

Upper and Lower Body Anaerobic Muscular Power is Adversely Affected by Active Dehydration

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Abstract: A gap exists in the knowledge of acute dehydration and its effect on anaerobic muscular power. Therefore the purpose of this study was to examine the effects of active dehydration by exercise in a hot humid environment on anaerobic muscular power.

Muscular strength and power is considered a basic component of physical performance. The factors affecting strength have been studied intensively for more than half a century. While much work on the effects of water depletion on physical performance, has been summarized, in part, by Adolph (1947) there is a lack of experimental evidence concerning the effects of dehydration on anaerobic muscular power. Exercise and sports participation in hot and humid climates has recently received considerable attention throughout sports governing bodies, the athletic training community, and the media (Nielsen et al. 1981; Ftaiti, Grelot, Coudreuse, & Nicol, 2001; Jacobs, 1980). While Certified Athletic Trainers and coaches alike strive to increase performance, it is also necessary to understand how dehydration may adversely affect that goal. Allied health care providers, coaches, and governing bodies of sports need to be knowledgeable of the effects of dehydration and exercise in extreme temperatures.

There are two primary anaerobic energy sources, the phosphagen system and anaerobic glycolysis system. These two systems work together to provide the body with an immediate source of ATP for sports of very short duration or for burst-like sports, such as American football and basketball. Proposed physiologic mechanisms for a decrease in anaerobic muscular power are lacking; however, Sjogaard (1986) suggested that a loss of intracellular potassium might hyperpolarize the membrane electrochemical potential and reduce muscle contractibility. Faulkner (1980) who postulated that high muscle temperatures may elevate hydrogen ion concentration may inhibit phosphofructokinase activity and therefore anaerobic performance. This muscular function has been evaluated in dehydrated participants in previous studies using Wingate type tests (Jacobs, 1980; Webster, Rutt, & Weltman, 1988). Jacobs (1980) found that dehydration did not alter anaerobic exercise performance or post-exercise blood lactate levels. On the other hand Webster et al. (1988) found a 21% reduction in anaerobic power and a 10% reduction in anaerobic capacity in dehydrated (5% of body weight) participants. These studies demonstrate that discrepancies exist in evaluating muscular anaerobic muscle function. Further, the method of inducing dehydration through active (exercise combined with heat stress) or passive (e.g., heat exposure in saunas) means may produce varying degrees of muscle temperature increase and muscle function impairment.

Traditionally, researchers have investigated the detrimental effects of excessive heat on exercise performance and the clinical manifestations of exercise-induced hyperthermia. Discrepancies exist in the current body of knowledge regarding exercise-induced dehydration and its effects on muscular strength and power. A paucity of data exists on the effects of active dehydration induced by exercise in hot and humid environment specifically on muscular power. Therefore, the purpose of this study was to examine the effects of active dehydration by exercise in a hot humid environment on upper-body and lower-body anaerobic muscular power.

Methods

Experimental Design and Procedures

The experimental design consisted of a test-retest within subjects design. The independent variable was hydration (euhydrated and dehydrated) and the dependent variables were upper-body and lower-body anaerobic power. Participants ($n = 7$) performed the upper- and lower-body Wingate anaerobic test under each of two experimental conditions: euhydrated and dehydrated ($3.3 \pm 2\%$ reduction in body mass).

A familiarization session was conducted in which potential participants read and signed the health/injury history questionnaire and the informed consent form approved by the Florida International University Institutional Review Board. Participants were familiarized with the Wingate anaerobic tests. Instruction was provided in the proper use of the equipment as well as the proper techniques used with the cycle ergometer. Participants were instructed to abstain from ingestion of alcohol, caffeine, non-prescription medication, and dehydrating behaviors (sauna, diuretics, sweat suits, etc.) for the duration of the study. At the end of the familiarization session, baseline body mass and resting heart rate were measured and recorded.

Participants reported to the FIU Sport Science Research Laboratory at 9:30 am wearing an athletic supporter, mesh shorts, cotton t-shirt, sweat socks and running shoes. Participants were asked to completely void urine and body mass data were recorded. A euhydrated body mass was confirmed as less than +1% (or 0.4 kg) of baseline body mass recorded the previous day. A euhydrated condition Wingate anaerobic test was administered immediately followed by the heat stress trial to induce the criterion body mass loss of $\geq 3.0\%$ of baseline nude body mass. Several measurements of environmental conditions were recorded throughout the heat stress trial and recovery period. Upon completion of the heat stress trial, participants removed all clothing and towed dry for measurement of nude body mass. After dehydration was confirmed, the recovery period consisted of participants resting in thermoneutral environment until core body temperature returned to baseline (52.5 ± 20.1 min, range = 28 – 80 min). This delay was provided to allow muscle and core body temperature to return to normal and to allow the effects of heat exposure and exercise to subside before upper and lower body anaerobic power was assessed. Participants completed four administrations of a 30 s Wingate anaerobic tests (2 upper-body and 2 lower-body in the euhydrated and dehydrated conditions), and peak power, mean power, and decrease in power output were calculated and recorded.

Measurements and Procedures

Heat stress trial. A heat stress trial consisted of 45-90 min of treadmill exercise in a hot and humid environment (ambient temperature = 33.1 ± 3.1 °C, range 28.5-40.5 °C; relative humidity = $55.1 \pm 8.9\%$, range = 40.7-68.1%) with limited fluid intake. The heat stress trial commenced with a 5 min warm-up at 3.0 mph and the participants exercised for 40% of each participant's age predicted heart rate range. Treadmill speed was then increased, and the participants exercised at 60% of their age predicted heart rate range until at least a 3% body mass loss was achieved. A 60s rest was administered every 15 min of exercise. Ambient temperature and relative humidity were measured at 30 min intervals throughout the heat stress trial and the recovery period. All exercise was performed on a standard motor driven treadmill. As safety precautions, mean arterial pressure, heart rate, and core body temperature were measured within the first 10 min of exercise and monitored every 5 min throughout heat stress trial and recovery. If core body temperature exceeded 39.0 °C, the heat stress trial was terminated.

Wingate anaerobic tests. Participants completed the 30s Wingate anaerobic test on a cycle ergometer following a 3 min warm-up. The warm-up included 5s sprints against no

resistance after the first and second min. The warm-up was followed by a 2 min period of stretching. Participants were allowed to maximize pedal speed approximately 2s prior to test initiation in order to overcome the inertia of the flywheel. At time of test initiation, a predetermined load equal to 0.075 kg per kg of body weight was applied and a count of pedal revolutions began. Participants were asked to cycle as quickly and as forcefully as possible while remaining seated through the entire 30s duration of exercise. Pedal revolutions were recorded at 5s intervals using an electromagnetic counter (Nu-Metrics, Uniontown, PA). When the 30s test was completed, the load was reduced and the participants cooled down by pedaling against no resistance. Peak power was determined by number of pedal revolutions in the first 5s of frictional load. Mean power output was determined by averaging the six, 5s mean power output values (Seiler et al., 1990). Verbal encouragement was provided throughout the test.

The upper body Wingate anaerobic test was performed following the same instructions as the lower body test. The upper body test consisted of the cycle ergometer equipped with handles where the pedals are normally located. Participants were asked to sit in a comfortable position so that the feet were flat on the floor and so the cycle ergometer could be pedaled with no restrictions. At time of test initiation a predetermined load of 0.050 kg per kg of body mass was applied to the flywheel (Nindl, Mahar, Harman, & Patton, 1995).

Mood ratings. Mood was assessed to identify confounding variables that may affect performance of the upper and lower-body Wingate anaerobic tests. Mood was assessed prior to each administration of the Wingate anaerobic test. Motivation level was assessed by a visual analog scale designed to present to the respondent a rating scale with minimum constraints. The visual analog scale consisted of a 13 cm line with the left side being labeled “No Motivation At All” and the right side labeled “Highest Possible Amount of Motivation.” Participants marked the location on the line corresponding to the amount of motivation experienced at that time. The mark on the line was measured from the left to the nearest 0.1 cm and recorded for data analysis. Fatigue severity was determined using a question reading “At this moment what is your severity of fatigue?” with a 9-point Likert scale response. The response scale consisted of 1 = not at all, 3 = mild, 5 = moderate, 7 = severe, 9 = worst imaginable.

Participants. Seven apparently healthy (mean age = 27.1 ±4.6 years, and mass = 86.4 ±9.5 kg) males volunteered for the study. Participants were recruited from the student body at Florida International University and the surrounding community who have had no history of heat-induced illness and were resistance trained (anaerobic and aerobic workout at least two to three times per week). Males were selected to reduce the variability of ovarian hormone levels and substrate utilization between genders during exercise. Participant’s fitness level and health history was ascertained via the health history questionnaire and each participant was fully informed of the procedures and risks by signing an informed consent form approved by the Florida International University Institutional Review Board.

Statistical Analyses

The research design consisted of a test-retest design with the euhydrated and dehydrated condition as a within-subjects variable. Dependent t-tests were used to identify differences between the euhydrated and dehydrated conditions on mood ratings, thermoregulatory and cardiovascular responses to exercise, upper and lower body mean power output, upper and lower body peak power output, and upper and lower body decrease in power output over time. Descriptive statistics were performed for the anthropometric and environmental conditions measures. Data were analyzed using the SPSS 11.0 for Windows Statistical Package (SPSS, Chicago, IL) Significance was set at $P \leq .05$ for all statistical analyses.

Results

Participants rated mood prior to both upper and lower body anaerobic power performance tests. Motivation ratings were not significantly different ($t_6 = 2.322, P = .059$) in the euhydrated and dehydrated conditions; however, motivation was 23.0% decreased from the euhydrated (8.9 \pm 1.5 cm) to the dehydrated condition (6.8 \pm 3.2 cm). Fatigue severity was significantly ($t_5 = -4.134, P = .009$) increased 70% in the dehydrated (5.0 \pm 2.0) compared to the euhydrated (1.5 \pm .8) condition. Upper body mean power data revealed a significant ($t_6 = 3.307, P = .016$) 7.17% decrement in the dehydrated (1195.71 \pm 244.14 Watts) compared to the euhydrated (1406.86 \pm 260.31 Watts) condition. Lower body mean power data revealed a significant ($t_6 = 5.071, P = .002$) 19.20% decrement in the dehydrated (2202.00 \pm 377.04 Watts) compared to the euhydrated (2725.14 \pm 555.56 Watts) condition. Upper body peak power data revealed a significant ($t_6 = 2.456, P = .049$) 14.48% decrement in the dehydrated (1620.00 \pm 258.58 Watts) compared to the euhydrated (1894.29 \pm 346.16 Watts) condition. Lower body peak power data revealed a significant ($t_6 = 7.091, P \leq .001$) 18.36% decrement in the dehydrated (2888.57 \pm 448.07 Watts) compared to the euhydrated (3538.29 \pm 617.79 Watts) condition. No significant differences between the euhydrated and dehydrated conditions were found for upper body decrease in power output ($t_6 = -.266, P = .799$) or for lower body decrease in power output ($t_6 = -.247, P = .813$).

Discussion

The purpose of this study was to determine the effects of dehydration on anaerobic muscular power while controlling those extraneous factors that could affect anaerobic muscular power. In the current study participants rested in a thermoneutral environment (approximately 1.5 hr) following heat stress trial to reduce the effects of exercise and increased core body temperature on the anaerobic muscular performance test. Results from this investigation suggest that active dehydration of 3.3% body mass loss via exercise in a hot and humid environment has a negative effect on anaerobic muscular power. Previous studies (Houston, Marrin, Green, & Thompson, 1981; Jacobs, 1980; Nielsen et al., 1981; Webster et al., 1988) reported various effects of dehydration on muscular strength and power, although not all confounding variables were controlled, various methods were used, and the findings were inconclusive.

Anaerobic muscular performance has been evaluated using Wingate-type cycle ergometer tests and supramaximal endurance tests. Jacobs (1980) performed a comprehensive evaluation using anaerobic exercise performance tests including a Wingate test in participants that were euhydrated and dehydrated by 2%, 4%, and 5% body mass. Other researchers (Griewe, Staffey, Melrose, Narve, & Knowlton, 1988) examined peak torque during a maximal isometric voluntary contraction or time to fatigue for knee extensors and elbow flexors with no effects of dehydration (4% or more body mass loss) compared to euhydrated participants. Hedley, Climstein, and Hansen (2002) found no significant difference in one repetition maximum bench press but leg press strength was significantly decreased after the hyperthermic exposure (30 min of sauna exposure) compared to normothermic conditions. Further, these researchers reported a significant increase in muscular power after heat exposure. These researchers found that dehydration did not affect anaerobic exercise performance.

Our findings are similar to previous studies examining wrestlers and the effects of weight loss practices on muscle performance. Webster et al. (1988) reported a 21% reduction in anaerobic power and a 10% reduction in anaerobic capacity in participants dehydrated 5% of body weight. These researchers reported a large decrement in force production however his findings cannot be attributed to dehydration alone since participants exercised an additional 1-2 hours (after their 1.5 hour wrestling practice in order to make weight), in a rubberized suit,

performing primarily aerobic exercise. The extra exercise likely lowered both muscle and liver glycogen stores particularly since participants exercised 12 – 14 hours prior to laboratory testing.

Reducing or eliminating confounding variables is difficult in studies designed to simulate actual exercise environments. Similar to the current study, fatigue may have confounded results of previous studies examining exercise performance in simulated wrestling practices. Participants performed treadmill running while wearing an impermeable jacket and pants impeding sweat evaporation to induce dehydration and hyperthermia. On average, the pre-fatigue strength tests were completed 20 minutes before the treadmill run and the post fatigue tests started 8-12 minutes after the run to induce dehydration (Ftati, Grelot, Coudreuse, & Nicol, 2001). Findings of these studies cannot be attributed entirely to dehydration because of the fatiguing nature of the dehydration protocol. In one of the more comprehensive studies Nielsen et al. (1981) compared the results of a supramaximal exercise performance on participants dehydrated by diuretics (18% decrease in performance), sauna (35% decrease in performance), and exercise (44% decrease in performance). Each of the preceding procedures resulted in a relatively large reduction in plasma volume which has been considered the most likely physiological mechanism explaining the performance decrements during dehydration. Dehydration that develops during exercise is associated with relatively small reductions in plasma volume as compared to subjects that remain euhydrated during exercise (Sawka, 1988). Passive dehydration induced by diuretics or sauna exposure is not a good model for studying the effects of dehydration that develops during exercise, although it can be appropriate for studying the effects of beginning exercise in a hypohydrated state. Furthermore, passive modes of dehydration are unrelated to *in situ* physical activity in which most individuals participate. Our study utilized an *in vivo* active dehydration protocol which was designed to closely simulate typical physical activity environment. However in our study there was an average delay of 1½ hours from completion of heat stress trial to actual anaerobic power testing, during which core body temperature was measured every five minutes and participants were not allowed to proceed to power testing until core body temperature had returned to pre-heat-stress-trial measures. This would have presumably allowed recovery from the fatiguing nature of the heat stress trial.

Our findings concur with previous studies that demonstrated reductions in muscular strength due to dehydration (Bosco & Terjung, 1968; Webster et al., 1988) achieved by fluid restriction and by a combination of exercise and heat exposure. The most compelling decreases in muscular strength have been demonstrated using prolonged fluid restriction accompanied by a caloric deficit (Bosco & Terjung, 1968; Houston et al., 1981). Proposed physiologic mechanisms for a decrease in anaerobic muscular power are lacking; however, Sjogaard (1986) suggested that a loss of intracellular potassium might hyperpolarize the membrane electrochemical potential and reduce muscle contractibility. In the current study, electrolyte concentration was not measured, so loss of intracellular potassium theory cannot be confirmed. Our findings may be supported by Faulkner (1980) who postulated that high muscle temperatures may elevate hydrogen ion concentration and may inhibit phosphofructokinase activity and therefore anaerobic performance.

Dehydration may be achieved through passive methods such as fluid and food restriction, diuretics, or sauna exposure or by active methods such as exercise heat stress. In the current study, we demonstrated that active dehydration through exercise performed in a hot humid environment elicited reduced muscular power. Our findings suggest that actively dehydrated individuals have decreased muscular power and athletes may be more susceptible to injury or

reduced athletic performance when dehydrated by at least 3% body mass.

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