

Taunton, J.E., Maron, H., & Wilkinson, J.G. (1981). Anaerobic performance in middle and long distance runners. *Canadian Journal of Applied Sport Science*, 6, 109-13.

Tharp, G.D., Johnson, G., & Thorland, W. (1984). Measurement of anaerobic power and capacity in elite young track athletes using the Wingate test. *Journal of Sports Medicine*, 24, 100-106.

Tharp, G.D., Newhouse, R.K., Uffelmann, L., Thorland, W., & Johnson, G. (1985). Comparison of sprint and run times with performance on the Wingate Anaerobic Test. *Research Quarterly*, 56, 73-76.

Thompson, J.M. (1981). Prediction of anaerobic capacity: a performance test employing an optimal exercise stress. *Canadian Journal of Applied Sport Science*, 6, 16-20.

Vandewalle, H., Peres, G., & Monod, H. (1987). Standard anaerobic tests. *Sports Medicine*, 4, 268-289.

Volkov, N.I., & Lapin, V.I. (1979). Analysis of the velocity curve in sprint running. *Medicine and Science in Sports*, 11, 332-337.

Weinstein, Y., Bediz, C., Dotan, R., & Falk, B. (1998). Reliability of peak-lactate, heart rate, and plasma volume following the Wingate test. *Medicine and Science in Sports and Exercise*, 30, 1456-1460.