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Changes in Hydration Factors Over the Course of Heat Acclimation in Endurance Athletes

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The purpose of this study was to examine the effect of heat acclimation (HA) on thirst levels, sweat rate, and percentage of body mass loss (%BML), and changes in fluid intake factors throughout HA induction. Twenty-eight male endurance athletes (mean ± *SD*; age, 35 ± 12 years; body mass, 73.0 ± 8.9 kg; maximal oxygen consumption, 57.4 ± 6.8 $\mathrm{ml \cdot kg^{-1} \cdot min^{-1}}$) completed 60 min of exercise in a euhydrated state at 58.9 ± 2.3% velocity of maximal oxygen consumption in the heat (ambient temperature, 35.0 ± 1.3 °C; relative humidity, 48.0 ± 1.3%) prior to and following HA where thirst levels, sweat rate, and %BML were measured. Then, participants performed 5 days of HA while held at hyperthermia (38.50–39.75 °C) for 60 min with fluid provided ad libitum. Sweat volume, %BML, thirst levels, and fluid intake were measured for each session. Thirst levels were significantly lower following HA (pre, 4 ± 1; post, 3 ± 1, $p < .001$). Sweat rate (pre, 1.76 ± 0.42 L/hr; post, 2.00 ± 0.60 L/hr, $p = .039$) and %BML (pre, 2.66 ± 0.53%; post, 2.98 ± 0.83%, $p = .049$) were significantly greater following HA. During HA, thirst levels decreased (Day 1, 4 ± 1; Day 2, 3 ± 2; Day 3, 3 ± 2; Day 4, 3 ± 1; Day 5, 3 ± 1; $p < .001$). However, sweat volume (Day 1, 2.34 ± 0.67 L; Day 2, 2.49 ± 0.58 L; Day 3, 2.67 ± 0.63 L; Day 4, 2.74 ± 0.61 L; Day 5, 2.74 ± 0.91 L; $p = .010$) and fluid intake (Day 1, 1.20 ± 0.45 L; Day 2, 1.52 ± 0.58 L; Day 3, 1.69 ± 0.63 L; Day 4, 1.65 ± 0.58 L; Day 5, 1.74 ± 0.51 L; $p < .001$) increased. In conclusion, thirst levels were lower following HA even though sweat rate and %BML were higher. Thirst levels decreased while sweat volume and fluid intake increased during HA induction. Thus, HA should be one of the factors to consider when planning hydration strategies.

Keywords*:* fluid intake, heat adaptation, heat exposure, rehydration, thirst

Exercise in the heat can cause physiological strain, such as increased heart rate (HR) and internal body temperature, and decreased exercise performance (Périard et al., 2015; Tyler et al., 2016). In addition, dehydration exacerbates these negative implications during exercise in the heat (Adams et al., 2018; Funnell et al., 2019). Typically, 1.5–2.0% dehydration impairs endurance performance (Adams et al., 2019; Bardis et al., 2013; Sawka et al., 2007). Thus, maintaining appropriate hydration is important to reduce physiological strain, to improve exercise performance, and also to diminish thirst (González-Alonso et al., 1995; McKinley & Johnson, 2004). While thirst plays an important role for fluid replacement as a key signal to initiate drinking, there are controversial opinions around the concept of using the sensation of thirst as an optimal rehydration strategy. Some researchers have indicated drinking to thirst is enough to optimize performance while others do not agree (Goulet, 2019; Kenefick, 2019; McKinley & Johnson, 2004). Different rehydration strategies can be used in the different situations.

There are mainly three rehydration strategies which are used in the sport settings. The first strategy, *drinking to thirst*, describes when individuals drink in response to feelings of thirst (Kenefick, 2018). The second strategy involves individuals drinking when they have a desire to drink, termed ad libitum drinking (Kenefick, 2018). The first two strategies are sometimes used interchangeably; however, “ad libitum drinking” includes other factors to induce drinking behavior in addition to thirst, such as fluid palatability, environmental and social factors, and individuals’ knowledge about hydration (Armstrong & Kavouras, 2019; Hew-Butler et al., 2006). The final strategy is *planned drinking,* which is used to describe a predetermined drinking plan. This may include the amount and timing of fluid intake and is determined before exercise based on sweat rate (Kenefick, 2018). Optimal hydration status is critical to improve exercise performance and to mitigate physiological strain; however, several factors may impact hydration strategies (Adams et al., 2018; Armstrong & Kavouras, 2019). For example, when exercise duration is prolonged and sweat rates are high, ad libitum drinking might be less effective. This is of potential importance as typically those undertaking heat acclimation (HA) tend to be preparing for prolonged events with high sweat rates.

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In addition to hydration, HA is also an impactful strategy to mitigate negative effects of exercise in the heat (Alhadad et al., 2019). HA refers to the process of multiple, repeated heat exposures to induce positive physiological, perceptual, and performance adaptations (Périard et al., 2015). Adaptations induced by HA include decreases in HR, internal body temperature, skin temperature, rating of perceived exertion for a given workload, and sweat sodium and chloride concentrations which is likely due to a by-product of a negative sodium balance, as well as increases in plasma volume and sweat rate (Armstrong et al., 1985; Armstrong & Maresh, 1991; Tyler et al., 2016). These adaptations independently and collectively improve exercise performance in a hot environment by enhancing thermoregulatory efficiency and, thus, decreasing the overall physiological strain (Nuccio et al., 2017).

Some factors related to hydration status, such as sweat rate and plasma volume, are known to increase following HA (Périard et al., 2015). In addition, it has been demonstrated that heat acclimatization induces increased arginine vasopressin (AVP) secretion, an antidiuretic hormone, which results in increased water absorption and total body water (Mudambo et al., 1997). There is limited research examining the adaptation of thirst following HA while limited data suggested HA decreases thirst sensations (Ormerod et al., 2003; Sunderland et al., 2008; Tyler et al., 2016; Yeargin et al., 2006). Further understanding of this adaptation could help determine hydration strategies that can become useful following HA. Thus, the first purpose of this study was to examine the effect of HA on thirst levels, sweat rate, and percentage body mass loss (%BML).

Few studies have examined the effects of hydration status during HA induction on the magnitude of physiological adaptations following HA. While future research in this area is warranted, dehydration during HA induction does not seem to induce additional adaptations (Sekiguchi et al., 2020). Maintaining euhydration during HA induction may enhance adaptations (Travers et al., 2020), while other paper reported dehydration might be beneficial to induce better adaptations (Garrett et al., 2014). Regardless of adaptations resulting from HA, dehydration impairs exercise performance, and increases the risk of heat illness during each HA session completed (Adams et al., 2018; Armstrong et al., 2007). Understanding these factors will allow individuals to optimize hydration strategies during HA induction by changing strategies if needed. Therefore, the second purpose of this study was to investigate changes in factors related to fluid intake throughout HA induction.

Methods

Endurance-trained athletes (runners, cyclists, and triathletes) were recruited from the local community through study flyers for inclusion using the following criteria: (a) a maximal oxygen consumption (VO_2max) > 45 ml·kg^{-1}·min^{-1}, (b) 18–55 years old, (c) no history of heat illness, and (d) no current injury limiting physical activity participation. Twenty-eight male endurance athletes (mean ± *SD*; age, 35 ± 12 years; body mass [BM], 73.0 ± 8.9 kg; body fat percentage, 11.0 ± 5.3%; height, 178.6 ± 6.2 cm; VO_2max, 57.4 ± 6.8 ml·kg^{-1}·min^{-1}) participated in this interventional study. Following an explanation of study procedures, participants provided written and informed consent to participate in this study. This was approved by the institutional review board at the University of Connecticut.

Participants performed a VO_2max test with a graded running exercise on a standardized treadmill (T150; COSMED, Traunstein, Germany) to measure VO_2max and the velocity of VO_2max at the beginning of the study. Before the test, participants completed 5 min of a self-selected pace warm-up on the treadmill. Following each 2-min stage, the speed was increased by either 0.5 or 1.0 mile/hr. Participants continued exercise until reaching their maximal effort.

Prior to (pre-HA) and following HA sessions (post-HA), participants completed 60 min exercise trials at 59 ± 2% velocity of VO_2max at 2% grade on the treadmill in the heat (mean ± *SD*; ambient temperature, 35.0 ± 1.3 °C; relative humidity, 48.0 ± 1.3%; wet bulb globe temperature, 29.5 ± 1.5 °C; wind speed, 4.0 ± 0.3 mile/hr). Pre- and posttrials were performed around the same time of day within each participant. Participants were instructed to consume similar diets at pre- and posttrials for 3 days prior to the trials and consume additional fluid, such as 500 ml of water, before coming to the lab to be euhydrated. Prior to each trial, urine specific gravity (USG) and urine color were analyzed to ensure each participant began trials in a euhydrated state (mean ± *SD*; USG, 1.011 ± 0.014; color, 2 ± 1; Armstrong, 2007). If the participant's USG was ≥1.020 and ≤1.025, the participant was asked to consume 500 ml of water about 30–45 min before beginning the trial (Huang et al., 2020). If the participant's USG was >1.025, the test was rescheduled for a different day to ensure euhydration prior to the trials. Seven participants at pre-HA and four participants at post-HA consumed additional 500 ml, while two participants consumed both at pre- and posttrials. Fluid consumption was not permitted during the trial. Rectal temperature (T_{rec}; MP160; BIOPAC Systems Inc., Goleta, CA), HR (H10®; Polar Electro™, Kempele, Finland), and thirst level (Engell et al., 1987) were measured every 5 min throughout the trial. Thirst level was measured by a 1–9 Likert scales, 1 (*not thirsty at all*) to 9 (*very very thirsty*). %BML and sweat rate were also measured by taking a nude body mass measurement prior to and following the exercise trial.

Following the pre-HA trial, participants performed 5 days of HA in the lab over an 8-day period (6 ± 1 days; Chalmers et al., 2014). During HA, participants performed exercise in the heat (mean ± SD; ambient temperature, 38.7 ± 1.0 °C; relative humidity, 51.3 ± 2.4%; WBGT, 33.8 ± 1.2 °C) to induce hyperthermia for 60 min. This method is referred to as hyperthermic zone HA and involves internal body temperature being maintained between 38.50 °C and 39.75 °C. Participants began HA sessions with a higher intensity exercise (~70% velocity of VO_2max) to increase T_{rec} quickly to 38.5 °C and continued to exercise remaining 60 min with adjusted intensity to maintain desired T_{rec} zone. Fan was not utilized during HA sessions. Participants were allowed to drink ad libitum (temperature of water approximately 17 °C), throughout the sessions and were given no feedback regarding their drinking behavior from researchers. Researchers ensured that participants had fluid readily available to them as to not influence their behaviors. For each HA session, T_{rec} and HR were recorded every 5 min, and thirst level was recorded every 15 min. Fluid intake was measured for each session. %BML and BML were determined by taking a nude body mass measurement prior to and following each session. Sweat volume was also calculated by the addition of fluid intake to BML. After the five sessions of HA, the post-HA trial was performed to investigate adaptations following HA. The days between the last HA session and post-HA trial were 3 ± 1 days.

Data are reported as mean ± *SD*, mean differences ± *SE* with 95% confidence intervals (CIs), and effect size (ES). ES calculated using Cohen's *d* with the resulting effects identified as either small (0.2–0.49), medium (0.5–0.79), or large (>0.8) (McGough & Faraone, 2009). Daily fluctuations of BM during the 5 days of HA were calculated based on the BM measured prior to the pre-HA trial. Dependent *t* tests were performed to determine changes in variables from pre-HA and post-HA trials for each variable in average. Two-way repeated-measure analysis of variance with Tukey post hoc test was performed to examine differences in thirst level throughout 60 min of exercise between pre-HA and post-HA. Repeated-measures analysis of variance were performed to determine differences in variables across the 5 days of HA with least significant differences post hoc comparisons. Data of normality were not reported based on the justification provided in the previous study (Hopkins et al., 2009). All statistical analyses were completed using SPSS Statistics (version 25.0; IBM Corp., Armonk, NY) with significance set at $p \le .05$.

To establish an estimate of power and to project proper sample size, body temperature differences from previous research examining differences between a group who received heat exposures and a group who did not receive heat exposures was examined. Internal temperature was 0.47 °C with a 95% CI [−0.24, 1.19] and an effect size of 0.68 lower in the heat exposure group compared with the control group (Pryor et al., 2018). For a two-sided test with .05 alpha level and desired power level of 0.8, the estimated sample size would be 24 participants total.

Results

Average duration of each HA session was mean ± *SD*, 82 ± 5 min (Day 1, 81 ± 7 min; Day 2, 81 ± 6 min; Day 3, 83 ± 7 min; Day 4, 83 ± 8 min; Day 5, 83 ± 8 min). Average T_{rec} during the entire session was 38.85 ± 0.25 °C (Day 1, 38.87 ± 0.41 °C; Day 2, 38.94 ± 0.30 °C; Day 3, 38.85 ± 0.38 °C; Day 4, 38.82 ± 0.29 °C; Day 5, 38.80 ± 0.31 °C) and during hyperthermia period was 39.18 ± 0.17 °C (Day 1, 39.16 ± 0.42 °C; Day 2, 39.25 ± 0.22 °C; Day 3, 39.17 ± 0.35 °C; Day 4, 39.18 ± 0.28 °C; Day 5, 39.13 ± 0.22 °C). Also, average HR during the entire session was 133 ± 12 bpm (Day 1, 137 ± 13 bpm; Day 2, 134 ± 14 bpm; Day 3, 132 ± 11 bpm; Day 4, 132 ± 13 bpm; Day 5, 132 ± 14 °C) and during hyperthermia period was 133 ± 12 bpm (Day 1, 138 ± 14 bpm; Day 2, 134 ± 15 bpm; Day 3, 132 ± 14 bpm; Day 4, 133 ± 14 bpm; Day 5, 130 ± 14 °C). Maximum and average T_{rec} (maximum T_{rec}; pre, 39.05 ± 0.54 °C, post, 38.78 ± 0.49 °C, $p = .005$; average T_{rec}, pre, 38.31 ± 0.44 °C, post, 38.08 ± 0.41 °C, $p = .004$) and HR (maximum HR; pre, 157 ± 17 bpm; post, 151 ± 15 bpm, $p = .002$; average HR; pre, 140 ± 14 bpm, post, 135 ± 11 bpm, $p = .002$) during trials were significantly lower in post-HA compared with pre-HA. These data indicated HA was successfully achieved by 5 days of hyperthermic zone HA.

Figure 1 indicates changes in thirst levels, sweat rate, and % BML between pre-HA and post-HA trials. Average thirst levels during 60 min exercise trials were significantly lower at post-HA compared with pre-HA (mean ± *SD*; pre-HA, 4 ± 1; post-HA, 3 ± 1; 95% CI [−1.25, −0.42], ES = 0.61, $p < .001$). Also, Figure 2 indicated the changes in thirst throughout 60 min. Thirst level was higher at pre-HA compared with post-HA at 30 min ($p = .008$), 50 min ($p = .008$), 55 min ($p = .005$), and 60 min ($p < .001$). Sweat rate was significantly greater at post-HA compared with pre-HA (mean ± *SD*; pre-HA, 1.76 ± 0.42 L/hr; post-HA, 2.00 ± 0.60 L/hr; 95% CI [0.01, 0.46], ES = 0.46, $p = .039$). In addition, %BML was higher post-HA compared with pre-HA (mean ± *SD*; pre-HA, 2.66% ± 0.53%; post-HA, 2.98% ± 0.83%; 95% CI [0.00, 0.65], ES = 0.46, $p = .049$).

Changes in thirst levels, sweat volume, and fluid intake during HA induction are displayed in Table 1. Over the course of 5 days of HA, thirst levels decreased (mean ± *SD*; Day 1, 4 ± 1; Day 2, 3 ± 2; Day 3, 3 ± 2; Day 4, 3 ± 1; Day 5, 3 ± 1; $p < .001$). However, there were no interaction effects between every 15 min time points data and days of HA induction ($p = .051$). Sweat volume (mean ± *SD*; Day 1, 2.34 ± 0.67 L; Day 2, 2.49 ± 0.58 L; Day 3, 2.67 ± 0.63 L; Day 4, 2.74 ± 0.61 L; Day 5, 2.78 ± 0.83 L; $p = .004$) and fluid intake (mean ± *SD*; Day 1, 1.20 ± 0.45 L; Day 2, 1.52 ± 0.58 L; Day 3, 1.69 ± 0.63 L; Day 4, 1.65 ± 0.58 L; Day 5, 1.74 ± 0.51 L; $p < .001$) increased. There were no changes in %BML (mean ± *SD*; Day 1, 1.63 ± 0.97%; Day 2, 1.46 ± 0.94%; Day 3, 1.40 ± 1.18%; Day 4, 1.56 ± 0.84%; Day 5, 1.47 ± 1.01%; $p = .697$) or BML (mean ± *SD*; Day 1, 1.18 ± 0.66 kg; Day 2, 1.04 ± 0.62 kg; Day 3, 1.00 ± 0.83 kg; Day 4, 1.11 ± 0.57 kg; Day 5, 1.06 ± 0.72 kg; $p = .710$) throughout the 5 days of HA. Daily BM fluctuations on average compared with euhydrated BM were within 1% before each HA session (mean ± *SD*; Day 1, −0.47 ± 1.01%; Day 2, −0.49 ± 1.08%; Day 3, −0.50 ± 1.15%; Day 4, −0.24 ± 1.46%; Day 5, −0.65 ± 1.05%; $p = .449$).

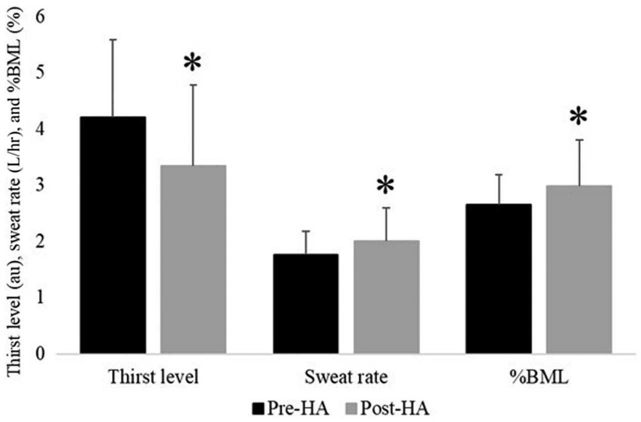

Figure 1 — Changes in average thirst level, sweat rate, and %BML prior to (pre-HA) and following HA tests (post-HA). %BML = percentage of body mass loss; HA = heat acclimation; au = arbitrary units. *Statistical significance from before HA, $p \le .05$.

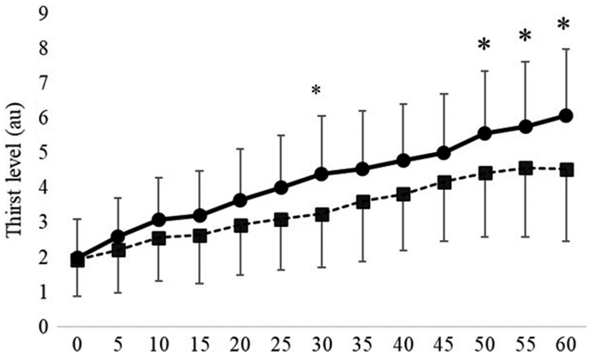

Figure 2 — Changes in thirst level throughout 60 min of exercise prior to (pre-HA) and following HA tests (post-HA). HA = heat acclimation; au = arbitrary units. *Statistical significance from before HA, $p \le .05$.

Discussion

The purposes of this study were to examine (a) the effect of HA on thirst levels, sweat rate, and %BML and (b) the changes in factors

Table 1 Changes in Thirst Level, Sweat Volume, %BML, and Fluid Intake Over the Course of 5 Days HA

Days			MD ± *SE*	ES	[95% CI]	*p* value
Thirst level (au)						
Day 1	vs.	Day 2	1 ± 0	0.41	[0.27, 0.83]	<.001*
		Day 3	1 ± 0	0.34	[0.13, 0.81]	.009*
		Day 4	1 ± 0	0.44	[0.33, 0.84]	<.001*
		Day 5	1 ± 0	0.59	[0.40, 1.05]	<.001*
Sweat volume (L)						
Day 1	vs.	Day 2	−0.15 ± 0.09	0.24	[−0.34, 0.04]	.125
		Day 3	−0.33 ± 0.11	0.51	[−0.57, −0.10]	.006*
		Day 4	−0.40 ± 0.11	0.62	[−0.63, −0.18]	.010*
		Day 5	−0.40 ± 0.17	0.50	[−0.75, −0.06]	.024*
%BML						
Day 1	vs.	Day 2	0.16 ± 0.16	0.18	[−0.17, 0.49]	.321
		Day 3	0.23 ± 0.22	0.21	[−0.21, 0.67]	.297
		Day 4	0.07 ± 0.17	0.08	[−0.27, 0.40]	.698
		Day 5	0.16 ± 0.25	0.16	[−0.35, 0.66]	.529
Fluid intake (L)						
Day 1	vs.	Day 2	−0.32 ± 0.10	0.62	[−0.52, −0.11]	.004*
		Day 3	−0.49 ± 0.11	0.90	[−0.71, −0.27]	<.001*
		Day 4	−0.45 ± 0.11	0.87	[−0.66, −0.23]	<.001*
		Day 5	−0.54 ± 0.10	1.12	[−0.75, −0.32]	<.001*

Note. Values are reported as MD ± *SE*, 95% CI, and ES. MD = mean differences; ES = effect size; %BML = percentage of body mass loss; au = arbitrary units; CI = confidence interval.

*Statistical significance, $p \leq .05$.

related to fluid intake throughout HA induction. This study found thirst levels were lower post-HA compared with pre-HA, even though sweat rate and %BML were higher. In addition, thirst levels decreased while sweat volume and fluid intake increased over the course of 5 days of HA.

This study indicated thirst levels were lower following HA induction. Thirst is induced by high plasma osmolality (Ramsay, 1989). Thirst and AVP secretion are sensitive to increases in plasma osmolality, which is caused by the stimulation of osmoreceptors (McKinley & Johnson, 2004; Ramsay, 1989). Thus, dehydration stimulates thirst and AVP secretion to increase fluid intake and fluid retention (McKinley & Johnson, 2004; Ramsay, 1989). However, HA induced lower thirst levels even though % BML was greater due to higher sweat rate as an adaptation of HA. This finding was similar to one study demonstrating decreased thirst levels during heat acclimatization in untrained female individuals (Ormerod et al., 2003). Another previous study indicated AVP secretion at rest was higher following heat acclimatization (Mudambo et al., 1997). While our study did not measure plasma AVP, it is another variable that can be examined in prospective HA studies. Other factors that may contribute to thirst sensation, such as aging and pregnancy, have been associated with changes in the thirst "set-point" (Ramsay, 1989). Future studies will be required to explore the effect of HA on the thirst "set-point" mechanism.

Our study demonstrated lower thirst levels with significantly higher %BML following HA. Especially, lower thirst levels were observed during later phase of exercise. Also, thirst levels gradually decreased, and fluid intake increased as HA sessions progressed from Day 1 to Day 5. Using these findings, it is important to determine appropriate fluid replacement strategies during exercise after HA induction. While *drinking to thirst* may be enough to maintain optimal hydration for some athletes, relying solely on thirst signaling may not be the best plan for endurance athletes competing in the heat. *Planned drinking* provides a hydration strategy regardless of changes in thirst sensation and can mitigate potential performance decrements and minimize the risk of dehydration and hyponatremia. HA status should be considered as an important factor when determining hydration strategies along with other critical factors, such as environmental conditions, exercise intensity, and fluid palatability (Goulet, 2019; Kenefick, 2018; Sandick et al., 1984).

During HA induction, thirst levels decreased while sweat volume and fluid intake increased over the course of 5 days of HA. Increased fluid intake may contribute to diminishing the average perception of thirst in this study. There were no interactions between every 15 min thirst level data and days of HA induction due to ad libitum drink, which indicated the timing of drinking was random and thirst level could be dissipated when drinking. This finding is different from the previous studies indicating fluid intake decreased during HA in untrained individuals (Ormerod et al., 2003). Participants of the current study were endurance-trained athletes and therefore might have been aware of the importance of hydration from daily training experiences as well as learning behaviors. This awareness might have modified their fluid intake after Day 1 of HA, which might influence on thirst levels. A previous study indicated that heat acclimated endurance athletes successfully maintained <1% of BML with ad libitum drinking during running in the heat (Wilk et al., 2010). This supports the idea that endurance-trained athletes might be able to modify fluid intake based on their perception of fluid loss (Wilk et al., 2010).

It is known that drinking induces oropharyngeal stimulation, which deceases thirst without changes in actual hydration status measured by plasma osmolality (Figaro & Mack, 1997). In our study, there were no significant changes in %BML and BML due to an increase in sweat volume during HA induction. This is an expected adaptation due to HA. Even though we observed increased fluid intake during HA, fluid intake as a behavior may contribute to decreased thirst sensation in athletes who undergo HA (Périard et al., 2015). In addition, average daily fluctuations of BM in participants before each HA session was <1% compared with euhydration BM measured prior to the pre-HA test while some people indicated greater that 1% of changes (Day1; 7, Day 2; 7, Day 3; 10, Day 4; 11, Day 5; 3). This indicated most participants successfully replaced fluid loss from the previous HA session (Cheuvront et al., 2004).

Areas for future research include analyzing AVP secretion in plasma during and after HA induction. Our study did not measure plasma AVP levels; however, it would be interesting to see if there are any changes due to HA (Mudambo et al., 1997). AVP analysis might provide the evidence indicating why thirst was lower following HA, and this could be because of the change in the "set-point" of thirst. Also, plasma osmolality and plasma volume are variables that might be considered to include for the study since they are related to thirst sensation. A limitation to our protocol included lack of urine analyses performed during the 5-day HA. However, daily BM fluctuations in most participants were within 1% compared with their euhydration BM. In addition, even though thirst levels were lower following HA, the average perceptions indicated "a little thirsty" following HA while "moderate-little thirsty" prior to HA with medium effects; thus, the results need to be interpreted carefully in terms of practical differences. In addition, there was no control group for HA induction, and the effects of exercise on thirst levels are unknown.

Conclusion

Thirst levels were lower at post-HA compared with pre-HA even though sweat rate and %BML were higher. Thus, HA should be one of the factors to consider when planning hydration strategies. In addition, thirst levels decreased and sweat volume and fluid intake increased over the course of 5 days HA. Endurance-trained athletes might be able to adjust their hydration strategies during HA. Coaches, athletes, sport scientists, and medical professionals can use the information from this study to create optimal hydration strategies for their athletes when exercising in the heat. While *drinking to thirst* might be suitable in some situations, *planned drinking* might be ideal following HA since thirst levels diminish while %BML is higher.

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