Original Article

EFFECT OF THERMAL-INDUCED DEHYDRATION ON $\dot{V}O_2$ RECOVERY TIME AND HEART RATE RESPONSE

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The effect of acute, thermal-induced, dehydration on $\dot{V}O_2$ recovery time and heart rate response following short-duration submaximal arm ergometry, done in a temperature-controlled, thermoneutral environment was investigated. Ten males performed three, 1 min, submaximal bouts of arm ergometry, at an intensity equal to $1.5\,\mathrm{W\,kg^{-1}}$ of body mass, in both hypohydrated and euhydrated conditions. Dehydration was induced via intermittent dry sauna exposure and water restriction, followed by a 1 h, thermoneutral, pre-exercise, recovery period. Euhydration was characterized by the sauna exposure with water replacement equivalent to loss of body mass. The randomized, cross-over design was analyzed using analysis of variance with repeated measures on all factors. Volunteers lost a significant ($p < 0.05$) amount and percentage of body mass (1.9 ± 0.35 kg; $2.3 \pm 0.36\%$), and when hypohydrated showed a significant increase in urine specific gravity (1.015 ± 0.007). The mean time for recovering to baseline $\dot{V}O_2$ in the euhydrated condition (363.72 ± 41.17 s) was not significantly different ($p > 0.05$) from the hypohydrated condition (339.43 ± 28.51 s), and the mean heart rate at recovery baseline for the euhydrated condition (60.37 ± 3.62 beats min^{-1}) was not significantly different from the hypohydrated condition (61.72 ± 2.97 beats min^{-1}). Thus hypohydration of 2.3% of body mass had no significant effect on $\dot{V}O_2$ recovery time and heart rate response following intermittent exercise. While there are many reasons to hydrate well during exercise, the results from this investigation suggest that moderate levels of dehydration may not increase the time required to recover between repeated bouts of short-duration submaximal exercise done in temperate environments.

Keywords: arm ergometry, dehydration, euhydration, submaximal exercise

Introduction

Involuntary and/or voluntary dehydration is commonly experienced by individuals who engage in physical activity, particularly, if the activity is done in the heat or is associated with weight class oriented sports. There are several ways by which dehydration can be induced. These include thermal-induced (Hedley et al. 2002; Bigard et al. 2001; Schoffstall et al. 2001; Barr 1999; Greiwe et al. 1998; Montain et al. 1998; Torranin et al. 1979), exercise-induced (Webster et al. 1990), diuretic ingestion (Caldwell et al. 1984), water restriction (Bosco et al. 1968), or a combination of all the above.

There are clear safety reasons for following appropriate hydration practices. Likewise, there has been a substantial amount of research performed on the effects

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of hypohydration on muscular and cardiovascular performance, some of which has been confounding. Various investigators have concluded that hypohydration has a detrimental effect on muscular strength (Schoffstall et al. 2001; Webster et al. 1990; Bosco et al. 1968), muscular endurance (Bigard et al. 2001; Montain et al. 1998), and muscular power (Viitasalo et al. 1987). Other researchers, however, have demonstrated no significant effect on muscular strength (Bigard et al. 2001; Greiwe et al. 1998), muscular endurance (Serfass et al. 1984), or muscular power (Park et al. 1990). With regard to cardiovascular responses, hypohydration has been shown by some to have a detrimental effect on $\dot{V}O_{2max}$ (Caldwell et al. 1984) and others suggest that it has no effect (Dengel et al. 1992). Physical work capacity appears to suffer deleterious effects from moderate-level hypohydration (Armstrong et al. 1985). Less is known about the effect that hypohydration may have on the duration of recovery from exercise.

The time it takes to return to resting $\dot{V}O_2$ levels following exercise can last for extended periods. There are several proposed reasons as to why this occurs. These include the metabolism of lactate (Brooks et al. 2000b); restoration of ATP (Bahr 1992), creatine phosphate (Brooks et al. 2000a), and muscle O_2 stores (Bahr 1992; Stainsby & Barclay 1970); increased body heat production (Brooks et al. 2000b; Claremont et al. 1975); increased levels of circulating catecholamines (Powers & Howley 2001; Horowitz 1979); and uncoupling of oxidative phosphorylation via calcium ions (Brooks et al. 2000b). The time required to return oxygen uptake to baseline may be impacted by hypohydration and could potentially influence the amount of time required to recover between bouts of exercise. This may have direct implications in exercise programing that involves repeated bouts of work such as those in typical circuit or interval training sessions. A study of the timing associated with recovery between repeated bouts of submaximal exercise, as measured by return to baseline $\dot{V}O_2$, might provide insight into the effect that moderate hypohydration has on exercise recovery. Therefore, the purpose of this investigation was to examine the effect of acute thermal-induced dehydration on $\dot{V}O_2$ recovery time and heart rate response following repeated bouts of short-duration submaximal arm ergometry. It was hypothesized that thermal-induced dehydration will significantly increase the time to recover to baseline $\dot{V}O_2$ and increase heart rate at baseline.

Methods

Subjects

Ten, low-risk (ACSM 2000), male volunteers participated in this investigation. Subject descriptive data are found in Table 1. All subjects signed an informed consent form and completed a health-history questionnaire. Approval from human subjects was obtained from the California State University, Fresno Committee for the Protection of Human Subjects. All testing took place at the Human Performance Laboratory (HPL) on the campus of California State University, Fresno during the fall of 2004.

Familiarization session

The first day of the 3-day testing session consisted of a familiarization/practice session. During this session subjects performed a practice baseline $\dot{V}O_2$ establishment protocol, using the same mouthpiece and metabolic cart that would be used during the actual trial. Subjects also practiced exercising on the Monark 881E arm crank ergometer (Monark Exercise AB, Vansbro, Sweden) at a work rate identical to the one that would be used during the subsequent two experimental sessions. All volunteers were asked to keep a diet record and were instructed to eat the same diet the previous evening and morning of each experimental session. They were instructed to abstain from exercise, alcohol, tobacco, and caffeine for 24 h prior to the experimental sessions. Finally, the subjects were instructed to drink at least 1 L of water the day before and 1 L of water 2 h before arriving for testing.

Experimental sessions

Sessions 2 and 3 were used as experimental sessions and were separated by not less than 3 days. Subjects reported for testing where they voided their bladders and a dry, nude, initial pretrial body mass assessment was conducted. Change in the hydration status was assessed by evaluating the changes in urine specific gravity, via HydraTrend Hydration Monitoring Test Strips (UriDynamics, Indianapolis, IN, USA), and by monitoring the changes from initial pretrial body mass values. Subjects then began a randomly assigned hypohydration or euhydration protocol. Once this hypohydration or euhydration protocol was completed, subjects showered and passively recovered for 1 h in a thermoneutral environment to promote body cooling. Subjects then rested on an examination table for 5 min and baseline $\dot{V}O_2$ was assessed. The baseline value of $\dot{V}O_2$ was recorded as the average absolute $\dot{V}O_2$ for the last 30 s of the 5-min assessment period. Ten seconds after baseline $\dot{V}O_2$ was established, subjects sat up and exercised on the arm crank ergometer at a work rate equal to 1.5 W kg^{-1} of body mass for 1 min. Immediately following each exercise bout subjects immediately laid back on the examination table for assessment of time to recover to baseline $\dot{V}O_2$. Time to recover to baseline $\dot{V}O_2$ was recorded 10 s after the cessation of exercise. Once baseline $\dot{V}O_2$ was re-established, subjects rested an additional 2 min prior to repeating the exercise protocol. This exercise/recovery protocol was repeated thrice.

The second experimental session was conducted at least 3 days after the first experimental session. This session was the same as the first, with two exceptions. First, the alternative experimental condition (euhydration or hypohydration) was used. Second, prior to beginning the three exercise trials subjects rested on the examination table until they reached a baseline $\dot{V}O_2$ equivalent to that recorded during their first experimental session.

Hypohydration and euhydration procedures

Subjects were dehydrated via intermittent sauna exposure to approximately 2% of body mass by sitting passively in a sauna heated to approximately 48.9°C for six, 15-min sessions. Each session was followed by a 5-min recovery period outside the sauna. During this recovery period, the volunteers dried-off and a nude body mass assessment was performed. Following the sixth and final body mass assessment, and prior to the initial baseline $\dot{V}O_2$ assessment, subjects recovered for 1 h in a thermoneutral environment where they were allowed to shower and change. No fluids were ingested at any time during the hypohydration procedure. The euhydration procedure was identical to the hypohydration procedure with the exception that subjects were instructed to drink a volume of water during each 5-min sauna recovery equal to the body mass lost during the previous 15-min sauna session. Subjects continued to consume water during the 1-h recovery period that preceded the exercise sessions.

Statistical analysis

A 2 × 3, hydration status by trial analysis of variance (ANOVA) with repeated measures on all factors was used to analyze the effect of hydration status on the time taken to recover to a baseline $\dot{V}O_2$ during three consecutive 1-min trials. The primary dependent variable for this within-subjects ANOVA was recovery time. The within-subjects factors were hydration status with two levels (hypohydration of 2.3% and euhydration) and trials with three levels (first, second, and third trial).

Recovery heart rate at baseline was also analyzed using a 2 × 3 ANOVA with repeated measures. The design was the same as $\dot{V}O_2$ recovery time with the exception that the dependent variable was heart rate at baseline $\dot{V}O_2$. Because a significant main effect for trial existed, in the absence of interaction, multiple pairwise comparisons among the trial mean recovery time and the main effect means were conducted.

The dependent variables used to assess hydration status were change in body mass and change in urine specific gravity from pre- to post-hypohydration/euhydration values. Each variable was examined for significance with a 2 × 2 repeated measures ANOVA. Statistical significance for all procedures was set at $p < 0.05$ (Figure 1).

Table 1. Mean (±SD) subject descriptive characteristics

	Mean	±SD	Range
Age (yrs)	26.70	5.98	19.00
Height (cm)	179.07	7.78	27.94
Pre E mass	86.47	6.86	20.22
Pre D mass	86.60	7.28	22.82
Body fat (%)	18.21	6.34	19.60
Work rate (W)	86.60	6.95	21.00

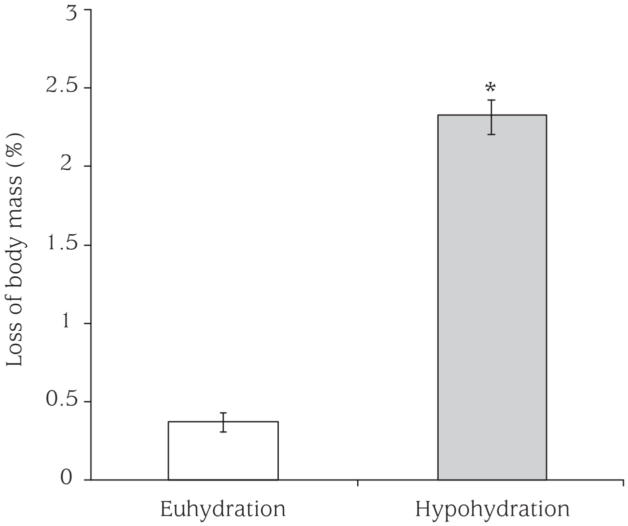

Fig. 1 Average percent mass loss following euhydration and hypohydration procedures. * Significant difference ($p < 0.05$) in loss of body mass between procedures.

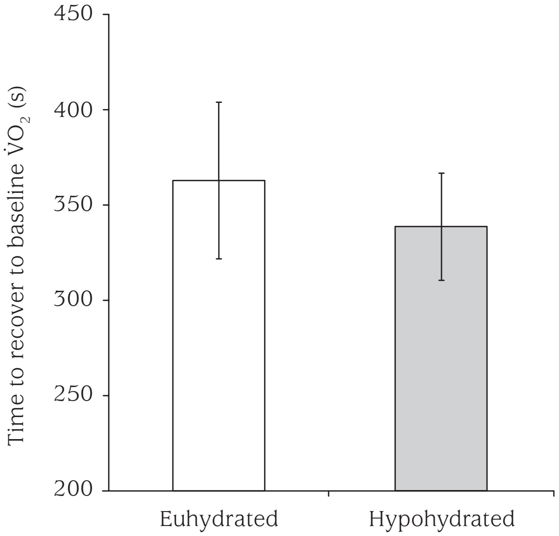

Fig. 2 Average time to recover to baseline $\dot{V}O_2$ for euhydrated and hypohydrated trials.

Table 2. Indices of hydration status for euhydration and dehydration trials

	Euhydration trial	Dehydration trial
Body mass loss (kg)	0.33 ± 0.19	1.99 ± 0.35*
Mass loss (%)	0.38 ± 0.21	2.30 ± 0.36*
Pretrial urine specific gravity	1.007 ± 0.007	1.004 ± 0.005
Post-trial urine specific gravity	1.0025 ± 0.003	$1.015 \pm 0.007^{\dagger}$

*$p < 0.05$.
$^{\dagger}p < 0.001$.

Results

Hypohydration and euhydration indices

The data suggest that subjects were equally hydrated prior to beginning both experimental trials. Similarly, the relative changes in body mass and urine specific gravity suggest that both the hypohydration and euhydration procedures were effective. Data related to indices of hydration for the hypohydration and euhydration procedures are given in Table 2.

$\dot{V}O_2$ recovery time

Mean (±SE) time to recover to baseline $\dot{V}O_2$ in the euhydrated and hypohydrated condition was 363.72 (±41.17) s and 339.43 (±28.52) s, respectively (Figure 2). There was neither a significant main effect ($p > 0.05$) for treatment nor significant ($p > 0.05$) treatment X trial interaction and no significant main effect ($p > 0.05$) for trial (independent of hydration status). The average time to recover to baseline $\dot{V}O_2$ for trials 1, 2, and 3 were 364.45 (±36.59) s, 348.60 (±32.64) s, and 339.30 (±33.73) s, respectively.

Heart rate response

Heart rate response, reported as the mean (±SE) and measured as the heart rate at the moment $\dot{V}O_2$ returned to baseline, was 60.37 (±3.62) and 61.72 (±2.97) beats min^{-1} for the euhydrated and hypohydrated trials, respectively. The results showed no significant main effect for treatment ($p > 0.05$) (Figure 3). Likewise, there was no significant ($p > 0.05$) treatment X trial interaction but there was a significant main effect ($p < 0.05$) for trial (independent of hydration status). Multiple pairwise comparisons revealed that in trial 3, heart rate was significantly higher ($p > 0.05$) than trials 1 and 2 (Figure 4).

Discussion

There are many important reasons to hydrate properly before, during, and after physical activity. These reasons range from promotion of health and safety to potentially

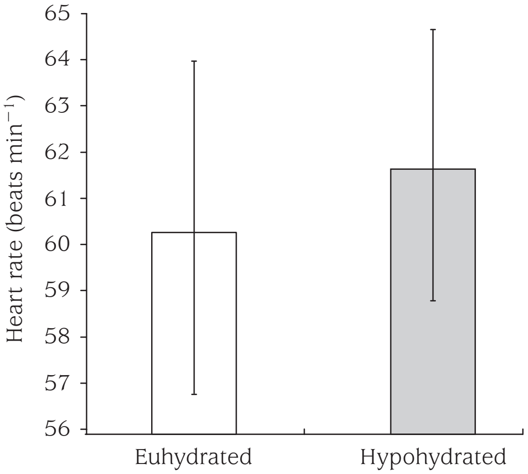

Fig. 3 Average recovery heart rate for euhydrated and hypohydrated trials.

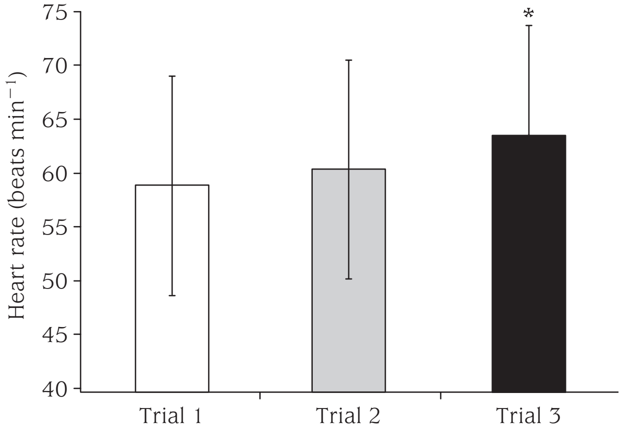

Fig. 4 Average recovery heart rate at baseline $\dot{V}O_2$ for each trial. * Significant difference ($p < 0.05$) in recovery heart rate compared to trials 1 and 2.

influencing physical performance. There has been a substantial amount of research conducted on the effects of dehydration on measures of physical performance such as muscular strength, muscular endurance, muscular power, $\dot{V}O_2$ uptake, and cardiovascular endurance. Research describing the effect of dehydration on $\dot{V}O_2$ recovery time and heart rate response following repeated bouts of submaximal exercise is very limited. The results of this investigation clearly show that $\dot{V}O_2$ recovery time was not adversely affected by acute thermal-induced dehydration of 2.3% of body mass.

While these findings are statistically insignificant, they are important as they suggest that modest levels of dehydration do not seem to adversely affect time to recovery $\dot{V}O_2$ or recovery heart rate. This is true in spite of the fact that research has shown that this modest level of hypohydration has resulted in decreases in physical work capacity (Armstrong et al. 1985) and reduction in walking endurance performance and $\dot{V}O_{2max}$ (Craig & Cummings 1966).

The results of this study are similar to other research reports that are related to the effect of dehydration on physiological and performance variables (Greiwe et al. 1998; Dengel et al. 1992; Park et al. 1990; Serfass et al. 1984). Ultimately, physical performance, and in this case recovery time, is most likely dependent not only on hypohydration, but also on environmental factors. Results of these studies examining $\dot{V}O_2$ in temperate environments imply that the nature of the testing environment may have as much of an impact on physical performance as the level of dehydration (Dengel et al. 1992; Caldwell et al. 1984). The results from this investigation illustrate that modestly hypohydrated individuals exercising in a temperature-controlled thermoneutral environment will recover as quickly as if they were euhydrated in the same environment.

Previous research suggests that dehydration has more pronounced effects as work demands increase (Armstrong et al. 1985). The data from this study suggest that as long as exercise is done in a thermoneutral environment, as was previously stated, and is submaximal, modest dehydration does not affect the recovery time. It would be interesting to examine the effect that modest dehydration might have on recovery time and heart rate response following a work demand that was greater than the 1-min exercise trials at 1.5 W kg^{-1} used in the current study.

Finally, the insignificant change in recovery heart rate between euhydration and hypohydration trials seen in the current study suggest that cardiac output may not be compromised by a modest level of hypohydration. This conclusion is consistent with Hoffman (2002), who suggested that cardiac output can be maintained at hypohydration levels of greater than 2% in the absence of a thermal stress.

In conclusion, the time required to recover from repeated bouts of submaximal exercise, done in a temperature-controlled, thermoneutral environment, was unaffected by a modest level of dehydration equivalent to 2.3% body mass. This has practical application for circuit training exercise programs and work tasks that may require intervals of exertion followed by short rest periods. While this conclusion is supported by the results of this investigation, further research is required to determine if higher levels of dehydration or exercise in the heat induces an increase in recovery time or if recovery time following higher work demands are influenced by moderate levels of hypohydration. The researchers feel that the results obtained from this investigation, and the questions that arose as a result, clearly suggest the need to better understand the ramifications of hydration status on activities that require repeated bouts of physical activity.

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