Drinking Behavior and Perception of Thirst in Untrained Women During 6 Weeks of Heat Acclimation and Outdoor Training

Jennifer K. Ormerod, Tabatha A. Elliott, Timothy P. Scheett, Jaci L. VanHeest, Lawrence E. Armstrong, and Carl M. Maresh

The purposes of this study were to characterize measures of fluid intake and perception of thirst in women over a 6-week period of exercise-heat acclimation and outdoor training and examine if this lengthy acclimation period would result in changes in fluid intake that differ from those previously reported in men utilizing a shorter acclimation protocol of 8–10 days. Voluntary water intake (11–17 °C) and perception of thirst were measured in a group of 5 women (21–26 yr) undergoing exercise-heat acclimation for 90 min/day, 3 days/wk (36 °C, rh 50–70%) and outdoor training 3 days/wk for 6 weeks. Decreased drinking during acclimation was characterized by a decrease in the number of drinks (35 ± 10 to 17 ± 5; \( p < .05 \)), greater time to first drink (9.9 ± 2.0 to 23.1 ± 4.7 min; \( p < .05 \)), and a decrease in total volume ingested per week (3310 ± 810 to 1849 ± 446 ml; \( p < .05 \)) through the 6-week study. Mean perceived thirst measurements remained low and showed only slight variance (3 ± 0.4 to 5 ± 0.4). These observations support a psycho-physiological response pattern different than that previously observed during 8–10 day acclimation protocols in men.

Key Words: voluntary dehydration, drinking behavior, perceived thirst

Under normal resting conditions, thirst is an adequate stimulus for total fluid replacement because water balance in healthy, hydrated people is maintained from day to day. However, when exposed to exercise in the heat, humans do not voluntarily replace all water losses experienced due to sweating. This lag in fluid intake has been referred to as voluntary dehydration (23)—the normal dipsogenic drive is not...
able to fully replace fluid that is lost during an acute exercise bout, even though it is not the result of conscious behavior (12, 15).

Much of the contemporary research on drinking behavior focuses on the explanation of the neurophysiology of drinking in nonhuman species. There are two general systems, identified mainly from animal studies, that regulate drinking during and following exercise: a sodium ion-osmotic-vasopressin pathway (1) and a renin-angiotensin II-aldosterone pathway (9). The contemporary theory of drinking holds that thirst sensations are secondary to changes in plasma osmolality, plasma volume, and angiotensin II (8, 10, 22). However, thirst sensations may contribute to the initiation, maintenance, and termination of drinking in humans (7, 19, 24), and this suggests that thirst sensations should not be considered secondary to neurophysiological stimuli.

In addition, there are behavioral, environmental, and social factors that may significantly influence thirst and drinking behavior during exercise (16). Some of these include fluid palatability (quality, flavor, temperature, taste, odor, and color; 3, 24, 29), food intake (28), mood state of the individual (4), time allowed for fluid consumption (15), and gastric distention (15, 17, 20). Drinking behavior and fluid replacement are multifaceted processes that are difficult to ascribe solely to any single factor. Physiological, psychological, environmental, and host factors all contribute to the degree to which fluid consumption is sufficient in response to exercise-induced dehydration.

Previous research by Greenleaf et al. (14) and Hubbard et al. (16) found that the increase in drinking behavior during heat acclimation was characterized by a progressively shortened time to first drink, a greater number of drinks per experimental day, and a larger volume per drink over 8–10 consecutive days of acclimation in men. No research to date has examined fluid consumption with an exercise-heat acclimation period longer than 10 days. Moreover, of the few studies that have examined the effects of heat acclimation on fluid replacement in humans, none have examined this in women. The purposes of this study were to (a) characterize the measures of fluid intake and perception of thirst in women over a 6-week period of exercise-heat acclimation (90 min/day, 3 days/wk), and (b) examine if this 6-week exercise-heat acclimation period would result in changes in fluid intake in women that differ from those previously reported during heat acclimation protocols of 8–10 days in men (14, 16). We hypothesized that (a) the longer acclimation period would result in notable differences in fluid replacement compared to previous studies that involved shorter acclimation periods, and (b) total fluid consumption would initially increase (weeks 1–2), followed by a decrease as the exercise-heat acclimation process progresses, resulting from a decrease in the number of drinks, volume per drink, greater time to first drink, and longer time between drinks.

It is important to acknowledge that this study was designed in conjunction with a larger study that examined thermoregulation, reproductive function, stress hormone, and immune responses to 6 weeks of exercise-heat acclimation and outdoor training in women using different birth control preparations. As such, the present study was designed with specific methodological constraints, which limited the scope of the study. Due to this, the present study was focused strictly on characterizing the drinking behavior of women during a lengthened heat acclimation protocol and did not examine possible physiological mechanisms.
Methods

Subjects

Five untrained, unacclimated women volunteered to take part in this study. Subjects were required to meet the following criteria: (a) in good health, based on a medical and gynecological examination within the previous 12 months, including a normal papanicolaou smear; (b) free of any chronic disease including thyroid disease; (c) lack of any recent (3 months) changes in menstrual status; (d) no history of eating disorder or depressive illness within the past 3 years and an appropriate score on the Eating Disorders Inventory; (e) the absence of any contraindications revealed in a medical history that might preclude participation, including a history of heat-related illness, CVD, chronic respiratory disorder, hypertension, metabolic disorder, drug or alcohol dependence; and (f) not routinely taking a prescription or over-the-counter medication that would alter variables measured. The subjects gave their informed consent to the experimental procedures after having the possible benefits and risks of the study fully explained to them. Prior to heat acclimation, subjects underwent a menstrual screening, body composition analysis, and maximal oxygen uptake protocol. Seven day nutritional dietary records were also completed to insure that dietary intakes were appropriate to support the nutritional demands and caloric expenditure of training. All subjects were eumenorrheic ovulatory and using no hormonal contraception during the time of the study. All forms and experimental protocols were approved by the Institutional Review Board at The University of Connecticut. Physical characteristics of the subjects are given in Table 1.

Exercise-Heat Tolerance Testing

Exercise-heat tolerance tests (EHT) were performed at the beginning and end of the 6-week training program to ensure that subjects had heat acclimated following the 6-week protocol. To enhance the stress associated with the EHT, subjects underwent a 24-hour water restriction prior to testing, providing an approximate −3% level of dehydration. EHT involved walking on a motorized treadmill at 93.6 m · min⁻¹ and 5% grade. Walking speed was verified for each test with a hand-held tachometer (Cole Parmer Instrument Co., Model 8240-20, Chicago, IL). The mean

Table 1  Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>23.0</td>
<td>1.0</td>
<td>21.0</td>
<td>26.0</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.0</td>
<td>2.0</td>
<td>154.9</td>
<td>167.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>65.5</td>
<td>5.3</td>
<td>54.1</td>
<td>86.0</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>29.2</td>
<td>2.3</td>
<td>23.1</td>
<td>37.3</td>
</tr>
<tr>
<td>VO₂max (ml · kg · min⁻¹)</td>
<td>36.8</td>
<td>1.6</td>
<td>32.4</td>
<td>41.1</td>
</tr>
</tbody>
</table>
temperature and percent humidity were 38 °C and 50–70%, respectively. No water was consumed during the EHT. The following perceptual and physiological measures were taken at regular intervals before, during, and after EHT testing: oxygen uptake, minute ventilation, and respiratory exchange ratio using an online system (Medical Graphics Corp., CPX/D System, St. Paul, MN); rectal temperature (rectal thermistor, YSI Inc., model YSI 401, Yellow Springs, OH), heart rate via cardiotachometer (Polar Electro, model Vantage XL, Finland), and exercise time were primary variables representing exercise-heat tolerance.

**Training Protocol**

Each subject underwent an exercise training plus exercise-heat acclimation program of 6 weeks. Training sessions were held 6 days per week. Outdoor training sessions on Tuesday, Thursday, and Saturday involved moderate running and calisthenics (pushups and sit-ups), with a progressive increase in volume and speed of running across weeks. The number of pushups and sit-ups were also progressively increased for 6 weeks. Training sessions on Monday, Wednesday, and Friday involved exercise-heat exposures of 90 min in an environmental chamber (36 °C, rh 50–70%). Subjects were encouraged to exercise continuously as long as possible during these sessions, but were required to remain in the chamber for the complete 90-min period. Exercise training employed a circuit of bench stepping, cycle ergometry, and treadmill walking. Subjects were permitted to drink ad libitum during all sessions. Water bottles (32 oz.) were provided to each subject to accurately measure water consumption.

On outdoor training days, upon reporting to the laboratory subjects completed a series of stretching and warm-up exercises. Following this warm-up period, subjects were evaluated on how many sit-ups and pushups they could complete within a 30-s time period. Subjects then completed a timed 2.8-km outdoor run. Values were recorded daily after each series of calisthenics and running exercises. Outdoor testing began in late January and followed through 6 weeks.

On indoor training days, each subject provided a urine sample upon arrival for the determination of urine specific gravity ($U_{sg}$) by refractometry (Spartan, model A300Cl, Japan) and urine color by urine color chart (5) to assess hydration status (2). The subjects then entered the environmental chamber (36 °C, rh 50–70%, Minus Eleven Inc., Model 2000, Malden, MA) to begin the 90-min heat acclimation session. Subjects exercised (bench stepping, cycle ergometry, treadmill walking) continuously as long as possible throughout the 90 min. Subjects drank water ad libitum throughout the exercise-heat exposure. Special care was taken not to emphasize drinking, ensuring the subjects drank willfully without any encouragement from the researcher. Although subjects were aware that their drinking behavior was being monitored, they were not informed as to the purpose of these measures so not to bias their behavior.

**Drinking Measurements**

Each subject’s water bottles were filled with cold water and the temperature of the water was recorded prior to entering the environmental chamber. Water temperature was monitored throughout the 90-min acclimation period, with the goal of maintaining an optimal temperature of 11–17 °C (10). Water bottles were weighed with an electronic balance (Ohaus Corp., model GT 8000, Florham Park, NJ) upon
entering the chamber and were then placed within reach of each of the subjects. The
time of each subject’s first drink was recorded. Each subject’s water bottle was
weighed prior to and following refilling to monitor consumption and then replaced
back in front of the subject. This process was repeated for the entire 90 min of
exercise-heat exposure. Water bottles were refilled with cold water (11–17 °C) at
min 30 and 60 to ensure optimal drinking temperatures, or if empty or if water
temperature was not optimal.

**Perceptual Measurements**

During each 90-min indoor training session, perceptual responses for thirst were
obtained. Subjects were carefully instructed in the use of a thirst sensation scale
prior to the start of each experimental session. Thirst sensations were reported using
a 9-point thirst scale (21) with verbal anchors ranging from 1 (*not thirsty*) to 9 (*very,
very thirsty*) at min 0, 15, 30, 45, 60, 75, and 90. Subjects responded to the question:
How thirsty do you feel now?

**Physiological Measurements**

Rectal temperature ($T_{re}$), blood pressure (BP), and heart rate (HR) were recorded
every 15 min during exercise in the heat (i.e., min 15, 30, 45, 60, 75, and 90). $T_{re}$ was
monitored using a thermistor inserted 10 cm beyond the external anal sphincter and
connected to a thermometer (Cole-Parmer Inst. Co., model 8402-00, Chicago, IL).
BP was measured using a mercury sphygmomanometer and stethoscope. HR was
monitored via a transmitting cardiotachometer fitted to the chest (Polar Electro,
model Vantage XL, Finland).

**Statistical Analysis**

Univariate repeated measures analysis (ANOVA) was used to evaluate within sub-
ject differences between weeks 1–6. Where significant differences ($p < .05$) were
identified, group $t$ tests were used for post hoc comparisons. A Pearson product-
moment correlation was also used to examine correlations between variables through-
out weeks 1–6. Alpha was set at $p < .05$ for all statistical tests. Values are reported as
mean ± SE.

**Results**

**EHT Acclimation Adaptive Response**

Mean (±SE) terminal exercise heart rate (HR) and rectal temperature ($T_{re}$) during
pre-acclimation EHT were 184 ± 2 beats/min and 38.8 ± 0.2 °C, respectively.
During post-acclimation EHT, these values decreased to 154 ± 3 beats/min ($p < .05$)
and 38.5 ± 0.2 °C ($p < .05$), respectively. These data indicate that subjects heat
acclimated following the 6-week protocol.

**Hydration Status**

Mean urine specific gravity remained relatively stable (1.015 ± 0.004 to 1.017 ±
0.003) from week 1 to week 6, with no statistically significant changes in these
measures during the 6-week heat acclimation period. There were also no significant
changes in urine color determined prior to the exercise-heat acclimation sessions throughout the 6-week period. Thus, hydration status prior to exercise-heat acclimation sessions remained essentially constant throughout the study.

**Fluid Intake Variables**

The mean voluntary fluid intake during exercise-heat acclimation sessions decreased from 3310 ± 810 ml during week 1 to 2255 ± 449 ml ($p < .05$) during week 3, and then leveled off between 2126 ± 517 ml to 1849 ± 446 ml ($p < .05$) during weeks 4–6 (Figure 1). The mean number of drinks per week during the acclimation sessions decreased progressively from 35 ± 10 during week 1 to 22 ± 6 ($p < .05$) during week 3 to between 20 ± 5 to 17 ± 5 ($p < .05$) during weeks 4–6 (Figure 1). The data collected for weeks 2, 3, and 4 also showed a significant change in number of drinks taken in comparison to that for week 6 (Figure 1). The mean number of drinks between week 2 and week 6 decreased significantly from 23 ± 4 to 17 ± 5 drinks ($p < .05$). The mean number of drinks consumed during week 6 (17 ± 5) was significantly lower than weeks 3 and 4 at 22 ± 6 to 20 ± 5 drinks per week ($p < .05$). The average volume per drink showed a tendency to increase steadily from 102 ± 18 ml during week 1 to 120 ± 23 ml during week 6, although the differences were not significant during any week of acclimation.

The mean time for the subjects to take their first drink during acclimation (Figure 1) showed a tendency to increase progressively from 9.9 ± 2.0 min during week 1 to 23.1 ± 4.7 min during week 6 ($p < .05$). Thus, as 6 weeks of heat acclimation progressed, subjects began drinking (i.e., first drink) later, took a decreased average number of drinks, and consumed less in total average volume during each trial.

**Perceptions of Thirst**

The mean thirst ratings were not statistically different between weeks 1–6 at min 15, 30, and 45. However, at 60 min (Figure 2) thirst ratings began to significantly decrease from 5 ± 0.4 during week 1 to 4 ± 0.4 ($p < .05$) during week 2 and then remained constant at 4 ± 0.3 during weeks 3–6. This decrease was also evident at 75 min (Figure 2), where there was a significant decrease in average perceived thirst ratings during weeks 2–6 compared to week 1 of acclimation (i.e., 5 ± 0.4 during week 1 vs. 4 ± 0.3 during weeks 2–6; $p < .05$). There was a trend for thirst ratings to progressively decrease at 90 min (Figure 2) from weeks 1–6, but this difference only was significant during week 2 of acclimation (4 ± 0.5 during week 1 vs. 3 ± 0.2 during week 2; $p < .05$).

**Variable Correlational Analyses**

The correlation between average number of drinks and average thirst ratings indicated that as the number of weeks of exercise-heat acclimation progressed, the number of drinks ingested was significantly correlated with their perceived thirst ratings (Table 2). This trend began during week 4 and followed through week 6 of the study. During week 4 of acclimation the average number of drinks (20 ± 5) were strongly correlated with perceived thirst rating averages at 30, 45, 60, and 75 min. Average thirst ratings and number of drinks (19 ± 6) consumed also were significantly correlated during week 5 at min 15, 30, 45, 60, 75, and 90. During week 6, the
Figure 1 — Mean (±SE) drinking parameters during each week. Values represent the average of the three exercise-heat acclimation training sessions each week. *Significantly different (p < .05) from week 1 of acclimation. #Significantly different (p < .05) from week 6 of acclimation.
Figure 2 — Average (±SE) weekly perceived thirst ratings measured after 60, 75, and 90 min of heat exposure. Values represent the average of the three exercise-heat acclimation training sessions each week. *Significantly different (p < .05) from week 1 of acclimation.
Table 2  Correlation Between Average Number of Drinks Each Week and Average Thirst Ratings at Various Time Points

<table>
<thead>
<tr>
<th>Time elapsed during heat acclimation tests (min)</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.48</td>
<td>0.55</td>
<td>0.79</td>
<td>0.82</td>
<td>0.50</td>
<td>0.21</td>
</tr>
<tr>
<td>2</td>
<td>0.77</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.67</td>
<td>0.63</td>
</tr>
<tr>
<td>3</td>
<td>0.64</td>
<td>0.76</td>
<td>0.87*</td>
<td>0.82</td>
<td>0.58</td>
<td>0.61</td>
</tr>
<tr>
<td>4</td>
<td>0.67</td>
<td>0.91*</td>
<td>0.87*</td>
<td>0.88*</td>
<td>0.99*</td>
<td>0.42</td>
</tr>
<tr>
<td>5</td>
<td>0.99*</td>
<td>0.93*</td>
<td>0.99*</td>
<td>0.91*</td>
<td>0.91*</td>
<td>0.96*</td>
</tr>
<tr>
<td>6</td>
<td>0.91*</td>
<td>0.99*</td>
<td>0.98*</td>
<td>0.93*</td>
<td>0.97*</td>
<td>0.98*</td>
</tr>
</tbody>
</table>

Note. *Indicates average number of drinks each week that were significantly correlated to average perceived thirst ratings, $p < .05$.

number of drinks consumed ($17 \pm 5$) significantly correlated with thirst ratings at 15, 30, 45, 60, 75, and 90 min. The correlation between average thirst ratings and average volume per drink was not significant throughout the 6-week study period, at any time. Additionally, average urine specific gravity ($U_{\text{sp}}$) measures were significantly correlated with urine color ($U_{\text{color}}$) during weeks 1–6 of the study (Table 3).

Discussion

Voluntary dehydration is caused by the delay of drinking sufficient fluid to compensate for fluid loss when humans are subjected to stressful conditions, such as exercise and/or heat exposure, as in the present study. Greenleaf et al. (14) and Hubbard et al. (16) examined drinking and water balance in men during exercise and heat acclimation through 8 consecutive days of exposure. They reported that increased drinking during acclimation was caused by a shortened time to first drink, a significant increase in the number of drinks consumed per exposure, and an increase in mean volume per drink.

In contrast, the present study examined thirst and drinking behavior in women during exercise-heat acclimation through 6 weeks of exposure. As acclimation progressed, there was a decrease in total fluid consumption, resulting from a decrease in the number of drinks, greater time to first drink, and a decrease in total volume ingested per week. Analysis of the data from weeks 1–3, a comparable time frame to the 8–10 day protocols, revealed little agreement with the findings reported by Greenleaf et al. (14), during an 8-day protocol using male subjects. During weeks 1–3 of the present study, the time to first drink increased steadily, the number of drinks decreased, the volume per drink increased (similar finding to Greenleaf et al., 14), and total fluid consumption decreased steadily. One explanation may be that the 3 days per week of outdoor training influenced the strength of these variables and ratings, if not their direction. Another logical explanation may be that the present study alternated heat exposure with winter outdoor training sessions, producing a
### Table 3  Correlation Between Average Urine Specific Gravity and Average Urine Color Each Week

<table>
<thead>
<tr>
<th>Variable</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Uₜₙ</td>
<td>1.015 ± 0.004</td>
<td>1.018 ± 0.002</td>
<td>1.018 ± 0.003</td>
<td>1.013 ± 0.003</td>
<td>1.018 ± 0.003</td>
<td>1.017 ± 0.003</td>
</tr>
<tr>
<td>Mean Uₜₙₑ</td>
<td>2 ± 0.5</td>
<td>2 ± 0.2</td>
<td>3 ± 0.4</td>
<td>2 ± 0.4</td>
<td>3 ± 0.5</td>
<td>2 ± 0.4</td>
</tr>
<tr>
<td>r</td>
<td>0.89*</td>
<td>0.88*</td>
<td>0.98*</td>
<td>0.89*</td>
<td>0.93*</td>
<td>0.93*</td>
</tr>
</tbody>
</table>

*Indicates significant correlation, *p* < .05. Mean (±SE) values are representative of the average of the three exercise-heat acclimation training sessions each week.

**Note.**
relatively slow acclimation to the heat. It is also plausible that these findings were due to a gender difference rather than an acclimation effect (see below).

**Psychological Contributions to Fluid Intake**

Psychological factors also may have contributed to the decrease in fluid consumption throughout the 6 weeks of acclimation. The momentary disposition of a subject to drink was expressed in selective ingestion. The choice of the subject to drink was characterized by volume and frequency of consumption. The decrease in fluid consumption over the 6 weeks of acclimation may have been due the subjects’ perception of thirst. Average perceived thirst scale measurements remained relatively low and showed only a slight variance throughout the 6-week acclimation protocol. On a thirst scale that ranged from 1 (*not thirsty at all*) to 9 (*very, very thirsty*), subjects’ perceptions of thirst averaged between a low of 3 (*a little thirsty*) and a high of 5 (*moderately thirsty*) throughout the study. Overall, perceived thirst ratings were reported to have either significantly decreased at various time points throughout the 6 weeks of acclimation or remained relatively stable.

The decrease in fluid consumption over the 6-week protocol may have additionally been affected by any of the following factors: a negative allesthesia to drinking water, the mood state of the individual, the degree of distraction the individual was subjected to while in the heat chamber, or a hereditary predisposition to be a light or reluctant drinker (28). It is also important to consider subject drinking behavior between training sessions (this was not measured and may be a limitation of the study design), where subjects may have increased fluid intake prior to or following exercise-heat acclimation sessions, thereby possibly influencing drinking behavior during their next training session.

**Thirst Ratings**

In the present study, water temperatures were monitored throughout the 90-min acclimation periods and water was replaced when the temperature exceeded 15 °C. This was controlled because warm, unpalatable water may contribute to low ratings of thirst. It has been demonstrated that humans prefer to drink cool fluids (3, 6). Following dehydration, maximum water intake has been observed at a fluid temperature of 15 °C, with colder and warmer fluids ingested in smaller volumes (6). Therefore, the effect of water temperature on intake was negligible.

We identified other unexpected, interesting findings. These included a lack of significance in mean thirst ratings at 90 min and an increase in average volume per drink throughout the 6-week protocol. Mean thirst ratings were not significantly different throughout weeks 1–6 at 15, 30, and 45 min, although there were significant decreases throughout the 6 weeks at 60 and 75 min of acclimation. There was a trend for thirst ratings to progressively decrease also at 90 min, but this difference reached significance only during week 2 of acclimation. As the number of weeks of heat acclimation progressed, the number of drinks ingested was strongly correlated with their perceived thirst ratings (Table 2). During the last 3 weeks of the heat acclimation, the perception of thirst appears to have been the most important factor determining the frequency of the subjects drinking. However, there was no correlation between average thirst ratings and average volume per drink throughout the 6-week study period.
Although total fluid consumption decreased throughout the 6-week study, there was an unexpected increasing trend (NS) in average volume per drink from weeks 1–6. Despite this tendency to increase the volume per drink, the frequency of drinks and total volume per week decreased. Although the subjects may have been attempting to replace water lost through sweating by increasing volume per drink, they may not have fully replaced all water losses due to the progressive decrease in number of drinks throughout the study. This may have been due to the fact that the normal dipsogenic drive was not strong enough to fully replace fluid that was lost during the exercise bout.

**Conclusion**

Because this is the first study to examine thirst and fluid intake during a lengthy exercise-heat acclimation protocol in women, there is much to learn about the effects of varying exercise-heat acclimation protocols. It is important to recognize that the observations reported in the present study support a different psycho-physiological response pattern than that previously observed during the 8–10 day protocol in men. In addition, women in the present study exhibited a different fluid consumption response to heat acclimation than did men in previous studies (14, 16). Specifically, these women demonstrated a decrease in mean water intake as heat acclimation progressed (Figure 1). In contrast, the data on male subjects (14, 16) indicate an increase in mean water intake as acclimation progresses. It is also possible that this finding may be the result of a gender difference rather than an acclimation duration effect. When females exercise at similar intensities to men (absolute intensities do not greatly differ), the heat to be dissipated requires similar amounts of sweat for both males and females. Females, however, produce sweat from a smaller reservoir of body fluids than do men (26). Therefore, for a given evaporative load, females will concentrate their body fluids at a greater rate than that of men. When exposed to environments where evaporation accounts for much of the heat loss, such as in the high temperatures of the heat chamber in the present study, the rate of increase in body fluid osmolality in females will lead to lower sweat rates and elevated body temperatures than in males when acclimated to the heat (26). This lower sweat output may make women less vulnerable to dehydration in the heat, and perhaps is reflected in the current data by the decrease in mean total fluid consumption as heat acclimation progressed. Hence, the data collected in the present study may represent a unique psycho-physiological response pattern in women that deserves further investigation.

One pitfall of the study is that sweat rates during heat acclimation sessions were not measured due to methodological constraints. The question then arises, if sweat rates were reduced, were these women drinking more appropriately by decreasing their fluid intakes? However, if sweat rate was maintained or increased and these women drank less, then this finding is contrary to what has been previously documented in other studies and warrants further research to examine possible mechanisms. Another limitation to the study design is that physiological hormone-related parameters were not measured during acclimation trials. It is important to reiterate that, because this study was designed in conjunction with a larger study being conducted in our laboratory, the scope of the present study was limited. Despite these limitations, this study did report an interesting finding, specifically that women who acclimatized to the heat drank less during exercise in the heat.
Based on the results of this study, the following conclusions were drawn: First, a lengthy acclimation protocol (6 weeks vs. 8–10 days) resulted in a decrease in total fluid consumption, resulting from a decrease in the number of drinks, greater time to first drink, and a decrease in total volume ingested each week. One factor that may have impacted these results was the exercise-heat acclimation protocol. This study design employed a unique exercise-heat acclimation protocol that involved both indoor training (3 days/wk), as well as outdoor training (3 days/wk). These additional 3 days per week of outdoor training likely influenced the strength and/or direction of these physiological ratings and variables. Second, thirst ratings were relatively low throughout the study. This suggests that the perception of thirst in this study does not appear to be a sufficient stimulus for maintaining fluid ingestion under physiological and psychological stressors such as exercise, hot environments, and dehydration.

References


**Acknowledgments**

The authors would like to thank the subjects who participated in the study and Dr. Emily M. Haymes for her editorial assistance.