AN ABSTRACT OF THE THESIS OF

Aaron B. Sidner for the degree of Master of Science in Human Performance presented on July 29, 1997.

Title: The Effects of High Resistances on Peak Power Output and Total Mechanical Work During Short-duration High Intensity Exercise in the Elite Female Athlete.

Redacted for privacy

Abstract approved :

Paul A. Borsa

The purpose of this investigation was to determine the effects of high resistances on peak power output and total mechanical work as indices of anaerobic power and anaerobic capacity using the Wingate Anaerobic Test. It was hypothesized that increased resistance would result in increased peak power output without a simultaneous decrease in total mechanical work. Ten (N=10) basketball and seven (N=7) volleyball NCAA Division 1 female athletes completed one 20 second trial at each of four resistances (7.5%, 8.5%, 10.5% and 12.5% of body weight) on a Monark 824e weight ergometer in a single exercise session (10 minutes rest between trials). Results showed statistically significant (p=0.05) increases in peak power output with increased resistance for absolute values (range: 752.2-971.5 watts), relative to mass values (range:10.5-13.5 watts/kg), and relative to lean mass values (range:12.8-16.8 watts/lbm). Similarly, increased resistance resulted in increased TMW (absolute (range:1274.3-1431.7 joules), relative to mass (range:17.8-20.1 joules/kg), and relative to lean mass (range: 21.8-24.5 joule/lbm)). The differences in peak power output and total mechanical work obtained from the 10.5% and 12.5% resistances were not statistically different (although they continued to demonstrate an upward trend) and thus it was not possible to determine which resistance was optimum for determining peak power output and total mechanical work values in a power-trained population. We concluded that the use of at least a 10.5% of body weight resistance was required to elicit true peak power output and total mechanical work in adult, power-trained subjects as opposed to the 7.5% factor typically used. The results of this study provide the basis for using a Wingate Anaerobic Test modified by increasing the test resistance to determine fatigue curve profiles for various sport, age, gender and ability groups. Additionally, power vs. time data from this study support the need to experimentally determine the duration of the test for optimal evaluation of anaerobic power and capacity characteristics.

The Effects of High Resistances on Peak Power Output and Total Mechanical Work During Short-Duration High Intensity Exercise in Elite Female Athletes.

by

Aaron B. Sidner

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirement for
the degree of

Master of Science

Presented on July 29, 1997
Commencement June 1998

Master of Science of Aaron B. Sidner presented on July 29, 1997.

APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

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Aaron B. Sidner, Author

ACKNOWLEDGMENTS

I would like to thank all those whose support made this project possible. In particular, I would like to applaud the subjects for a fantastic effort during testing and I wish them luck in their future endeavors. I would also like to thank Susan Fox, OSU Human Performance Laboratory Director for always being willing to assist in any manner.

To the members of my committee, I would like to reflect on something my mother said to me years ago. She simply told me, “You’ve chosen well.” I think that definitely applied to this group of talented educators (She later told me “You got lucky!” regarding the same situation, also applicable here!).

Individually, I thank Dr. Phil Brownell for in one week justifying two years of Physics and Chemistry of which I had little or no interest in. Thank you, Dr. Brownell, for helping me see the integration of several seemingly unrelated subjects into a much more thorough understanding of my physical world.

I thank Dr. Anthony Wilcox for asking the questions that led me to my line of research and for holding me to a standard of excellence in my oral and written communication. Thanks, Dr. Wilcox, for making me a better thinker.

I thank Dr. Joanne Engel for being a true student advocate and a shining example of a teacher. Dr. Engel, you always made me feel I had someone on my side. Thanks, that allowed me to smile and truly enjoy this process.

I thank Dr. Paul Borsa, my major professor, for challenging me to get it done. Thanks for holding me accountable, Dr. Borsa. I would probably still be working on this if it were not for your ‘encouragement’ and guidance.

Lastly, I want to acknowledge the support of my wife Sabrina and our four wonderful children for their patience with me in the process. I love you all and it will all be worth it! And thank you Jesus Christ for giving me the grace and desire to explore the limits of Your marvelous design!

- Aaron B. Sidner

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CHAPTER ONE
INTRODUCTION

Peak athletic performance requires an optimal combination of muscular power, fatigue resistance, and mechanical efficiency. Strength and conditioning specialists, coaches, and exercise scientists have sought to discover methods of maximizing muscular power output and efficiency while minimizing fatigue. This process involves research aimed at identifying the underlying mechanisms of these performance characteristics through invasive and noninvasive means.

Muscular power output is a result of the contractile and metabolic characteristics of skeletal muscle tissue. Muscular power output can be generated through aerobic (oxidative) and anaerobic (high energy phosphate and glycolytic) metabolic pathways. The term supramaximal describes exercise at intensities greater than the intensity associated with maximum oxygen uptake. Supramaximal exercise can only be performed for short durations and is supported from predominately anaerobic pathways. Depletion of the major substrates responsible for supplying the energy for anaerobic power is the primary cause of muscular fatigue. The major substrates include high energy phosphates (primarily creatine phosphate) and glucose/glycogen. The optimal combination of the contractile and metabolic characteristics must be present in order for the athlete to sustain peak power and resist fatigue.

The ability to accurately assess anaerobic power output is dependent on the test protocol and equipment used. To specifically determine peak power output and mechanical work performed during supramaximal exercise, it is vital that the appropriate resistance, duration, and mode of exercise be selected. If these parameters, resistance, duration and mode, are not properly selected, the determined performance measures may not reflect the subjects' true capabilities.

The Wingate Anaerobic Test (WAT) is the most widely used test for assessing anaerobic power and capacity (Inbar et al., 1996). The WAT protocol requires the athlete to pedal a stationery bicycle ergometer at maximal velocity for a duration of 30 seconds against a preset resistance of 7.5% body weight. Many researchers (Katch et al., 1977, Hill & Smith, 1993) suggest that the duration is insufficient to fully tax the glycolytic capacity; however extending the duration significantly increases the aerobic contribution (Serresse et al., 1987, Medbo & Tabata, 1989, Serresse et al., 1991).

The standardized testing protocol which utilizes 7.5% of body weight as the test resistance has been used to evaluate differences in anaerobic power output between subjects. However, it is suggested that the 7.5% resistance fails to determine true maximal values defined as the actual peak power output and mechanical work values the subjects are capable of producing. For example, Maud and Schultz (1989) published normative values for a large, diverse population that included professional ice hockey players. Using the 7.5% of body weight resistance, the players produced relative peak power output values ranging from 8.30-9.58 watts per kilogram (W/kg). In contrast, Rhodes et al. (1986), also using professional ice hockey players, observed relative peak power output values averaging 12.01 W/kg using a test resistance of 9.0% of body weight. Luschinger et al. (1987) found similar results with another group of elite hockey players (resistance greater than 9.0%), suggesting that the resistance utilized in the Maud & Schultz study did not allow their athletes to achieve their true peak power.

Recently, investigators and practitioners have begun using higher resistances than the standard 7.5% of body weight resulting in a greater anaerobic power measure. The study conducted by Evans and Quinney (1981) was one of the first of several investigations to use various approaches to determine optimal resistance. The researchers selected a range of resistances (4.1%-9.2%) and found group peak power output mean values equal to 11.27 W/kg at a mean optimal resistance of 9.7% of body weight. Patton et al. (1985) used a range of 5.5%-11.5% of body weight and observed an average peak power output of 11.8 W/kg at a mean optimal resistance of 9.6% of body weight. From these and other studies, it is likely that the optimal resistance for the Wingate Anaerobic Test is indeed greater than the 7.5% of body weight originally determined.

In the attempt to determine an optimal resistance, several recent studies have failed to utilize resistance levels that resulted in parabolic maxima for the power vs. resistance curves; the range of resistances did not include a resistance after which further increases in resistance resulted in decreases in peak power output. For trained populations, it has been suggested that the optimal resistance may exceed 10% of body weight (Beld et al. 1989, Davy et al., 1989). In a study conducted by Vandewalle et al. (1985), power-trained athletes, using an individually optimized resistance (mean optimal resistance of 13% of body weight) achieved an average peak power output of 17 W/kg. Mannion et al. (1993) used resistances as high as 14.5% of body weight. The range of resistances at which maximal peak power output occurred did not allow a decisive conclusion regarding a single optimal resistance (note: this was not the aim of their study). These and numerous other investigations support the conjecture that 7.5% of body weight is not a sufficient resistance to determine true anaerobic power capability. The resistance that may be optimal for a population of trained athletes is not yet determined.

It is suggested that there are gender differences in peak power output capability (Hill & Smith, 1993). However, little research regarding the determination of an optimal resistance has included or focused on female athletes, especially power-trained female athletes. Based on the results of the studies of Beld et al. (1989) and Davy et al. (1989), the optimal test resistance for determining a true peak power output measure in this population would be greater than 10.5% of body weight.

The present study was conducted to determine an optimal resistance to be used when evaluating anaerobic power capability in female trained athletes. As no study using this population was found that selected *a priori* resistances greater than 10.5%, a resistance of 12.5% was included in the test range in order to increase the probability of finding a test resistance capable of eliciting true maximum power and work capacity measures.

PURPOSE STATEMENT

The purpose of this study was to ascertain the optimal test resistance to determine anaerobic muscular power characteristics during an abbreviated Wingate Anaerobic Test protocol in power-trained female athletes.

RESEARCH HYPOTHESES

We hypothesized the following:

1. Increased resistance would result in a significant increase in peak power output.
2. Increased resistance would not result in a decrease in total mechanical work.

STATISTICAL HYPOTHESES

When comparing values for the dependent variables of peak power and total mechanical work, the statistical hypotheses are as follows:

Ho: a) $\mu1 = \mu2 = \mu3 = \mu4$,

b) $\pounds3 < \pounds2 < \pounds1 < \pounds4$

Ha: a) $\mu1 < \mu2 < \mu3 < \mu4$,

b) $\pounds1 \leq \pounds2 \leq \pounds3 \leq \pounds4$

Where: $\mu1$, $\mu2$, $\mu3$ and $\mu4$ are peak power outputs and $\pounds1$, $\pounds2$, $\pounds3$ and $\pounds4$ are total mechanical work measures for four independent measures (resistance).

ASSUMPTIONS

The following assumptions with regard to the sample population were made:

1. All subjects possess similar intramuscular metabolic characteristics.

2. All subjects performed maximal efforts for the duration of the tests.

DELIMITATIONS

The population chosen for analysis consists of female intercollegiate varsity athletes representing a Division 1 NCAA institution. Specifically, a homogenous pool of seven volleyball and ten basketball players participated in this study.

LIMITATIONS

The limitations of the study are noted as follows:

1. The homogeneity of the subject pool limits the generalizability of the findings in regards to body size (specifically muscular cross-sectional area), age, gender and training background.

2. The amount of resistance able to be applied to the flywheel of the ergometer is limited to values equal to 12.5% of body weight for the selected subject population.

OPERATIONAL DEFINITIONS FOR DEPENDENT VARIABLES

Peak Power Output (PPO) - the highest three second average power output achieved during the test.

Total Mechanical Work (TMW) - the total mechanical work performed during the test determined by the integral of the power vs. time curve.

CHAPTER TWO
REVIEW OF LITERATURE

This review of the literature will provide a description of the Wingate Anaerobic Test (WAT), the development of the WAT, subsequent modifications and applications, and contemporary research as it applies to the current project.

HISTORY

In 1973, Canada's Gordon Cumming presented a paper at the International Symposium on Pediatric Work Physiology at Israel's Wingate Institute detailing studies he and colleagues had conducted correlating athletic performance and aerobic power with various physical characteristics in children. Additionally, anaerobic power was assessed using the Margaria sprint protocol (Margaria et al., 1966) and a new cycle ergometer test in which the subjects were asked to pedal at maximum speed for 30 seconds against a set resistance. The test was termed the Wmax30 (Cumming, 1973) and it was this presentation that provided the impetus for researchers at the Wingate Institute to begin development of their own cycle ergometer test.

The Wingate group specified several objectives of their project (Inbar et al., 1996) including the following: 1) that the test directly measure muscle power, 2) that it be objective (not dependent on subjective interpretation), 3) be sensitive to intrasubject changes, and 4) be specific to anaerobic muscle performance as opposed to general fitness. Their project, headed by Ayalon et al. (1974) yielded a test that would become the Wingate Anaerobic Test (WAT).

One of the primary uses of the WAT is to assess the current training status of athletes. It is important to make accurate assessments of athletes as they enter new training cycles, to evaluate the effectiveness of their training programs, and determine the impact of the competitive season on the athlete's physiology (Rhodes et al., 1986). Along with recovery from injury evaluation, the WAT is also used to determine athletic aptitude.

As many sports require an ability to generate high levels of muscular power and to perform repeated bouts of high intensity, the WAT has been used to determine an athlete's potential to do such work. Similarly, the WAT has been used to differentiate between athletes of various competitive levels in many sports including cycling (Tanaka et al., 1993), alpine skiing (White & Johnson, 1991) and also athletes of different training backgrounds and disciplines (Nakamura et al., 1986).

In research settings, the WAT has been used to better clarify the physiological events that drive, support, and occur as a result of high intensity exercise. While many other uses are described throughout the literature, the following are pertinent examples. Campbell et al. (1979)

and Komi et al. (1977) used the WAT to determine the relationship between muscle fiber composition and anaerobic power. Gratas-Delamarche et al. (1994) investigated lactate and catecholamine responses to high intensity exercise and Mannion et al. (1995) challenged the role of buffer capacity in high intensity exercise performance. Hebestreit et al. (1993) compared differences in recovery rate from supramaximal exercise in boys and men. Very recently, Hussain et al. (1996) used the WAT to examine exercising limb hemodynamics. The aforementioned studies are examples of research that, using a modified WAT protocol, results may be affected and thus different conclusions may be reached.

It is hypothesized that by decreasing the duration and increasing the resistance, the WAT will be more sensitive to important differences between subjects. The increased sensitivity of the WAT may potentially reduce errors in the decision making process (as used by coaches and clinicians) and may provide greater insight into the mechanisms involved in and influenced by such exercise activity.

Early research with the WAT focused mainly on identification of power characteristics for various populations. For example, Beckenholdt & J. Mayhew (1983) and Crielaard & Pirnay (1981) studied elite athletes from different sporting events. However, after the initial WAT validation studies, Evans and Quinney used 12 male physical education students and varsity athletes to determine appropriate resistance settings for supramaximal testing (1981). They asserted that "an optimal combination of resistance setting and pedaling speed" was required to obtain true maximal power outputs. They used an initial resistance of 4.0 kp and conducted successive trials with resistances increasing by the absolute mass of 1 kp per test to establish a power vs. force curve. Mean values (+/- SD) were reported as 836.6W (127.4) for peak power, 11.27 W/kg (1.38) for peak power relative to body wt., and 94.5 rpm (8.4) as the observed optimal pedaling speed.

Important aspects from this investigation are that, even though peak power outputs are relatively low compared to more recent studies (Beld et al., 1989, Davy et al., 1989, Skinner & O'Connor, 1987), they are still greater than the means of the same measure using the 0.075 kg/kg body weight (bw) resistance value determined in the original Wingate studies and most commonly utilized. Evans and Quinney determined an optimal resistance of 7.21 kp (+/- 1.5) which, based on the subject data provided, corresponded to a resistance factor of approximately 0.097 kg/kg bw.

Doton and Bar-Or (1983) sought to further optimize the resistance factor with the goal being to maximize mean power output as stated in the aims of the study. Using physical education student volunteers, they determined that improved performance would result from using an optimal resistance value as a guideline and modifying the resistance on an individual basis according to body composition, body type and anaerobic fitness level.

A range of five randomly assigned resistance values based on those routinely utilized in their laboratory were used to generate an optimal resistance defined using a parabola-fitting technique. The range for leg exercise was from 2.43 to 5.39 Joule/revolution/kg bw (0.041-0.092 kg/kg bw). They found the optimal load for maximizing mean power in males was 5.13 J/rev/kg bw (0.087 kg/kg bw). However, as seen from the lack of parabolic maxima in the watts vs. resistance graphs (especially for the male subjects), test resistances were insufficient to determine a maximal peak power output. Had the range of resistance values not been limited to the reported values, it is likely that increased peak power outputs would have been observed.

Patton et al. (1985) examined 19 male military personnel. Using a resistance range of 0.055-0.115 kg/kg bw, their results showed mean optimal resistance for peak power output to be 0.096 kg/kg bw. A similar resistance was found for mean power output. Patton et al. also noted a wide variability in the resistance at which peak power output was obtained. The same finding was evident in previous studies (Doton & Bar-Or, 1983, Evans & Quinney, 1981).

To restate the above mentioned studies, it is apparent that the initially prescribed resistance was optimal when investigating mean power output in non-trained or younger subjects similar to those (similar to the population of Cumming, 1973). Any deviation from this subject profile resulted in an increased optimal resistance. While much of the literature discussed resistance, very little research has addressed the appropriateness of the 30s duration.

CONTEMPORARY RESEARCH

Several researchers have chosen higher braking force factors based on individual experience and the recommendations of Bar-Or (1987). Still others have continued to utilize multiple braking forces in force-velocity protocols similar to Vandewalle et al. (1985). However, few of the studies have focused their efforts on establishing the resistance values necessary to develop maximal peak power values. Their conclusions, therefore, are equivocal regarding such an optimal load value for this parameter.

Maud & Schultz (1989) published normative values for WATs. Using a very large population (112 men and 74 women) they developed percentile ranks for both genders. Furthermore, by compiling results from other researchers, they presented a table of values for elite competitors. Using the prescribed 0.075 kg/kg bw resistance factor, the 95th percentile for peak power in males was reported to be 866.9 W (11.08 W/kg). The elite power athletes (volleyball players and professional hockey players), however, demonstrated values ranging from 8.30 to 9.58 W/kg. According to the table of norms, these highly trained subjects would rank as a group near the 50th percentile. Contrary to their findings, it appears that the resistance was insufficient to accurately evaluate the power-trained populations due to the fact that pedaling velocity was maximized.

In contrast to the Maud & Schultz data, studies utilizing higher braking forces yield results more reasonable considering the subjects tested. Rhodes et al. (1986) used a resistance of 0.090 kg/kg bw to evaluate professional hockey players and found a mean peak power output of 1064.3 W (12.04 W/kg) for the group of defensemen. Luchsinger et al. (1987) reported peak power outputs of 1076 (+/- 110) W also using hockey players and also using a resistance of 0.090 kg/kg bw.

Gratas-Delamarche et al. (1994), using an optimized resistance value from Vandewalle's force-velocity protocol, observed peak power outputs as high as 1138 W, 16.2 W/kg for a group of trained sprint athletes (18.2 W/kg corrected for lean body mass). Vandewalle et al. (1987) reported power-trained athletes (rugby backs, sprinters, etc.) achieved optimal resistance values corresponding to approximately 0.13 kg/kg bw and producing peak power output group means as high as 1226 W (17 W/kg). One individual actually achieved a peak output of 19.8 W/kg. This value is similar to the 19.9 W/kg power outputs recorded by Horswill (1979) utilizing the Margaria Sprint Protocol with wrestlers.

Several recent studies have failed to reach resistance levels that resulted in actual declines in peak power output and therefore concluded that the true optimal resistance was "greater than" the scope of their study. Sposa et al. (1987) used soccer players as test subjects and reported 0.100 kg/kg bw produce the highest peak power but that no peak and subsequent decline (power vs. resistance curve) was observed. Beld et al. (1989) reported that the optimal load was greater than 0.105 kg/kg bw using untrained, endurance trained and power trained males. Davy et al. (1989), using conditioned athletes (training background not specified), observed increases in peak power up to their maximal test value of 0.120 kg/kg bw and, although increase at the three highest resistance was not significantly different, there was an obvious trend toward a yet higher load value being optimal. The highest reported optimal resistance values are cited by Mannion et al. (1993) as being "between 9 and 14% body weight" based on earlier studies (Mannion et al., 1986).

It is important to note that in the study by Beld et al. (1989), differences among the groups were not found to be significant. This observation supports the hypothesis that, working on the expectation of higher values from the power-trained athletes, the resistance must be sufficient to differentiate between the groups and that currently used resistances are less than optimal for accomplishing this.

Very little research has investigated the optimal duration of the WAT. Several studies have used various extended durations such as 45s (Vandewalle et al., 1987b), 60s (Gastin et al., 1991) and 90s (Serresse et al., 1991) but no studies were found that used abbreviated durations (above 10-15s).

SUMMARY

To summarize, the Wingate Anaerobic Test has undergone numerous modifications since its creation; however, further adjustments are necessary to maximize its validity and accuracy in determining peak muscular power output and the capacity of the muscles to do work using primarily the glycolytic and high energy phosphate metabolic pathways. It is hypothesized that the principle adjustments are lessening the duration of the trial (to 20s) and increasing the resistance factor. Furthermore, the establishment of normalized resistance factors for various populations is necessary for more reasonable test results without sacrificing the simplicity of the protocol. For elite, power-trained athletic populations, it is suggested that this resistance factor may be as high as 13-16% of body weight, a factor nearly double the currently prescribed load. It will be necessary to utilize a sufficiently large number of homogenous, representative subjects to justifiably establish such a normalized factor. Doing so may reduce the variability in the optimal resistance for peak power output determination.

CHAPTER THREE
METHODS

This chapter includes subject characteristics, the experimental design, the testing procedure and test protocol along with the statistical analysis techniques to be utilized during this study.

SUBJECTS

Seventeen subjects (N=17) between the ages of 18 and 25 years were recruited for this study. The subjects for this investigation were power-trained female athletes currently participating in collegiate varsity athletics. As per institutional regulations, the research proposal was submitted to the Oregon State University Institutional Review Board (IRB) for the Protection of Human Subjects for approval. Permission to recruit subjects was obtained from the coaching staff (see Appendix C). Final approval of selections was also be obtained from the coaching staff. Each subject completed an Informed Consent Form (see Appendix B) prior to participation.

EXPERIMENTAL DESIGN

This experiment was a single blind study utilizing a 4x1 (conditions x trials) factorial design. A factorial ANOVA was used determine significant mean differences between conditions and a

Scheffe post hoc analysis was used to identify the specific mean differences. An alpha level of 0.05 was chosen to determine statistical significance. All data were reduced and analyzed using Statview® 4.02 statistical software for Macintosh (Abascus Concepts, Inc., Berkeley, CA). Subjects were required to report to the laboratory on *one* occasion at which they completed one test at each resistance. The order of the four resistances was randomized and counter-balanced across subjects. The experiment was blind due to the fact that the subject had no knowledge of the resistance being applied.

MEASUREMENT APPARATUS

Body composition was determined via skinfold measurements using a multi-site equation for female athletes (Jackson et al., 1980). Subjects were weighed on a calibrated scale on the test day for calculation of resistance. Exercise was performed on a self-calibrating Monark 824e weight ergometer (Monark, Sweden). The ergometer fed velocity data directly to an on-line computer using POWER® software from Sports Medicine Industries, Inc. (St. Cloud, MN) where power data was displayed each second for the duration of the exercise bout.

TESTING SCHEDULE

The subjects reported to the OSU Human Performance Laboratory for pre-exercise measures and testing. To ensure standardized testing conditions, all trials were performed between 1:00pm and 5:00pm within a seven-day period. Prior to testing, each subject was measured for height, weight and body composition (skinfolds).

Peak Power Output

Peak power was assessed with an on-line computer. Power was measured and reported each second for the duration of the test. Peak power was the highest three-second average output achieved during the test. Power was determined by counting the flywheel revolutions per minute (velocity) and multiplying the number of revolutions times the resistance (force), thus yielding mechanical power (force X velocity).

Total Mechanical Work

Total mechanical work was determined as the integral of the power vs. time curve (area under the curve).

MODIFIED WINGATE ANAEROBIC TEST PROTOCOL

The protocol for the modified WAT was as follows. The resistances were determined as 0.075, 0.085, 0.105 and 0.125 kg/kg bw (actual test order randomized as previously described). The duration of the WAT was 20 seconds. A minimum 5 minutes warm-up of light resistance pedaling (40W) was followed by a short rest period as determined by each subject.

When the subject was ready (as determined through verbal verification) the subject was instructed to begin pedaling against zero resistance and given a 10 second count down. As per standardized instructions, the subject reached peak pedaling velocity by time 0 (end of the countdown) at which point the entire resistance was applied and the subject maintained a maximum effort for a period of 20 seconds. Vigorous verbal encouragement in addition to elapsed time information was given throughout the duration of the exercise bout. At the conclusion of the 20 seconds, the resistance was removed and the subject allowed to cool down pedaling at a mild resistance according to individual preference.

CHAPTER FOUR
RESULTS

SUBJECTS

Seventeen subjects (N=17) representing Division 1 intercollegiate women's volleyball (N=7) and basketball (N=10) teams participated in this study. The overall group data were (mean±SD): age = 19.9±1.17 yrs., height = 70.4±3.33 in., weight = 71.7±7.36 kg, % body fat = 18.1±3.16 and lean body mass = 58.6±4.86 kg. Descriptive data for the subjects are shown in Table 4 (see APPENDIX F).

PEAK POWER OUTPUT (PPO)

Results demonstrate statistically significant mean differences in PPO with increasing resistance. Results are expressed in three terms: watts (W), watts per kilogram (W/kg) and watts per kilogram lean body mass (W/lbm). These values denote absolute peak power output, peak power output relative to body mass, and peak power output relative to lean body mass, respectively. Four resistance factors (7.5%, 8.5% 10.5% and 12.5% of body weight) were applied in random order to determine the peak power output results (W, W/kg and W/lbm).

A factorial ANOVA revealed statistically significant differences for power output between the factors for absolute power [$F_{(3,63)}$=10.397;

$p<0.0001$], relative power [$F_{(3,63)}=17.265$; $p<0.0001$], and power relative to lean body mass [$F_{(3,63)}=22.771$; $p<0.0001$].

Pairwise comparisons revealed statistically significant differences in peak power output between 7.5% and 10.5% ($p=0.0054$), 7.5% and 12.5% ($p<0.0001$) and 8.5% and 12.5% ($p=0.0058$) for absolute peak power output measures (W). The pairwise comparisons of relative peak power output measures (W/kg) revealed statistically significant differences in peak power output between 7.5% and 10.5% ($p=0.0001$), 7.5% and 12.5% ($p<0.0001$), 8.5% and 10.5% ($p=0.0194$) and 8.5% and 12.5% ($p=0.0003$). The pairwise comparisons of peak power output measures relative to lean body mass (W/lbm) revealed statistically significant differences in peak power output between 7.5% and 10.5% ($p<0.0001$), 7.5% and 12.5% ($p<0.0001$), 8.5% and 10.5% ($p=0.0137$) and 8.5% and 12.5% ($p<0.0001$). The complete ANOVA tables are shown in Table 2a with post-hoc analyses shown in Table 3a. Peak power output data are shown in figures 1a-c (following page) and in Table 1 below.

Resistance	(W)	(W/kg)	(W/lbm)	(J)	(J/kg)	(J/lbm)
7.50%	752.2	10.5	12.8	1274.3	17.8	21.8
Max.	996	11.9	14.5	1532.9	20.9	24.9
Min.	552	8.69	10.5	1042.5	15.3	19.4
8.50%	809.9	11.3	13.8	1340.5	18.8	22.9
Max.	1082	12.9	15.9	1620	20.8	25.3
Min.	642	9.4	11.5	1131.2	16.7	20.5
10.50%	917.6	12.8	15.6	1413.4	19.8	24
Max.	1118	14.6	17.8	1663.4	23.1	28.1
Min.	729	8.55	10.9	1175.2	14.2	18.1
12.50%	971.5	13.5	16.8	1431.7	20.1	24.5
Max.	1255	15.5	18.8	1703.5	23.5	28.6
Min.	710	10.2	13.5	1196.5	16.1	20.4
MEAN	862.8	12	14.8	1365	19.1	23.3
SD	99.74	1.37	1.76	72.17	1.01	1.21

Table 1. Mean, minimum and maximum values for Peak Power Output & Total Mechanical Work at each resistance with overall mean and SD.

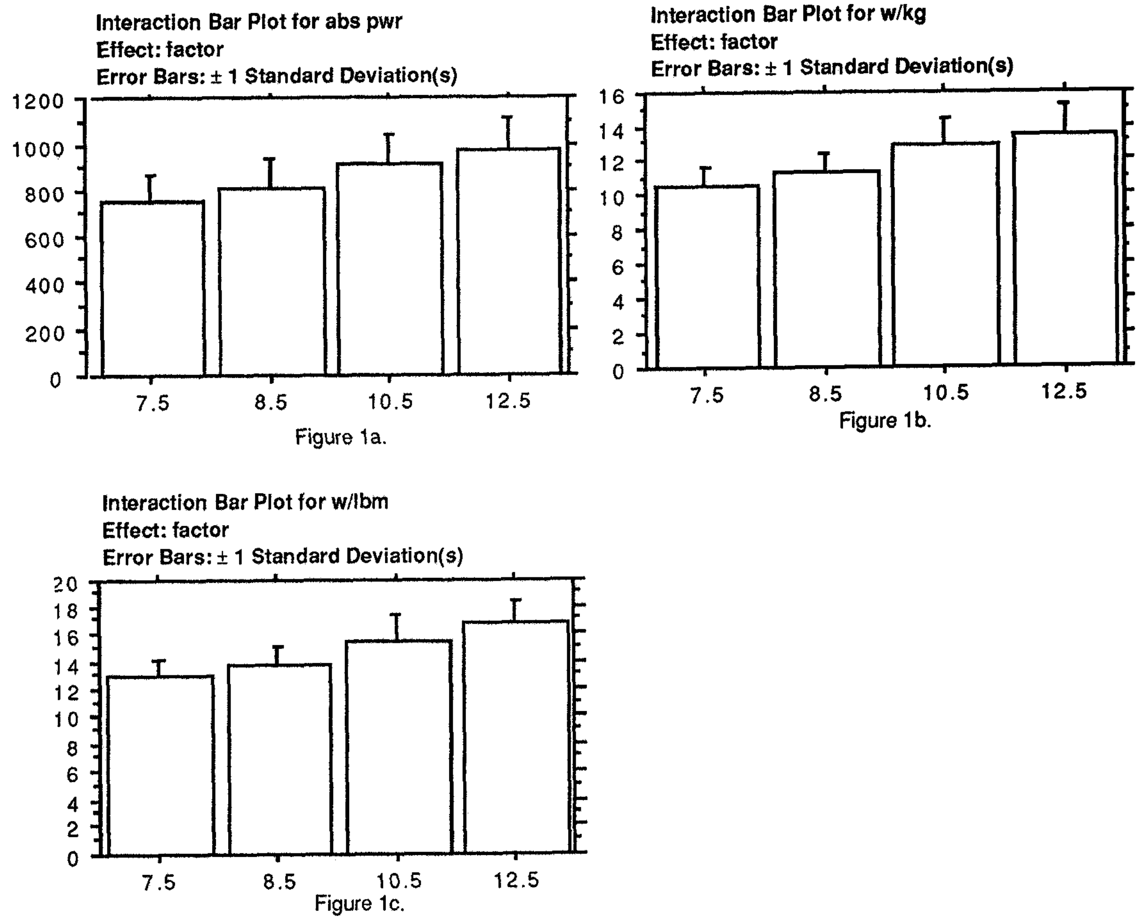
Interaction Bar Plot for abs pwr
Effect: factor
Error Bars: ± 1 Standard Deviation(s)

Figure 1a.

Interaction Bar Plot for w/kg
Effect: factor
Error Bars: ± 1 Standard Deviation(s)

Figure 1b.

Interaction Bar Plot for w/lbm
Effect: factor
Error Bars: ± 1 Standard Deviation(s)

Figure 1c.

Figures 1a-c. Mean values for peak power output. For all of the figures above, the x-axis labels are the test resistances expressed as % body weight. The y-axis labels are power outputs in watts(abs pwr), watts per kilogram of body mass (relative power) and watts per kilogram of lean body mass (relative to lbm). * denotes statistically significant differences from 7.5% body weight. # denotes statistically significant differences from 8.5% body weight.

TOTAL MECHANICAL WORK (TMW)

Results further demonstrate statistically significant mean differences in TMW with increasing resistance. TMW results are also expressed in absolute, relative to body mass, and relative to lean body mass. The units are joules (J), joules per kilogram (J/kg), and joules per kilogram lean body mass (J/lbm). Four resistance factors (7.5%, 8.5% 10.5% and 12.5% of body weight) were applied in random order to determine the total mechanical work performed (J, J/kg and J/lbm).

A factorial ANOVA revealed an upward trend in differences in TMW between the factors for absolute work [$F_{(3,63)}$=3.987; p<0.0115], relative work [$F_{(3,63)}$= 5.307; p<0.0025], and work relative to lean body mass [$F_{(3,63)}$= 6.276; p<0.0009]. A Scheffe post-hoc analysis revealed statistically significant differences in TMW between 7.5% and 12.5% (p=0.0295) in absolute terms (J). The post-hoc analysis of relative TMW (J/kg) revealed statistically significant differences between 7.5% and 10.5% (p=0.0316), 7.5% and 12.5% (p=0.0082). The post-hoc analysis of TMW relative to lean body mass (J/lbm) also revealed statistically significant differences between 7.5% and 10.5% (p=0.0224), 7.5% and 12.5% (p=0.0025). The complete ANOVA tables for TMW measures are shown in Table 2b with post-hoc analyses shown in Table 3b. Total mechanical work data are shown in figures 2a-c.

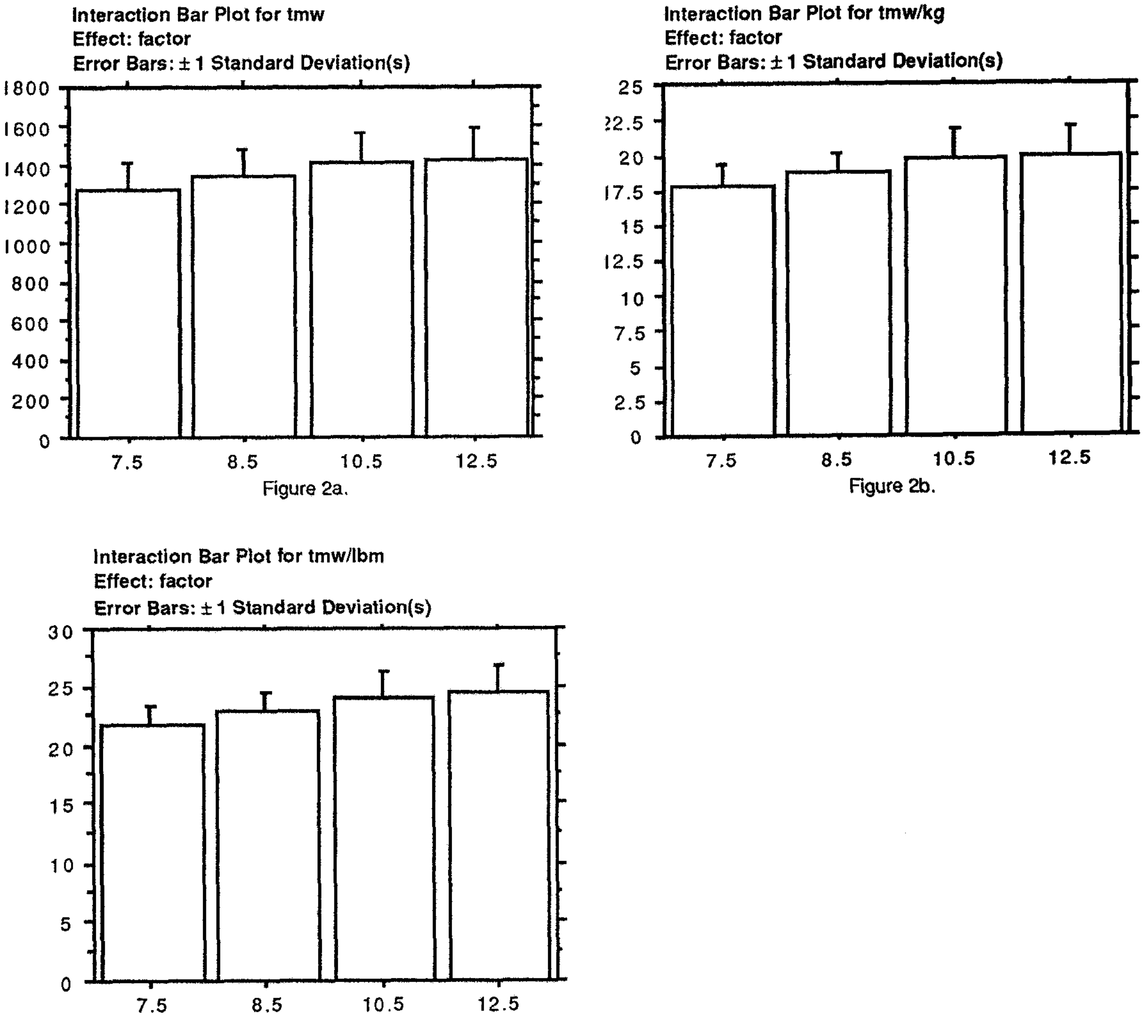

Figure 2a.

Figure 2b.

Figure 2c

Figures 2a-c. Mean values for total mechanical work. For all of the figures above, the x-axis labels are the test resistances expressed as % body weight. The y-axis labels are TMW outputs in joules (TMW), joules per kilogram of body mass (relative TMW) and joules per kilogram of lean body mass (relative to lbm). * denotes statistically significant differences from 7.5% body weight. # denotes statistically significant differences from 8.5% body weight.

CHAPTER 5
DISCUSSION

The purpose of this study was to investigate the effects of various resistances on anaerobic muscular power characteristics during an abbreviated Wingate Anaerobic Test (WAT) in power-trained female athletes. Our objective was to demonstrate how increasing resistance affects power output characteristics. The findings of this study suggest that it is possible to utilize test resistances greater than the previously prescribed resistance (7.5% of body weight) in order to elicit a greater peak power output without causing a decrease in total mechanical work (TMW).

In developing the WAT, the creators' intent was to produce a test that would measure specifically 'anaerobic' power characteristics. It was held that mean power output (watts) over the duration of the test was the best demonstration of 'anaerobic capacity'. Therefore, the determination of the optimal test resistance factor was based on that resistance which maximized mean power output (Dotan & Bar-Or, 1983). Using incremental increases in resistance, that resistance which optimized mean power output was determined, and thus has been the primarily utilized test factor for the WAT protocol. The use of this resistance, however, has lead to a consistent underestimation of peak power output as determined by the WAT, particularly when used with power-trained athletes (compare results of hockey players in studies by Rhodes et al.(1986) and Luchsinger et al. (1987) with those of Maud & Schultz (1989)).

The results of this study are consistent with previous research which demonstrates that utilizing a higher resistance results in greater peak power output (Beld et al., 1989, Serresse et al., 1991). Previously, the highest resistance methodically evaluated (that is not resulting from individualized force-velocity tests (e.g. Mannion, et al., 1993)) in the female athletes was 10.5% of body weight (Davy et al., 1991). The test resistances used in the present study were thought to represent a range of resistances that, for this subject population, would include a resistance at which a decrease in peak power output would be observed. As stated in the methods, subjects were tested up to 12.5%. The resulting peak power output measures still demonstrated an upward trend, though the peak power output measures at the 10.5% and 12.5% resistances were not statistically significant from each other (figures 1a-c).

PEAK POWER OUTPUT

The present study focused on maximizing peak power output (PPO) as being determined by the product of resistance (force) and velocity (flywheel revolutions per minute). Using the current WAT protocol with a resistance of 7.5% of body weight, velocity (and thus

PPO) cannot be further increased. Additionally, power-trained athletes would be able to maintain an adequate pedaling velocity in spite of increased resistance. Therefore, the test resistances selected for this study were quite high when compared to earlier investigations. The result, as hypothesized, was that a significantly greater PPO was elicited at the higher resistances (10.5% and 12.5%).

One of the primary arguments against the WAT protocol is related to the inertia generated by the ergometer flywheel at the onset of the test (Bassett, 1989). As stated in the protocol description, the subjects were instructed to be at maximum pedaling velocity at the time the resistance was applied to the flywheel. It may be argued that the greater PPO measures in this study were simply due to pretest flywheel inertia. In an effort to combat this source of measurement error, the timing of the resistance application was such that the full resistance was present at the beginning of the 20 second test period. This was accomplished by applying the resistance just prior to the start of the timing period so that any slack in the basket attachment was taken up prior to timing. While this adjustment didn't completely compensate for the error associated with the flywheel inertia, it is suggested that the error was greatly reduced.

Another precaution against the measurement error associated with power output measures resulting from the pretest flywheel inertia was the configuration of the averaging period in the analysis software.

While measurements were taken every second of the test, PPO was determined as the greatest three-second average sampled during the test. If this averaging period had been shorter, the potential for an erroneous spike to be interpreted as a PPO would have been increased. Similarly, selecting a longer averaging period would result in a masking of the true PPO measure as it occurs within the initial five seconds of the exercise bout.

TOTAL MECHANICAL WORK

Traditionally, peak power output (watts) has been used to indicate 'anaerobic power' while mean power output (watts) has been used to describe 'anaerobic capacity'. In this study, we measured TMW (joules) performed during the test as a determination of anaerobic capacity (Poole et al., 1988). We feel that the term 'anaerobic capacity' implies an ability to perform work at a high level of exercise intensity and therefore requires the use of a work measures (joules) as opposed to a power measure (watts).

It was hypothesized that the participants would possess sufficient muscular power to overcome substantial increases in test resistance without a compromise in TMW. The findings of the study support this hypothesis. Furthermore, a consistent trend toward increased TMW at greater resistances was observed. We suggest that the greater TMW represents a more complete taxation of the anaerobic energy pathways. This better reflects anaerobic capacity from the standpoint that the greater work performed during the exercise bout must be supported by energy derived from anaerobic systems. Spriet (1996) suggested that the anaerobic systems appear to have a defined functional duration but the extent to which greater taxation occurs is a function of the intensity of the work effort. The results of the present study support this postulate.

During the original WAT development, test duration was not determined experimentally but arbitrarily as a duration that would sufficiently tax the anaerobic energy systems, those being the high energy phosphate (HEP) and glycolytic pathways. This investigation demonstrated that the significant differences in peak power output resulting from increased resistance during the early stages of the test were not exhibited past seven to ten seconds of the test (e.g. figure 3). It is hypothesized that increasing the intensity (resistance) of the exercise bout will more effectively elicit a greater anaerobic response compared to increasing the duration (resulting in a greater aerobic contribution (Kavanagh & Jacobs, 1988, Serresse et al., 1987)). Similarly, when testing primarily for nonsport-specific anaerobic capacity, it appears that the standard 30 second duration is excessive, and that a shorter duration test may more effectively isolate anaerobic characteristics.

The results from this study show that a still greater resistance may produce even higher PPO values without significantly compromising TMW when testing a power-trained population. Therefore, it is suggested that the optimal test resistance be greater than 10.5% of body weight. Because no significant difference for either PPO and TMW was observed between the 10.5% and 12.5% resistances, it is not possible to draw definite conclusions at this time as to the optimal resistance for assessing both PPO and TMW.

SUBSTRATE UTILIZATION PATTERNS

Using higher resistances (> 10.5% of body weight) may better demonstrate substrate utilization patterns, and may more effectively detect changes in those patterns resulting from training adaptation or pharmacological intervention. As seen in figure 3 below, a greater change in slope of the power vs. time plot was observed when higher resistance was used. The point of this change in slope (going from steep to less steep) corresponds with the shift in reliance on the HEP system to reliance on the glycolytic system.

CONCLUSIONS

The purpose of this investigation was to determine the effects of various resistances on anaerobic muscular power characteristics during an abbreviated Wingate Anaerobic Test (WAT) in power-trained female athletes. It was found that increasing the resistance to 12.5% of body weight resulted in both greater PPO and TMW compared to the same measures using the 7.5% resistance used in the current protocol. The results for both PPO and TMW were greater at 12.5% resistance than at 10.5% resistance but the differences were not statistically significant. Further research should include higher resistances to see whether increasing test resistance will result in significant increases in both PPO and TMW, or if further increases will result in a decline in PPO and compromised TMW. Finally, the subject pool should be expanded to include male power-trained athletes and both male and female non-athletes and endurance-trained athletes.

FUTURE DIRECTIONS

The findings of the present study provide the foundation for several future directions for research. The first should be to determine optimal sport-specific and gender-specific resistance for evaluating PPO and TMW. As different populations are tested, it is likely that optimal resistances will vary across gender, body mass index, sport (and activity level), and age. A critical aspect of the present study was the reporting of results relative to both body mass and lean body mass. Reporting the results relative to lean body mass eliminates gender differences and allows accurate comparison of male and female subjects. Further development may lead to a calculation of test resistance based on lean body mass as opposed to total body mass.

Increased sensitivity of the WAT is very important when investigating adaptations to various training protocols. After being used to determine sport-specific, and gender-specific fatigue curve profiles, the WAT can accurately evaluate the effects of training and provide insight as to how the training protocols may be modified. This dimension of guiding adjustments to training protocols is of great importance to both the injured athlete in rehabilitation and to the athlete making adjustments in training. More research using participants from a variety of sports is needed to provide sport-specific fatigue curve profiles and to provide a table of standard PPO and TMW capabilities.

The optimization of test duration is a complicated issue. We suggest that the optimal duration of a standardized WAT be less than the 30 seconds as originally selected. This hypothesis is based on the observation of an increased aerobic contribution to the work effort seen when the test in prolonged (>20 seconds). Additionally, the fatigue curves generated from various resistances are not significantly different from one another beyond 18-23 seconds indicating a sufficient taxation of the anaerobic energy pathways. While the anaerobic taxation is not complete, the increasing magnitude of the aerobic contribution is such that no further relevant information about the anaerobic system is obtained.

If the purpose of testing is to determine systemic responses and metabolic requirements of a specific activity (Rhodes et al., 1986), it is appropriate to select a WAT duration that best matches the activity in question. For example, if the goal of the testing is to determine the ability of a hockey player to generate maximum power over the duration of a shift which lasts approximately 45 seconds, using a 45 second WAT will yield the most relevant information. *However*, it must also be noted that there is a tendency to 'pace' during extended exercise bouts, thus the PPO may not reflect the subject's true peak power measure. Testing purpose is therefore critical to both experimental design and interpretation of findings.

Finally, modifying the WAT by increasing the test resistance makes the WAT an ideal tool to evaluate the effects of oral creatine supplementation for high intensity exercise. The analysis of these effects can be approached from the hypotheses that creatine supplementation can lead to increased TMW and how supplementation can cause a right-shift in the fatigue curve demonstrating an enhanced HEP system (able to support high intensity work by HEP for longer duration). The modified WAT also can be used to effectively evaluate the systemic ability to combat the decrements in PPO indicating an increased rate of resynthesis. This is observed when short rest periods are interspersed between repeated bouts of high intensity.

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APPENDICES

APPENDIX A

Standardized Instructions for the Wingate Anaerobic Test Protocol

The following are the standardize instructions for the Wingate test protocol. A hard copy was presented to each participant in addition to verbal instructions. Participants were asked to read and ask questions prior to beginning the testing procedure.

- Following warm-up, the you shall remain seated on the test ergometer. You will continue resting until you feel ready to perform the test trial.

- You will then be given a 10s countdown during which you will begin pedaling against zero resistance. Your are instructed to be at maximum pedaling velocity by the time you reach time zero (end of the 10s countdown). At this point the entire resistance will be applied to the ergometer.

- You will then continue to maintain the highest pedaling velocity you are able to generate for a period of 20s. You will receive verbal encouragement in addition of elapsed time information throughout the duration of the test. After 20s, the tester will have you stop pedaling (as soon as your momentum allows), you will move to a cool down ergometer where you may pedal against mild resistance as long as you feel necessary.

These instructions were repeated prior to each exercise bout for each subject.

APPENDIX B

Informed Consent

A. **Title of the Research Project.** The effects of high resistances of peak power output and total mechanical work during short-duration high intensity exercise.

B. **Investigators.**
Primary Investigator: Paul Borsa, Ph.D., ATC, Assistant Professor, Department of Exercise and Sport Science, College of Health and Human Performance

Co-investigator: Aaron Sidner, BS

C. **Purpose of the Research Project.** The purpose of this study is to investigate the effects of increased resistances on peak power output and total mechanical work during a modified Wingate Anaerobic Test (WAT) in power-trained female athletes. The WAT as currently practiced uses a resistance that is insufficient to yield a true maximum peak power output. This study will use three resistances greater than the currently prescribed resistance along with the current prescribe resistance to determine if a true maximal peak power can be obtained using the test range of resistances specified in the protocol and to examine the effect using these resistances has on total mechanical work.

D. **Procedures.** I have received an oral and written explanation of this study and I understand that as a participant in this study the following things will happen:

1. **Pre-study Orientation.** Prior to my participation, I will have attended a brief orientation meeting detailing the study, methods and what shall be expected of me as a participant. Following the verbal explanation of the study, pre-exercise measurements will be height, weight and skinfold measures to estimate body composition.

2. **What participants will do during the study.** I will be asked to report to the Human Performance Laboratory on one occasion. This session will last no more than 75 minutes. At the session, I will complete the informed consent (receive verbal description), record pre-exercise measurements and receive a brief orientation to the exercise protocol. The exercise protocol will require me to pedal on a cycle ergometer as fast as possible for a period of

twenty seconds against various resistances based on my body weight. Following standardized warm-up, I will complete four 20 second exercise bouts, one trial at each of four test resistances. I will be allowed a 10 minute recovery period between each bout.

3. **Foreseeable risks or discomforts.** I understand there are foreseeable risks or discomforts to me if I agree to participate in the study. The exercise protocol may produce transient light-headedness and/or nausea. In some cases, mild muscular soreness may result. I understand that this will not be significantly different from normal training discomfort.

4. **Benefits to be expected from the research.** I understand that as a benefit from my participation in this study, I will receive information concerning my ability to generate muscular power and sustain high intensity exercise. This information may be beneficial in evaluating my training regimen.

5. **Alternative procedures or course of treatment.** There are no feasible alternatives procedures available for this study.

E. **Confidentiality.** Any information obtained from me will be kept confidential. A code number will be used to identify any test results or other information that I provide. The only persons who will have access to this information will be the investigators and no names will be used in any data summaries or publications. Where appropriate, the coaching staff may view the results from this study, however no names will be released as individual results will remain confidential.

F. **Compensation for Injury** I understand the University does not provide a research subject with compensation or medical treatment in the event the subject is injured as a result of participation in the research project.

G. **If I have questions.** I understand that any questions I have about the research study and/or specific procedures should be directed to Aaron Sidner, Langton Hall 121g (737-6790) or Paul Borsa, Langton Hall 223A (737-6787), Oregon State University, Corvallis, Oregon.

H. **Understanding and Compliance.** My signature below indicates that I have read and that I understand the procedures described above and give my informed and voluntary consent to participate in this study. I understand that I will receive a signed copy of this consent form.

I. **Voluntary Participation.** I understand that, while this study is supported by the coaching staff, my participation is completely voluntary and that I may either refuse to participate or withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled.

Signature of subject

Name of Subject Date Signed

Subject's Present Address Phone

I certify that I have explained to the above individual the nature and purpose, potential risks and benefits of this study. I have answered any questions that have been raised, and have witnessed the above signature. Also, I have provided the subject with a copy of this signed document.

Signature of Principal Investigator Date Signed

APPENDIX C

Coaches Letters

May 16, 1997

Judy Spoelstra
Oregon State University
Gill Coliseum
Corvallis, OR 97331

To whom it may concern:

I hearby grant Paul A. Borsa and Aaron Sidner permission to approach the Oregon State University Women's Basketball Team concerning their research topic, 'The effects of high resistances of peak power output and total mechanic work during short-duration high intensity exercise.'

I am aware that this will require 1 session. Assessment will involve modified Wingate Anaerobic Tests (on a Monark cycle ergometer) in the Human Performance Lab, Women's Building room 19 at Oregon State University. These procedures have been fully explained to my staff and me by the principal investigators.

I also understand that the completion of the Wingate tests will require 20 second 'all-out efforts' by the athletes which may produce generalized muscle soreness and mild discomfort (including transient light-headedness and/or nausea). I have been assured that this should not negatively affect the athlete. Furthermore, subjects injured or deemed otherwise unable to participate by the team doctor or athletic trainer will be excluded from the study.

Sincerely,

Coaching Staff

May 16, 1997

Jeff Mozzochi
Oregon State University
Gill Coliseum
Corvallis, OR 97331

To whom it may concern:

I hearby grant Paul A. Borsa and Aaron Sidner permission to approach the Oregon State University Women's Volleyball Team concerning their research topic, 'The effects of high resistances of peak power output and total mechanic work during short-duration high intensity exercise.'

I am aware that this will require 1 session. Assessment will involve modified Wingate Anaerobic Tests (on a Monark cycle ergometer) in the Human Performance Lab, Women's Building room 19 at Oregon State University. These procedures have been fully explained to my staff and me by the principal investigators.

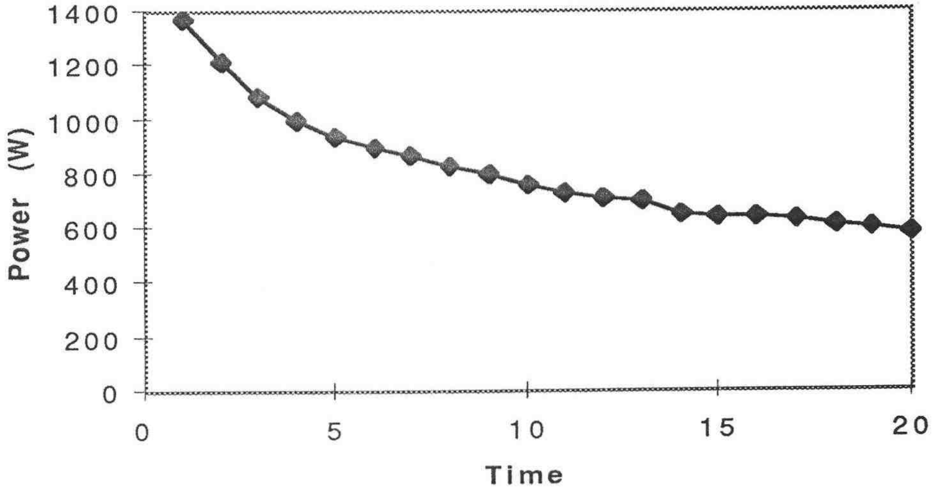
I also understand that the completion of the Wingate tests will require 20 second 'all-out efforts' by the athletes which may produce generalized muscle soreness and mild discomfort (including transient light-headedness and/or nausea). I have been assured that this should not negatively affect the athlete. Furthermore, subjects injured or deemed otherwise unable to participate by the team doctor or athletic trainer will be excluded from the study.

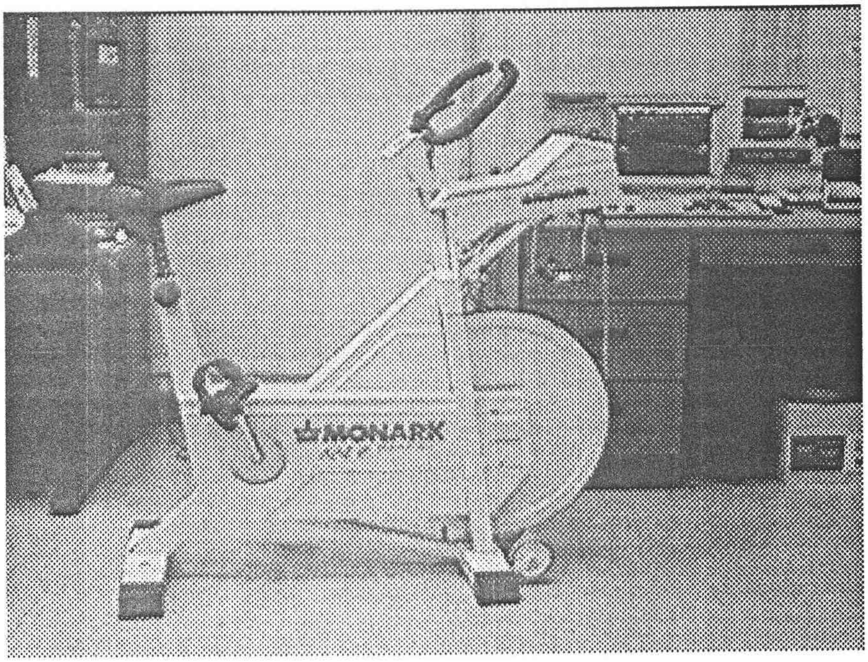
Sincerely,

Coaching Staff

APPENDIX D

Printout from a Wingate Anaerobic Test and the Cycle Ergometer





APPENDIX E

Statistical Analysis Tables and Miscellaneous Figures

Table 2a. Means and ANOVA tables for Peak Power Output measures.

ANOVA Table for abs pwr

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	504335.989	168111.996	10.397	<.0001
Residual	63	1018620.996	16168.587		

Model II estimate of between component variance: 9073.27

Means Table for abs pwr
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	752.235	117.348	28.461
8.5	17	809.882	122.552	29.723
10.5	16	917.562	122.810	30.703
12.5	17	971.529	143.995	34.924

ANOVA Table for w/kg

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	95.740	31.913	17.265	<.0001
Residual	63	116.449	1.848		

Model II estimate of between component variance: 1.795

Means Table for w/kg
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	10.495	1.064	.258
8.5	17	11.292	.997	.242
10.5	16	12.837	1.574	.394
12.5	17	13.486	1.682	.408

ANOVA Table for w/lbm

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	157.240	52.413	22.771	<.0001
Residual	63	145.011	2.302		

Model II estimate of between component variance: 2.992

Means Table for w/lbm
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	12.842	1.282	.311
8.5	17	13.822	1.255	.304
10.5	16	15.615	1.841	.460
12.5	17	16.761	1.634	.396

Table 2b. Means and ANOVA tables for Total Mechanical Work results.

ANOVA Table for tmw

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	263257.636	87752.545	3.987	.0115
Residual	63	1386695.022	22011.032		

Model II estimate of between component variance: 3925.741

Means Table for tmw
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	1274.262	131.304	31.846
8.5	17	1340.512	144.253	34.986
10.5	16	1413.367	155.823	38.956
12.5	17	1431.732	160.797	38.999

ANOVA Table for tmw/kg

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	51.519	17.173	5.307	.0025
Residual	63	203.880	3.236		

Model II estimate of between component variance: .832

Means Table for tmw/kg
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	17.847	1.535	.372
8.5	17	18.753	1.416	.343
10.5	16	19.769	2.155	.539
12.5	17	20.059	2.007	.487

ANOVA Table for tmw/lbm

	DF	Sum of Squares	Mean Square	F-Value	P-Value
factor	3	74.355	24.785	6.276	.0009
Residual	63	248.802	3.949		

Model II estimate of between component variance: 1.244

Means Table for tmw/lbm
Effect: factor

	Count	Mean	Std. Dev.	Std. Err.
7.5	17	21.788	1.526	.370
8.5	17	22.912	1.594	.387
10.5	16	24.006	2.371	.593
12.5	17	24.512	2.326	.564

Table 3a. Scheffe post-hoc analyses showing the sources of variation for Peak Power Output measures.

Scheffe for abs pwr
Effect: factor
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
7.5, 8.5	-57.647	125.284	.6288	
7.5, 10.5	-165.327	127.227	.0054	S
7.5, 12.5	-219.294	125.284	<.0001	S
8.5, 10.5	-107.680	127.227	.1275	
8.5, 12.5	-161.647	125.284	.0058	S
10.5, 12.5	-53.967	127.227	.6871	

Scheffe for w/kg
Effect: factor
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
7.5, 8.5	-.797	1.340	.4111	
7.5, 10.5	-2.342	1.360	.0001	S
7.5, 12.5	-2.991	1.340	<.0001	S
8.5, 10.5	-1.545	1.360	.0194	S
8.5, 12.5	-2.194	1.340	.0003	S
10.5, 12.5	-.649	1.360	.6006	

Scheffe for w/lbm
Effect: factor
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
7.5, 8.5	-.980	1.495	.3237	
7.5, 10.5	-2.773	1.518	<.0001	S
7.5, 12.5	-3.919	1.495	<.0001	S
8.5, 10.5	-1.793	1.518	.0137	S
8.5, 12.5	-2.939	1.495	<.0001	S
10.5, 12.5	-1.146	1.518	.2061	

Table 3b. Scheffe post-hoc analyses showing the sources of variation for TMW measures.

Scheffe for tmw
Effect: factor
Significance Level: 5 %

	Mean Di...	Crit. Diff	P-Value	
7.5, 8.5	-66.250	146.177	.6401	
7.5, 10.5	-139.105	148.444	.0747	
7.5, 12.5	-157.470	146.177	.0295	S
8.5, 10.5	-72.855	148.444	.5782	
8.5, 12.5	-91.220	146.177	.3678	
10.5, 12.5	-18.365	148.444	.9884	

Scheffe for tmw/kg
Effect: factor
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
7.5, 8.5	-.906	1.772	.5447	
7.5, 10.5	-1.922	1.800	.0316	S
7.5, 12.5	-2.212	1.772	.0082	S
8.5, 10.5	-1.016	1.800	.4584	
8.5, 12.5	-1.306	1.772	.2250	
10.5, 12.5	-.290	1.800	.9750	

Scheffe for tmw/lbm
Effect: factor
Significance Level: 5 %

	Mean Diff.	Crit. Diff	P-Value	
7.5, 8.5	-1.124	1.958	.4435	
7.5, 10.5	-2.218	1.988	.0224	S
7.5, 12.5	-2.724	1.958	.0025	S
8.5, 10.5	-1.094	1.988	.4805	
8.5, 12.5	-1.600	1.958	.1496	
10.5, 12.5	-.506	1.988	.9111	

Figures 4a-d. Team Comparisons for Power vs. Time Plots.

These figures depict the power vs. time plots comparing the volleyball players with the basketball players. Note the changes in the point of intersection, the time at which basketball power output becomes greater than the volleyball power output.

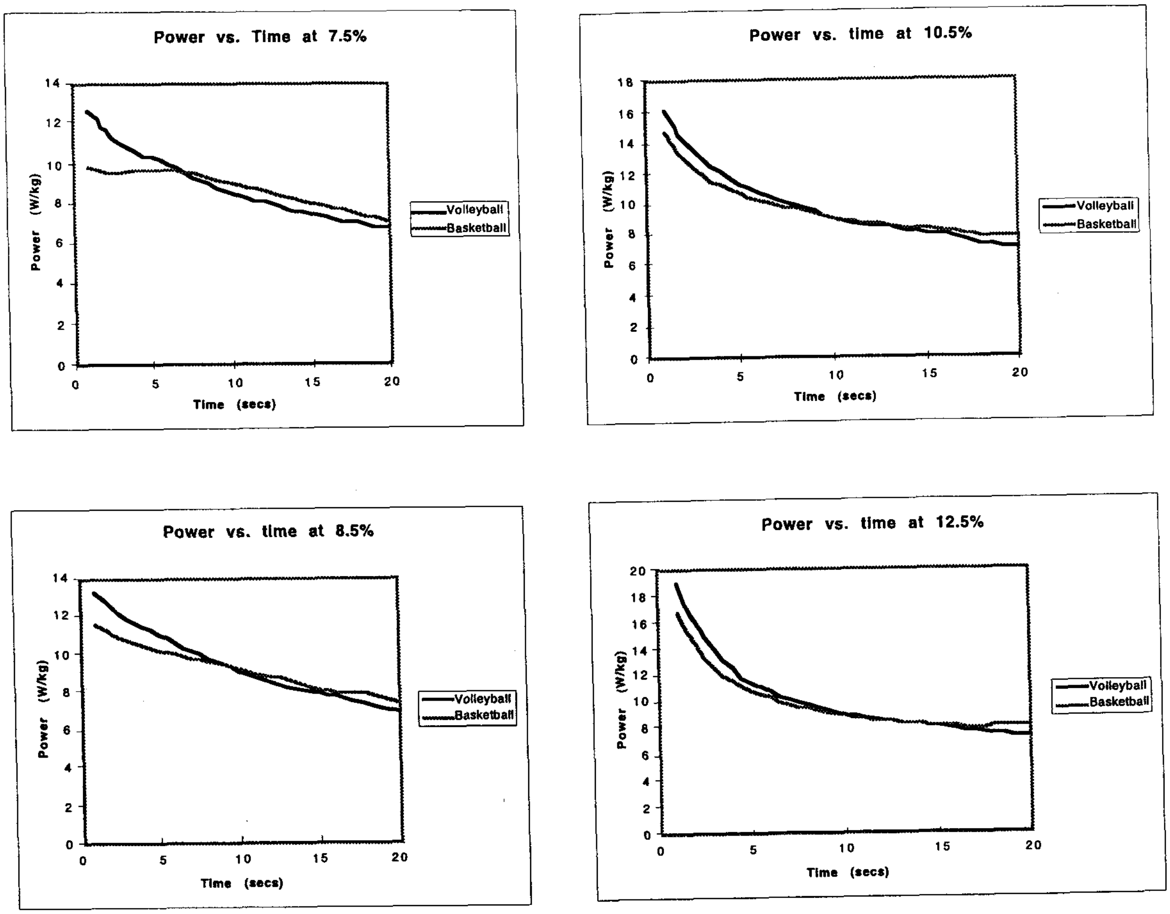
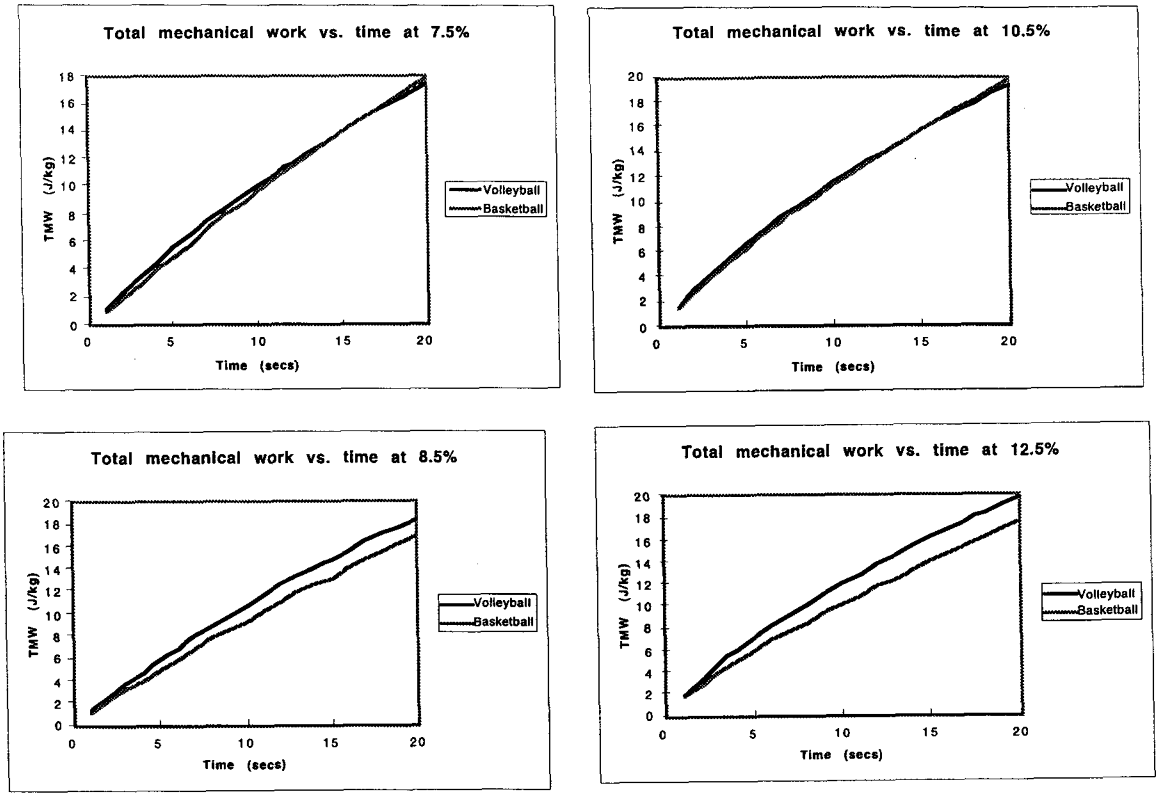


Figure a (top left) shows power/time curves generated at the 7.5% of body weight resistance. Figures b (bottom left) , c (top right) and d (bottom right) show power/time curves generated at the 8.5%, 10.5% and 12.5% of body weight resistance respectively.

Figures 5a-d. Team Comparisons for Mechanical Work vs. Time Plots.

These figures depict total mechanical work measures vs. time comparing the volleyball players to the basketball players. The line separation stems from the greater TMW generated during the early stages of the exercise bouts and may reflect an increased ability to tax the HEP metabolic pathway.



Total mechanical work vs. time at 7.5%

Total mechanical work vs. time at 10.5%

Total mechanical work vs. time at 8.5%

Total mechanical work vs. time at 12.5%

Figure a (top left) shows total mechanical work/time curves at the 7.5% of body weight resistance. Figures b (bottom left) , c (top right) and d (bottom right) show total mechanical work/time curves at the 8.5%, 10.5% and 12.5% of body weight resistance respectively.

APPENDIX F

Subject Data

Table 4. Individual subject data. This table contains the subjects' numerical code numbers and each athlete's anthropometric data taken just prior to the testing session in which they participated. Also shown are the team mean, minimum and maximum values along with the overall mean and SD.

#	ht (in)	wt (kg)	tricep	suprail.	abdom	thigh	Σ4SKF	age	Db	%bf	lbm (kg)
248	73	84	16	12	15	19	62	19	1.05586	18.8	68.2
134	70	67	15	6	11	20	52	18	1.06163	16.3	56.1
715	71	77	18	11	11	22	62	19	1.05586	18.8	62.5
642	72	67	12	8	15	19	54	22	1.06019	16.9	55.7
942	69	73	15	11	15	19	60	21	1.05684	18.4	59.6
710	72	67	16	7	18	26	67	22	1.05288	20.1	53.5
374	73	75	16	6	14	21	57	19	1.05869	17.6	61.8
volleyball	71.43	72.9	15.43	8.71	14.14	20.9	59.1	20	1.05742	18.1	59.6
max.	73	84	18	12	18	26	67	22	1.06163	20.1	68.2
min.	69	67	12	6	11	19	52	18	1.05288	16.3	53.5
462	66	62	13	5	12	17	47	18	1.06457	15	52.7
315	76	74	16	10	10	24	60	21	1.05684	18.4	60.4
428	76	85	12	17	18	25	72	19	1.05039	21.3	66.9
764	66	68	17	21	28	22	88	19	1.04208	25	51
194	68	67	12	5	6	17	40	20	1.06862	13.2	58.1
814	74	90	20	16	20	26	82	21	1.04499	23.7	68.7
275	70	71	13	6	11	28	58	21	1.05797	17.9	58.3
348	66	60	7	7	7	14	35	21	1.07161	11.9	52.8
617	64	65	15	11	13	27	66	19	1.05365	19.8	52.1
914	70	67	16	6	12	24	58	20	1.05805	17.8	55
basketball	69.6	69.7	14.1	10.4	13.7	22.4	60.6	20	1.05671	18.4	57.6
max.	76	90	20	21	28	28	88	21	1.07161	25	68.7
min.	64	60	7	5	6	14	35	18	1.04208	11.9	51
overall	70.35	71.7	14.65	9.71	13.88	21.8	60	20	1.0571	18.3	58.4
SD	3.552	8.33	2.957	4.66	5.195	3.99	13.3	1.3	0.00743	3.29	5.67

APPENDIX G

Table 5. Individual Test results. The following data are the peak power output and total mechanical work results for each subject (#) at each resistance (%). The results are expressed in the units shown at the top of each column.

#	%	(W)	(W/kg)	(W/lbm)	(J)	(J/kg)	(J/lbm)
462	7.5	552	8.95	10.5	1043	16.8	19.8
	8.5	642	10.4	12.2	1131	18.2	21.5
	10.5	875	14.2	16.6	1278	20.6	24.2
	12.5	913	14.8	17.3	1196	19.3	22.7
	MEAN	745.5	12.1	14.1	1162	18.7	22.1
	SD	176.1	2.85	3.34	99.87	1.62	1.86
315	7.5	663	8.97	11	1206	16.3	20
	8.5	695	9.4	11.5	1238	16.7	20.5
	10.5	802	10.8	13.3	1311	17.7	21.7
	12.5	873	10.2	17.1	1479	20	24.5
	MEAN	758.3	9.86	13.2	1309	17.7	21.7
	SD	96.88	0.84	2.78	122.1	1.66	2.01
428	7.5	741	8.69	11.1	1299	15.3	19.4
	8.5	925	10.9	13.8	1430	16.8	21.4
	10.5	729	8.55	10.9	1210	14.2	18.1
	12.5	940	11	14.1	1365	16.1	20.4
	MEAN	833.8	9.78	12.5	1326	15.6	19.8
	SD	114.3	1.34	1.71	93.93	1.12	1.41
764	7.5	627	9.28	12.3	1117	16.4	21.9
	8.5	680	10.1	13.3	1261	18.5	24.7
	10.5	•	•	•	•	•	•
	12.5	772	11.4	15.1	1281	18.8	25.1
	MEAN	693	10.3	13.6	1220	17.9	23.9
	SD	73.37	1.09	1.44	89.5	1.31	1.74
194	7.5	654	9.76	11.3	1206	18	20.7
	8.5	668	9.97	11.5	1192	17.8	20.5
	10.5	737	11	12.7	1330	19.8	22.9
	12.5	876	13.1	15.1	1202	17.9	20.7
	MEAN	733.8	11	12.6	1232	18.4	21.2
	SD	101.5	1.52	1.75	65.31	0.95	1.14
814	7.5	996	11.1	14.5	1533	17	22.3
	8.5	951	10.6	13.8	1574	17.5	22.9
	10.5	1104	12.3	16.1	1663	18.5	24.2
	12.5	1104	12.3	16.1	1586	17.6	23.1
	MEAN	1039	11.5	15.1	1589	17.7	23.1
	SD	77.55	0.86	1.13	54.56	0.62	0.79
275	7.5	716	10.1	12.3	1313	18.5	22.5
	8.5	853	12	14.6	1431	20.2	24.5
	10.5	990	13.9	17	1489	21	25.5
	12.5	1040	14.6	17.8	1668	23.5	28.6
	MEAN	899.8	12.7	15.4	1475	20.8	25.3
	SD	145.8	2.05	2.5	148.2	2.08	2.54
348	7.5	704	11.7	13.3	1256	20.9	23.8
	8.5	674	11.2	12.8	1235	20.6	23.4
	10.5	818	13.6	15.5	1284	21.4	24.3
	12.5	710	11.8	13.5	1236	20.6	23.4
	MEAN	726.5	12.1	13.8	1253	20.9	23.7
	SD	63	1.05	1.19	23.11	0.38	0.43

Table 5 (Continued).

#	%	(W)	(W/kg)	(W/lbm)	(J)	(J/kg)	(J/lbm)
617	7.5	634	9.75	12.2	1146	17.6	22
	8.5	727	11.2	14	1205	18.5	23.1
	10.5	832	12.8	16	1328	20.4	25.5
	12.5	845	13	16.2	1370	21.1	26.3
	MEAN	759.5	11.7	14.6	1262	19.4	24.2
	SD	98.95	1.52	1.9	104.6	1.63	2.01
914	7.5	756	11.3	13.8	1372	20.5	24.9
	8.5	810	12.1	14.7	1392	20.8	25.3
	10.5	977	14.6	17.8	1545	23.1	28.1
	12.5	1009	15.1	18.4	1512	22.6	27.5
	MEAN	888	13.3	16.1	1455	21.8	26.5
	SD	123.9	1.85	2.25	86.13	1.29	1.59
248	7.5	963	11.5	14.1	1485	17.7	21.4
	8.5	1082	12.9	15.9	1620	19.3	23.4
	10.5	1118	13.3	16.4	1656	19.7	23.9
	12.5	1255	14.9	18.4	1639	19.5	23.7
	MEAN	1105	13.1	16.2	1600	19.1	23.1
	SD	120.2	1.43	1.76	78.29	0.91	1.15
134	7.5	800	11.9	14.2	1270	19	22.6
	8.5	865	12.9	15.3	1324	19.8	23.6
	10.5	941	14	16.7	1361	20.3	24.3
	12.5	1038	15.5	18.4	1509	22.5	26.9
	MEAN	911	13.6	16.1	1366	20.4	24.4
	SD	102.4	1.53	1.81	102.6	1.5	1.84
374	7.5	817	10.9	13.2	1416	18.9	22.9
	8.5	906	12.1	14.7	1517	20.2	24.5
	10.5	1043	13.9	16.9	1646	21.9	26.6
	12.5	1161	15.5	18.8	1704	22.7	27.6
	MEAN	981.8	13.1	15.9	1571	20.9	25.4
	SD	151.4	2.02	2.45	129.2	1.71	2.11
715	7.5	876	11.4	14	1257	16.3	20.1
	8.5	903	11.7	14.5	1305	16.9	20.9
	10.5	1066	13.8	17.1	1408	18.3	22.5
	12.5	1154	15	18.5	1516	19.7	24.3
	MEAN	999.8	13	16	1371	17.8	22
	SD	132.7	1.72	2.12	115.2	1.52	1.86
642	7.5	737	11	13.2	1278	19.1	23
	8.5	743	11.1	13.3	1358	20.3	24.4
	10.5	884	13.2	15.9	1464	21.8	26.3
	12.5	986	14.7	17.7	1389	20.7	24.9
	MEAN	837.5	12.5	15	1372	20.5	24.7
	SD	120.1	1.79	2.15	76.74	1.11	1.36
942	7.5	809	11.1	13.6	1345	18.4	22.6
	8.5	852	11.7	14.3	1411	19.3	23.7
	10.5	888	12.2	14.9	1464	20.1	24.6
	12.5	944	12.9	15.8	1351	18.5	22.7
	MEAN	873.3	12	14.7	1393	19.1	23.4
	SD	57.16	0.76	0.96	56.22	0.79	0.94
710	7.5	743	11.1	13.9	1122	16.7	20.5
	8.5	792	11.8	14.8	1164	17.4	21.2
	10.5	877	13.1	16.4	1175	17.5	21.4
	12.5	896	13.4	16.8	1334	19.9	24.3
	MEAN	827	12.3	15.5	1199	17.9	21.9
	SD	71.98	1.07	1.35	92.91	1.4	1.68