Voluntary Dehydration in Runners Despite Favorable Conditions for Fluid Intake

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This study investigated the relationship between runners’ perceptions of fluid needs and drinking behavior under conditions of compensable heat stress (ambient temperature = 20.5 ± 0.7 °C, 68.9 °F; relative humidity = 76.6%). Eighteen experienced runners (15 men, 40.5 ± 2.5 y, and 3 women, 42 ± 2.3 y) were given ad libitum access to a sports drink (6% carbohydrate-electrolyte solution) at Miles 2, 4, 6, and 8. After the run (75.5 ± 8.0 min), subjects completed questionnaires that required them to estimate their individual fluid intake and sweat loss. Dehydration averaged 1.9% ± 0.8% of initial body weight (a mean sweat loss of 21.6 ± 5.1 mL·kg⁻¹·h⁻¹). Subjects replaced only 30.5% ± 18.1% of sweat loss and underestimated their sweat loss by 42.5% ± 36.6% (P ≤ 0.001). Subjects’ self-estimations of fluid intake (5.2 ± 3.2 mL·kg⁻¹·h⁻¹) were not significantly different from actual fluid intake (6.1 ± 3.4 mL·kg⁻¹·h⁻¹) and were significantly correlated (r = 0.63, P = 0.005). The data indicate that even under favorable conditions, experienced runners voluntarily dehydrate (P ≤ 0.001), possibly because they are unable to accurately estimate sweat loss and consequently cannot subjectively judge how much fluid to ingest to prevent dehydration. This conclusion suggests that runners should not depend on self-assessment to maintain adequate hydration, underscores the need for runners to enhance their ability to self-assess sweat losses, and suggests that a predetermined regimen of fluid ingestion might be necessary if they wish to maintain more optimal hydration.

Key Words: hydration, fluid needs, sweat loss, thirst, runners

Dehydration can negatively affect exercise performance, thermoregulation, and cardiovascular response (2, 4, 6, 7, 37, 39). Runners are particularly vulnerable to dehydration because of the intensity and duration of their training and racing, the challenge of drinking while running, and the stresses often imposed by running in conditions of heat stress. Even though experienced runners are typically aware of the consequences of dehydration, when given free access to fluids during exercise they often develop a progressive weight loss, termed “voluntary dehydration” by Rothstein et al. in 1947 (35). It is not uncommon for individuals to dehydrate by 2–5% or more of their body weight (1, 5, 11, 17, 18, 20, 21, 25, 31, 33, 35). For
example, Pugh et al. (31) reported that the runners they studied drank as little as 400 mL during a marathon race and developed a mean weight loss of 2.9 kg (5.9% of initial body weight), even though a beverage was readily available at each aid station. Along the same lines, Coyle and Montain (13) pointed out that runners generally drink only about 0.5 L of fluid per hour, which can allow them to dehydrate at rates of approximately 0.5–1.0 L/h. In addition to the typical reasons for avoiding drinking (fear of gastrointestinal distress and not wanting to slow down to drink), voluntary dehydration might also be prompted by runners’ inability to perceive their sweat losses and, therefore, the fluid intake needed to prevent dehydration.

Medical and sports-nutrition organizations have issued guidelines encouraging fluid replacement commensurate with fluid loss during sport or physical activity (3, 30). These position statements represent a broad scientific consensus. There is, however, some discussion relative to an alternative point of view that argues that it is preferable to “drink to thirst” (26). This alternative advice is meant to help some runners reduce the risk of hyponatremia caused by zealous overdrinking. Both hyponatremia and dehydration are health- and performance-threatening conditions that result from a mismatch of perceived versus actual fluid needs during exercise. Although there is a large body of information on the physiology and perception of thirst (14, 22, 32, 36, 38) and on hydration (16, 23), there is very little published research on the perception of fluid consumption or the perception of sweat rate. We sought to more fully understand how runners’ perceptions of their fluid needs matched their actual drinking behaviors. In addition, we were particularly interested in examining these behaviors when fluid was freely available. This study explored a potentially important element in reducing the risk of both dehydration and hyponatremia: individual perceptions of sweat loss and fluid intake.

Methods

Subjects

Eighteen seasoned marathoners (15 men and 3 women) participated in this study. The mean age of the men was 40.5 ± 2.5 y, and the mean age of the women was 42.0 ± 2.3 y. Each subject participated in roughly 12 competitive events per year and averaged 8 h of training per week. None of the subjects had participated in studies that required self-report of fluid loss or intake. All were familiar with sports drinks and had used them in training and competition. Subjects were informed both verbally and in writing of the experimental protocol and risks of the study. An institutional human-subjects review panel, following guidelines of the American College of Sports Medicine, evaluated and approved the study protocol. Subjects were informed that the purpose of this study was to investigate perceptual, sensory, and physiological responses to ingesting beverages during a 10-mile (16-km) run. They were not informed that fluid intake was being assessed.

Procedures

Subjects were instructed to eat and drink on the day of the study as they normally would for a race. The experimental protocol, a 10-mile (16-km) race, was held on a 400-m outdoor track and commenced at 5:00 PM. The 10-mile distance was
chosen to provide sufficiently challenging exercise conditions, as well as a realistic time frame for investigating fluid loss and replacement. Subjects were encouraged to view this as a competitive race experience and were informed that race times would be kept and posted after the race. The mean ambient temperature averaged 20.5 ± 0.7 °C with a relative humidity of 76.6% ± 1.7%; that is, the environmental conditions were those of compensable heat stress. Prerace and postrace nude, dry body weights were recorded using a portable Mettler balance (model #PW200; Mettler-Toledo, Inc, Worthington, OH) and rounded to one-tenth of a kilogram. Body-weight measures were adjusted for urine excretion in the 1 runner who urinated during the run.

A cold beverage (lemon-lime flavored 6% carbohydrate-electrolyte solution) was available to the subjects as they passed Miles 2, 4, 6, and 8. The beverage was served in a sports bottle (708 mL, 24 oz) that was equipped with an easy-open cap to allow fast and efficient fluid intake. Bottles were handed to the runners from the side of the track to facilitate beverage acquisition with minimal change of pace or running lane. Subjects were allowed to drink as much as they desired, carried their bottles with them as long as they wished, and then discarded them to the inside of the track. To mimic what happens during a road race, drinking was not mandatory. Subjects who decided to bypass a designated beverage station, however, were not able to obtain additional beverage until the next scheduled station.

Before the start and immediately after the race, subjects indicated how thirsty they were by marking a 100-point unstructured line scale, anchored on the left by not thirsty and on the right by very thirsty (8). Immediately after the race (just before the postrace body-weight measurement), subjects completed a written survey to determine how well they thought they had hydrated in relation to their sweat loss. The survey asked the following questions: 1) How much sweat did you lose? 2) How much fluid did you ingest? 3) Was this enough to replace your sweat loss? and 4) If not, what percentage of your sweat loss did you replace? Responses were written in a fill-in-the-blank format. Perceived estimates of sweat loss and fluid intake were converted to milliliters. In addition, subjects completed a questionnaire providing information on drink palatability using a 9-point hedonic-category scale (29) (from 1 = dislike extremely to 9 = like extremely).

**Statistical Analysis**

Results for sweat loss and fluid intake (mL·kg\(^{-1}\)·h\(^{-1}\) ± standard deviation) are reported relative to body mass and exercise duration. Statistical significance was assessed using a paired-comparison t-test and confidence intervals. Calculations were made using SPSS software (Version 14.0, SPSS, Inc, Chicago). Pearson correlation coefficients were calculated to determine the association between perceived and actual sweat loss and fluid intake. A probability level of 0.05 was selected as the criterion for statistical reliability. Statistical powers of the tests for mean comparisons and for correlations for large effects were at least 64% and 59%, respectively (12) (defining the likelihood of obtaining statistically significant results for mean differences equivalent to 0.8 standard deviation and correlations of at least 0.50). Actual power levels might have been higher, because the current design was a repeated-measures design, and power is being conservatively reported here based on nonrepeated-measures designs.
Results

The subjects’ mean sweat loss of 21.6 ± 5.1 mL·kg\(^{-1}\)·h\(^{-1}\) was significantly greater than their perceived sweat loss of 12.0 ± 7.4 mL·kg\(^{-1}\)·h\(^{-1}\) (\(P = 0.001\), 95% CI = 5.6–13.6 mL·kg\(^{-1}\)·h\(^{-1}\); Figure 1a), an underestimation of sweat loss of 42.5% ± 36.6% (95% CI = 24.4–60.6%). The correlation between sweat loss and fluid intake (mL·kg\(^{-1}\)·h\(^{-1}\)) was low and not significant (\(r = -0.21\), \(P = 0.39\); see Figure 2a). No subject was observed to overhydrate (range of percentage of sweat loss that was replaced: 5–67%). The correlation between perceived sweat loss and actual sweat loss was low and not significant (\(r = 0.21\), \(P = 0.40\); see Figure 3). No statistically significant relationship was found between perceived sweat loss and final hydration status (percentage dehydration; \(r = 0.12\), \(P = 0.65\)) or between perceived sweat loss and fluid intake (\(r = -0.18\), \(P = 0.47\)).

During exercise, subjects voluntarily replaced an average of 30.5% ± 18.1% of their sweat loss (range 5.1–67.4%, 95% CI = 21.5–39.5%). In spite of access to cool fluid at predetermined points in the race (i.e., every 2 miles), runners dehydrated by an average of 1.9% ± 0.8% body weight (range 0.8–3.2%, 99.9% CI = 1.2–2.6%). An analysis of voluntary fluid intake after Miles 4, 6, 8, and 10 failed to reveal significant differences among these race segments.

![Figure 1](image)

**Figure 1** — (a) Actual versus perceived sweat loss and (b) actual versus perceived fluid intake (mL·kg\(^{-1}\)·h\(^{-1}\)). Box plots indicate mean (heavy line) and median (thin line), with 5th, 10th, 25th, 75th, 90th, and 95th percentiles. Effect sizes (ES) of mean differences and \(p\)-values are indicated for actual versus perceived sweat loss and fluid intake.
Figure 2 — (a) Individual subject data for fluid intake versus sweat loss fitted with linear regression and 95% CI. Sweat loss and fluid intake (mL·kg⁻¹·h⁻¹) were not significantly related to each other ($r = -0.21, P = 0.39$). (b) Individual subject data for fluid intake versus postrace thirst fitted with linear regression and 95% CI. The relationship between postrace thirst and fluid intake approached statistical reliability ($r = -0.45, P = 0.06$).
Twelve of 18 subjects (67%) felt that they did not drink enough to replace their sweat loss. Their self-perceived estimate of the percentage of sweat that they replaced was $43.8\% \pm 23.0\%$, significantly greater than the actual percentage of sweat ($29.1\% \pm 20.0\%$) that these 12 subjects replaced ($P = 0.04$, 95% CI for the difference = 1.2–28.2%).

There was no significant difference between average fluid intake of $6.1 \pm 3.4$ mL·kg$^{-1}$·h$^{-1}$ and perceived fluid intake of $5.2 \pm 3.2$ mL·kg$^{-1}$·h$^{-1}$ ($P = 0.21$, 95% CI = −0.5 to 2.3, Figure 1b). Subjects underestimated their actual fluid intake by only $8.7\% \pm 28.2\%$ (ns, 95% CI = −5.2% to 22.6%). The correlation between perceived fluid intake and actual fluid intake was positive and significant ($r = 0.63$, $P = 0.005$; see Figure 4.)

Subjects rated their perceived thirst at the start and finish of the race on a 100-point scale as $43 \pm 21$ and $61 \pm 18$, respectively ($P = 0.009$, 95% CI of the difference = 5–31). There was no significant correlation between thirst at the beginning of the race and fluid intake, perceived fluid intake, sweat loss, perceived sweat loss (all mL·kg$^{-1}$·h$^{-1}$), or percentage dehydration ($r = -0.16$, $P = 0.52$; $r = -0.11$, $P = 0.66$; $r = -0.16$, $P = 0.52$; $r = 0.13$, $P = 0.60$; and $r = -0.08$, $P = 0.75$, respectively). There was no significant correlation between perceived thirst at the end of the race and perceived fluid intake, sweat loss, perceived sweat loss, or percentage dehydration ($r = -0.24$, $P = 0.33$; $r = -0.13$, $P = 0.61$; $r = 0.04$, $P = 0.88$; and $r = 0.21$, $P = 0.40$, respectively). The correlation between postrace thirst and fluid intake approached statistical significance ($r = -0.45$, $P = 0.06$), with postrace thirst accounting for about 20% of the variation in fluid intake (see Figure 2b).
The subjects’ finishing times for the 10-mile run ranged from 63 to 92 min (mean: 75.5 ± 8.0 min). Race finishing time was not significantly correlated with sweat loss, perceived sweat loss, fluid intake, perceived fluid intake (all L/kg), or percentage dehydration ($r = -0.35$, $P = 0.15$; $r = -0.20$, $P = 0.42$; $r = 0.04$, $P = 0.88$; $r = 0.11$, $P = 0.67$; and $r = -0.25$, $P = 0.32$, respectively).

Mean hedonic response for overall beverage acceptability was 6.3 ± 2.2, falling above the midpoint of the 9-point category scale.

**Discussion**

This study examined the relationship between perceived and actual fluid needs and drinking behaviors in seasoned runners during a 10-mile (16-km) race in conditions of compensable heat stress. Among other findings, the results confirm the prevalence of voluntary dehydration in runners; the average sweat loss for the subjects in this study was more than 3 times the volume they voluntarily consumed. Voluntary dehydration during physical activity has been a commonly observed phenomenon. Rothstein (35) reported voluntary dehydration in men who became dehydrated while working in the desert, despite having unlimited access to water. Noakes et al. (25) reported voluntary dehydration in athletes, finding that on average only 30% of the weight lost was replaced during running and canoeing events. A similar finding was observed in nonathletic children performing exercise (39) and in physical work simulating an industrial setting (10), despite subjects’ having unlimited access to water.
Our results are in accordance with those just described; the difference between fluid intake and sweat loss in the present study was similar to that previously reported for athletes (25), with our subjects replacing on average only about 30% of acute weight loss (predominantly sweat but including respiratory water and loss of glycogen and fat). Because multiple factors (e.g., palatability, beverage composition, beverage temperature, ease of access) can influence drinking behavior (10, 16, 27, 34), care was taken to avoid barriers to drinking to maximize the opportunity for fluid ingestion. To this end, we recruited seasoned runners who had competed in several marathons and road races. The assumption was that these runners, naïve to the purpose of the study, would be astute about their fluid needs, would be experienced at drinking during running, and would drink accordingly during exercise.

The beverage provided was a chilled, palatable, familiar, widely available sports drink that contained sodium and was noncarbonated. Research has shown that flavor, palatability, presence of sodium, and low temperature of a beverage contribute to stimulating fluid intake and maximize the volume ingested (27). Even in conditions enhanced for ease of fluid ingestion, however, our subjects replaced only one-third of their sweat losses. Perhaps, as with elite runners (9), our subjects restricted fluid intake because of the competitive conditions of the protocol.

In an attempt to more fully explore the perception of voluntary dehydration, we surveyed subjects immediately after the race for an estimation of their individual sweat loss and fluid intake, whether they felt they had drunk enough to replace lost sweat, and, if not, how much they did replace. The subjects’ perception of what they had consumed was a reasonable approximation of actual intake; they did not misjudge their intake (underestimating it by only 8.7%). The subjects drastically underestimated their sweat losses, however; perception of fluid loss was only 42.5% of actual fluid loss. Among subjects who reported that they did not replace their sweat losses, the estimated percentage of how much sweat was replaced was about 50% greater than that actually replaced. No significant relationship was found between subjects’ perceived sweat loss and actual sweat loss or between perceived sweat loss and postrace percentage of dehydration. In addition, there was no significant relationship found between thirst either at the beginning or after the run and sweat loss, perceived sweat loss, perceived fluid intake, or percentage dehydration. There was no relationship between sweat loss and individual fluid intake.

Based on these results, we find no basis, over the range of dehydration observed, to think that subjects accurately perceive fluid loss or fluid need or are able to use thirst as a guide for rehydration. The inability to estimate fluid loss might be an important contributing factor in voluntary dehydration. This is of particular interest because of the relatively mild environmental conditions in this study. The magnitude of the effect size for the difference between perceived and actual sweat loss was quite substantial, indicating a large deficiency in subjects’ typical sensitivity to fluid loss. It remains for future research to determine whether the magnitude of this effect persists under different (warmer and colder) environmental conditions.

In addition to the numerous factors that influence fluid intake during exercise, our data suggest that runners experience voluntary dehydration in part because of inaccurate perceptions of sweat loss. If true, this observation has 2 practical implications. First, it emphasizes the need for athletes to develop a more accurate understanding of the actual magnitude of their sweat loss. This is most easily accomplished by recording body weights before and after exercise, with the goal
of minimizing body-weight deficits by adequate drinking while avoiding the weight gain (overdrinking) often associated with hyponatremia. Second, it underscores the need for athletes to follow an individualized drinking strategy that is reflective of their sweat rates and consistent with their ability to ingest adequate fluid volumes during races and training sessions. The present findings also suggest that it might be worthwhile to enhance self-perception of sweat loss via training. In addition to weighing before and after exercise (a procedure that is recommended for its accuracy but one that is not always practical or convenient), the use of self-report scaling methods might be of value. Krogstad and Piechnik (19) have validated a self-report assessment scale for palmar sweating in patients with focal hyperhidrosis against an objective method of evaporation from the skin surface. The use of a visual analog scale (from 0 = no sweating to 10 = worst imaginable sweating) demonstrated that subjects can reliably report the magnitude of sweating under these conditions. There are apparently no studies extending this sensory method or any version of it to the self-perception of whole-body sweating. It is possible that optimization and use of a self-evaluation scale for the assessment of sweating could enhance athletes’ monitoring of sweat loss, resulting in better matching of fluid intake to sweat loss.

Limitations

It is possible that our subjects lacked the visual and tactile cues associated with sweating (i.e., damp skin and clothing) because of favorable conditions for radiative and evaporative heat exchange. Although we did not account for wind velocity, wind direction, running speed, clothing, or other factors that might affect sweat evaporation, the subjects were visibly sweating, so at least some visual and tactile cues were present. If such cues do provide feedback by which exercising subjects gauge sweat rate, environmental conditions favorable to rapid evaporative heat loss (e.g., exercise in the desert) might be expected to contribute to even greater voluntary dehydration (in addition to other possible influences such as thirst, performance, behavioral history, and intent). We are not aware of any studies that have addressed this possibility. Other factors not accounted for in the present study could have also contributed to voluntary dehydration. All subjects received the same flavor of sports drink (lemon-lime) as would be available in a competitive event. The flavor of the sports drink might not have been the ideal choice for each individual participant. Research shows, however, that even less-desirable flavors of sports drinks promote greater fluid intake than plain water under exercise conditions (28).

The competitive intensity of the race and the weight of the bottle might have discouraged runners from carrying the bottle for a longer distance to drink on the run. In support of this possibility, laboratory-based studies (10, 34) in which subjects had easy access to a beverage during exercise (without having to carry it) showed that a sports drink promoted voluntary intake that matched or more nearly matched sweat loss compared with the fluid intake of the subjects in the current study. It would also have been instructive to interview subjects as to why they felt they drank as much or as little as they did. Although not necessarily conclusive, such probing could generate additional hypotheses for future testing. Replication of the current design with a greater number of subjects would provide increased
power and further enhance our ability to achieve statistical significance with medium and small effects. Future research should investigate sex differences in perceived sweat loss and perceived fluid intake because the current study lacked sufficient sample sizes to achieve desirable statistical power for assessing sex differences. In addition, using a longer race distance under more challenging environmental conditions and a different time of day might have resulted in greater performance differences.

Of both practical and scientific importance is that the runners’ perceptions of thirst did not ensure adequate fluid intake. There was no compelling evidence under the conditions in this study that runners’ thirst was linked to a reduction in dehydration. The measurements of thirst before and after the race accounted for only 3% and 20% of the variation in fluid intake, respectively. Thirst did not ensure adequate fluid intake, nor was it predictive of drinking behavior. These results are wholly consistent with the voluntary dehydration that is often reported during exercise (15, 17, 25, 34, 35, 39).

In summary, the results indicate that judging by thirst is an ineffective way for many runners to protect their hydration status. Consequently, runners should either employ a predetermined fluid-replacement regimen based on body-weight change or strive to enhance self-perception of sweat loss, rather than rely on thirst. Future research should take a closer and more controlled look at why experienced athletes are not more successful at perceiving their fluid needs and assess the effectiveness of efforts designed to improve voluntary fluid consumption.

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References


