THE EFFECT OF RAPID DEHYDRATION ON REPEATED BOUTS OF SHORT-TERM, HIGH-INTENSITY CYCLING EXERCISE IN COLLEGE WRESTLERS

by

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INTRODUCTION

A large majority of athletic events and acts of daily living involve short-term, high-intensity (anaerobic) exercise which is often intermittent, separated by periods of moderate activity (Williams, Barnes, and Signorile, 1988). The ability to produce muscular power during anaerobic activity is dependent on the production of force and velocity by the contracting muscle(s). As velocity increases the amount of force skeletal muscle is able to exert declines (Fenn and Marsh, 1935; Hill, 1922; Thortensson, Grimby, and Karlsson, 1976; Wilke, 1950).

A variety of testing methods have been designed to measure and assess anaerobic power. Examples of these methods include; stair climbing in the Margaria power test, the vertical jump first used by Sargent (1921), 40-50 yard sprints, high speed treadmill running, and cycle ergometry (Bar-Or, Dotan, and Inbar, 1977; Houston, Marrin, Green, and Thomson, 1981; Margaria, Aghemo, and Rovelli, 1966). These modalities have been utilized to assess and predict performance of a variety of athletic populations under changing environmental and physical conditions (Houston et al. 1981; Klinzing and Karpowicz, 1986; Tharp, Johnson, and Thorland, 1984; Viitasalo, Kyrolainen, Bosco, and Alen, 1987; Webster, Rutt, and Weltman, 1990).

One such condition receiving a considerable amount of research has been the effects of dehydration on physical performance. It is generally accepted that acute dehydration does not affect isometric strength while detrimental to aerobic performance (Armstrong, Costill, and Fink, 1985; Bosco and Terjung, 1968; Caldwell, Ahonen, and Nousiainen, 1984; Saltin, 1964; Serfass, Stull, Alexander, and Ewing, 1984; Vaccaro, Zauner, and Cade, 1976). However, for short-term, high-intensity activity the consequence of acute dehydration is not well established (Jacobs, 1980; Webster et al. 1990).

Using dehydration as a method of rapid weight reduction is a common practice for participance in sports which utilize weight classifications. Perhaps the most notorious athletes for their weight reduction methods are high school and college wrestlers. When reducing weight prior to a match it is not unusual for wrestlers to lose up to 10% or more of total body weight within a few days primarily via acute dehydration. At a reduced weight wrestlers believe they will have a greater relative strength and therefore have an advantage over opponents in lower weight classifications (ACSM, 1976; AMA, 1967; Herbert and Ribisl, 1972; Houston et al. 1981; Jacobs, 1980; Widerman and Hagan, 1982).

Because of the ease and reliability of force and velocity measurements associated with stationary cycle ergometry it has become the most widely used laboratory method of determining anaerobic power under changing physical conditions. In 1977 Bar-Or et al. developed a cycle ergometer anaerobic power test known as the Wingate Anaerobic Test (WAnT) which measures power developed during 30 seconds of all-out cycling. Bar-Or et al. (1977) reported test-retest correlations of 0.95 to 0.97 for the WAnT utilizing primarily adolescent subjects. Since then several investigators have demonstrated high reliability for an array of anaerobic power cycling tests using various populations (Bar-Or, 1987; Nadeau and Brassard, 1983; Patton, Murphy, and Fredrick, 1985; Williams et al. 1988).

Studies have employed such cycling protocols to evaluate the effects of dehydration on wrestlers. For example, the WAnT was used by Guastella, Wygand, Davy, and Pizza (1988) and Jacobs (1980), while Webster et al. (1990) employed a 40 second maximal cycle ergometer test to measure power output before and after dehydration. Other methods used to assess the effects of dehydration on the anaerobic performance of wrestlers have included; maximal treadmill running to exhaustion, the performance of a specialized wrestling test involving a variety of activities (approximately 2 minutes in duration), and 30 seconds of maximal arm ergometer cranking (Houston et al. 1980; Klinzing, and Karpowicz, 1986; Park, Roemmich, and Horswill, 1990).

STATEMENT OF THE PROBLEM

The research designed to investigate the effect of rapid weight reduction on anaerobic power has resulted in conflicting reports. For example, studies by Guastella et al. (1989), Houston et al. (1981), and Jacobs (1980) reported that dehydration had no affect on anaerobic power, while studies by Webster et al. (1988), Klinzing and Karpowicz (1986), Park et al. (1990), and Saltin (1964) reported a reduction in the subjects ability to produce power after dehydration.

The inconsistency of these studies may be due to the different modes of power assessment as well as differences in the effects of magnitude, duration, and method of dehydration across studies. Data from Caldwell et al. (1984) and Saltin (1964) indicate that different methods and duration of dehydration have differential effects on performance. The magnitude of weight reduction for studies involving wrestlers has ranged from 2-8 % of normal body weight in 2-96 hours and was achieved through food restriction, fluid deprivation, exercise, and/or thermal exposure (Guastella et al. 1988; Herbert and Ribisl, 1972; Houston et al. 1981; Klinzing and Karpowicz, 1986; Ribisl and Herbert, 1970; Tuttle, 1943; Webster et al. 1990; Widerman and Hagan, 1982). The lack of congruence in the aforementioned reports illustrates the need for further investigation in this area.

In addition, the methods utilized by previous researchers to evaluate anaerobic power in wrestlers have consisted of single exercise bouts. For example, Guastella et al. (1988), Park et al. (1990), and Webster et al. (1990) used single bout cycle ergometer protocols of 30-40 seconds to assess the effects of weight reduction on anaerobic power output of wrestlers.

A collegiate wrestling match is six minutes in total duration and is divided into three, two minute periods interspersed with approximately one minute rest intervals. Throughout a match, intermittent maneuvers are performed at a high intensity and short duration, taxing the anaerobic system heavily. Therefore, single bout protocols do not assess a wrestler's ability to repeatedly produce anaerobic power typical of a match situation. In addition, the duration of continuous high-intensity power production in a match rarely lasts for more than 10 seconds, rendering 30-40 second assessment trials inappropriate. The purpose of the present investigation was to assess the effect of rapid dehydration on repeated bouts of short-term, high-intensity cycling exercise in college wrestlers.

SIGNIFICANCE OF THE STUDY

The protocol used in the present study to assess anaerobic power output consisted of five, ten second maximal cycling bouts interspersed with 20 second rest intervals. This allows for the assessment of a wrestler's ability to produce intermittent bursts of anaerobic power. Such a protocol is more applicable to a competitive situation and provides additional information on anaerobic endurance than the traditional single bout protocols.

To investigate the effects of dehydration on repeated anaerobic power the wrestlers performed two trials of the aforementioned protocol before and after dehydration. They were advised to reduced weight via dehydration as they would before weigh-in and were instructed to maintain caloric intake throughout dehydration. In contrast to previous studies, the method of dehydration was that typically used by wrestlers and the maintenance of caloric intake ensured changes occurring in anaerobic power across conditions were a result of dehydration only.

RESEARCH HYPOTHESIS

The following null hypotheses were developed to define the objectives of the present study:

1. Ho: There is no change in peak power, average power, time to peak power, power fatigue rate, and power fatigue index between bouts 1 through 5 during the performance of five, 10 second maximal cycling bouts interspersed with 20 second rest intervals.

2. Ho: There is no change in peak power, average power, time to peak power, power fatigue rate, and power fatigue index between hydrated and dehydrated conditions during the performance of five, 10 second maximal cycling bouts interspersed with 20 second rest intervals.

DELIMITATIONS

The following delimitations were incorporated into the study by the investigator:

1. The investigation was delimited to 20 male volunteers from the Virginia Tech wrestling team.
2. A criterion measure for minimal weight reduction was set at 3% of normal body weight in 48 hours.
3. Abstinence from diuretic and other drug induced methods of dehydration was requested.
4. No strenuous exercise 12 hours prior to each cycling trial.
5. Resistance of the ergometer was set at 0.10 kg/kg hydrated body weight for both hydrated and dehydrated trials.
6. Peak power, average power, time to peak power, power fatigue rate, and power fatigue index were the power output indices measured for both cycling trials.

LIMITATIONS

The investigator recognized the following limitations;

1. Due to the investigation of a specific population, i.e. male college wrestlers, the results are limited in the application to other populations.
2. Due to the low number of subjects completing the study (n = 8) statistical significance of some results may be masked.

3. The cycling exercise protocol used in the present study maybe limited in its application specifically to a wrestling activity.

4. Variations in subjects percent body fat may influence ergometer results.

BASIC ASSUMPTIONS

The following assumptions were made prior to the start of the investigation;

1. The subjects complied with pretest instructions not to engage in strenuous physical activity within 12 hours of each trial.

3. The subjects performed at a maximum level during all bouts for both trials.

4. An accurate record of dietary consumption was kept by each subject.

DEFINITIONS AND SYMBOLS

Acute/rapid dehydration- A reduction in normal body weight of at least 3% by means of dehydration within 48 hours.

Anaerobic power- a general term referring to the ability of an individual to produce force and velocity during short-term, high-intensity exercise.

Average power (AP)- An average of the total power attained every half pedal revolution during each bout, measured in Watts.

Hematocrit (HTC)- The percentage of packed red blood cells to whole blood.

Normal body weight- an average of two total body weight measurements conducted 48 hours apart while the subjects were not on a weight reduction regimen.

Peak Power (PP)- the highest power output achieved during a half pedal revolution within each bout, measured in Watts.

Plasma osmolality (PO)- the number of moles of solute in a kilogram of plasma.

Power fatigue index (PFI)- the percent decline in power from PP to the end of a bout.

Power fatigue rate (PFR)- the rate of power decline from PP to the end of a bout, measured in Watts/second.

Time to peak power (TTPP)- the time from the onset of a bout until PP is attained.

SUMMARY

Using dehydration as a method of rapid weight reduction is a common practice for high school and college wrestlers (ACSM, 1976; AMA, 1967; Houston et al. 1981; Widerman and Hagan, 1982). Research has indicated that acute dehydration does not affect isometric strength however, is detrimental to aerobic performance (Armstrong et al. 1985; Bosco and Terjung, 1968; Caldwell et al. 1984; Saltin, 1964; Serfass et al. 1984; Vaccaro et al. 1976). Investigation of the effects of acute dehydration on short-term, high-intensity activity has produced conflicting results (Jacobs, 1980; Webster, et al., 1990).

In addition to inconsistent results, these studies employ single exercise bouts of 30-40 seconds to assess anaerobic power. A majority of athletic events, including wrestling, involve intermittent short-term, high-intensity activity interspersed with periods of moderate activity (Williams et al. 1988). Thus, these protocols do not assess a wrestler's ability to repeatedly produce short-term (10 to 15 seconds), anaerobic power typical of a match situation.

The purpose of the present study was to design an effective method to assess repeated short-term, high-intensity power out in college wrestlers. Furthermore, the study sought to examine the consequence of rapid dehydration on power output during these repeated bouts.

Chapter II

REVIEW OF LITERATURE

This review focuses on anaerobic power, dehydration, and fatigue with specific applications to wrestlers. The section on fatigue reviews biochemical aspects of local muscular fatigue and thus, is not as specific to a wrestling population. However, this section provides information which may help explain possible interactions between muscular power output and dehydration.

ANAEROBIC POWER

Short-term, high-intensity (anaerobic) exercise typically ranges from 10-30 seconds in duration and is often intermittent, separated by periods of moderate activity (Williams et al. 1988). The development of muscular power in such a relatively short time interval is dependent on the force and velocity produced by the contracting muscle(s). As velocity increases the amount of force skeletal muscle is able to exert declines (Fenn and Marsh, 1935; Hill, 1922; Thortensson et al. 1976; Wilke, 1950).

A variety of testing methods have been designed to measure and assess anaerobic power. Examples of these methods include stair climbing, the vertical jump, 40-50 yard sprints, high speed treadmill running, and cycle ergometry (Bar-Or, et al., 1977; Houston et al. 1981; Margaria et al. 1966; Sargent (1921)). These modalities have been utilized to predict and assess performance of a variety of athletic populations from track and field athletes to wrestlers (Houston et al. 1981; Klinzing and Karpowicz, 1986; Tharp et al. 1984; Viitasalo et al. 1987; Webster et al., 1990).

Assessment

Because of the ease and reliability of force and velocity measurements associated with stationary cycle ergometry it has become the most widely used laboratory method of determining anaerobic power. In 1977 Bar-Or et al. developed a popular cycle ergometer anaerobic power test known as the Wingate Anaerobic Test (WAnT) which measures power developed during 30 seconds of all-out cycling. The test begins with the subject free-wheel pedaling prior to the addition of a resistance to the flywheel which initiates power data collection. Power is calculated from the resistance applied to the flywheel (force) and the velocity determined from the number of pedal revolutions (1 revolution = 6 meters) occurring every 5 seconds.

The protocols employed to evaluate anaerobic power, such as the WAnT, have primarily consisted of single exercise bouts. This has been the case for the assessment of all types of athletes including wrestlers. For example, the WAnT was used by Guastella et al. (1989) and Jacobs (1980) while Webster et al. (1990) employed a 40 second maximal cycle ergometer test to assess the anaerobic power of wrestlers. Recently, Park et al. (1990) examined arm power during 30 seconds of maximal isokinetic arm cranking.

Other methods have been used to measure the anaerobic performance of wrestlers such as, a tread mill run to exhaustion method (8.0 mph, 20% grade) with an average time of 56.4 sec (Houston et al. 1980). Klinzing and Karpowicz (1986) attempted to develop a specific wrestling test using a variety of exercise tasks. The test incorporated running, jumping, and lifting type exercise and the wrestlers completed the test in approximately two minutes.

The aforementioned research indicates a need for the development of protocols which assess intermittent bursts of anaerobic activity typical of many athletic events (Williams et al. 1988). A college wrestling match is six minutes in total duration, divided into three, two minute periods interspersed with approximately one minute rest intervals, and involves intermittent short-term high-intensity exercise. Thus, protocols involving single exercise bouts of 30 to 60 seconds do not assess a wrestler's ability to repeatedly produce anaerobic power typical of a match situation. In addition, the duration of continuous power production in a match is most frequently less than 30 seconds.

The effects of prior submaximal aerobic exercise of varying intensity on anaerobic have been conducted and indicate the importance of warm-up prior to anaerobic exercise (Dolan and Sargeant, 1984). However, investigations using protocols designed to evaluate repeated production of anaerobic power are limited. In 1986, McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton, and Jones examined power indices for four 30 second maximal isokinetic (100 rpm) cycling bouts interspersed with four minute rest intervals. The results indicated a steady reduction in peak power (W), average power (W), and total work (kJ) for bouts one through three. There was no difference in these parameters between bouts three and four. The power fatigue index (%) for peak power and average power did not change significantly across the four bouts.

Reliability

The reliability of short-term, high-intensity cycle ergometery was initially investigated by Bar-Or et al. in 1977 as part of the development of the WAnT. Bar-Or et al. (1977) reported test-retest correlation of 0.95 to 0.97 for the WAnT utilizing primarily adolescent subjects. Since then several other investigators, including Bar-Or (1987), have demonstrated reliability for an array of anaerobic power cycling test using various populations.

Patton et al. (1985) found the WAnT to have a day to day correlation of 0.93 for peak power, 0.93 for average power, and 0.74 for power fatigue rate at a resistance of 4.41 joules/rev/kg BW. Similar correlations were reported at a resistance of 5.59 joule/rev/kg BW. Significant test-retest reliability for a five second all out cycling protocol at resistances ranging from 9.8 to 63.6 N was reported in a study by Nadeau et al. (1983). This study indicated that reliable measurement of power indices is possible across a range of resistances and for both female and male subjects. For isokinetic ergometer systems, varying pedal speeds, correlation coefficients for power output have been reported as high as 0.99 (McCartney, Heigenhauser, and Jones, 1983a). These studies suggest anaerobic power cycling tests are reliable for a range of resistance settings.

Although anaerobic tests are reliable at various resistances it is important to establish optimal loading for the protocol and parameters under consideration. Optimal loading increases the researchers ability to detect changes between conditions and enhances reliability. When the WAnT was first developed, a load of .075 kg/kg body weight was suggested as optimal by the Wingate Institution (Vandewalle, Peres, and Monod, 1987). However, the primary subjects in this investigation were adolescents.

It was later determined that the optimal ergometer loading to elicit peak power in adults ranged from 0.087 to 0.12 kg/kg body weight depending on gender and level of conditioning (Beld, Skinner, and Tran, 1989; Davy, Pizza, Guastella, McGuire, and Wygand, 1989; Dotan and Bar-Or, 1983). Beld et al. (1989) reported significant differences in peak power for loads ranging from 0.075 to 0.15 kg/kg body weight in young men performing the Wingate Anaerobic Test. At loads ranging from 0.1 to 0.12 kg/kg body weight there was not a significant difference in power production (Davy et al. 1989). These data indicate that optimal loading can occur as low as 0.1 kg/kg body weight.

An investigation examining high-intensity cycling tests of varying duration with a constant resistance was performed by Burke, Wojcieszak, Puchow, and Michael, (1985). Four separate high-intensity cycling trials of 15, 30, 60, and 120 seconds were administered at a constant load of 5 kp. Intraclass correlations for average power (W), total work (kJ), and time to peak power (sec) were 0.86, 0.79, and 0.97 indicating stability of these parameters across varying durations. More recently, Williams et al. (1988) found high intraclass correlations ranging from 0.91 to 0.97 for power indices during separate 15 second maximal cycling bout. These studies, in conjunction with the study by Nadeau and Brassard (1983) in which a five second protocol was used, suggest reliable power data can be obtained using protocols of various duration.

Test-retest reliability was examined in a pilot study for the protocol used in the present study (Appendix B). The protocol consisted of five, 10 second maximal effort bouts interspersed with 20 second rest intervals. Pearson's correlation coefficients ranged from 0.92 to 0.95 for peak power, average power, and total work indicating reliable day to day power output. Time to peak power and fatigue indices were not as highly correlated.

In addition to reliable power measurement, the ability of investigators to collect data for anaerobic power test has improved significantly with the intervention of microcomputer integrated cycle ergometery (Harman, Knuttgen, and Frykman, 1987; McCartney et al. 1983a; Patton et al. 1985; Williams et al. 1988). The ergometer design, microcomputer interface, computer software, and protocol used in the current study were modeled after that used by Williams et al. (1988).

Validity

It is important to determine if the method of assessment utilized in a study is actually a measure of the desired parameter. Blood lactic acid (LA), a byproduct of glycolysis, is an indirect measure of anaerobic metabolism within the skeletal muscles and therefore, has been utilized extensively to validate anaerobic power tests.

Normal resting blood LA values range from 1.0 to 2.5 mmol/l (McArdle, Katch, and Katch, 1986). After all-out 30 second cycle ergometer bouts, Bar-Or et al. (1977) reported a significant increase in blood LA. More recently Guastella et al. (1988) reported increases in blood LA specifically for wrestlers, three minutes post WAnT to a level of 7.5±1.78 mmol/l. Other investigations including Bar-Or (1987), Jacobs (1986), Tamayo, Sucec, and Phillips (1984), and Vandewalle et al. (1987), reported similar changes in blood LA levels after all-out anaerobic cycling test for athletic and normal populations.

Changes in blood LA have been reported for intermittent anaerobic ergometer tests and tests of varying duration. McCartney et al. (1986) found increases in blood LA to 28.9±2.7 mmol/kg following intermittent 30 second maximal cycling bouts with four minute recovery intervals. Single exercise bouts ranging from 10 to 120 seconds have elicited significant increases in blood LA and decreases in pH (Burke, Wojcieszak, Puchow, and Michael, 1985). Similar increases in blood LA have been reported for wrestlers in hydrated and dehydrated conditions by Guastella et al. (1988), Jacobs (1980), and Webster et al. (1990).

In addition to blood LA measurement, direct intramuscular LA measurements, via muscle biopsies, have shown muscle LA to significantly increase after only 10 seconds of maximal cycling exercise (Jacobs, Tesch, Bar-Or, Karlsson, and Dotan, 1983b). Hermansen and Osnes (1972) compared blood and muscle LA levels during intermittent tread mill or cycling maximal exercise to exhaustion. Blood LA increased continuously while muscle LA increased during exercise and recovered slightly during the rest intervals reaching an upper limit. This suggests that blood LA may not directly indicate changes in intramuscular pH (Roberts and Smith, 1989).

As demonstrated by the aforementioned studies, extensive blood and muscle LA validation has been conducted on a variety of anaerobic power protocols. These results indicate that high-intensity exercise of 10 seconds or more engages anaerobic metabolism.

DEHYDRATION

A considerable amount of research has been conducted on the effects of dehydration on physical performance. It is generally accepted that acute dehydration does not affect isometric strength, and is detrimental to aerobic performance (Armstrong, et al. 1985; Bosco and Terjung, 1968; Caldwell et al. 1984; Saltin, 1964; Serfass et al. 1984; Vaccaro et al. 1976). However, for short-term, high-intensity activity the consequence of acute dehydration is not well established (Jacobs, 1980; Webster et al. 1990).

Wrestlers often use dehydration as a method of rapid weight reduction prior to weigh-in (ACSM, 1976; AMA, 1967; Houston et al. 1981; Widerman and Hagan, 1982). This section of the review concentrates on changes in performance and physiological parameters associated with dehydration typical of that performed by wrestlers in order to qualify for a lower weight classifications.

Weight Reduction

The magnitude of weight reduction for studies involving wrestlers has ranged from 2-8% of normal body weight and has been achieved through food restriction, fluid deprivation, exercise, and/or heat exposure. When reducing weight prior to a match it is not unusual for wrestlers to lose up to 10% or more of total body weight within a few days. Much of the weight wrestlers lose is due to acute dehydration. Research designed to specifically examine the effect of dehydration on wrestling performance is limited and has produced conflicting results (Guastella et al. 1988; Herbert and Ribisl, 1972; Houston et al. 1981; Klinzing and Karpowicz, 1986; Ribisl and Herbert, 1970; Tuttle, 1943; Webster et al. 1990; Widerman and Hagan, 1982).

Different methods of dehydration have been shown to have a varied influence on performance. Saltin (1964) and Caldwell et al. (1984) compared the physical performance of subjects after dehydration via heat exposure, diuretic, exercise, and exercise and heat exposure combined. They concluded that the method and quantity of weight reduction is a factor in later performance. Data from Saltin (1964) and other studies suggest that dehydration in 24 hours or less by means of exercise and exercise in combination with heat exposure and/or diuretics is the most detrimental to anaerobic performance (Houston et al. 1981; Jacobs, 1980; Webster et al. 1990).

Anaerobic Power

A study by Jacobs (1980) specifically examined the effects of dehydration on the WAnT at varying degrees of weight reduction due to passive thermal dehydration. During six hours of dehydration, WAnT's were administered at 2%, 4%, and 5% total body weight reduction. There were no differences in power indices across the three degrees of weight reduction. Guastella et al.

(1988) also used the WAnT to examine the effects of food and fluid restriction over seven days eliciting a weight loss of 4.2% in ten high school wrestlers. The results indicated a trend for weight reduction to decrease peak power and total work, however the results were not significant.

In contrast, Webster et al. (1990) used a 40 second maximal cycle ergometer test to measure power before and after wrestlers lost 4.9% total body weight in 36 hours due to exercising in a rubber suit and low caloric intake. The weight reduction caused a decline in anaerobic power (81.4±13.3 to 63.9±9.4 kg m/sec.) and capacity (1984.3±189.3 to 1791.4±198.0).

Conflicting reports exist for other less common anaerobic protocols. For example, Saltin (1964) used a constant load cycle ergometer time to exhaustion method. Trials conducted before and after 2.5-4 hours of dehydration caused by thermal, metabolic, and thermal and metabolic combined heat stress. The results indicated a significant decline (6 to 4 minutes) for all dehydrated situations. Studies by Herbert (1972) and Ribisl (1972) report a decrease in the ability of wrestlers to perform a cycling physical work capacity test (PWC-170) immediately following acute weight reduction and after subsequent rehydration (approximately five hours later). Similarly, Klinzing and Karpowicz (1984) reported a decline in performance after dehydration and subsequent rehydration for an extensive performance test designed specifically for wrestlers involving several forms of exercise.

However, Houston et al. (1981) using a run to exhaustion protocol on a tread mill (8 mph, 20% grade) found that after 96 hours of dehydration and caloric restriction (8% weight reduction) there was not a significant difference in running times. The aforementioned studies do not agree on the effects of dehydration on anaerobic power which may result from the use of different power tests and varying magnitude, duration, and method of dehydration.

Plasma Osmolality and Hematocrit

In addition to the measurement of body weight reduction as an indicator of dehydration, changes in hematocrit (HTC,%), plasma osmolality (PO, mOsmol/l), and urinary profiles have been used to verify dehydration. Senay and Christensen, (1965) examined changes in HTC during progressive dehydration. HTC significantly increased during dehydration at a rate slightly faster than percent body weight reduction. Subsequent dehydration studies by Costill and Fink (1974) Dill and Costill (1974), and Vaccaro et al. (1975, using wrestlers as subjects) confirmed Senay's HTC results. Costill and Fink (1974) reported a change in HTC of 42.8±0.6% to 46.1±1.3% (X±SD) after a 4% weight loss due to thermal dehydration. More recently Nose, Mack, Shi, and Nadel (1988a) found a significant increase in HTC after 90-110 minutes of dehydration from heat exposure which elicited a mean of 2.3% weight reduction.

Similar to HTC, increases in PO are directly related to the degree of dehydration. Costill and Fink (1974) found PO to increase from an average of 305 mosmol/l to 325 mosmol/l after a 4% weight reduction by thermal dehydration. This indicates with a 4% reduction in weight there is a 5.6% increase in PO. Nose et al. (1988a) revealed significant increases in PO after dehydration and throughout subsequent rehydration. Increases in plasma osmolarity have been shown to have a one to one ratio with increasing percent dehydration (Senay and Christensen, 1965; Saltin, 1973).

Urinary profiles (ie. osmolarity, specific gravity, and electrolyte concentration) increase in a similar manner as plasma constituents during dehydration. Zambraski, Foster, Gross, and Tipton (1975) and Hursh (1979) used urine specific gravity to determine the dehydration state of wrestlers. In the present study HTC and PO were utilized as indicators of dehydration and the plasma samples were also analyzed for electrolyte concentrations.

Increasing plasma electrolyte concentrations associated with progressive dehydration partially accounts for the increases observed in PO. Plasma protein levels have been reported to increase as dehydration progresses which will enhance the elevation of PO (Costill, Cote, and Fink, 1976; Vaccaro, et al. 1976). The research on HTC and PO confirm the reliability of these measures to validate dehydration.

Electrolytes

Through the analysis of plasma electrolytes, several investigations have demonstrated an increase in plasma sodium (Na+), potassium (K+), and chloride (Cl-), as a result of progressive dehydration (Caldwell et al. 1984; Costill et al. 1976; Nose, Mack, Shi, and Nadel, 1988b; Sejersted and Hallen, 1987; Senay and Christensen, 1965). Changes in the extracellular and intercellular concentrations of these electrolytes (including calcium and magnesium) also exist as a result of dehydration. Such changes may affect performance by altering normal biochemical function within the muscle (Costill et al. 1976; Sjogaard, 1986).

Costill et al. (1976) examined electrolyte concentration (using the Cl- method) of human quadriceps muscle biopsies extracted during progressive dehydration due to exercise in a warm environment (0-5.8% weight reduction). Extracellular Na+, Cl-, and K++ increased slightly (insignificant) with the onset of dehydration and then remained unchanged. Mg++ tended to decline throughout dehydration but, these changes were not significant. Similarly, intracellular Na+ and Mg++ did not change significantly although Mg++ tended to decline. Intracellular K+ however declined significantly during progressive dehydration. The K+ concentration went from 161.7 meq/l water predehydration to 178.9 meq/l water at 4.1% dehydration. No change occurred from 4.1 to 5.8% dehydration.

Water

In the same study by Costill, et al. (1976) venous, extracellular, and intracellular water loss during dehydration was also examined. Intracellular water content of the muscle tissue declined significantly at each level of dehydration totaling an 8% reduction at the end of dehydration (5.8% of body weight) while extracellular content did not change significantly. The water loss from plasma, extracellular, and intracellular compartments was 11, 39, and 50% respectively at 5.8% weight reduction.

A more recent study by Nose et al. (1988b) investigated fluid shifts during 90-110 minutes of dehydration by exercising in heat which produced a 2.3% weight reduction. Their results were similar to those of Costill, et al. (1976) suggesting that significant water content is lost from intracellular spaces of the muscle. The conclusion of both these investigations was that intercellular water is utilized to maintain plasma volume during dehydration.

Lactic Acid and pH

LA is produced in working muscle during anaerobic activity as a byproduct of glycolysis and causes an increase in plasma and muscle LA as well as pH (Hermansen and Osnes, 1972; Jacobs, 1986). Literature specifically relating to LA and pH changes during dehydration is limited. A study by van Beaumont, Underkofler, and van Beaumont (1981) is one of the few which examined plasma pH during passive thermal dehydration. Venous pH was reported to increase slightly from 7.34 to 7.43 during two hours of dehydration. Maximal and submaximal exercise elicited a significant decline in plasma pH which recovered approximately 30 minutes after exercise.

Research measuring intramuscular LA and pH during dehydrations separate from exercise was not found in the present review of literature. Changes in intramuscular LA and pH associated with exercise is discussed in the following section on muscle fatigue.

FATIGUE

Muscle fatigue has been defined as a progressive reduction in the ability to maintain muscular force or power production from the onset of physical activity (Asmussen, 1979; Mutch and Banister, 1983; Roberts and Smith, 1989; Vollestad and Sejersted, 1988). The magnitude and rate of localized muscle fatigue depends largely on the intensity and duration of the work performed. Subject conditioning, muscle fiber type and distribution, type of contractions, and environmental conditions are other factors which may influence fatigue (Roberts and Smith, 1989). This review addresses possible sites and mechanisms of anaerobic muscular fatigue. That is, fatigue occurring within the first 60 seconds of high intensity exercise.

Sites of Fatigue

Possible sites of fatigue may exist at several points along the chain of neuromuscular events leading to contraction. Studies examining fatigue of human quadriceps muscles report the primary mechanism of fatigue lies in the muscle, distal to the neuromuscular junction (Bigland-Richie, Furbush, and Woods, 1986; Bigland-Richie, Jones, and Woods, 1979). Most recently Bigland-Richie et al. (1986) examined central and peripheral factors of fatigue during intermittent contractions of the human quadriceps. Fatigue during voluntary contractions was not different from that observed during superimposed externally stimulated contractions. They concluded that the central nervous system was capable of completely activating the quadriceps muscles during fatigue. Thus, the remainder of this review concentrates on muscular as opposed to neural fatigue.

Within the muscle mechanisms of fatigue may involve; 1) action potential propagation over the sarcolemma and internally via t-tubules, 2) Ca++ release and storage from the sarcoplasmic reticulum (SR), 3) actin-myosin cross-bridge formation, and 4) high energy phosphate supply (Vollestad and Sejersted, 1988).

Electrolytes

Changes in cellular metabolyte and electrolyte concentrations associated with exercise are believed to cause dysfunction at these locations which results in fatigue. Intracellular and extracellular shifts in K+ and Na+ concentrations have been reported to persist in fatiguing muscle at a sufficient magnitude to impair muscular membrane excitation and recovery (Sjogaard, 1986; 1983). After maximal exercise to exhaustion Sjogaard in 1983 and later in 1986 observed a reduction in intracellular K+ and an increase in extracellular K+. Na+ concentration increased in both the extracellular and intracellular spaces.

This may have a greater impact on action potential propagation via the t-tubules where fewer Na+-K+ pumps exist and the diffusion rate of the t-tubule openings is less than that of the sarcolemma (Almers, 1980; Venosa and Horowics, 1981). For these reasons it has been concluded that greater increases in extracellular K+ may occur in the t-tubules than in venous and interstitial fluids (Sjogaard, 1983). A reduction in t-tubule action potential propagation has been suggested as a possible cause of fatigue by several researchers (Roberts and Smith, 1989; Vollestad and Sejersted, 1988).

Shifts in fluid volume across the venous, interstitial, and intracellular compartments have been associated with Na+ and K+ flux (Sejersted, Vollestad, and Medbo, 1986; Sjogaard, 1986). After short-term maximal exercise Sejersted et al. (1986) reported a decline in plasma volume (up to 20%) and an increase in muscular fluid volume for humans. The flow of water between compartments affects relative electrolyte concentrations and thus may influence muscular fatigue by altering membrane excitation and recovery.

In addition to Na+ and K+ shifts, there is a significant Ca++ flux across the exercising muscle sarcolemma. The SR Ca++ concentration is reported to decline and sarcoplasmic Ca++ concentration increases as muscles fatigue. The Ca++ shift causes increased activity of proteolytic enzymes in the sarcoplasm which subsequently may inhibit SR ATPase reuptake of Ca++, contractile protein function, and cause Ca++ leakage into the t-tubules and interstitial fluid. Ca++ leaking into the t-tubules could block action potential propagation and sarcoplasmic Ca++ is consumed by mitochondrion which reduces mitochondrial ATP production (Belcastro, Maclean, and Gilchrist, 1985; Fitts, Courtright, Kim, and Witzmann, 1982; Inesi and Hill, 1983; Richardson, Palmerton, and Chenan, 1980; Roberts and Smith, 1989; Vollestad and Sejersted, 1988).

Research has suggested these factors result in a reduction of Ca++ active transport into the SR and less Ca++ available for reuptake into the SR from the sarcoplasm. Consequently, there is a gradual reduction in SR Ca++ release during repeated muscular contraction which may limit Ca++-troponin binding causing fatigue

(Belcastro et al. 1985; Fitts et al. 1982; Inesi and Hill, 1983; Vollestad and Sejersted, 1988).

Lactic Acid and pH

A reduction in muscle pH from lactic acid (LA) and Subsequent H+ accumulation during fatigue may impede Ca++ binding. In a study using isolated rabbit SR vesicles, Inesi and Hill (1983) examined the influence of Ca++ and H+ on ATPase reactions. Their study indicated that as muscle H+ increased a larger amount of Ca++ was needed for ATPase activation. Reports that H+ competes with Ca++ for troponin binding sites and that a reduction in pH decreases troponin affinity for Ca++ have been presented in other studies as summarized by Roberts and Smith (1989). This suggests that increased muscle H+ may diminish the biochemical efficiency of Ca++ during excitation-contraction limiting cross-bridge formation.

Several other researchers have indicated high correlations exist between reduced muscle and blood pH and muscle fatigue. LA accumulation in muscle has been shown to occur in the first 10 seconds of maximal exercise demonstrated by Jacobs, Bar-Or, Dotan, Karlsson, and Tesch (1983a) in a study comparing 10 and 30 second maximal cycling bouts. McCartney, Heigenhauser, and Jones (1983b) found that a decrease in blood pH by metabolic and respiratory acidosis caused a slight reduction in power output during a 30 second sprint. They attributed the lack of a more significant reduction in power output to a limited change in muscle pH due to induced blood acidosis.

An earlier study by Hermansen and Osnes (1972) compared blood and muscle LA levels during intermittent tread mill or cycling maximal exercise to exhaustion (five 40-60 second bouts interspersed with four minutes of rest) and supports this hypothesis. Blood LA increased continuously while muscle LA increased during exercise and recovered slightly during the rest intervals. Muscle LA reached a limit but blood LA steadily increased. This suggests that blood LA does not indicate changes in intramuscular pH (Roberts and Smith, 1989). These studies seem to indicate that changes in muscle pH may be a limiting factor in short-term, maximal power production. However, a direct relationship between pH and fatigue is difficult to establish since muscle pH can not be determined from the measurement of changes in blood pH.

Ammonium

Ammonium is another byproduct of high-intensity exercise stemming primarily from the deamination of the phosphagen AMP which has received considerably less attention than LA and pH. The accumulation of blood ammonium has been linked to muscle fatigue. Regular training reduces the blood ammonium levels which is proportional to a delay in the onset of fatigue. Ammonium released from exercising muscles has also been suggested to have toxic effects on the CNS (Mutch and Banister, 1983).

Creatine Phosphate and ATP

The utilization of other phosphagens, creatine phosphate (CP) and ATP, provide the primary energy supply during high-intensity, short-term exercise (Hirvonen, Rehunen, Rusko, and Harkonen, 1987; Jacobs et al. 1983a; Saltin, 1973). Consequently, there is a substantial depletion of intramuscular CP and ATP during high-intensity work which has been suggested to be a limiting factor in the maintenance of short-term power output (Bergstrom, Harris, Hultman, and Nordesjo, 1971; Hirvonen et al. 1987; Jacobs et al. 1983a; Saltin, 1973).

Saltin (1973) indicates that ATP and CP levels in thigh muscles do not begin to reach maximal depletion until 20-30 seconds of heavy exercise. However, Bergstrom et al. (1971) suggests that ATP and CP may be depleted at the cross-bridges before significant whole muscle phosphagen depletion occurs. In 1987 Hirvonen et al. measured muscle ATP, CP, and LA before and after 40, 60, 80, and 100 meter maximal sprints. By comparing changes in substrate concentrations to subject speed at the varying distances they concluded that fatigue during short-term, high-intensity exercise is a result of phosphagen depletion and a shift to glycolysis.

This is supported by studies where a large reduction in twitch tension was observed in CP depleted muscle before any measurable H+ accumulation (indicating the production of LA) (Roberts and Smith, 1989). Therefore, phosphagen depletion may directly effect muscle tension prior to the possible influence of pH on the efficiency of energy related chemical reactions as aforementioned.

Glycogen

Energy utilization from glycolysis during short, maximal exercise is evident from the accumulation of muscle LA, a product of glycolysis, within the first 10 seconds of maximal exercise

(Jacobs et al., 1983a; Saltin, 1973). In a recent study by Symons and Jacobs (1989) the effects of muscular glycogen depletion was examined (through muscle biopsy) on isokinetic, isometric, and external stimulation contractions of human quadriceps. Their results indicated that glycogen depletion of the human quadriceps does not impair short-term, high-intensity performance. These results are comparable to those of Fitts et al. (1982) in a study using rats which determined that muscle fatigue is not correlated to muscle glycogen depletion. The investigations imply that sufficient muscle glycogen remains even after depletion to sustain short-term maximal work.

SUMMARY

The objective of the present review was to examine research related to the measurement of short-term, high-intensity (anaerobic) exercise and investigate the effects of acute dehydration on such exercise. In addition, possible biochemical mechanisms within the muscle which may explain fatigue and the effects of dehydration were surveyed.

Anaerobic power is an important component in activities, like wrestling, which rely heavily on power production during intermittent bursts of maximal exercise. Traditional research designed to evaluate anaerobic power has involved single exercise bouts. For example, one of the most widely used and reliable anaerobic power tests, the Wingate Anaerobic Test, involves 30 seconds of maximal cycling (Bar-Or et al. 1977). These protocols do not analyze a subject's ability to repeatedly produce anaerobic power characteristic of a majority of athletic events.

The use of cycling anaerobic power tests as well as other methods has produced inconsistent results pertaining to the effect of rapid dehydration procedures used by wrestlers on power output. Some investigations report a decrement in power resulting from dehydration while others report dehydration has no affect on power production (Jacobs, 1980; Webster et al. 1990). Thus, the explanation for the possible effects of dehydration and the pattern of power output during repeated short-term, high-intensity exercise is still unclear.

Several mechanisms including shifts and/or depletion of electrolytes and fluids, changes in pH, calcium depletion, and energy supply may be associated with power output, fatigue, and dehydration. Inconsistency across studies examining anaerobic power and dehydration illustrates the need for further research in this area. Therefore, the purpose of the present study was to design an effective method to assess repeated production of anaerobic power output and to examine the consequence of rapid dehydration on power output during these repeated bouts.

THE EFFECT OF RAPID DEHYDRATION ON REPEATED BOUTS OF SHORT-TERM, HIGH-INTENSITY CYCLING EXERCISE IN COLLEGE WRESTLERS

(Abstract)

Sinclair A. Smith

This study examined the effects of acute dehydration on repeated bouts of anaerobic cycling exercise. Eight college wrestlers performed 2 cycle ergometer trials before (hydrated, H) and 48 hrs after dehydration (D) via exercise, fluid restriction, and heat exposure. The trials consisted of a 4 min warm-up followed by 5, 10 s maximal bouts interspersed with 20 s rest intervals. The ergometer was preloaded with .1 kg/kg of H bodyweight. Peak power (PP,W), average power (AP,W), time to peak power (TTPP,s), power fatigue rate (PFR,W/s), and power fatigue index (PFI,%) were recorded by an integrated microcomputer. Pretrial plasma osmolality (PO), HTC, plasma electrolytes, and caloric intake (Kcal) were also measured. The wrestlers lost 4.5±1.0% (X±SD) bodyweight from H to D trials which increased PO and HTC ($p<.01$). There was a decline in plasma [K+] ($p<.05$) and no change in Kcal. PP values for H bouts 1-5 were 1004±54, 918±47, 809±46, 727±38, and 681±40 and for D bouts 1-5 were 937±52, 836±46, 766±40, 702±41, and 706±32 (X±SEM). AP results were similar to PP and thus not shown. There were no differences in H and D trials for TTPP, PFR, and PFI. After dehydration PP and AP were reduced during bouts 1-3 ($p<.05$) and appear to level in bouts 4 and 5 coinciding with H PP and AP. These results suggest that rapid dehydration by wrestlers causes a decrease in PP and AP production during initial bouts of repeated anaerobic exercise. With the onset of fatigue in later bouts PP and AP are unaffected.

Chapter III

JOURNAL MANUSCRIPT

INTRODUCTION

Using dehydration as a means of rapid weight reduction is a common practice among athletes competing in events with weight classifications. Perhaps the most notorious athletes for their weight reduction methods are high school and college wrestlers. When reducing weight prior to a match, it is not unusual for wrestlers to lose up to 10% or more of total body weight in a few days primarily via acute dehydration (ACSM, 1976; AMA, 1967; Herbert and Ribisl, 1972; Houston, Marrin, Green, and Thomson, 1981; Widerman and Hagan, 1982).

A considerable amount of research has been conducted on the effects of dehydration on physical performance. It is generally accepted that acute dehydration is detrimental to aerobic performance while it does not affect isometric strength (Armstrong, Costill and Fink, 1985; Bosco and Terjung, 1968; Caldwell, Ahonen, and Nousiainen, 1984; Saltin, 1964; Serfass, Stull, Alexander, and Ewing, 1984; Vaccaro, Zauner, and Cade, 1976). However, for short-term, high-intensity activity, such as that encountered in wrestling, the consequence of acute dehydration is not well established. For example, studies by Webster, Rutt, and Weltman (1990), Klinzing and Karpowicz (1986), and Saltin (1964) using various methods of assessment have indicated rapid dehydration is detrimental to anaerobic performance. In contrast, Jacobs (1980), Houston et al. (1981), and Gaustella, Wygand, Davy, and Pizza (1988) found no difference in anaerobic performance after dehydration. The inconsistency of these studies is most likely a result of variations in method, duration, and magnitude of dehydration (Caldwell et al. 1984; Saltin, 1964). In addition, the methods used are not always typical of those chosen by wrestlers to reduce weight (Webster, et al. 1990).

To assess anaerobic performance the aforementioned studies employed single exercise bouts of 30 seconds or more in duration. A majority of athletic events, including wrestling, involve intermittent short-term, high-intensity activity interspersed with periods of moderate activity (Williams, Barnes, and Signorile, 1988). Thus, a single bout protocol may not truly assess a wrestler's ability to repeatedly produce short-term (10 to 15 seconds), anaerobic power typical of a match situation. The present study sought to design an effective method to measure repeated production of anaerobic power and examine the consequence of rapid dehydration typically used by college wrestlers on power output.

METHODS

Subjects

Subjects consisted of volunteers from the Virginia Tech wrestling team. Each wrestler was required to read and sign an informed consent explaining participation procedures, risks, and benefits before the onset of the study.

Eleven wrestlers completed two cycle ergometer anaerobic power tests (trial one and two). The trials were administered during preseason training and were scheduled 48 hours apart. In addition, the wrestlers were instructed to abstain from heavy exercise 12 hours prior to their scheduled trial times. Eight of the eleven wrestlers, age 20.4±1.8 years (X±SD) and height 174.1±6.7 cm (X±SD), met all the criterion measures of the study (see results). The others were excluded from the final analysis.

Power Testing

A modified 818 Monark cycle ergometer integrated with a microcomputer was used to collect and record the wrestlers' power output data. The ergometer design, supporting computer software, data collection procedure, and protocol were modeled after that used by Williams, et al (1988). The software program determines power output for each one half pedal revolution and calculates the following power indices; peak power (PP), average power (AP), time to peak power (TTPP), power fatigue rate (PFR), and power fatigue index (PFI).

The protocol for both trails consisted of a four minute warm up at 50 rpm (50 watts), followed by five, ten second maximal effort cycling bouts. The bouts were interspersed with four, 20 second rest intervals. Resistance for each maximal bout was set at 0.1 kg/kg normal body weight. The ergometer seat height was adjusted so that the subjects legs were in full extension when the heel was placed on the pedal. This allowed for a slight bend at the knee when the feet were placed in the toe clips, secured, and the knee extended. All bouts began with the pedals in a static horizontal position and the subjects' preferred limb forward. During the 20 second rest intervals the ergometer was unloaded by the investigator enabling the wrestlers to pedal against zero resistance. This avoided venous pooling in the lower extremities. Five seconds before the start of each bout, the pedals were reset to the original starting position. For participant safety during the exercise protocol a continuous five lead ECG monitored the wrestlers from rest to completion of all bouts.

A pilot study examining test-retest reliability for the present protocol found correlations of 0.92 to 0.95 for power output parameters (Smith, Williams, Ward, Davy, and Franke, 1989). Therefore, reliability measurements were not included in the present methodology.

Dehydration Regime

In addition to power data, the investigators measured body weight using a balance scale 48 hours before trial one and then immediately before trials one and two with subjects wearing only exercise shorts. Analysis of these measurements determined the quantity of weight reduction due to dehydration. A "normal" or hydrated body weight was derived from an average of the weights recorded 48 hours and immediately before trial one.

During the 48 hours between trials one and two the wrestlers were instructed to undergo a five percent reduction in their normal body weight by means of dehydration as if they were reducing weight in preparation for a match "weigh-in". Trial two served as the weigh-in deadline. If a wrestler did not reduce weight to a minimum of three percent of normal body weight their data was excluded from final analysis. The use of diuretics and laxatives to induce weight reduction was prohibited.

A daily record of food consumption was kept by the wrestlers for the 48 hours prior to trial one and the 48 hours of dehydration between trials. The wrestlers used the records from the initial 48 hours as a guide for consumption during dehydration. Caloric intake (Kcal) for both 48 hour intervals was calculated using the USDA's Dietary Analysis Program for the personal computer (1988). The investigator specifically emphasized the importance of maintaining caloric intake throughout the study to ensure weight reduction via dehydration only.

Plasma Analysis

Blood samples were drawn five to ten minutes pre-exercise via venipuncture for both trials. Capillary tubes were immediately filled from the samples and centrifuged to determine hematocrit (HTC). The samples were then centrifuged and stored at 35 degrees Fahrenheit. Twenty-four hours after the completion of trial two, plasma osmolality (PO) for all the samples was measured via freezing point depression by a Fiske model OS Osmometer. In addition, plasma sodium (Na+), potassium (K+), and chloride (Cl-) concentrations were measured via potentiometry and calcium (Ca++) concentration via spectrophotometry by an automated Kodak Ektachem 700 Analyzer.

Statistics

A two-way, repeated measures ANOVA and subsequent Duncan's Multiple Range Post Hoc Test ($p=0.05$) were used to assess differences in PP, TTPP, PFR, PFI, and AP between hydrated vs. dehydrated trials and bouts one through five. Paired t-tests were used to analyze hydrated vs. dehydrated body weight, Kcal, PO, and HTC as well as Na+, K+, Cl-, and Ca++ plasma concentrations.

RESULTS

Eight wrestlers lost 4.5±1.0% (X±SD) of their normal body weight during the 48 hours of dehydration meeting the criterion measure of 3.0% or greater. The wrestlers chose exercise in combination with fluid restriction and/or heat exposure as the method of dehydration. Analysis of dietary records indicated no significant difference in Kcals ($p>0.05$) between hydrated and dehydrated conditions. However, there were individual fluctuations in Kcals between the two conditions. Blood analysis found an increase in PO and HTC after dehydration. Plasma $Na+$, $Cl-$, and $Ca++$ concentrations remained constant across the two conditions, while plasma $K+$ concentration declined slightly (table 1).

The power output data, illustrated in Figures 1 through 5, reveal similar changes between bouts regardless of the wrestlers hydration state. PP and AP declined steadily from bouts one to four ($p<0.05$) with no difference between bouts four and five for both conditions (Figures 1 and 2). Similarly, TTPP declined from bout one to five while PFI increased (Figures 3 and 4). There were no differences found for PFR across bouts with the exception of dehydrated bout five which was higher than the other dehydrated bouts only ($p<0.05$, Figure 5). Thus, PP and AP declined initially and then appear to level in later bouts. In addition, the relative power decline from PP to the end of each bout, PFI, increased while the absolute rate of fatigue, PFR, remained fairly constant across bouts.

The comparison of hydrated and dehydrated power indices shows a reduction in PP and AP after dehydration for bouts one through three with no difference between conditions in bouts four and five (Figures 1 and 2). Dehydration did not elicit significant changes in TTPP, PFI, or PFR (Figures 3, 4, and 5).

DISCUSSION

Two primary effects of repeated anaerobic power production and rapid dehydration were indicated by the present study. First, during the performance of repeated bouts of high-intensity cycling exercise there is a progressive reduction in overall power output which appears to level in the later bouts. Secondly, dehydration of 4.5% body weight elicits a reduction in power output during the initial bouts but not in later bouts.

Power Output

Regardless of hydration state, PP and AP declined steadily from bout one to four in the present study with no difference between bouts four and five. McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton, and Jones (1986) reported a similar trend during the performance of four, 30 second maximal cycling bouts separated by four minute recovery intervals on an isokinetic ergometer (100 rpm). Their results show a steady reduction in PP and AP for bouts one through three with no significant difference in these parameters between bouts three and four. The present findings and those of McCartney et al. (1986) suggest that intermittent maximal cycling power output declines steadily though initial bouts and then begins to level in later bouts.

One possible explanation for such a pattern was presented by Hirvonen, Rehunen, Rusko, and Harkonen (1987). They suggest that fatigue during short-term, high-intensity exercise is a result of phosphagen depletion and a shift to glycolysis. Although McCartney et al. (1986) found that muscle ATP and creatine phosphate (CP) were almost completely restored during the four minute rest intervals, ATP and CP depletion may exist at the cross-bridges without significant whole muscle depletion (Roberts, and Smith, 1989).

Therefore, the initial reductions in power across the first four bouts in the present study may have resulted from a rapid reduction in available high-energy phosphates, CP and ATP, followed by a leveling of power output at the transition to a primarily glycolytic energy supply. Energy utilization from glycolysis during short, maximal exercise is evident from the accumulation of muscle lactic acid, a byproduct of glycolysis, within the first 10 seconds of maximal exercise (Jacobs, Tesch, Bar-Or, Karlsson, and Dotan 1983; Saltin, 1973). In addition, Symons and Jacobs (1989) found that depletion of muscular glycogen did not affect the performance of high-intensity exercise suggesting that even with depletion sufficient glycogen levels are available to maintain short-term power output. Clearly more work is needed to identify such a mechanism.

Other biochemical changes associated with maximal exercise may cause reductions in power output. For example, reductions in intramuscular pH and cellular shifts in electrolyte concentrations have been reported to persist at a sufficient magnitude to impair muscular contractility (Hermansen and Osnes, 1972; Jacobs et al. 1983; McCartney, Heigenhauser, and Jones, 1983; Sejersted, Vollestad, and Medbo, 1986; Sjogaard, 1983; 1986). Thus, several mechanisms may be involved in the decline of power across bouts observed in the present study.

Weight Reduction

In the present study the wrestlers reduced weight via dehydration which is substantiated by the Kcal, PO, and HTC results. Overall Kcal consumption during the 48 hours of dehydration was not significantly different from the previous 48 hours. Recent research has indicated a reduced caloric intake prior to the performance of an anaerobic power test does not effect power output (Symons and Jacobs, 1989). Therefore, any individual fluctuation in caloric intake should not have influenced power output in the present study.

In addition, the increase in PO and HTC observed after weight reduction is indicative of dehydration as indicated by several studies (Costill, Cote, and Fink, 1976; Costill and Fink, 1974; Nose, Mack, Shi, and Nadel, 1988; Senay and Christensen, 1965; Vaccaro et al. 1976). The majority of these studies also reported an increase in plasma electrolyte concentration. Na+, Cl-, and Ca++ plasma concentrations were unchanged after dehydration in the present study with a slight reduction in K+. The variation in electrolyte concentrations after dehydration between studies is most likely a factor of duration and method of dehydration (Caldwell et al. 1984). Other plasma constituents, for example plasma proteins, not measured in the present study reportedly increase in concentration with dehydration and may account for the rise in PO (Costill et al. 1976; Vaccaro et al. 1976).

Effects of Dehydration

Acute dehydration reduced the ability of the wrestlers in the present study to produce power during bouts one through three without affecting bouts four and five. Although several studies have used single bout power tests to assess the effects of dehydration on anaerobic power, the use of repeated maximal cycling bouts is a novel protocol. For example, Webster et al. (1990) using a 40 second maximal cycling bout reported reductions in power after dehydration comparable to those in bout one of the present study. The wrestlers in Webster's et al. (1990) study lost 4.9% body weight by exercising in a rubber suit 12 hours before weigh-in. Studies using other methods to assess anaerobic performance have indicated a reduction in performance after dehydration (Klinzing and Karpowicz 1986; Saltin, 1964).

In contrast, two studies using the Wingate Anaerobic Test (30 seconds of maximal cycling) found no significant difference in anaerobic power after a 4.2% weight reduction in seven days via food and fluid deprivation and progressive weight reduction of 2, 3, and 5% in six hours via passive thermal dehydration respectively (Guastella et al. 1989; Jacobs, 1980). In addition, Houston et al. (1981) found no difference in the anaerobic performance of wrestlers using a treadmill run to exhaustion test (average duration approximately one minute) after an 8% weight reduction in 96 hours via dehydration and food restriction.

Perhaps differences in dehydration method coupled with testing protocol account for the varied anaerobic power results. For example, a treadmill run to exhaustion test lasting approximately one minute may not be sensitive enough to detect the effects of dehydration where as cycle ergometry tests with high test-retest reliability for power output may detect changes in performance (Bar-Or, 1987; Vanderwalle, Peres, and Monod, 1987; Williams et al. 1988).

Furthermore, the results of the aforementioned studies in conjunction with data from Caldwell et al. (1984) and Saltin (1964) indicate the effects of dehydration on performance are related to the method, duration, and magnitude of dehydration. The wrestlers in the present study and others chose to use exercise in combination with fluid deprivation and/or heat exposure as the primary method of rapid weight reduction (Webster et al. 1990; Widerman and Hagan, 1982). This method of dehydration appears to be the most detrimental to anaerobic performance (Saltin, 1964; Webster et al. 1990) and may affect the same mechanisms believed to be involved in muscle fatigue during maximal exercise. For example, shifts in electrolyte concentration found after dehydration are similar to those reported to exist in fatigued muscle after maximal exercise which has been purposed to impair muscular contractility (Costill et al. 1976; Sjogaard 1983; 1986).

In the present study plasma electrolyte concentrations remained relatively stable. However, plasma concentrations may not represent changes in extracellular and intracellular concentrations which would more directly affect contractility. In addition, other cellular components such as pH, ATP, and CP may change with dehydration affecting power output ability (Costill, et al. 1976; Sjogaard 1983; 1986). Whatever mechanisms are affected by rapid dehydration, the result is a reduction in the ability to produce power during initial bouts of repeated anaerobic cycling exercise, while later bouts are unaffected.

Conclusion

Decreases in PP and AP production after dehydration demonstrated by the present study suggests that dehydration may elicit a decrement in performance capacity during activities which involve repeated short-term, high-intensity exercise. This could be a crucial consideration in events, such as wrestling, which rely heavily on a participant's ability to produce high levels of power output quickly and in the early stages of an event. As exercise time progresses the effects of muscle fatigue seem to over come the effects of dehydration. Thus, dehydration may not be as much of a limiting factor in PP and AP production in the later stages of an event correlating to the time frame of the protocol used in the present study.

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Table 1

	Hydrated		Dehydrated	
Variable	$\bar{X}$	SEM	$\bar{X}$	SEM
BW (kg)	76.3**	3.9	72.8**	3.6
Kcal	2884	476	2583	338
HTC (%)	45.7**	0.9	50.2**	0.3
PO (mosmol/L)	282.5**	1.5	288.6**	1.4
Na+ (mmol/L)	149.4	1.9	147.6	2.3
Cl- (mmol/L)	118.0	1.9	117.4	1.1
K+ (mmol/L)	4.87*	0.16	4.36*	0.19
Ca++ (mg/dL)	10.57	0.16	10.57	0.11

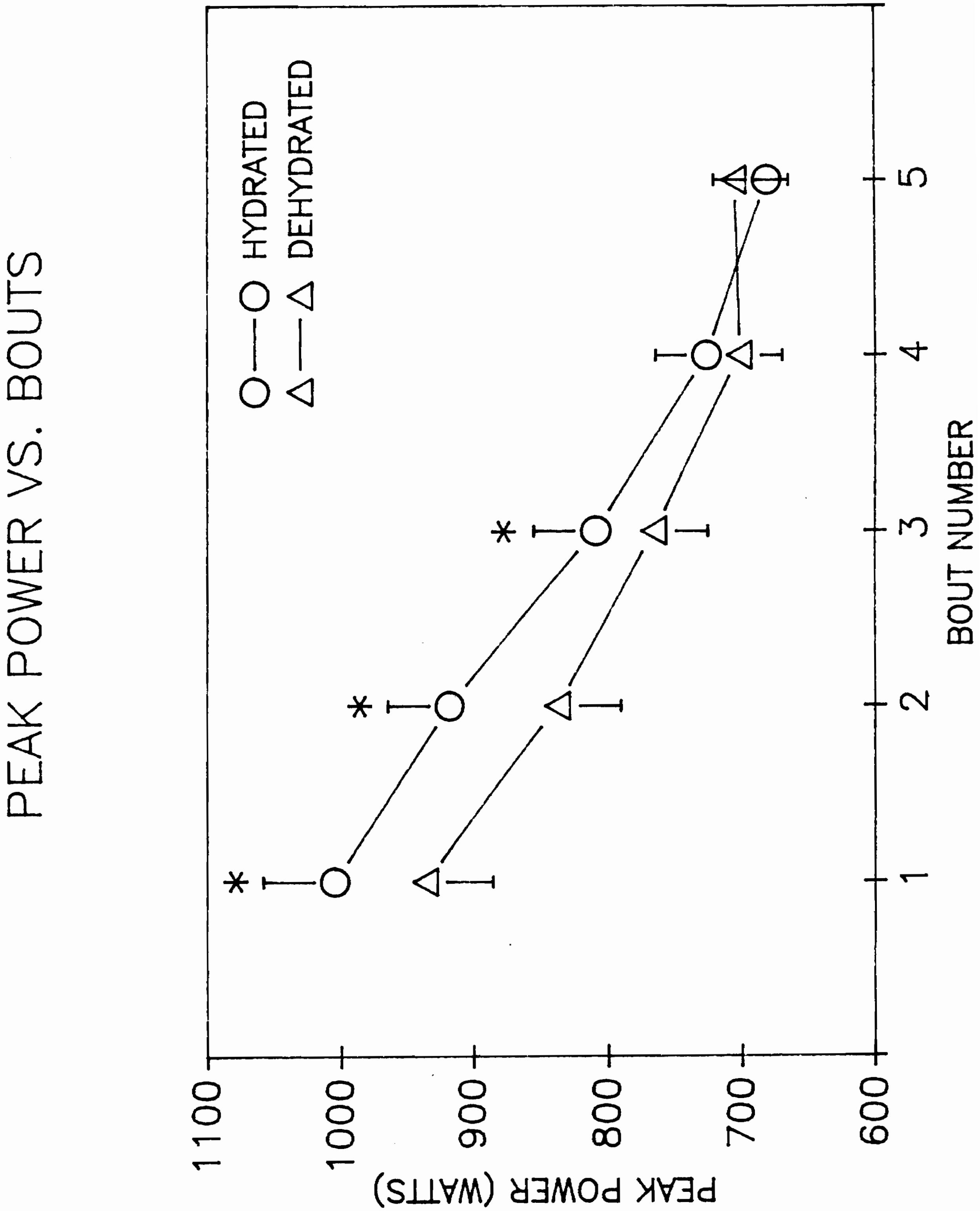

PEAK POWER VS. BOUTS
O—O HYDRATED
Δ—Δ DEHYDRATED
PEAK POWER (WATTS)
1100
1000
900
800
700
600
BOUT NUMBER
1
2
3
4
5
*
*
*
*

Figure 1

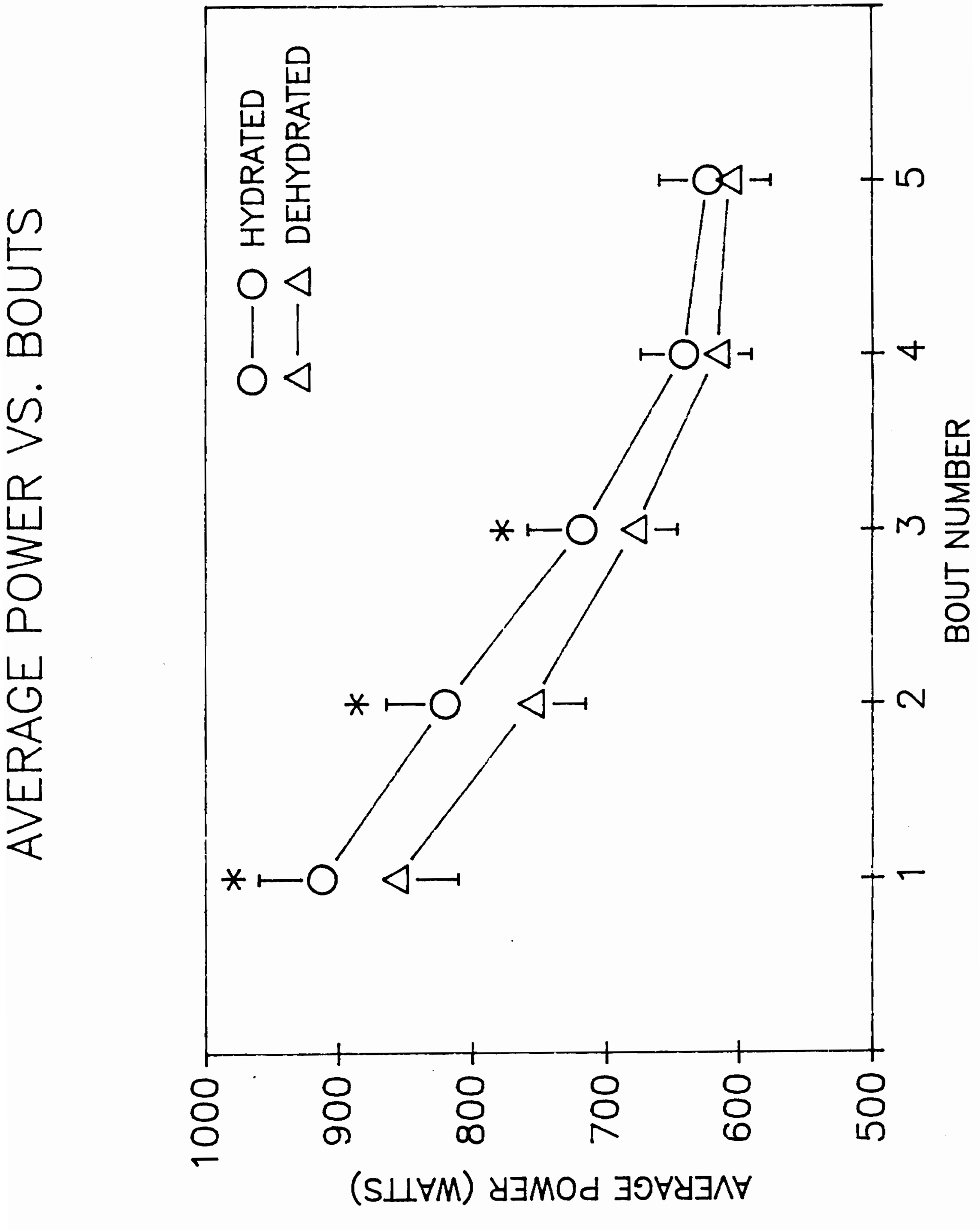

AVERAGE POWER VS. BOUTS
HYDRATED
DEHYDRATED
AVERAGE POWER (WATTS)
1000
900
800
700
600
500
BOUT NUMBER
1
2
3
4
5
*
*
*

Figure 2

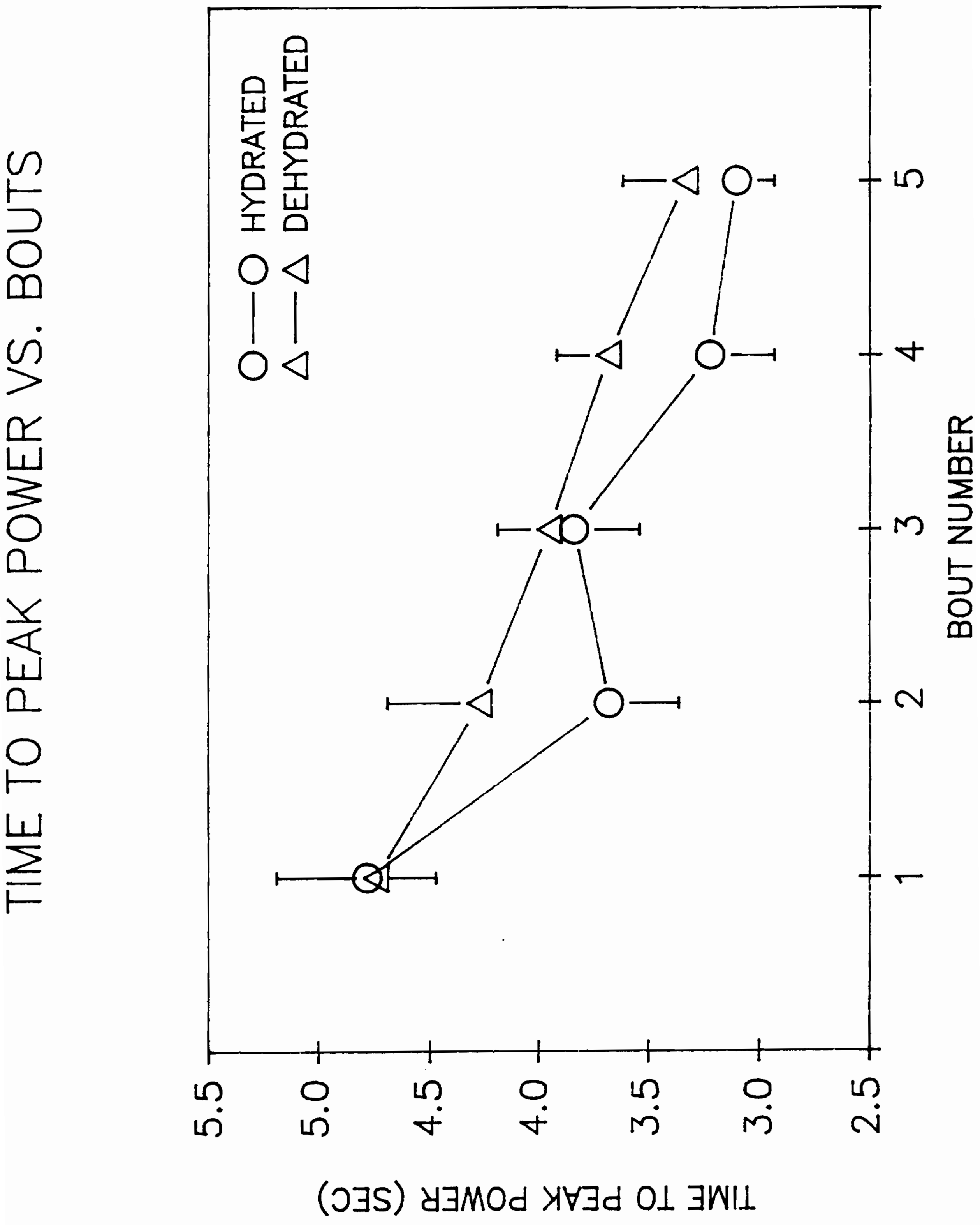
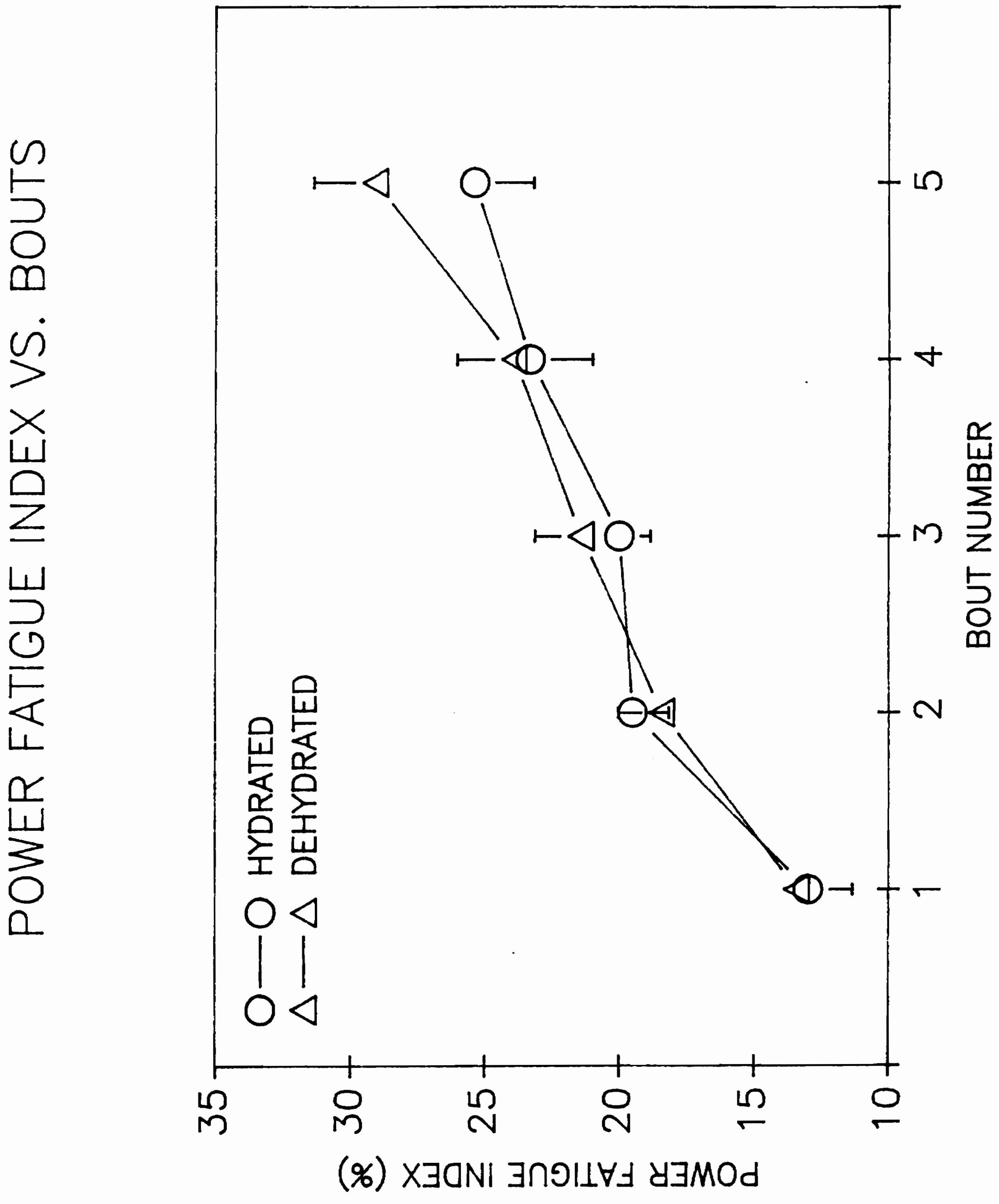

TIME TO PEAK POWER VS. BOUTS
O—O HYDRATED
Δ—Δ DEHYDRATED
TIME TO PEAK POWER (SEC)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
BOUT NUMBER
1
2
3
4
5

Figure 3



POWER FATIGUE INDEX VS. BOUTS

Figure 4

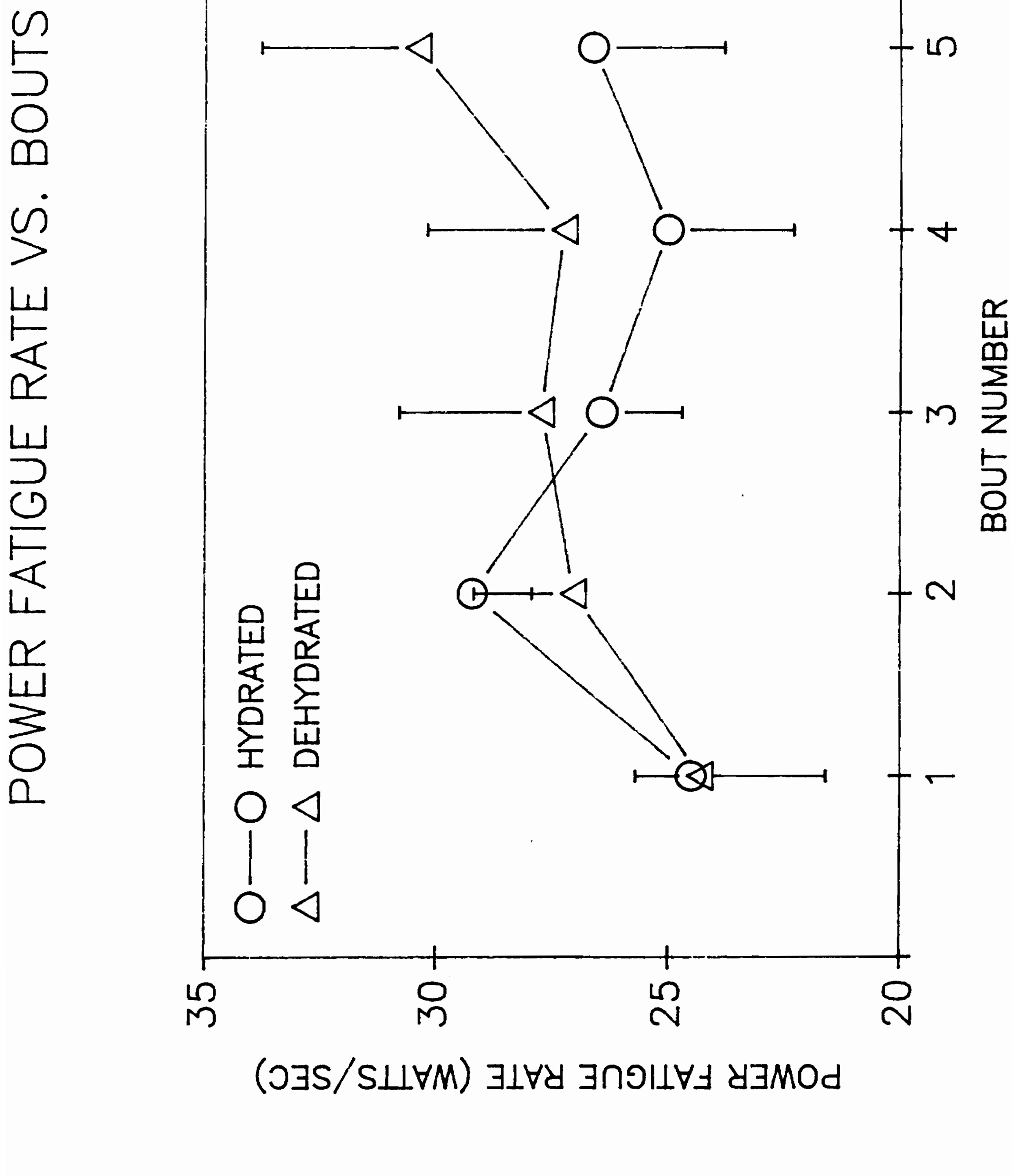

POWER FATIGUE RATE VS. BOUTS
○—○ HYDRATED
△—△ DEHYDRATED
POWER FATIGUE RATE (WATTS/SEC)
35
30
25
20
BOUT NUMBER
1
2
3
4
5

Figure 5

Chapter IV

SUMMARY

Wrestlers frequently reduce weight via acute dehydration to qualify for lower weight classifications. The present study examined the effects of acute dehydration on repeated bouts of short-term, high-intensity cycling exercise. Eight college wrestlers performed two exercise trials on a cycle ergometer before (hydrated) and 48 hours after weight reduction via dehydration. The cycling protocol consisted of a four minute warm-up followed by five, 10 second maximal effort bouts interspersed with 20 second rest intervals. The ergometer was preloaded with 0.1 kg/kg of hydrated bodyweight and was integrated with a microcomputer for data collection (Appendix C). Peak power (PP,W), average power (AP,W), time to peak power (TTPP,sec), power fatigue rate (PFR,W/sec), and power fatigue index (PFI,%) were recorded by the integrated microcomputer (Appendix F).

Pretrial plasma osmolality (PO), hematocrit (HTC), and dietary records (Kcals) were also measured to ensure weight reduction by means of dehydration (Appendix F). In addition to PO and HTC, pretrial plasma concentrations for sodium (Na+), potassium (K+), chloride (Cl-), and calcium (Ca++) were measured. Further details on the methodology of the current study are presented in Appendix A.

The wrestlers lost 4.5±1.0% bodyweight via dehydration from exercise in conjunction with fluid deprivation and/or heat exposure which was associated with an increase in PO and HTC. Caloric intake did not change significantly across the eight wrestlers although there were individual fluctuations. Electrolyte concentrations did not change with the exception of a slight decline in plasma K+ after dehydration (Appendix E).

The power indices indicate similar changes between bouts for both hydrated and dehydrated conditions. For example, PP and AP declined steadily from bouts one to four with no difference between bouts four and five for both conditions. Similarly, TTPP declined from bout one to five while PFI increased. No differences were found for PFR across bouts except for dehydrated bout five which was higher than the other dehydrated bouts only (Appendix D). Therefore, PFI increased across the five bouts while the PFR remained fairly constant.

Comparing hydrated and dehydrated power indices shows a reduction in PP and AP after dehydration for bouts one through three with no difference between conditions in bouts four and five. Dehydration did not elicit significant changes in TTPP, PFI, or PFR (Appendix D). Thus, rapid dehydration causes a decline in power output during initial bouts of repeated anaerobic exercise. With the onset of fatigue in later bouts the effect of dehydration is not significant.

DISCUSSION

The present study revealed two major consequences involving repeated anaerobic power production and the effects of rapid dehydration on power production: 1) During the performance of repeated bouts of high-intensity cycling exercise there is a progressive reduction in overall power output which appears to level in the later bouts. And 2) dehydration of 4.5% body weight elicits a reduction in power output during the initial bouts but not in later bouts.

Power Output

In the present study PP and AP declined initially and then leveled in the later bouts regardless of hydration state. McCartney et al. (1986) reported a similar reduction in power output during intermittent cycling bouts. The design differed from the present protocol in that an isokinetic ergometer (100 rpm) was used to measure power output during four, 30 second maximal bouts separated by four minute recovery intervals. Their results show a steady reduction in PP and AP for bouts one through three. There was no significant difference in these parameters between bouts three and four.

The findings of McCartney et al. (1986) support those of the present study and suggest that intermittent maximal cycling power output declines steadily though initial bouts and then begins to level in later bouts. A possible explanation for such a pattern was proposed by Hirvonen et al. (1987) who measured muscle ATP, creatine phosphate (CP), and lactic acid (LA) before and after 40, 60, 80, and 100 meter maximal sprints. They concluded that fatigue during short-term, high-intensity exercise is a result of phosphagen depletion and a shift to glycolysis. However, McCartney et al. (1986) found that muscle ATP and CP were almost completely restored during the four minute rest intervals between bouts. The rest intervals in the present study were considerably shorter, 20 seconds, allowing less time for ATP and CP replenishment. In addition, Bergstrom et al. (1971) purposed that ATP and

CP depletion may occur at the cross-bridges without significant whole muscle depletion.

Thus, the initial reductions in power across the first three bouts in the present study may have resulted from a rapid reduction in available high-energy phosphates, CP and ATP, followed by a leveling of power output at the transition to a primarily glycolytic energy supply. Glycogen depletion was shown not to affect the performance of high-intensity exercise in a recent study by Symons and Jacobs (1989). This suggests that sufficient glycogen should be available during the five exercise bouts of the present study and would explain leveling of power production at the transition to a primarily glycolytic energy source. Energy utilization from glycolysis during short, maximal exercise is evident from the accumulation of muscle LA, a byproduct of glycolysis, within the first 10 seconds of maximal exercise (Jacobs et al. 1983b; Saltin, 1973).

If ATP and CP supply is sufficient across bouts then other biochemical changes associated with maximal exercise may cause the reduction in power output. For example, changes in cellular electrolyte concentrations during maximal exercise have been associated with reduced power output. Sjogaard (1983; 1986) observed a reduction in intracellular K+ and an increase in extracellular K+ while Na+ concentration increased in both the extracellular and intracellular spaces. These cellular shifts in K+ and Na+ concentrations persist at a sufficient magnitude to impair muscular membrane excitation and recovery during exercise (Sjogaard, 1986; 1983).

In addition to electrolyte flux, a reduction in muscle pH from LA and subsequent hydrogen ion (H+) accumulation during short-term, high-intensity exercise has been shown to reduce power output (Hermansen and Osnes, 1972; Jacobs et al. 1983a; McCartney et al. 1983a). The accumulation H+ competes with Ca++ for troponin binding sites and a reduction in pH decreases troponin affinity for Ca++ (Roberts and Smith, 1989). Inesi and Hill (1983) reported that as muscle H+ increased a larger amount of Ca++ was needed for ATPase activation. These results suggest that increased muscle H+ may diminish the biochemical efficiency of Ca++ during excitation-contraction limiting cross-bridge formation and subsequently reducing power output across bouts (Roberts and Smith, 1989).

Caloric Intake and Blood Analysis

The wrestlers lost 4.5% body weight via dehydration which is substantiated by the Kcal, PO, and HTC results. Overall Kcal consumption during the 48 hours of dehydration was not significantly different from the previous 48 hours. Recent research has indicated a reduced caloric intake prior to the performance of an anaerobic power test does not effect power output (Symons and Jacobs, 1989). Therefore, any individual fluctuation in caloric intake should not have influenced power output in the present study.

In addition, the increase in PO and HTC observed after weight reduction is indicative of dehydration as indicated by several studies (Costill et al. 1976; Costill and Fink, 1974; Nose et al. 1988a; Senay and Christensen, 1965; Vaccaro et al. 1976). The majority of these studies also reported an increase in plasma electrolyte concentration. Na+, Cl-, and Ca++ plasma concentrations were unchanged after dehydration in the present study with a slight reduction in K+. The variation in electrolyte concentrations after dehydration between studies is most likely a factor of duration and method of dehydration as indicated by data from Caldwell, et al. (1984). Other plasma constituents, for example plasma proteins, not measured in the present study reportedly increase in concentration with dehydration and may account for the rise in PO (Costill et al. 1976; Vaccaro et al. 1976)

Effects of Dehydration

Whatever the mechanism for reducing power output may be, acute dehydration reduced PP and AP in the present study during bouts one through three with no effect in bouts four and five. Although several studies have used single bout power tests to assess the effects of dehydration on anaerobic power, the use of repeated maximal cycling bouts is a novel protocol. Acute dehydration has been shown to reduce anaerobic power in single exercise bouts. Most recently Webster et al. (1990) reported a reduction in anaerobic power during 40 seconds of all-out cycling following a 4.9% reduction in body weight due to dehydration from exercising in a rubber suit. The duration for weight reduction was 36 hours. Studies using other methods to assess anaerobic performance have indicated that dehydration via exercise and heat exposure is detrimental to performance (Herbert and Ribisl, 1972; Klinzing and Karpowicz, 1986; Ribisl and Herbert, 1970; Saltin, 1964).

In contrast, two studies using the Wingate Anaerobic Test (30 seconds of maximal cycling) found no significant difference in anaerobic power after a 4.2% weight reduction in seven days via food and fluid deprivation and progressive weight reduction of 2, 3, and 5% in six hours via passive thermal dehydration respectively (Guastella et al. 1988; Jacobs, 1980). In addition, Houston et al. (1981) found no difference in treadmill run to exhaustion time (8 mph, 20% grade) after 96 hours of dehydration and food restriction (8% weight reduction).

The inconsistent results of these studies are most likely a result of different testing protocols and variations in method, duration, and magnitude of dehydration. For example, a treadmill run to exhaustion test lasting approximately one minute may not be sensitive enough to detect the effects of dehydration where as cycle ergometry tests with high test-retest reliability for power output may detect changes in performance (Bar-Or, 1987; Houston et al. 1981; Williams et al. 1988).

Furthermore, the results of the aforementioned studies in conjunction with data from Caldwell et al. (1984) and Saltin (1964) indicate the effects of dehydration on performance are related to the method, duration, and magnitude of dehydration. The wrestlers in the present study and others chose to use exercise in combination with fluid deprivation and/or heat exposure as the primary method of rapid weight reduction (Webster et al. 1990; Widerman and Hagan, 1982). This method of dehydration appears to be the most detrimental to anaerobic performance (Saltin, 1964; Webster et al. 1990) and may affect the same mechanisms believed to be involved in muscle fatigue during maximal exercise.

For example, changes in electrolyte concentrations after dehydration may influence power output. In the present study, plasma electrolyte concentrations remained relatively stable. However, the measurement of plasma constituents does not necessarily indicate changes in cellular content. Using human quadriceps muscle biopsies Costill et al. (1976) observed a slight increase (insignificant) in extracellular Na+ and K+ during progressive dehydration. Intracellular K+ declined significantly while Na+ remained unchanged. Plasma Na+ and K+ increased. These shifts in muscular Na+ and K+ are similar to those reported to exist in fatigued muscle after maximal exercise which may impair muscle membrane excitation and recovery (Sjogaard, 1986; 1983). Thus, possible changes in intracellular Na+ and K+ concentrations after dehydration may be responsible for the reduction in power output observed at the onset of maximal intermittent exercise in the present study. The water flux into muscles associated with maximal exercise may tend to normalize the effects of dehydration in the later bouts which would account for the leveling of power output (Sejersted, et al. 1986).

In addition, other cellular components such as pH, LA, ATP, and CP may change with dehydration affecting power output ability (Costill, et al. 1976; Sjogaard 1986; 1983). A decline in resting muscle pH as a result of dehydration may be associated with the reduction in power output after dehydration. Research examining intracellular pH during dehydration separate from exercise was not found. A study by van Beaumont et al. (1981) reported venous pH to increase slightly (7.34 to 7.43) during two hours of thermal dehydration. Here again, the measurement of venous LA and pH does not necessarily predict muscular changes.

Hermansen and Osnes (1972) compared blood and muscle LA levels during intermittent tread mill or cycling maximal exercise to exhaustion (five 40-60 second bouts interspersed with four minutes of rest). Blood LA increased continuously while muscle LA increased during exercise and recovered slightly during the rest intervals. Muscle LA reached an upper limit but blood LA steadily increased during intermittent maximal exercise.

If resting intramuscular pH is reduced via increased LA or other components as a result of dehydration, this may reduce initial power during repeated bouts by the inhibition of biochemical reactions. The fact that the reduction of intramuscular pH appears to have a lower limit could explain the leveling of both hydrated and dehydrated power output in later bouts of the present study. As LA is produced during the initial cycling bouts pH declines in both conditions until it equalizes at the lower limit.

Thus, changes in cellular components as well as possible psychological effects resulting from dehydration may be responsible for the reduction in power observed in the initial bouts of the present study. However, as the wrestlers fatigued in the later bouts, power output appeared to level and was unaffected by dehydration.

RESEARCH IMPLICATIONS

The primary objective of this study was to determine the implications of rapid dehydration on repeated production of anaerobic power. Decreases in PP and AP production after dehydration demonstrated by this study suggests that dehydration may elicit a decrement in performance capacity during activities which involve repeated short-term, high-intensity exercise. This could be a crucial consideration in events such as wrestling which rely heavily on a participant's ability to produce high levels of power output quickly and in the early stages of an event. As exercise time progresses the effects of muscle fatigue seem to overcome the effects of dehydration. Thus, dehydration would not be a limiting factor in PP and AP production in the later stages of an event correlating to the time frame of the protocol used in the present study.

There was an increase in the rate of fatigue in the dehydrated trial bout five. This too may decrease an individuals ability to perform. A decreased ability of an individual to resist fatigue with repeated utilization of anaerobic pathways would limit the endurance of power production in the later stage of an event. Obviously such a decline in the ability to maintain power output after dehydration would be detrimental in a competitive situation. However, it should be noted that no difference existed between hydrated and dehydrated PFR for all bouts. The only difference was an increase in PFR during dehydrated bout five.

The implications of the reduction in plasma K concentration and the consistency of the other electrolyte concentrations on performance are more difficult to extrapolate without knowledge of intra- and extracellular concentrations. These results suggest that the increase in PO was caused by the increase concentration of some other plasma constituent(s). For example, plasma protein levels have been shown to markedly increase with dehydration (Senay and Christensen, 1965). Perhaps further research utilizing muscle biopsies during repeated maximal exercise would better reveal the implications of dehydration on electrolytes.

RECOMMENDATIONS FOR FURTHER RESEARCH

The following are suggestions for further research relating to dehydration and anaerobic power:

1) Increasing the number of bouts performed in the present protocol would allow further analysis of the apparent leveling which occurs in PP and AP after bout four. Such a modification would also allow examination of dehydration effects on PFR which began to significantly increase in dehydrated bout five.

2) Since wrestling and numerous other activities involve extensive upper body exertion, a logical research progression would be to design a similar protocol to measure arm ergometer anaerobic power under varying conditions.

3) Examine the effects of different dehydration methods such as diuretic, sauna, and exercise induced dehydration (similar to the study conducted by Caldwell, et al. in 1984) on repeated bouts of anaerobic power.

4) Apply the concept of analyzing repeated bouts of anaerobic exercise to activities other than wrestling which involve repeated taxation of the anaerobic system. This idea has been

neglected in research.

5) Use the power curve and power indices utilized in this study to assess the performance of various populations. For example, assessment of 100 meter sprinters could reveal differences among the sprinters otherwise undetectable. One sprinter may produce a relatively high PP but then have a rapid PFR. Another sprinter of the same caliber may produce a lower PP but possess a slower PFR. More specific training methods could then be applied to each individual.

6) Utilize muscle biopsies extracted during repeated bouts of maximal exercise under hydrated and dehydrated conditions to evaluate changes in intra- and extracellular electrolytes, energy stores, lactic acid, and pH. This may give a better insight on what causes the changes observed with repeated maximal exercise and dehydration.

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Appendix A

METHODOLOGY

METHODOLOGY

Subjects

Subjects selection consisted of volunteers from the Virginia Tech wrestling team. Prior to the onset of the investigation each subject was required to read and sign an informed consent (Appendix G) explaining the participation procedures, risks, and benefits. Verbal discussion by the investigator regarding the information within the informed consent was conducted and the subjects were given the opportunity to ask any questions concerning this information.

Eight college wrestlers, age 20.4±1.8 years and height 174.1±6.7 cm, performed two cycle ergometer anaerobic power tests (trial one and two) during preseason training before they began their seasonal weight reduction regime. The trials were scheduled 48 hours apart and the investigator instructed the wrestlers to abstain from exercise 12 hours prior to their scheduled test time.

Power Testing

A front loading modified 818 Monark ergometer integrated with a microcomputer was used to collect and record the subjects power output data. Half peddle revolutions were counted at a frequency of 200 hertz by a magnetic reed switch mounted on the ergometer frame and two magnets mounted on the sprocket at 0 and 180 degrees (Appendix C). With the onset of pedal revolution the reed switch initiated soft-ware data collection by a AT-compatable microcomputer (200 Hz) which utilized the number of half revolutions, time, and the fly-wheel distance per half revolution to calculate velocity. Force was measured in N by an inline Genisco, Astro-Weigh GAU-250 force transducer mounted between the ergometer frame and friction belt which was attached to the load basket. The analog transducer signal was amplified by a MOD-x amplifier (3mV/5VDC). Both the reed switch and transducer signal were fed into a Metra Bit, 16 bit analog to digital converter before entering input ports of the microcomputer. A software program plotted a power vs. time graph for each bout and calculated the following power indices; peak power (PP), average power (AP), time to peak power (TTPP), power fatigue rate (PFR), and power fatigue index (PFI). The ergometer design, supporting software, and testing protocol were modeled after that used by Williams, et al. (1988).

The protocol for both trails consisted of a four minute warm up at 50 rpm (50 watts), followed by five, ten second maximal effort cycling bouts. Each bout was interspersed with a, 20 second rest interval. Resistance for each maximal bout was set at 0.1 kg/kg normal body weight (Bar-Or, 1987; Beld, et al. 1989; Davy, et al. 1989; Vanderwalle, et al. 1987). The ergometer seat height was adjusted so that the subjects legs were in full extension when the heel was placed on the pedal. This allowed for a slight bend at the knee when the feet were placed in the toe clips, secured, and the knee was extended. All bouts began with the pedals in a static horizontal position and the subjects' preferred limb forward. During the 20 second rest intervals the ergometer was unloaded by the investigator enabling the wrestlers to pedal against 0 resistance, to prevent venous pooling in the lower extremities. Five seconds before the start of each ten second maximum bout the pedals were reset to the original starting position. For participant safety during the exercise protocol a continuous five lead ECG monitored the wrestlers from rest to completion of trials one and two.

A pilot study examining test-retest reliability for the present protocol found correlations of 0.92 to 0.95 for power output parameters (Appendix B). Therefore, reliability measurements were not included in the present methodology.

Dehydration Regime

In addition to power data, a record of the wrestlers' total body weight was kept throughout the investigation. The investigators used a balance scale to measure body weight 48 hours before the first trial and then immediately prior to trials one and two with subjects wearing only exercise shorts. Analysis of these measurements determined the quantity of weight reduction due to dehydration. A "normal" or hydrated body weight was derived from an average of the weights recorded 48 hours before trial one and the weight recorded at trial one.

During the 48 hours between trials one and two the wrestlers were instructed to undergo a five percent reduction in their normal body weight by means of hypohydration as if they were reducing weight in preparation for a match "weigh-in". For this investigation trial two served as the weigh-in deadline. If a wrestler did not reduce weight to the minimum of three percent of normal body weight their data was excluded from final analysis. Dehydration methods were restricted to fluid deprivation, exercise, and/or heat exposure. The use of diuretics, laxatives, or any other drug to induce weight reduction was prohibited.

Dietary Records

In order to ensure that the weight reduction incurred was a result of dehydration a daily record of food consumption was kept by the wrestlers for the 48 hours prior to trial one and the 48 hours of dehydration between trials (Appendix H). The wrestlers used the record of food consumption for the initial 48 hours as a guide for consumption during dehydration. The USDA's Dietary Analysis Program for the personal computer developed by the Human Nutrition Information Service and the Extension System in 1988 was used to determine caloric intake. The investigators specifically emphasize the importance of maintaining caloric intake throughout the study to ensure valid dehydration results.

Blood Samples

In addition to dietary records, blood samples were analyzed to further validate weight reduction by dehydration. A registered nurse drew the samples five to ten minutes pre-exercise before warm-up via venipuncture for trials one and two. Each sample was collected in two, 10 ml draw Becton-Dickson, Vacutainer System test tubes one containing lithium (Li) heparin and the other void of anticoagulant. Immediately following extraction the samples were centrifuged at 7000 rpm by a DuPont, Sorvall RT 6000 refrigerated centrifuge for seven minutes and stored at 35 degrees Fahrenheit.

The samples void of anticoagulant were used to measure hematocrit (HTC) and plasma osmolality (PO). Before sample centrifugation a Damon, Micro-HTC capillary tube sample was taken, plugged, and placed in a Damon, Micro-HTC centrifuge at 7000 rpm for five minutes. The tubes were then immediately read on a Damon, Micro-Capillary Reader model CR to determine HTC. PO was measured using a Fiske Model OS Osmometer 24 hours after the completion of trial two. The osmometer measured osmolality in milliosmoles (mOsm±.01) by relating the freezing point depression of the solution to the molal concentration. An increase of one mOsm in osmolality corresponds to a freezing point depression of 0.00186 degrees C. Deionized water was used as the standard and the samples were void of anticoagulants to prevent their possible effect on ion concentration. Changes in PO and HTC were used as indicators of dehydration.

The plasma from the Li heparinized samples was analyzed for sodium (Na+), potassium (K+), chloride (Cl-), and calcium (Ca++) concentration for the hydrated and dehydrated conditions by an automated Kodak Ektachem 700 Analyzer. To determine Na+, K+, and Cl- concentrations the Ektachem measured the electrical potential between two ion selective electrodes. These electrodes measured the flow of current between a solution of known ion concentration (reference electrode) to that of the unknown sample (indicator electrode) across an ion selective membrane. The potentiometric measurements (volts) between the two solutions was compared to calibration parameters stored in the Ektachem's microcomputer which converted the voltage into ion concentration in millimoles per liter (mmol/L). Specific electrodes and membranes were used to determine the different ion concentrations.

The measurement of plasma Ca concentration by the Ektachem 700 was based on the reaction of an indicator dye with the plasma sample. A color change occurred when the dye and sample were mixed. The intensity of the color change was proportional to the amount of Ca present and was read photometrically. Kodak reports the coefficient of variation for Ca spectrophotometry and potentiometric ion measurement at less than 1.5 percent. The correlation of these two methods with others such as flame photometry, coulometric reference, and atomic absorption was reported to have a correlation coefficient of greater than .93 for the four ions tested.

Statistics

A repeated measures two-way ANOVA and subsequent Duncan's Multiple Range post hoc test (p=0.05) was utilized by the investigator to assess differences in PP, TTPP, PFR, PFI, and AP between hydrated and dehydrated trials and bouts one through five (Appendix D). Paired t-tests were used to analyze hydrated vs. dehydrated body weight, Kcal, PO, and HTC as well as Na+, K+, Cl-, and Ca++ plasma concentrations (Appendix E).

Appendix B

PILOT STUDY

EFFECTS OF REPEATED BOUTS OF SHORT-TERM, HIGH-INTENSITY EXERCISE ON POWER OUTPUT

S.A.Smith, J.H.Williams, C.W.Ward, K.P.Davy and W.D.Franke

(Pilot Study)

Presented as poster at the 1990 Southeast Chapter of the American College of Sports Medicine annual meeting, Columbia, SC.

INTRODUCTION

Traditionally, anaerobic power has been assessed with a single bout of high-intensity exercise. The purpose of the present study was to develop a reliable cycle ergometer protocol to measure the ability to repeatedly produce anaerobic power. Such a protocol may be more suitable for the evaluation of individuals involved in activities requiring repeated bouts of short-term, high-intensity exercise.

METHOD

A front loading modified 818 Monark cycle ergometer integrated with a microcomputer was utilized to examine the effects of repeated bouts of short-term, high-intensity exercise on power output indices. Nine college aged males performed 2 ergometer trials (T1 and T2) 1 to 5 days apart. The protocol consisted of a 4 minute warm-up (50W) followed by 5, 10 sec. maximal effort bouts interspersed with 20 sec. rest intervals. Each bout began with the pedals in a static horizontal position and the subjects' preferred limb forward. The ergometer resistance was set at 0.1 kg/kg body weight.

Peak power (PP), time to peak power (TTPP), power fatigue rate (PFR), power fatigue index (PFI, percent decline from PP), and average power (AP) were calculated for each bout. A repeated measures ANOVA and subsequent Newman-Keuls post hoc test was used to determine differences between bouts 1 through 5. T1 and T2 were compared using Pearson's Product Correlation.

RESULTS

The results for the 5 power indices for T1 and T2 are listed in Table 3. PP and AP decreased from bouts 1 to 5 while there was no changes in TTPP, PFR, or PFI. Thus, an inverse relationship exists between repeated anaerobic cycling bouts and the subjects' ability to maximally produce power. That PFI and PFR remained constant across bouts indicates no change in the rate or magnitude of fatigue during this type of exercise.

The correlation coefficients listed in Table 4 indicate a high day to day reliability for PP and AP. The fatigue indices and TTPP were not as reliable between days which may have been due to the homogeneity of the subject pool.

DISCUSSION

The high correlation for PP and AP suggests the protocol used in the present study provides a reliable measure of power output during intermittent maximal cycling bouts. Such a protocol may provide more information on anaerobic power producing ability and anaerobic endurance than the traditional single bout ergometer tests. Thus, it may be better suited for assessment and prediction of performance in events requiring repeated bouts of anaerobic activity.

Table 2

Results of the Repeated Measures ANOVA and Subsequent Newman-Keuls Post Hoc Test for the Power Indices PP, AP, TTPP, PFR, and PFI (X±SE).

Trial	Bout	PP (W)	AP (W)	TTPP(s)	PFR (W/s)	PFI (%)
1	1	939±55	832±49	3.6±.3	18.3±2.0	21.3±1.6
	2	866±53	742±41	3.8±.5	19.8±2.7	24.3±2.6
	3	754±32*	654±27*	3.1±.2	16.6±1.5	25.0±1.6
	4	686±30*	596±27*	3.1±.2	14.8±1.4	25.3±2.3
	5	631±30*	560±28*	3.5±.2	11.8±1.8	23.4±2.6
2	1	941±43	852±36	4.2±.5	14.6±1.3	16.1±1.2
	2	865±37	778±33	3.6±.4	14.7±1.4	19.2±1.7
	3	810±31*	703±28*	3.1±.2	16.1±2.3	22.9±2.3
	4	724±33*	637±28*	2.9±.2	13.8±2.4	21.8±2.7
	5	699±31*	613±27*	3.0±.3	13.3±1.8	20.8±2.1

* $p < 0.01$ vs. bout 1.

Table 3

Results of the Pearson's Product Correlation Between T1 and T2 for the Power Indices PP, AP, TTPP, PFR, and PFI.

Variable	r
PP	0.92
AP	0.95
TTPP	0.46
PFR	0.43
PFI	0.58

Appendix C

ERGOMETER DIAGRAM

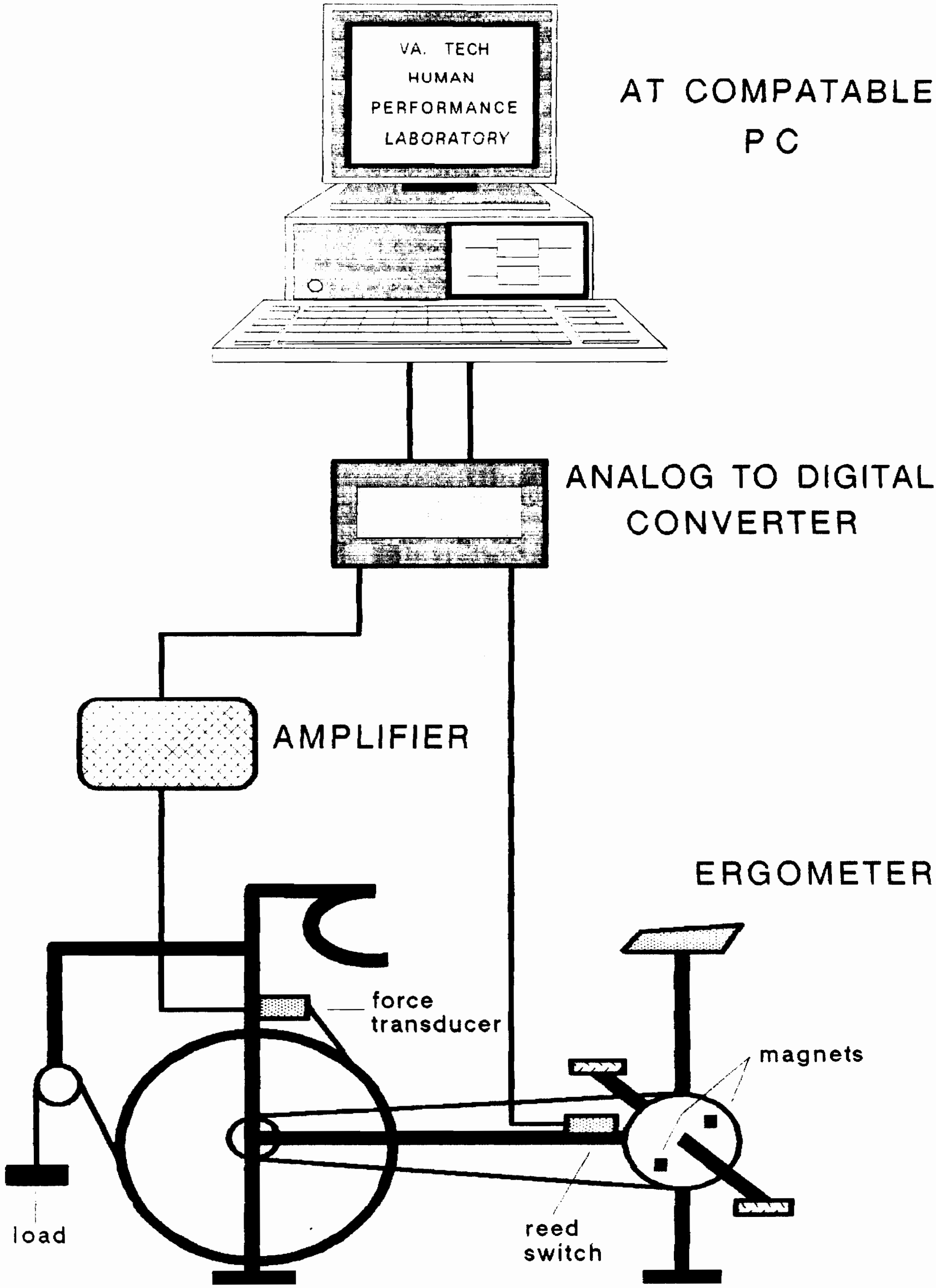
VA. TECH
HUMAN
PERFORMANCE
LABORATORY
AT COMPATABLE PC
ANALOG TO DIGITAL CONVERTER
AMPLIFIER
ERGOMETER
force transducer
magnets
load
reed switch

Figure 6

Appendix D

RESULTS OF REPEATED MEASURES ANOVA AND POST HOC TESTS

Table 4

Analysis of Variance Between Bouts 1 Through 5 for the 8 Subjects during the Hydrated and Dehydrated Conditions.

Hydrated Condition

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	1063081	96644	31.95	0.0001
Error	28	84686	3024		
Total	39	1147767			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	25.3	2.3	5.63	0.0001
Error	28	11.4	0.4		
Total	39	36.7			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	846.0	76.9	2.64	0.0187
Error	28	816.1	29.1		
Total	39	1662.0			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	1137.8	103.4	5.86	0.0001
Error	28	493.9	17.6		
Total	39	1631.6			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	903156	82105	67.40	0.0001
Error	28	34106	1218		
Total	39	937263			

Table 4 (continued)

Dehydrated Condition

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	781893	71081	46.09	0.0001
Error	28	43180	1542		
Total	39	825074			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	23.4	2.1	3.19	0.0065
Error	28	18.7	0.67		
Total	39	42.1			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	1377	125.2	4.44	0.0007
Error	28	789	28.2		
Total	39	2167			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	1702	154.7	14.37	0.0001
Error	28	301	10.7		
Total	39	2004			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	11	679288	61753	50.10	0.0001
Error	28	34514	1232		
Total	39	713802			

Table 5

Results of Duncan's Multiple Range Post Hoc Test Indicating Differences Between Bouts for Hydrated and Dehydrated Power Indices.

Hydrated Condition:

Variable	Bout	Mean	Std. Error	Grouping
PP (W)	1	1004.7	54.0	A
	2	918.4	46.7	B
	3	808.9	45.7	C
	4	726.7	38.4	D
	5	681.4	40.3	D
AP (W)	1	912.3	47.6	A
	2	820.2	43.8	B
	3	718.1	39.5	C
	4	640.9	33.1	D
	5	623.2	36.5	D
TTPP (sec)	1	4.78	0.31	A
	3	3.84	0.32	B
	2	3.68	0.30	BC
	4	3.22	0.29	BC
	5	3.10	0.17	C
PFR (W/sec)	2	29.22	1.25	A
	5	26.58	2.76	A
	3	26.35	1.73	A
	4	25.03	2.65	A
	1	24.46	2.92	A
PFI (%)	5	25.42	2.24	A
	4	23.34	2.33	AB
	3	20.05	1.18	B
	2	19.46	1.37	B
	1	13.04	1.65	C

Note: Means with the same letter under "Grouping" are not significantly different (alpha = 0.05).

Table 5 (continued)

Dehydrated Condition:

Variable	Bout	Mean	Std. Error	Grouping
PP (W)	1	936.6	51.8	A
	2	836.4	46.1	B
	3	765.8	40.2	C
	4	706.0	32.3	D
	5	701.8	41.1	D
AP (W)	1	856.7	46.8	A
	2	754.6	40.0	B
	3	678.5	33.1	C
	4	616.1	25.9	D
	5	607.4	31.0	D
TTPP (sec)	1	4.74	0.45	A
	2	4.27	0.42	AB
	3	3.95	0.24	ABC
	4	3.68	0.24	BC
	5	3.33	0.29	C
PFR (W/sec)	5	30.42	3.36	A
	3	27.73	3.06	AB
	4	27.21	2.95	AB
	2	26.99	2.18	AB
	1	24.32	1.35	B
PFI (%)	5	29.08	2.29	A
	4	23.87	2.16	B
	3	21.37	1.73	BC
	2	18.45	1.64	C
	1	13.39	0.69	D

Note: Means with the same letter under "Grouping" are not significantly different (alpha = 0.05).

Table 6

Analysis of Variance Between Hydrated and Dehydrated Conditions for the 8 Subjects during Bouts 1 Through 5.

Bout 1

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	324003	40500.5	36.95	0.0001
Error	7	7672	1096.1		
Total	15	331676			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	15.2	1.9	8.26	0.0058
Error	7	1.6	0.2		
Total	15	16.8			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	227.0	28.4	0.56	0.7810
Error	7	352.8	50.4		
Total	15	579.8			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	103.1	12.9	1.17	0.4240
Error	7	77.0	11.0		
Total	15	180.1			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	186.0	31523.2	22.28	0.0003
Error	7	9903.6	1414.8		
Total	15	262089.6			

Bout 2

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	256853	32106	19.87	0.0004
Error	7	11312	1616		
Total	15	268165			

Table 6 (continued)

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	7.6	0.95	0.75	0.6548
Error	7	8.8	1.3		
Total	15	16.4			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	324.1	40.5	5.89	0.0152
Error	7	48.1	6.9		
Total	15	372.2			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	146.0	18.3	1.13	0.4411
Error	7	112.8	16.1		
Total	15	258.8			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	207360	25920	27.23	0.0001
Error	7	6663	952		
Total	15	214024			

Bout 3

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	211873	26484	59.47	0.0001
Error	7	3117	445		
Total	15	214990			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	5.1	0.6	1.14	0.4374
Error	7	3.9	0.5		
Total	15	9.0			

Table 6 (continued)

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	551.4	69.0	3.25	0.0692
Error	7	148.6	21.2		
Total	15	700.0			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	215.4	27.0	4.91	0.0248
Error	7	38.4	5.5		
Total	15	253.8			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	151776	18972	43.52	0.0001
Error	7	3051	436		
Total	15	154828			

Bout 4

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	139074	17384	29.11	0.0001
Error	7	4181	597		
Total	15	143255			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	7.2	0.9	4.17	0.0379
Error	7	1.5	0.2		
Total	15	8.7			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	799	99.9	6.76	0.0103
Error	7	103	15.0		
Total	15	902			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	445	55.7	3.23	0.0699
Error	7	120	17.2		
Total	15	566			

Table 6 (continued)

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	95175	11896	13.03	0.0014
Error	7	6392	913		
Total	15	101567			

Bout 5

Dependent Variable: PP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	143304	17913	2.82	0.0952
Error	7	44542	6363		
Total	15	187847			

Dependent Variable: TTPP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	4.8	0.6	2.37	0.1362
Error	7	1.8	0.3		
Total	15	6.6			

Dependent Variable: PFR

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	1018	127	8.75	0.0049
Error	7	102	14.5		
Total	15	1120			

Dependent Variable: PFI

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	522	65.3	4.3	0.0350
Error	7	106	15.2		
Total	15	629			

Dependent Variable: AP

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	124253	15531	22.12	0.0003
Error	7	4915	702		
Total	15	129169			

Table 7

Results of Duncan's Multiple Range Post Hoc Test Indicating Differences Between Hydrated and Dehydrated Conditions.

Variable	Bout	Condition	Mean	Std. Error	Grouping
PP (W)	1	H	1004.7	54.0	A
		D	936.6	51.8	B
	2	H	918.4	46.7	A
		D	836.4	46.1	B
	3	H	808.9	45.7	A
		D	765.8	40.2	B
	4	H	726.7	38.4	A
		D	706.0	32.3	A
	5	H	681.4	40.3	A
		D	701.8	41.1	A
AP (W)	1	H	912.3	47.6	A
		D	856.7	46.8	B
	2	H	820.2	43.8	A
		H	754.6	40.0	B
	3	D	718.1	39.5	A
		H	678.5	33.1	B
	4	D	640.9	33.1	A
		H	616.1	25.9	A
	5	D	623.2	36.5	A
		H	607.4	31.0	A
TTPP (sec)	1	H	4.78	0.31	A
		D	4.74	0.45	A
	2	H	3.68	0.30	A
		D	4.27	0.42	A
	3	H	3.84	0.32	A
		D	3.95	0.24	A
	4	H	3.22	0.29	A
		D	3.68	0.24	A
	5	H	3.10	0.17	A
		D	3.33	0.29	A

Table 7 (continued)

Variable	Bout	Condition	Mean	Std. Error	Grouping
PFR (W/sec)	1	H	24.46	2.92	A
		D	24.32	1.35	A
	2	H	29.22	1.25	A
		D	26.99	2.18	A
	3	H	26.35	1.73	A
		D	27.73	3.06	A
	4	H	25.03	2.65	A
		D	27.21	2.95	A
	5	H	26.58	2.76	A
		D	30.42	3.36	A
PFI (%)	1	H	13.04	1.65	A
	1	D	13.39	0.69	A
	2	H	19.46	1.37	A
	2	D	18.45	1.64	A
	3	H	20.05	1.18	A
	3	D	21.37	1.73	A
	4	H	23.34	2.33	A
	4	D	23.87	2.16	A
	5	H	25.42	2.24	A
	5	D	29.08	2.29	A

Note: Means with the same letter under "Grouping" are not significantly different (alpha = 0.05).

Appendix E

RESULTS OF PAIRED T-TESTS

Table 8

Mean and Standard Deviation for Age, Height, and Percent Weight Reduction.

Variable	Mean	Std. Deviation
Age (years)	20.4	1.8
Height (cm)	174.1	6.7
Weight Reduction (%)	4.5	0.97

Table 9

Paired T-Test Results for Hydrated and Dehydrated Body Weight (BW), Caloric Intake (Kcal), Hematocrit (HTC), Plasma Osmolality (PO), and Electrolyte (Na+, Cl-, K+, and Ca++) Values.

	Hydrated		Dehydrated	
Variable	Mean	Std. Error	Mean	Std. Error
BW (kg)	76.3**	3.9	72.8**	3.6
Kcal	2884	476	2583	338
HTC (%)	45.7**	0.9	50.2**	0.3
PO (mosmol/L)	282.5**	1.5	288.6**	1.4
Na (mmol/L)	149.4	1.9	147.6	2.3
Cl (mmol/L)	118.0	1.9	117.4	1.1
K (mmol/L)	4.87*	0.16	4.36*	0.19
Ca (mg/dL)	10.57	0.16	10.57	0.11

** Means are significantly different $p < 0.01$.

* Means are significantly different $p < 0.05$.

Appendix F

RAW DATA

Raw Data for PP (W), TTPP (sec), PFR (W/sec), PFI (%), and AP (W).

Legend:

SUBJ = Subject Identification Number

COND = Hydrated (1) or Dehydrated (2) Condition

SUBJ	COND	BOUT	PP	TTPP	PFR	PFI	AP
1	1	1	782.74	5.05	17.91	11.33	720.37
1	1	2	714.64	4.47	27.50	21.29	630.45
1	1	3	593.58	3.55	17.09	18.58	541.06
1	1	4	554.92	4.43	14.02	14.08	509.73
1	1	5	593.11	3.32	21.96	24.75	516.67
1	2	1	740.39	4.17	19.64	15.46	684.39
1	2	2	671.02	3.60	23.44	22.36	598.63
1	2	3	589.63	4.77	19.49	17.28	534.65
1	2	4	549.53	4.24	16.66	17.47	484.23
1	2	5	583.99	3.85	28.32	28.32	512.91
2	1	1	967.52	4.80	23.94	12.86	883.76
2	1	2	888.99	3.43	29.48	21.77	791.35
2	1	3	809.25	3.69	31.59	24.61	714.98
2	1	4	705.93	3.94	33.45	28.71	618.00
2	1	5	569.41	3.60	33.26	31.80	567.89
2	2	1	861.98	4.91	18.98	11.20	781.51
2	2	2	806.81	4.86	27.50	17.39	738.69
2	2	3	755.94	4.91	39.90	24.54	660.12
2	2	4	692.41	3.91	32.14	26.04	604.69
2	2	5	620.37	4.82	40.33	33.91	518.29
3	1	1	1023.14	6.32	8.99	3.23	947.45
3	1	2	1074.50	3.61	29.49	17.55	952.78
3	1	3	924.49	4.55	26.81	15.81	815.41
3	1	4	822.98	3.21	25.07	20.68	727.62
3	1	5	558.14	3.19	25.36	20.12	758.69
3	2	1	957.62	6.22	30.95	12.22	885.89
3	2	2	881.74	5.29	34.91	18.64	804.11
3	2	3	833.64	2.96	23.83	20.11	739.48
3	2	4	746.77	4.44	33.34	24.82	669.55
3	2	5	843.50	2.13	36.67	33.79	704.83
4	1	1	865.56	5.29	32.20	17.53	787.75
4	1	2	765.94	2.93	24.23	22.37	678.60
4	1	3	663.88	3.90	23.54	21.61	585.04
4	1	4	601.63	2.97	21.66	25.29	519.41
4	1	5	550.01	2.77	14.59	19.18	481.62
4	2	1	752.39	6.66	26.02	11.57	686.61
4	2	2	625.87	6.53	16.98	9.42	581.74
4	2	3	629.18	3.91	19.57	18.95	569.63
4	2	4	603.95	3.47	15.03	16.25	552.80
4	2	5	575.77	3.57	16.09	17.97	524.80
5	1	1	912.83	5.23	21.03	10.99	814.55
5	1	2	878.14	3.38	31.41	23.66	771.10
5	1	3	754.61	4.05	25.40	20.02	670.94
5	1	4	675.48	3.03	21.22	21.38	603.15
5	1	5	661.29	2.54	22.24	25.11	575.50
5	2	1	946.65	5.45	25.90	12.43	875.32
5	2	2	850.71	3.98	28.76	20.33	765.59
5	2	3	739.61	3.82	23.63	19.76	667.31
5	2	4	672.82	3.55	22.89	21.96	599.86
5	2	5	635.97	3.20	19.65	28.41	568.18
6	1	1	1191.44	3.81	32.04	16.66	1079.07
6	1	2	959.93	5.18	25.00	12.56	880.06
6	1	3	903.49	5.12	28.16	15.22	803.81
6	1	4	829.34	3.03	18.46	15.51	759.66

Raw Data for PP, TTPP, PFR, PFI, and AP in bouts 1 through 5 (Continued).

SUBJ	COND	BOUT	PP	TTPP	PFR	PFI	AP
6	2	1	1103.32	3.56	22.99	13.43	996.14
6	2	2	922.93	3.81	21.60	14.50	831.56
6	2	3	835.17	4.34	21.53	14.59	751.57
6	2	4	751.24	4.31	28.01	21.21	662.37
6	2	5	766.99	3.52	24.96	21.09	684.56
7	1	1	1080.58	3.91	27.66	15.59	976.84
7	1	2	995.34	3.93	34.49	21.03	888.22
7	1	3	867.49	3.84	32.73	23.23	761.17
7	1	4	806.02	3.49	33.73	27.24	688.16
7	1	5	760.98	3.18	27.91	25.02	652.34
7	2	1	992.57	3.25	24.78	16.85	896.23
7	2	2	925.18	3.59	34.47	23.89	807.93
7	2	3	808.26	3.58	35.98	28.58	687.75
7	2	4	772.42	2,98	33.85	35.28	636.90
7	2	5	754.44	2.97	37.20	34.67	625.21
8	1	1	1213.71	3.86	31.89	16.12	1088.18
8	1	2	1069.52	2.52	32.13	15.48	969.20
8	1	3	954.28	2.02	25.47	21.30	846.24
8	1	4	817.04	1.66	32.63	33.29	701.41
8	1	5	825.01	2.39	40.58	37.41	693.02
8	2	1	1138.01	3.72	25.27	13.94	1047.49
8	2	2	1005.71	2.68	28.25	20.55	908.57
8	2	3	935.11	3.30	37.94	27.17	817.40
8	2	4	824.96	2.51	30.74	27.92	718.34
8	2	5	861.36	2.55	39.83	34.46	720.17

Raw Data for Subject Age (years), Height (HT,cm), Body Weight (BW,kg), % BW Reduction, Electrolytes Na (mmol/l), K (mmol/l), Cl (mmol/l), and Ca (mg/dl) for Hydrated (Hyd) and Dehydrated (Deh) Conditions.

ID#	Age	HT	Hyd BW	Deh BW	%BW Reduction
1	19	166.5	61.2	58.1	5.065364
2	20	170.5	73.2	70.8	3.278679
3	22	181.5	86.2	81.9	4.988396
4	20	163	67.9	65.2	3.97644
5	19	176	71.9	69.6	3.198892
6	24	180	83	78	6.024098
7	20	176	71.8	68.2	5.013937
8	19	179	94.9	90.5	4.63646

ID#	Na Hyd	Na Deh	K Hyd	K Deh
1	143	157	4.45	4.63
2	154	149	4.72	4.94
3	154	152	5.77	4.95
4	145	146	5.06	4.41
5	147	154	4.59	4.54
6	144	141	4.4	3.33
7	151	139	5.18	3.99
8	157	143	4.8	4.12

ID#	Cl Hyd	Cl Deh	Ca Hyd	Ca Deh
1	113	122	10.07	10.77
2	125	119	10.18	10.45
3	124	119	11.42	10.96
4	113	113	10.47	10.43
5	115	117	10.26	10.21
6	113	119	10.67	10.77
7	117	114	11	10.88
8	124	116	10.51	10.12

Raw Data for Hematocrit (HTC,%), Plasma Osmolality (PO,mOsmol/l), and Kilocalories (Kcals).

ID#	HTC Hyd	HTC Deh
1	42.5	49.5
2	47.5	.
3	.	.
4	45.5	51.5
5	42.5	49.5
6	48	.
7	47	.
8	47	.

ID#	PO Hyd	PO Deh
1	287	292
2	284	286
3	286	293
4	278	282
5	286	290
6	278	293
7	284	287
8	277	286

ID#	Kcal Hyd	Kcal Deh
1	1905	1348
2	3330	3907
3	5735	3035
4	2428	1165
5	3658	3509
6	2069	2690
7	2359	2562
8	1594	2450

Appendix G

INFORMED CONSENT

HUMAN PERFORMANCE LABORATORY

Division of Health, Physical Education and Recreation
Virginia Polytechnic Institute and State University

INFORMED CONSENT

I, ______________________________, do hereby voluntarily agree and consent to participate in a testing program conducted by the personnel of the Human Performance Laboratory of the Division of Health, Physical Education and Recreation of Virginia Polytechnic Institute and State University.

Title of the Study:

The effect of rapid dehydration on repeated bouts of short-term high-intensity cycling exercise in college wrestlers.

The purposes of this experiment include:

1. To assess the effect of rapid dehydration on anaerobic power and fatigue in college wrestlers using an repeated cycle ergometer test consisting of intermittent exercise bouts.
2. To assess the effect of rapid dehydration on cardiac function and hemodynamics.

I voluntarily agree to participate in this testing program. It is my understanding that my participation will include:

1. Exercising on a bicycle ergometer. The protocol will consist of a three minute warm up proceeded by five, ten second maximal effort cycling bouts. Four, 20 second rest intervals will separate the maximal bouts. A total of two trials will be administered 48 hours apart.
2. Abstinence from exercise 12 hours prior to each scheduled test trial.
3. A voluntary five percent reduction in total body weight occurring over a 48 hour period. The means of weight reduction will include fluid deprivation and perspiration fluid loss during exercise. The use of diuretics, laxatives, or any other drug to induce weight reduction will be prohibited.
4. Keeping a record of food consumption and body weight for four days during the study.
5. Two blood sample collections by means of venipuncture not exceeding 50 ml total. Collection will occur 48 hours apart, prior to exercise for the two trials. The venipuncture procedures will be conducted by a registered nurse.
6. Continuous five lead electrocardiographic (EKG) monitoring from rest to completion of all exercise trials.
7. Doppler echocardiographic measurements of ascending aortic blood flow conducted in conjunction with the exercise protocol.

I understand that my participation in this experiment may produce certain discomforts and risk. These discomforts and risk include:

1. Muscle soreness and fatigue associated with bicycle ergometer exercise.
2. Risk of injury including but not limited to tendinitis, bursitis, strains, sprains, fractures, contusions, abrasions, and even the possibility of death. The continuous EKG will alert the staff of potentially fatal cardiac events and allow them to respond immediately.
3. Weakness and dry mouth due to dehydration.
4. Possibility of infection from blood sample venipuncture. Strict aseptic technique will be utilized to significantly reduce this risk.

Certain personal benefits may be expected from participation in this experiment. These include:

1. Realizing the effects of rapid dehydration on repeated short duration, high intensity physical performance typically used in a wrestling match situation.
2. Knowledge of cardiac functional and hemodynamic changes as a result of rapid dehydration. This information as well as the information in number one will enable wrestlers to adjust their weight reduction methods to minimize the adverse effects of rapid dehydration.

Appropriate alternative procedures that might be advantageous to you include:

1. Physical examination by a physician prior to exercise participation and weight reduction.

NOTE:
Doppler echocardiographic measurements are noninvasive and do not emit electromagnetic radiation. The procedure utilizes ultrasound waves to assess hemodynamics and poses no reported health risks to subjects.

Appendix H

GUIDELINES FOR DIETARY RECORD

GUIDELINES FOR RECORDING FOOD CONSUMPTION: ANAEROBIC POWER IN COLLEGE WRESTLERS

NAME: ______________________________

DATES OF RECORD: Oct. 15-17, 17-19

As an important part if this study you are being asked to keep a record of everything you eat and drink for a total of four days. The purpose of this dietary record is to ensure a consistent caloric intake for the duration of the study. There should be no differences in food consumption between the hydrated and dehydrated conditions resulting from participation in this study.

Your dietary record for the first 48 hours of the study will be used as a guide for the last 48 hours. The investigators are asking that you consume the same quantity and type of food during the final 48 hours (dehydration period) as you did during the initial 48 hours of the study. This method is attempting to control for weight reduction as a result of dehydration and not caloric restriction.

THINGS TO REMEMBER:

1. <u>WRITE DOWN EVERYTHING YOU EAT AND DRINK.</u> Begin with the first thing you eat in the morning and end with the last thing you eat at night. This includes snacks, candy, desserts, condiments, and alcohol.

2. <u>WRITE DOWN EXACTLY HOW MUCH YOU HAD.</u> Use common household measurements, for example; cups, tablespoons, ounces, slices, etc.

3. <u>WRITE DOWN TYPE OF FOOD AND HOW IT WAS PREPARED.</u> Examples of different types of food include wheat bread vs. white, skim milk vs. 2%, etc. Examples of food preparation methods include baked, broiled, fried, toasted, etc.

4. <u>WRITE THE FOOD ITEM DOWN IMMEDIATELY AFTER YOU EAT IT.</u> Please do not wait until the end of the day. Carry your food record with you and write down food items throughout the day.

5. <u>WRITE EACH FOOD ITEM ON A SEPARATE LINE.</u>

6. <u>RECORD THE TIME YOU EAT AS CLOSELY AS POSSIBLE.</u>

** BE AS SPECIFIC AS POSSIBLE WHEN RECORDING FOOD TYPE AND **
** QUANTITY! (see example) **

DIET RECORD

ID #: ____________

Subject Name: ____________________________________

Sunday 10/15/89, Time:__________, Body Weight:__________kg, __________lbs.

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Monday 10/16/89

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Tuesday 10/17 REMEMBER NO STRENUOUS EXERCISE 12 HRS PRIOR TO TESTING

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Tuesday 10/17/89, Time:_________, Body weight:__________kg,________lbs.

Normal Weight:________kg________lbs. TARGET WEIGHT:________KG,________LBS.

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Wednesday 10/18/89

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Thursday 10/19 REMEMBER NO STRENUOUS EXERCISE 12 HRS PRIOR TO TESTING

OFFICIAL USE	FOOD ITEM	QUANTITY	TIME

Appendix I

DATA SHEET

EFFECTS OF DEHYDRATION ON ANAEROBIC POWER IN WRESTLERS:

DATA SHEET

ID # ____________

Name: ________________________________

Age: ________ Height: _________cm

<u>Sunday, 10/15/89</u> Time: __________

Body Weight (1): __________kg

<u>Tuesday, 10/17/89</u> Time: __________

Body Weight (2): __________kg Normal Weight: __________kg (BW1+BW2)/2

Target Weight: __________kg (NW x .05)-NW

Ergometer Load: __________kg, __________lbs (.1 kg x NW kg)

Seat Height: __________holes

Calibration Slope: ____________, Calibration Intercept: ____________

Blood Work, Hydrated (H):

HTC ___________, Osm ___________, K+ ___________, Ca+ ___________

Caloric Intake: _______________

<u>Thursday, 10/19/89</u> Time: __________

Body Weight (3): __________kg, ≤ Target Weight: __________kg

Ergometer Load: __________kg, __________lbs (.1 kg x NW kg)

Calibration Slope: ____________, Calibration Intercept: ____________

Blood Work, Dehydrated (D):

HTC ___________, Osm ___________, K+ ___________, Ca+ ___________

Caloric Intake: _______________

VITA

Sinclair Allan Smith was born November 22, 1964 in Fairfax, Virginia to Mrs. Rose Marie Smith and Mr. Aubrey Allan Smith. He has one younger sister, Elizabeth Susan Smith who is presently attending James Madison University in Harrisonburg, Virginia. Sinclair grew up in New Baltimore, Virginia where he graduated from Fauquier County High School in 1983. He then attended Virginia Tech in the Forestry and Wildlife curriculum. The following year he changed his major to biology and graduated with a Bachelor of Science in biology, November 17, 1987. For the preceding nine months, Sinclair worked as a physical therapy assistant at Montgomery Regional Hospital in Blacksburg, Virginia. In August of 1988 he went back to Virginia Tech to obtain a Master of Science degree in Exercise Physiology. While a graduate student, Sinclair taught weight training and physical fitness and worked in the Virginia Tech Cardiac Rehabilitation Program. Currently he is working on a research project involving the effects of varying degrees of seasonal weight reduction on myocardial adaptation in college wrestlers, in addition to his work with dehydration and anaerobic power. In February of 1990 Sinclair presented a poster on anaerobic power during repeated cycling bouts at the SEACSM annual meeting. He plans on submitting his other research findings for publication in the near future. After obtaining his masters degree, Sinclair would like to work in corporate or community fitness and remain involved with research. Eventually he wants to return to school and obtain a Ph.D. in Exercise Physiology.

Sinclair A. Smith

THE EFFECT OF RAPID DEHYDRATION ON REPEATED BOUTS OF SHORT-TERM, HIGH-INTENSITY CYCLING EXERCISE IN COLLEGE WRESTLERS

(Abstract)

Sinclair A. Smith

This study examined the effects of acute dehydration on repeated bouts of anaerobic cycling exercise. Eight college wrestlers performed 2 cycle ergometer trials before (hydrated, H) and 48 hrs after dehydration (D) via exercise, fluid restriction, and heat exposure. The trials consisted of a 4 min warm-up followed by 5, 10 s maximal bouts interspersed with 20 s rest intervals. The ergometer was preloaded with .1 kg/kg of H bodyweight. Peak power (PP,W), average power (AP,W), time to peak power (TTPP,s), power fatigue rate (PFR,W/s), and power fatigue index (PFI,%) were recorded by an integrated microcomputer. Pretrial plasma osmolality (PO), HTC, plasma electrolytes, and caloric intake (Kcal) were also measured. The wrestlers lost 4.5±1.0% (X±SD) bodyweight from H to D trials which increased PO and HTC ($p<.01$). There was a decline in plasma [K+] ($p<.05$) and no change in Kcal. PP values for H bouts 1-5 were 1004±54, 918±47, 809±46, 727±38, and 681±40 and for D bouts 1-5 were 937±52, 836±46, 766±40, 702±41, and 706±32 (X±SEM). AP results were similar to PP and thus not shown. There were no differences in H and D trials for TTPP, PFR, and PFI. After dehydration PP and AP were reduced during bouts 1-3 ($p<.05$) and appear to level in bouts 4 and 5 coinciding with H PP and AP. These results suggest that rapid dehydration by wrestlers causes a decrease in PP and AP production during initial bouts of repeated anaerobic exercise. With the onset of fatigue in later bouts PP and AP are unaffected.