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ORIGINAL RESEARCH

Thermoregulation During Extended Exercise in the Heat: Comparisons of Fluid Volume and Temperature

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Objective.—This study aimed to determine the physiological and thermoregulatory responses of individuals exercising in the heat (US military red flag conditions, wet-bulb globe temperature 31.5–32.2ºC) while consuming varied volumes of ambient temperature water and ice slurry.

Methods.—Participants (N = 12) walked on a treadmill for 3 hours at approximately 40% peak aerobic capacity in a hot environment while consuming ambient temperature (35.5°C) water (W), ice slurry (0°C, two-thirds shaved ice and one-third water) at a ratio of 2 $g \cdot kg^{-1}$ body mass every 10 minutes (FS), and reduced volume ice slurry as described at a rate of 1 $g \cdot kg^{-1}$ body mass every 10 minutes (HS). Trials were completed at least 14 days apart, in a randomized, repeated measures design.

Results.—Percent body weight loss was higher during the HS trial (1.8 ± 0.01%) compared with FS (0.5 ± 0.01%; $P < .001$) and W (0.6 ± 0.01%; $P < .001$). Mean rectal temperature at 3 hours was lower during FS (37.8 ± 0.7°C) compared with HS (38.1 ± 0.8°C) and W (38.2 ± 0.8°C) ($P = .04$ vs HS, and $P = .005$ vs W, main effect for trial). No differences were found in rectal temperature between HS and W. Heart rate was lower at the end of the third hour during FS (141 ± 10 beats/min) compared with HS (157 ± 19 beats/min) and W (154 ± 18 beats/min) ($P = .001$ and $P = .007$, respectively, time × trial interaction). There were no differences in heart rate between HS and W.

Conclusions.—The temperature of consumed fluids may be as important as the volume for the management of thermoregulation and other physiological responses for extended work in hot environments.

Key words: hydration, hyperthermia, heat stress, rectal temperature

Introduction

Vocations such as military training, wildland fire suppression, and varied athletic/recreational pursuits require humans to work or exercise in hot environments for extended periods of time. These activities also mandate the self-transport or frequent resupply of fluid to sustain performance for the duration of the work shift or event.[1] For these individuals the weight of fluid that must be carried increases the metabolic demand and subsequent heat production, posing hindrances to completing the job or event.[2] These individuals must determine and self-manage the necessary fluid requirements to stay safe without carrying excess weight that will reduce work output or exercise performance.

Fluid consumption is vital during exercise in hot environments because it allows the body to preserve plasma volume and sweat rate. Preserving plasma volume allows individuals to maintain cardiac output and physical performance. In humans, it has been established that rectal temperature is disproportionately increased during exercise in hot environments when inadequate fluid intake results in hypohydration compared with euhydration.[3–6] The compilation of these studies has been translated into a standardized approach to fluid intake to prevent excessive dehydration (greater than 2% body mass loss) that can degrade performance and increase the risk of heat injury during extended work in all environments.[7,8] However, the present drinking guidelines provide little information about the appropriate temperature of ingested fluids.[7,8]

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Numerous studies have demonstrated that ingesting cold fluids improves performance and/or lowers physiological stress metrics to varied types of exercise in warm to hot environments.[9–14] Mündel et al[15] found that participants who drank ad libitum consumed more cold fluid and gained a subsequent performance advantage (increased time to exhaustion on a cycle ergometer) than when they were provided ambient temperature fluid ad libitum. Several studies have also found lower whole body sweat production as a result of cold water ingestion.[10,11,16–18] Based on these previous data, it seems possible to reduce fluid volume while maintaining healthy hydration and thermoregulatory status by consuming cold fluids. If ingestion of cold fluids can reduce fluid needs, individuals with access to cold fluids and/or ice who are required to carry their own water supply, like military personnel, wildland firefighters, and endurance athletes, will be able to lighten their fluid load without compromising thermoregulatory safety.

The purpose of this study was to determine the physiological and thermoregulatory responses of individuals exercising in the heat (military red flag conditions, wet-bulb globe temperature 31.5–32.2°C) while consuming varied volumes of ambient temperature water and ice slurry. We hypothesized that 1) ice slurry would reduce physiological and thermoregulatory strain compared with the same volume of water, and 2) consuming one half the volume of ice slurry (equal to one half the recommended volume for these environmental conditions) compared with ambient temperature water (recommended volume for these environmental conditions) would result in no difference in physiological and thermoregulatory strain.[19]

Methods

PARTICIPANTS

Recreationally active men (N = 12, 24 ± 4 years) were recruited from the university and local community to take part in the study. Participants passed a prescreening Physical Activity Readiness-Questionnaire and read and signed an informed consent form that was approved by the university Institutional Review Board before participating in the study. Twelve participants were recruited, all of whom completed the entire data collection process.

PRELIMINARY TESTING

Hydrodensitometry

Body composition was assessed via an underwater weighing tank (Exertech, Dresbach, MN) utilizing estimated residual volume based on height and weight. Participants were required to fast for ≥3 hours prior to testing. Dry weight was determined using a digital scale (Befour Inc, Cedarburg, WI), and height was measured. Participants were weighed while completely submerged. Body density and percent body fat were estimated using the Siri equation.[20]

Peak aerobic capacity

Participants fasted for ≥3 hours prior to arrival for $VO_{2\ peak}$ testing. A running graded exercise test to volitional exhaustion, using the Bruce protocol, was performed on a treadmill ergometer (TMX225C, Fullvision Inc, Newton, KS).[21] Participants' expired gas was analyzed every 15 seconds by a metabolic cart (Parvomedics Inc, Sandy, UT) for the duration of the treadmill test. Heart rate was monitored and recorded using a heart rate watch and chest strap (Polar Electro, Kempele, FL).

EXPERIMENTAL TRIALS

Exercise protocol

The experimental trials consisted of 3 visits to the laboratory, with each visit separated by approximately 14 days to minimize carryover acclimation between trials. Participants arrived at the laboratory after completing an 8-hour fast. Participants maintained a 24-hour dietary log before their first trial and replicated this for the subsequent trials. Additionally, participants maintained a physical activity log for 48 hours before their first trial and replicated this for the additional trials. Participants were instructed to refrain from exercise for 24 hours before each trial, except for activities of daily college life (ie, walking or bike riding for transportation).

Upon arrival at the laboratory, participants consumed 200 mL of cool water, provided a urine sample, and had nude body weight measured (CW-11, Ohaus, Pine Brook, NJ). Urine specific gravity (USG) was measured before and after each trial (PAL-10S, Atago, Cohasset, MA). A 5 mL blood sample was collected using a venipuncture technique before and immediately after exercise. These samples were collected to evaluate changes in plasma electrolytes, hemoglobin, and hematocrit using the iSTAT CHEM8+ (Abbott Point of Care Inc, Princeton, NJ). Participants were then outfitted with 2 skin temperature sensors (T200, PhysiTemp, Clifton, NJ) to monitor changes in skin temperature (T_s). Sensors were placed on the chest approximately 5 cm above the left nipple on the pectoralis muscle and on the back (subscapular region) at a similar level. Skin temperature collection sites (chest and back) were combined into a single mean value for analysis. Rectal temperature (T_r) was continuously monitored (Mon-a-therm GP, Mallinckrodt Medical Inc, St. Louis, MO) throughout the duration of the trial. T_r and T_s were collected using DASYLab v12.0 Software (Measurement Computing