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PHYSIOLOGICAL RESPONSE TO EXERCISE IN THE HEAT FOLLOWING CREATINE SUPPLEMENTATION

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ABSTRACT

MARK KERN, LAURA JEAN PODEWILS, MATTHEW VUKOVICH, AND MICHAEL J. BUONO
Physiological Response To Exercise In The Heat Following Creatine Supplementation. JEPonline. 2001;4(2):18-27. The current investigation evaluated body water changes and indicators of heat tolerance with 28 days of creatine (CR) or placebo (PLC) supplementation. Twenty college-aged males were assigned to receive creatine or placebo in a randomized double blind fashion. Body weight, body water, hematocrit, and body composition were measured before and after the treatment period. Additionally, heart rate and core temperature responses to 60 minutes of exercise in the heat (37°C, 25% RH) were assessed. The CR group had greater gains in total body water (p=0.050) and body weight (p=0.034) than the PLC group. The rise in core temperature during the cycle ride was attenuated by creatine supplementation in comparison to placebo consumption. Gains in total body water over the four weeks were related to the attenuation of temperature rise during the ride following supplementation (n=19; r=0.569, p=0.011). No significant differences were detected for percent body fat, hematocrit values, or heart rate response to exercise. These results suggest that body weight gains with CR supplementation may partially reflect body water changes and may help attenuate the thermal burden associated with exercise in the heat.

Key Words: thermoregulation, ergogenic, heart rate, core temperature.

INTRODUCTION

A preponderance of research in recent years has been dedicated to the investigation of creatine supplementation for its potential role as an ergogenic aid for short-term, high intensity repeated bouts of exercise. However, many of the secondary observations of these studies remain unresolved, the most prominent of which is a marked increase in total body mass. An early investigation (1) demonstrated marked weight gains (3.2 and 3.8 kg) in two subjects administered creatine for 29 and 34 days, respectively. More recent studies have typically demonstrated gains of one kg or greater (2-10), and researchers arbitrarily suggest water retention as a possible causative factor (4), yet few researchers have addressed this issue directly (11).

The weight gain reported following creatine supplementation is associated with a decline in urinary volume suggestive of an increase in fluid retention. Hultman et al. (12) reported a mean decrement of 600 ml in urinary output among 31 male subjects following 6 days of creatine ingestion, which was markedly lower than the response to placebo ingestion. Additionally, recent work of Ziegenfuss et al. (11) indicated both body mass gains and expansion of total body water with 3 days of creatine supplementation. Using multifrequency bioimpedance analysis (MBIA), the investigators noted that the increase in body water was isolated to the intracellular volume (ICV) and not evident in the extracellular volume (ECV) compartment of the muscle. The authors suggest that creatine results in water retention related to osmotic load triggered by the enhanced cellular uptake of creatine with supplementation. Therefore, based on the possibility that creatine supplementation results in an increase in fluid retention and total body water, creatine may provide thermal regulatory benefits during exercise in the heat.

It has been well established that temperature regulation and exercise performance in the heat are critically dependent on the state of hydration of the body. The physiological indices associated with hypohydration have been extensively documented and include a decrease in sweat rate (13, 14), rises in core temperature and heart rate (13, 15, 16), and a decrease in overall performance (16).

The purpose of the current study was to evaluate body water changes in relation to gains in body weight following creatine supplementation and concurrently determine whether this may benefit thermal regulatory capacity during exercise in the heat. It was hypothesized that creatine supplementation would result in an increase in total body water and this would provide some thermal regulatory benefit during exercise.

METHODS

Subjects

Twenty healthy males who had not supplemented with creatine within the six months prior to data collection volunteered for this study. Individuals were 18 to 40 years of age, with no known cardiovascular disease as determined via a PAR-Q questionnaire. Mean \pm SD of age, height, weight, and VO_2max were 22.3 \pm 3.6 years, 176.4 \pm 5.4 cm, 75.2 \pm 8.1 kg, and 52.1 \pm 10.5 ml/kg/min, respectively. All subjects were moderately to highly active; participating in regular exercise (e.g., weight training, aerobic activities), recreational sports, or competitive sports. Subjects were fully informed of the potential risks and benefits prior to participation. All subjects signed an informed consent that was approved by the San Diego State University's Committee for the Protection of Human Subjects.

Study Design

Prior to the two days of testing that occurred both before and after supplementation with either creatine or placebo, subjects completed a three-day dietary and physical activity record and were asked to drink 690 mL of water 8 to 12 hours prior to reporting to the laboratory. On day one of testing, measurements were taken of height, weight, total body water (bioelectrical impedance), body composition (hydrostatic) and aerobic capacity (VO_2max). On day two of testing, nude body weight and urinary specific gravity were measured prior to a 60 minute exercise bout at 60% VO_2max on a cycle ergometer in a hot environment (37°C, 25% relative humidity, RH).

Following initial testing, subjects were randomly assigned in a double-blind fashion to either a placebo group or a creatine-supplemented group. All subjects were instructed to maintain their current nutritional and activity patterns and to avoid initiating a new exercise program. Following the 28 day supplementation period, subjects performed the two days of testing in the same manner as the pre-supplementation test. Testing occurred at the same time of day for both trials.

Supplementation protocol

Subjects in the creatine group consumed 4 doses of creatine/day (5.25 g per dose) for 5 days (21 g of creatine and 136 g/day). For the remaining 23 days, subjects consumed 2 doses of creatine/day (10 g of creatine and 68 g of carbohydrate/day) (Phosphagen HP, Experimental and Applied Sciences, Golden, CO). The placebo group

received, in equal dosages, the Phosphagen HP matrix minus the creatine (34 g carbohydrate/dose, artificial flavoring, food coloring).

Maximal oxygen consumption

All subjects completed a maximal, incremental exercise test on a Lode Excalibur (Netherlands) electronically-braked cycle ergometer to determine $\text{VO}_{2\text{max}}$. Following a 5 minute warm up at 50 watts, the workload was increased by 50 watts every 60 seconds until the subject reached exhaustion. A test was considered valid if at least two of the following criteria were met: volitional fatigue, heart rate at or near age-predicted max, respiratory exchange ratio greater than 1.0, or less than 3% change in oxygen uptake with increased workload. Expiratory gases were collected by Douglas bag. Heart rate was monitored with a Polar Heart Rate monitor (Polar Electro, Inc. Finland). Maximal heart rate was considered the highest value achieved. Expired gas was analyzed for oxygen and carbon dioxide using Vacumed (Ventura, CA) gas analyzers.

Total body water and hematocrit

Subjects were weighed and bioelectrical impedance (BIA) (RJL Systems Inc., Detroit, MI) was used to measure total body water. Total body water was assessed prior to supplementation and at weekly intervals throughout the study and at the end of the supplementation period. In order to minimize error, all subjects were asked to adhere to the following procedural guidelines prior to the test: 1) abstain from eating or drinking within 4 hours of the assessment; 2) avoid moderate or vigorous physical activity within 12 hours of the assessment; 3) abstain from alcohol consumption 48 hours prior to the assessment; and 4) avoid the consumption of any diuretic agents (i.e., caffeine and prescribed medications such as furosemide/Lasix) prior to the assessment. All subjects reported compliance to these guidelines. In a study of 206 men, Kotler et al. reported a correlation coefficient of 0.91 and SEE of 7.78% between BIA and the isotopic dilution technique of measuring body water (17). The equation developed by Kotler et al. was used to calculate total body water (17). Hematocrit was determined as the average of triplicate measurements at baseline and at the end of weeks 1, 2, 3, and 4 with a Hemastat II microcentrifuge (Separation Technology, Inc., Altamonte Springs, FL).

Body Composition

Body weight was assessed on a Fairbanks-Morse platform scale with a precision of ± 10 g. Fat free mass and percent body fat were assessed by hydrostatic weighing using a computerized load cell setup. Each subject performed at least 3 trials within ± 0.2 kg. These values were averaged together for the final result. Residual volume was measured via the oxygen dilution technique described by Wilmore et al. (18). Percent body fat was calculated from the Siri equation (19).

Urinary specific gravity

Upon reporting to the laboratory for the second day of testing both before and after supplementation, subjects provided a urine sample. Specific gravity was assessed using a vapor pressure osmometer (Wescor Model 5500, Logan, UT) to ensure that the subjects were adequately hydrated before participating in the exercise test in the heat. All subjects reported to the laboratory with a urinary specific gravity of less than 1.028, and thus were considered to be adequately hydrated (20).

Exercise test in the heat

Both before and after supplementation, subjects pedaled a cycle ergometer for 60 minutes at 60% $\text{VO}_{2\text{max}}$ in an environmental chamber. The cycle was electronically calibrated to maintain the specified workload throughout the ride regardless of pedaling cadence. Temperature and humidity were maintained at 37°C and 25% RH, respectively, during the test. Heart rate and rectal core temperature were recorded every 15 min during the exercise bout. Core temperature was assessed with a YSI probe inserted 10 cm past the anal sphincter. Immediately after the exercise bout, subjects were weighed again to determine total sweat rate. During the exercise, subjects did not ingest fluid, but were properly rehydrated before leaving the lab.

Statistical analysis

Data are expressed as mean \pm SD. Independent t-tests were conducted to establish group comparability at baseline on descriptive parameters (i.e., age, weight, height, lean body mass, percent body fat, and $\text{VO}_{2\text{max}}$). A 2 (group) X 5 (time points: minute 0, 15, 30, 45, and 60) single-factor repeated measures analysis of variance (ANOVA) was used to evaluate comparability on physiological responses (heart rate and rectal temperature) to exercise in the heat at baseline.

Data were also analyzed using a 2 (group) X 2 (pre-supplementation vs. post-supplementation) single factor repeated measures ANOVA to assess potential main effects of group or time and group by time interactions for variables assessed before and after the supplementation period. A summary variable depicting change during the exercise time (minute 60-minute 0) was calculated for heart rate and rectal temperature for the purposes of this comparison.

Relationships between alterations in body weight, lean body mass, body water, and core temperature responses to exercise before and after the trial period were explored via Pearson Product-Moment Correlations.

All statistical procedures were performed using the Statistical Package for the Social Sciences (SPSS), Version 7.5 (Chicago, IL). An alpha level of $p \leq 0.05$ was selected as the criterion for significance.

RESULTS

All twenty subjects who volunteered for the study completed the testing protocol. Physical characteristics, delineated by group, are presented in Table 1. There were no significant differences between group means for age ($df=17$, $t=0.15$, $p=0.887$), height ($df=17$, $t=1.06$, $p=2.60$), weight ($df=17$, $t=0.82$, $p=0.423$), fat-free mass ($df=17$, $t=1.20$, $p=0.246$), percent body fat ($df=17$, $t=-1.06$, $p=0.306$), or aerobic capacity ($df=17$, $t=-1.51$, $p=0.150$). Throughout the trial, subjects were asked to report any adverse reactions perceived to be associated with supplementation. No such occurrences were reported. However, one subject in the creatine group lost weight (2 kg) during the supplementation period, while all others gained weight. This weight loss was much greater than 2 SD from the mean weight change; thus, this subject was determined to be an outlier and his data were excluded from analyses.

Table 1. Subject characteristics and changes in body composition following 28 days of creatine (n=9) or placebo (n=10) supplementation.

<i>Variable</i>	<i>Creatine Pre-suppl.</i>	<i>Creatine Post-suppl.</i>	<i>Placebo Pre-suppl.</i>	<i>Placebo Post-suppl.</i>
<i>Age (yr)</i>	22.4±4.6		22.2±2.7	
<i>Height (cm)</i>	177.8±5.1		175.2±5.6	
<i>Weight (kg)</i>	76.8±10.6	78.9±10.6*	73.8±5.1	74.8±5.3
<i>Lean mass (kg)</i>	68.6±9.3	70.8±9.3*	64.5±5.2	65.1±6.1*
<i>Percent fat</i>	10.6±4.6	11.3±3.7	12.6±4.0	13.0±4.9
<i>VO₂max (ml/kg/min)</i>	48.4±7.9	47.6±9.7	55.4±11.7	51.8±13.6

Values are mean±SD. * $p \leq 0.05$ compared to pre-supplementation.

Body weight and composition

Analysis of body weight change revealed a significant ($df=1$, $F=5.28$, $p=0.034$) interaction between groups over the supplementation period, suggesting that body weight increased more following creatine use than placebo consumption. Individual body weight responses to treatment by either creatine or placebo are depicted in Figure 1. Lean body mass (LBM) increased significantly ($df=1$, $F=7.99$, $p=0.012$) during the 28 days of the treatment for both groups (Table 1). Percent body fat was similar between groups and did not change over the course of the study. Body weight gains and changes in lean body mass were positively correlated ($r=0.851$, $p<0.001$).

Figure 1. Individual body weight response to 28 days of supplementation with either creatine monohydrate or placebo.

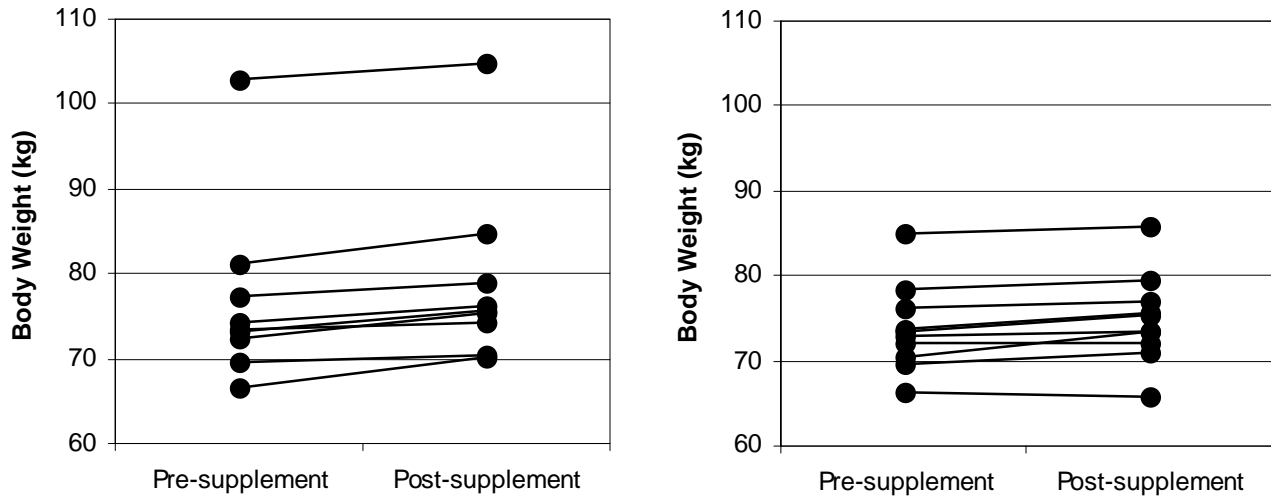
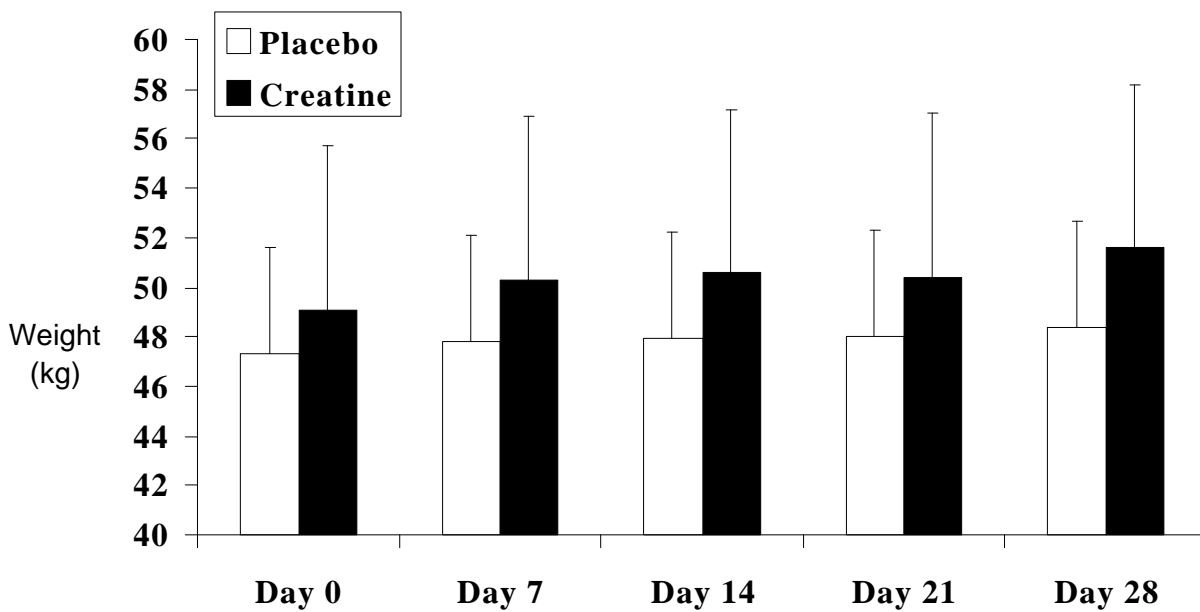


Figure 2. Total body water during 28 days of supplementation with either creatine monohydrate or placebo. A repeated measure ANOVA revealed a significant group X time interaction ($p=0.050$).



Body weight during the hour long exercise bout in the heat decreased significantly before (Placebo: -1.62 ± 0.50 %; $df=1$, $F=123.16$, $p<.001$; Creatine: -1.50 ± 0.55 %; $df=1$, $F=91.08$, $p<.001$) and after (Placebo: -1.61 ± 0.50 %; $df=1$, $F=94.92$, $p<.001$; Creatine: -1.49 ± 0.55 %; $df=1$, $F=68.17$, $p<.001$) the supplementation period. No difference was detected between groups ($df=1$, $F=0.368$, $p=0.552$).

Total body water and hematocrit

There were no significant differences ($df=17$, $t=0.715$, $p=0.484$) in total body water (TBW) prior to supplementation. However, there was a significant group by time interaction over the period of supplementation. The magnitude of change with 28 days of creatine supplementation was greater than placebo (group X time; $df=1$, $F=4.45$, $p=0.050$) (Figure 2). Additionally, overall changes in body water were related to body mass increases ($n=19$; $r=0.596$, $p=0.007$).

Hematocrit remained unchanged during the supplementation period for both the creatine (Pre: 49.7 ± 1.8 %; Post: 49.1 ± 1.8 %) and placebo (Pre: 51.7 ± 2.6 %; Post: 51.9 ± 2.6 %) groups. However, a main effect ($df=1$, $F=7.11$, $p=0.016$) was detected between the groups, which indicated that hematocrit was higher for the placebo than creatine group.

Heart rate

Pre-supplementation heart rate responses to 60 minutes of exercise in the heat were similar ($df=17$, $t=1.67$, $p=0.113$) between the two groups. Additionally, there were no significant differences in the heart rate response to exercise comparing pre-supplementation and post-supplementation trials for either group (time effect, $df=1$, $F=3.17$, $p=0.093$) or between groups (group effect, $df=1$, $F=0.16$, $p=0.161$) (Figure 3).

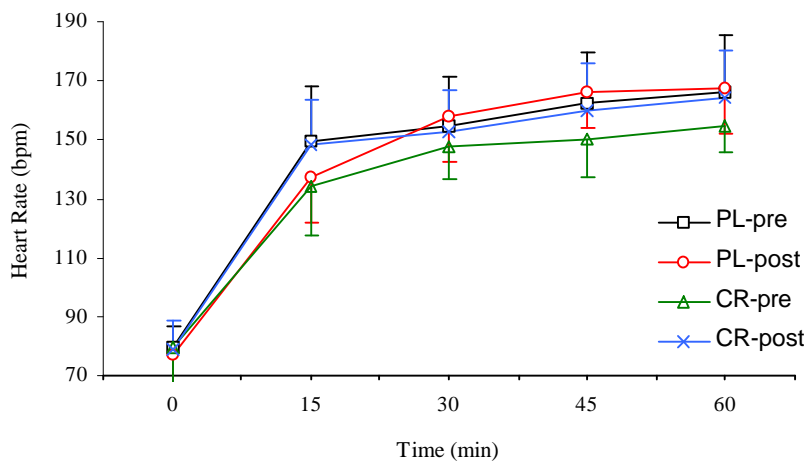


Figure 3. Heart rate response to 60 minutes of cycle ergometry before and after 28 days of supplementation with creatine monohydrate or placebo. (PL=placebo ; CR=creatine)

Core temperature

Both groups had similar ($df=1$, $F=1.13$, $p=0.303$) core temperature responses over the 60 minutes of exercise during the baseline protocol. Rectal temperature increased significantly during exercise in the heat for all subjects. However, a significant group by time interaction ($df=1$, $F=6.375$, $p=0.022$) was detected for differences (pre- vs. post-supplementation testing) in rectal temperature rise during exercise (minute 60 temperature – minute 0 temperature) (Figure 4). During post-supplementation testing, the creatine group's temperature rise averaged 0.37°C lower than pre-supplementation and 0.20°C lower than the post-supplementation temperature rise during the ride for the placebo group.

Further analysis of these findings revealed a significant positive relationship ($r=0.569$, $p=0.011$) between the attenuation in total rise in core temperature during exercise (pre-supplementation ride vs. post-supplementation ride) and the overall gain in body water during the supplementation period (week 4-week 0) for all subjects.

Evaluation of this relationship isolated to the CR group suggested a similar, yet non-significant relationship ($n=9$; $r=0.652$, $p=0.057$).

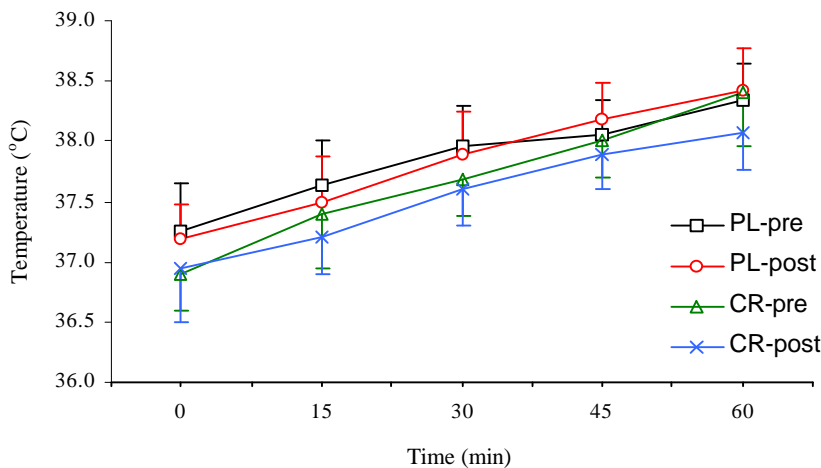


Figure 4. Rectal temperature response to 60 minutes of cycle ergometry before and after 28 days of supplementation with creatine monohydrate or placebo. (PL=placebo ; CR=creatine)

DISCUSSION

Body weight increased for all subjects in the creatine group (range= 0.79 to 3.62 kg). These findings are consistent with previous research suggesting that weight gain from creatine supplementation ranges from 0.9 to 1.7 kg (2,3,5,7,10). As anticipated, the increases in weight exceeded those observed in various common hyperhydrating regimens. For example, Greenleaf and Castle (6) required subjects to ingest 40 ml/kg of water an hour prior to exercise. This protocol elicited a 1.45 kg increase in weight. Additionally, glycerol supplemented individuals have averaged a 1.11 to 1.55 kg increase in body weight (21,22).

Results obtained via hydrostatic weighing indicate that the weight gain was due to an enhancement in lean body mass. Both Earnest et al. (5) and Kreider et al. (23) reported similar findings after evaluating body composition by hydrostatic weighing and DEXA instrumentation, respectively. Earnest et al. (5) detected increased weight (+1.7 kg, $p<0.05$) and lean body mass (+1.5 kg, $p=0.054$) in resistance training subjects receiving 20g creatine each day for 28 days. Kreider et al. (23) reported similar findings for weight gain (+2.2 kg, $p<0.001$) and lean body mass (+2.4 kg, $p<0.001$) in football players consuming either 15.75 g/d of creatine for 28 days during off-season resistance/football training.

Kreider et al. (23) evaluated total body water through bioelectrical impedance and failed to detect a “disproportionate” increase in total body water content following creatine supplementation. In the current investigation, total body water increased in both groups, with the creatine group exhibiting a greater rise. Hultman et al. (12) detected a decrement (0.6 L) in urinary volume during the first few days of creatine ingestion and explained the increase in body mass as attributable to water retention. Furthermore, data utilizing MBIA suggested an increase in the intracellular volume of the muscle and corresponding elevations in total body water and intracellular water following 3 days of supplementation (11). The increase in volume was attributed to water retention caused by the osmotic load resulting from an increase in the storage of creatine within the cell. Additionally, other researchers have suggested that creatine increases the intracellular water compartment (24). Although our results do not reveal the location of the increases, they are in concert with aforementioned studies that provide evidence that creatine increases total body water and influences overall body weight. This provides a plausible explanation for the ability of creatine supplementation to improve the thermoregulatory response to exercise in the heat.

In research detecting elevations in body fluid via glycerol hyperhydration, the usual rise in heart rate during exercise in the heat, often referred to as “cardiovascular drift”, has been attenuated by an increased stroke volume, enabling cardiac output to be maintained (21). In the present study, heart rates during the exercise in the heat under the same given workload and conditions do not appear to be influenced by creatine supplementation. Future investigations measuring overall plasma volume fluctuations and utilizing technology to assess fluid compartmentalization with creatine supplementation are warranted.

A clear attenuation in the rise of core temperature was detected during exercise following creatine supplementation compared to the placebo group. Post-supplementation testing measurements revealed a 0.20 °C advantage versus the placebo trial and a 0.37 °C advantage over their own pre-supplementation test for rectal temperature rise over 60 minutes of exercise in the heat. Likewise, Greenleaf and Castle (6) found a hyperhydration trial to have a 0.25 °C advantage over ad libitum fluid intake and a 0.87 °C advantage over hypohydrated conditions during a two hour exercise bout in thermoneutral (23.6 °C, 50% relative humidity) conditions. Similarly, glycerol-induced hyperhydration led to lower core temperatures (0.7-0.8 °C) during the final 60 minutes of a 90-minute exercise bout in the heat (21).

The concept of the specific heat of an individual provides a reasonable explanation for the attenuation of core temperature observed in these previous studies as well as the present study. Since 0.83 kilocalories of heat production/kg of body mass are required to raise core temperature 1 °C, an expansion of body water resulting in a greater body mass would lead to an increased distribution of heat within the body. Thus, the overall temperature increase would be attenuated by water expansion.

A significant correlation between total body water gain and attenuation of core temperature rise was detected overall for all subjects combined. This trend implies that the greater the capacity for increased body water, the greater attenuation of rise in core temperature. We expected to detect this relationship separately for the creatine group; however, we feel that we were inadequately powered to do so in the current study. The sample size was modeled after the study of Lyons et al. (21) with only 6 subjects; however, relationships of this sort were not explored in that investigation. We believe that increasing the number of subjects in each group may have revealed a statistically significant relationship.

CONCLUSION

The purpose of this study was two-fold: 1) to evaluate the changes in total body weight and body water in response to creatine monohydrate supplementation, and 2) if the hypothesized increases did occur, to determine whether this was sufficient to alter thermal regulation as measured by rectal temperature during a 60 minute ride at 37 °C. The results of this study indicate that creatine supplementation elevates body mass. These increases may partially reflect changes in body water stores and may be enough to improve thermal regulation during exercise in the heat, as evidenced by an attenuated rise in rectal temperature over a 60 min period of exercise post-supplementation. Further, amid anecdotal reports that creatine causes dehydration, muscle cramping, and heat exhaustion, the subjects in this study reported no overt side effects of creatine supplementation. In fact heart rate, hematocrit, body water loss, and temperature rise were clearly not adversely affected by creatine supplementation as would be expected if these testimonial reports were true. This study provides further support to the consensus statement of the American College of Sports Medicine that there exists no direct evidence that oral creatine supplementation is responsible for these disturbances (25).

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Dr. Matthew Vukovich, at the time of the research, was employed by Experimental and Applied Sciences. The data and results presented herein are completely independent of any affiliation or influence of Experimental and Applied Sciences, Dr. Vukovich, or any other representatives of Experimental and Applied Sciences.

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