Runners Greatly Underestimate Sweat Losses Before and After a 1-hr Summer Run

Eric K. O’Neal, Brett A. Davis, Lauren K. Thigpen, Christina R. Caufield, Anthony D. Horton, and Joyce R. McIntosh

The purpose of this study was to determine how accurately runners estimate their sweat losses. Male (n = 19) and female (n = 20) runners (41 ± 10 yr, VO2max 57 ± 9 ml·kg⁻¹·min⁻¹) from the southeastern U.S. completed an ~1-hr run during late summer on a challenging outdoor road course (wet bulb globe temperature 24.1 ± 1.5 °C). Runs began at ~6:45 a.m. or p.m. Before and after running, participants filled race-aid-station paper cups with a volume of fluid they felt would be equivalent to their sweat losses. Total sweat losses and losses by percent body weight differed (p < .01) between men (1,797 ± 449 ml, 2.3% ± 0.6%) and women (1,155 ± 258 ml, 1.9% ± 0.4%). Postrun estimates (738 ± 470 ml) were lower (p < .001) than sweat losses (1,468 ± 484 ml), equaling underestimations of 50% ± 23%, with no differences in estimation accuracy by percentage between genders. Runners who reported measuring changes in pre- and postrun weight to assess sweat losses within the previous month (n = 9, –54% ± 18%) were no more accurate (p = .55) than runners who had not (n = 30, –48% ± 24%). These results suggest that inadequate fluid intake during runs or between runs may stem from underestimations of sweat losses and that runners who do assess sweat-loss changes may be making sweat-loss calculation errors or do not accurately translate changes in body weight to physical volumes of water.

Keywords: hydration, running, urine specific gravity, fluid needs

Hydration guidelines established by the National Athletic Trainers’ Association (NATA; Casa et al., 2000) and American College of Sports Medicine (ACSM; Sawka et al., 2007) recommend that fluid intake during exercise be sufficient to limit loss of body mass to less than 2% while not exceeding sweat loss. It is also recommended that a volume of fluid equal to 125–150% of sweat loss be consumed between training bouts if the time between workouts is short and sweat losses are substantial. The key tenet in effective prescription of individualized fluid intake during and after exercise is accurate assessment of sweat loss using pre- and postexercise changes in body mass and accounting for fluid intake and voids (Maughan & Shirreffs, 2008). Although this strategy has been consistently promoted in the scientific community, a recent survey revealed only 2% of nonelite half- and full-marathon runners incorporate changes in body mass to evaluate their hydration status (O’Neal et al., 2011). In addition, Winger, Dugas, and Dugas (2011) reported that most runners simply drink to thirst. This approach follows the recommendation of the International Marathon Medical Directors Association (IMMDA; Hew-Butler, Verbalis, & Noakes, 2006), but these authors adamantly noted that the drinking-to-thirst strategy was most likely based simply on experience, not recommendations of the IMMDA. Collectively, data from these two surveys suggest that fluid-intake strategies of recreational distance runners lack objective considerations based on the most current guidelines (Casa et al., 2000; Sawka et al., 2007).

If changes in body weight are not frequently assessed (O’Neal et al., 2011), it is plausible that a runner’s basis for fluid intake would be somewhat predicated on perceptions of sweat loss. However, we are aware of only one investigation in which athletes were asked to estimate their sweat losses. Using a protocol in which participants reported via pen-and-paper questionnaire the volume of sweat they perceived they had lost after a 10-mile run in a temperate environment, Passe, Horn, Stofan, Horswill, and Murray (2007) found that experienced marathoners were poor predictors, underestimating actual sweat losses by 43% ± 37% (95% CI = 24–61%). Evidence demonstrating that runners have a significant disconnect between their perceived and actual sweat losses (Passe et al.) and rarely implement objective methods to determine sweat loss (O’Neal et al., 2011) makes application of the most current hydration guidelines nearly irrelevant for runners (Casa et al., 2000; Sawka et al., 2007), as most other techniques suggested to assess hydration status require technical expertise and equipment that runners are unlikely to possess (e.g., to measure urine specific gravity [USG] or plasma osmolality) or are subjective in nature (e.g., urine color and volume; Armstrong, 2007). A better understanding of how runners perceive their sweat losses could help in developing guidelines to promote...
fluid-intake behavior that would limit excessive hypo- or hyperhydration and the associated negative consequences on performance and health.

The investigation by Passe et al. (2007) was conducted in a temperate environment (21 °C and 77% relative humidity) with a limited number of runners ($n = 18$) who were predominantly male ($n = 15$). The primary purpose of the current study was to expand on some of the limitations offered by Passe et al., which include determining if similar sweat-loss underestimations would be exhibited in a larger sample of participants running in a hot environment and if sweat-loss-estimation accuracy would differ between genders. In addition, we sought to determine if sweat-loss estimation would be influenced when based on a physical volume of water versus a pen-and-paper questionnaire and if a basis for prediction error could be determined qualitatively through unstructured conversations with runners. Sweat-loss estimations were determined before and after a hot ~1-hr outdoor run by having runners fill 8-oz race-aid-station paper cups with a volume of fluid that they felt equaled their sweat losses.

**Methods**

**Participants**

Investigators recruited runners age 19–60 years at a meeting of a regional running club and by distributing flyers in person at local organized races. Forty-four runners were recruited and completed the initial screening session, but 5 were unable to complete the study due to injuries not related to it. A final sample of 39 runners (19 men, 20 women) completed all trials. The investigators’ intentions were to double the sample size of the Passe et al. (2007) investigation to more clearly depict the differences in sweat-loss estimations and actual sweat losses of the runners. A power analysis ($\alpha = .05, 1 - \beta = .80$) also determined that a minimum of 17 men and 17 women with a difference of 25% in mean sweat-loss-estimation accuracy ($\pm SD = 25\%$) would be needed to determine if there were differences between genders. All runners reported regularly training in the heat and that they could complete a continuous 1-hr outdoor run without difficulty. In the last 24 months, 21 runners had completed an organized race of marathon distance or longer, 10 had completed a half-marathon, and 7 had completed a 10-km race. One male runner had not competed in any organized road races but reported running 5 or more days per week and was very well trained (VO$_{2\text{max}}$ 69.7 ml · kg$^{-1}$ · min$^{-1}$). Participants reported having averaged 25 ± 12 miles of running a week over the previous 2 years. None had previously served as participants in investigations where change in body mass was assessed.

**VO$_{2\text{max}}$, Body Composition, and Health Screening**

Participants were instructed to refrain from alcohol and caffeine consumption and strenuous exercise for 24 hr before reporting to the laboratory. After explanation of the study and completion of a preactivity readiness questionnaire, heat-illness questionnaires, and a consent form, a manual blood-pressure measurement was taken in accordance with ACSM guidelines to screen for hypertension (2010). Percent body fat was estimated from three-site skinfold measurements (chest, umbilicus, and thigh for men and triceps, suprailliac, and thigh for women; Jackson & Pollock, 1985). VO$_{2\text{max}}$ was assessed by indirect calorimetry (Vista-Mini CPX, Vacumed, Ventura, CA) using breath-by-breath averages every 20 s during a graded treadmill test. Initial treadmill speed was set at 5, 6, or 7 miles/hr (~8, 9.5, or 11 km/hr) depending on individual running ability and increased by 1 mile/hr every 2 min until a final maximal speed of 7, 8, or 9 miles/hr (~11, 13.5, or 15 km/hr) was reached. Every subsequent 2 min the grade of the treadmill was increased by 2% until volitional fatigue. Two of the following three variables had to be met for a valid test: respiratory-exchange ratio of 1.1 or greater, 90% of age-predicted maximum heart rate, or an 18+ rating of perceived exertion. VO$_{2\text{max}}$ was calculated based on the average of the last three 20-s values of the test. Before leaving the laboratory, participants were reminded to report to the laboratory having hydrated as if preparing for a race and to avoid heavy physical activity in the 24 hr before their outdoor run. They were informed that their sweat loss would be determined by changes in pre- and postrun body weight and were asked if they had ever weighed themselves before and after a run to determine their sweat losses. Investigators strongly expressed to runners that if they had not previously assessed changes in their pre- and postrun body weight they should not do so until completion of their outdoor run. Runners who reported having measured their changes in body weight before were instructed to maintain their normal routines.

**Running Course**

A 5-km loop beginning adjacent to the laboratory and traversing primarily low-traffic neighborhoods was selected. There were a few short stretches of concrete sidewalk, but most of the course was asphalt. The course topography was divided into two halves of gradually ascending and descending slopes with grades of ~4% to +3% and a few short stretches of flat terrain. Roughly half of the course was shaded by trees depending on the time of day runs were completed. Turns were marked with signs to direct runners. Aid stations were set up at the beginning of the course and at the 2.5-km marker. Bottles of chilled (3–4 °C) water (~237 ml) with spill-proof nozzles were offered to runners at 2.5-km intervals during the run. Runners who chose to drink had the option of carrying their bottle to the next aid station or could deposit the bottles in a container ~50 m from the aid station where it was received. Specific instructions were given to the runners to not pour water from the bottles on themselves and that water was not to be spat out. All bottles were marked with a participant’s identification number, and change in bottle weights was measured for sweat-loss calculations and to
assess run fluid consumption. A restroom was located in a building adjacent to one of the aid stations, and urine voids for 2 participants were collected there for sweat-loss calculations.

Running Trial

Running sessions took place from July to late August. Participants were asked to prepare for the running trials in regard to sleep, nutrition, and hydration as they normally would for an organized race. On arrival at the laboratory, they were asked to make a void, and USG was assessed in duplicate, with values being confirmed by agreement from two investigators using a handheld refractometer (SUR-NE 300, Atago, Tokyo, Japan). Participants then were weighed in minimal clothing on a digital scale (BWB-800, Tanita Co., Arlington Heights, IL) to the nearest 0.1 kg. The same clothing was worn for prerun and postrun measurements. Participants then changed into their own shorts and undergarments. All were provided with a brightly colored 100% polyester T-shirt (Dri-FIT Poly, Nike Inc., Beaverton, OR) and fitted with a heart-rate monitor (Team2 System, Polar Electro Oy, Kempele, Finland) that continuously measured and recorded heart rate in 5-s increments. All clothing (shoes, shorts, T-shirt, undergarments, hats, and cloth heart-rate-monitor strap) worn during the run and a towel participants used to dry themselves with before their postrun weight measurement were weighed together on a digital scale (KD-200–210, Tanita Co., Arlington Heights, IL) and rounded to the nearest 0.2 g before and after the run to assess the volume of sweat retained in clothing and on the skin’s surface postrun. All voids after initial weigh-in were collected, measured, and incorporated in sweat-loss calculations.

In a private room, participants were individually presented with a stack of 237-ml (8-fluid-oz) paper cups and a pitcher containing ~3 L of water. They were informed that each cup would hold 237 ml of water. The runners were then asked to predict the volume of sweat loss they believed they would experience during their 1-hr run by filling the cups with water. Verbal instructions were given by the investigators that the cups could be filled to any level; the weight of the water would be measured, and incorporated in sweat-loss calculations.

Participants returned to a private room immediately after their run, dried off thoroughly, and changed into their prerun clothing for a postrun weight measurement. They completed a postrun sweat-loss estimation and were then given free access to consume chilled (~5–6 °C) water in the air-conditioned laboratory for 1 hr. Ad libitum water consumption was measured in the 1-hr recovery period. A questionnaire concerning hydration-monitoring strategies and confidence in estimations was administered during the recovery period. Session rating of perceived exertion was also assessed on a 0–10 scale (Borg, 1982).

Near the end of the 1-hr recovery period, investigators briefed the runners on their actual sweat losses, percentages of sweat loss retained in clothing or toweled off the skin and sweat evaporated or cast off from skin. Investigators also discussed how to accurately calculate sweat losses and prescribe hydration strategies based on ACSM (Sawka et al., 2007) and NATA (Casa et al., 2000) guidelines.

### Table 1  Prerun Urine Specific Gravity (USG)

<table>
<thead>
<tr>
<th>Level of Dehydration</th>
<th>Minimal, ≤1.020</th>
<th>Significant, 1.021–1.030</th>
<th>Serious, &gt;1.030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women, n = 17</td>
<td>1.018 ± 0.009</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Men, n = 18</td>
<td>1.021 ± 0.009</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>a.m., n = 17</td>
<td>1.021 ± 0.008</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>p.m., n = 18</td>
<td>1.018 ± 0.010</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Total, n = 35</td>
<td>1.019 ± 0.009</td>
<td>17</td>
<td>15</td>
</tr>
</tbody>
</table>

*Note. Four runners were unable to provide a prerun USG sample. No differences (p > .05) were found between genders or time of day.*

*Classifications based on NATA (Casa et al., 2000) guidelines.*
Statistical Analyses

Independent t tests were administered to determine if there were differences between men and women for prerun USG, run WBGT, prerun estimation accuracy, postrun estimation accuracy, percent body-weight loss, total sweat loss, percentage of total sweat loss retained in clothing and on skin postrun, and questionnaire items. Independent-samples t tests were also used to determine differences between runners who reported having measured their changes in body mass in the previous month and runners who had not for postrun prediction accuracy, postrun sweat-loss estimations, sweat loss, and confidence in estimations. Repeated-measures analysis of variance was used to determine differences in prerun sweat-loss estimations, actual sweat losses, and postrun sweat-loss estimations for men, women, and all runners. Bonferroni post hoc tests were incorporated when significant main effects were found. Pearson’s r was used to determine if pre- and postrun estimations were correlated or if runners with higher confidence levels in estimations more accurately predicted sweat loss than those with less confidence. Data were analyzed with a statistical software package (PASW 18, IBM Inc., Armonk, NY). An alpha level of .05 was used to denote significance in all analyses.

Results

Description of Participants, Environmental Conditions, Run Data, and Prerun USG

Descriptions of participants including age, height, weight, percent body fat, and VO₂max are listed in Table 2. Morning runs had significantly lower \( p < .001 \) WBGT \((23.3 ± 1.4 ^\circ C)\) and dry temperature \((25.1 ± 1.6 ^\circ C)\) and higher relative humidity \((85.8% ± 7.0\%)\) than evening runs \((24.9 ± 1.2 ^\circ C, 28.7 ± 1.3 ^\circ C, 71.9% ± 10.1\%)\). Male and female runners were distributed as evenly as participants’ schedules would allow between morning \((9 \text{ women and 10 \text{ men})\} and evening \((11 \text{ women and 9 \text{ men})\} runs. \text{Mean overall values for WBGT \((24.1 ± 1.5 ^\circ C)\}, \text{dry temperature, \((27.0 ± 2.4 ^\circ C)\}, \text{and relative humidity \((79% ± 11%)\)) did not differ between runs for men and women \((p > .05).\) Mean finishing time \((59.14 ± 3.46 \text{ min})\}, \text{average run heart rate \((161 ± 12 \text{ beats/min})\}, and \text{session rating of perceived exertion \((6.9 ± 0.8)\)) were also not different between genders \((p > .05).\) Male \((5.40 ± 0.61 \text{ min/km})\) runners had a significantly faster pace \((p = .01)\) than female \((5.95 ± 0.67 \text{ min/km})\) runners and ran longer distances \((11.1 ± 1.11 \text{ km and 10.0 ± 1.04 km; \(p < .01).\) Prerun USG did not differ between men and women or between morning and evening runs \((p > .05).\) Average USG and categorical classification are displayed by gender and time of day in Table 1. Four runners were unable to provide a urine sample.

Sweat Estimates, Sweat Losses, and Fluid Intake

Men had 34% \((642 \text{ ml})\) greater average sweat losses than women based on total volume \((Figure 1; \(p < .001\)) and percentage body weight \((2.3% ± 0.6\% \text{ vs. } 1.9% ± 0.4\%; \(p = .03).\) Runners’ pre- and postrun sweat-loss estimates did not differ when analyzed by gender or collectively \((Figure 1; \(p > .05)\) and were significantly correlated \((men \text{ } r = .90, \text{women } r = .73, \text{all runners } r = .88).\) Significant \((p < .001)\) prerun and postrun sweat-loss underestimations of 44.4% ± 26.2% \((95\% \text{ CI } = 36.0–53.0\%)\) and 49.6% ± 23.0% \((95\% \text{ CI } = 42.1–57.0\%)\) were found. To a significant \((p = .001)\) positive correlation \((r = .52)\) was found between postexercise estimated and actual sweat losses \((Figure 2).\) The Bland-Altman error analysis \((Figure 3)\) for difference in postrun sweat-loss estimate and actual sweat losses revealed a bias in underestimation error \((95\% \text{ upper and lower levels of agreement } 187 \text{ and } –1,647 \text{ ml, with heavier sweaters underestimating by a greater volume than lighter sweaters } (r = –.51).\) Sweat losses \((p = .83)\) and postrun estimations \((p = .70)\) did not differ between runners who had and had not assessed their changes in body mass pre- and postrun in the previous month \((Figure 4).\) Likewise, postrun estimation accuracy \((p = .55)\) did not differ between runners who reported having weighed themselves before and after a run in the last month \((underestimation = 53.6% ± 18.2\%; 95\% \text{ CI } = 39.6–67.5\%)\) and those who did not \((underestimation = 48.3% ± 24.4%; 95\% \text{ CI } = 39.3–57.4\%).\) Runners who had assessed sweat losses by change in body weight in the last month also reported no differences from runners who had not assessed sweat losses by change in body weight in subjective responses \((100 \text{ mm visual analog scale: } 0 = \text{strongly disagree, } 100

| Table 2 Description of Participants, \(M ± SD\) |
|-----------------|-----------------|-----------------|
| Women, \(n = 20\) | Men, \(n = 19\) | Total, \(N = 39\) |
| Age (years)     | 41 ± 9          | 41 ± 12         | 41 ± 10         |
| Height (cm)     | 164 ± 6         | 177 ± 6         | 170 ± 9         |
| Weight (kg)     | 61.1 ± 7.6      | 77.0 ± 5.6      | 68.9 ± 10.4     |
| % body fat      | 22.6 ± 4.4      | 14.0 ± 4.7      | 18.4 ± 6.2      |
| \(VO₂max\) (ml · kg⁻¹ · min⁻¹) | 52.3 ± 7.2 | 61.2 ± 8.8 | 56.6 ± 9.1 |

(p = .01) guidelines. Investigators explored rationales for participants’ estimation biases through unstructured conversations concerning sweat losses and hydration-strategy guidelines with the participants. This project was approved by the University of North Alabama institutional review board.
Figure 1 — Prerun estimates, postrun estimates, and actual sweat loss ($M \pm SD$) for women ($n = 20$), men ($n = 19$), and all runners ($N = 39$). Pre- and postrun estimates did not differ for any group. †Significant difference ($p < .001$) from pre- and postrun estimates. ‡Significant difference ($p < .01$) from men.

Figure 2 — Correlation for actual sweat loss and postrun sweat-loss estimations ($r = .52, p < .001$). The X represents a participant who reported experiencing previous performance decrements believed to have been related to ineffective hydration strategies. The participant’s training history, sweat loss, sweat-loss estimates, and fluid intake are described in detail in the Discussion section.
Figure 3 — Bland-Altman plot with 95% upper and lower limits for differences in postrun sweat-loss estimate and actual sweat loss. The X represents a participant who reported experiencing previous performance decrements believed to have been related to ineffective hydration strategies. The participant’s training history, sweat loss, sweat-loss estimates, and fluid intake are described in detail in the Discussion section.

Figure 4 — Postrun estimates for runners who reported measuring changes in body mass (BM) before and after a run in the previous month (n = 9; 5 women and 4 men) and runners who had not (n = 30; 15 women and 15 men). No differences (p > .05) between genders were found for sweat losses, postrun estimates, or sweat-loss-estimate accuracy. †Sweat-loss estimations significantly different (p < .001) from postrun estimates.
= strongly agree) to the statement “I was very confident in my postrun estimation” (p = .49; 49 ± 22 mm, 55 ± 21 mm).

Sweat volume retained in shoes and clothing and towed off skin postrun was greater (p = .01) for men (494 ± 304 ml) than for women (275 ± 205 ml) but did not differ (p = .36) based on percentage of total sweat loss (men = 25.5% ± 10.9%; women = 22.1% ± 11.6%; total = 23.8% ± 11.2%). Postrun sweat-loss estimates were moderately correlated (r = .39, p = .013) with sweat retained in clothing and on skin. Fluid intake during runs (p = .10) and the 1-hr recovery (p = .07) showed a tendency for differences between genders but were only statistically significantly different (p = .02) between men and women when total fluid intakes were compared (Table 3). Percentage of sweat loss replaced during the run and 1 hr postrun were not different between genders (p = .15; Table 3). No runners consumed a volume of water that exceeded sweat loss during their run. Table 4 lists the hydration-status assessment techniques reported by the participants.

### Discussion

The purpose of this study was to examine how accurately distance runners would estimate their sweat losses when filling race-aid-station cups with the amount of water they believed represented their sweat losses. The most significant finding of this study was that runners underestimated their sweat losses by half (Figure 1). These results reinforce those reported by Passe et al. (2007), who found sweat-loss underestimations of 43% ± 37% when reported as pen-and-paper responses by runners completing a 10-mile run in a temperate environment. Pre- and postrun estimations did not differ and were highly correlated, suggesting that runners had somewhat fixed perceptions and expectations of their sweat losses. Conversations with runners about their actual sweat losses and a brief tutorial on designing individualized hydration strategies postrecovery revealed that many runners failed to consider evaporative sweat loss to any great extent when making their estimations. A moderate correlation between estimated sweat loss and sweat retained in clothing and on skin postrun supports this conclusion.

Although there was a bias for heavier sweaters to underestimate their sweat losses by a greater total volume than lighter sweaters, a consistent trend in underestimation error relative to sweat loss was evident, with runners being generally perceptive of whether they were light or heavy sweaters based on the relationship of their actual and estimated sweat losses (Figures 2 and 3). However, there were exceptions. Participant X (data depicted by an X marker in Figures 2 and 3) was an Ironman distance triathlete with a personal-best marathon time of 3:25 who expressed particular concern about multiple training bouts and competitions in which he believed his hydration or nutritional approaches were ineffective, leading to severe and unexpected performance decrements. Participant X reported never weighing himself before and after a run to determine his sweat losses. While he underestimated his sweat losses over fourfold (sweat loss = 2,281 ml, postrun sweat estimation = 510 ml), he drank 615 ml of water during his run, exceeding his estimated sweat loss. Passe et al. (2007) found that runners could accurately

### Table 3 Fluid Intake and Sweat Losses, M ± SD

<table>
<thead>
<tr>
<th></th>
<th>Women, n = 20</th>
<th>Men, n = 19</th>
<th>Total, N = 39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run intake (ml)</td>
<td>177 ± 161</td>
<td>272 ± 196</td>
<td>223 ± 183</td>
</tr>
<tr>
<td>Recovery intake (ml)</td>
<td>626 ± 238</td>
<td>865 ± 504</td>
<td>742 ± 404</td>
</tr>
<tr>
<td>Sweat loss (ml)</td>
<td>1,155 ± 258</td>
<td>1,797 ± 449</td>
<td>1,468 ± 484</td>
</tr>
<tr>
<td>Total fluid intake (ml)*</td>
<td>803 ± 210</td>
<td>1,137 ± 546</td>
<td>966 ± 438</td>
</tr>
<tr>
<td>Sweat lost/replaced (%)</td>
<td>73 ± 25</td>
<td>62 ± 21</td>
<td>67 ± 23</td>
</tr>
</tbody>
</table>

*Significant difference (p = .02) between genders.

### Table 4 Reported Hydration-Status-Assessment Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Reporting “Yes”</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td>Difference in pre- and postrun weight</td>
<td>7</td>
</tr>
<tr>
<td>Changes in day-to-day body weight</td>
<td>7</td>
</tr>
<tr>
<td>Urine color</td>
<td>26</td>
</tr>
<tr>
<td>Urine volume</td>
<td>16</td>
</tr>
<tr>
<td>Frequency of urination</td>
<td>14</td>
</tr>
<tr>
<td>Thirst</td>
<td>27</td>
</tr>
</tbody>
</table>
estimate the volume of fluid they consumed during a 10-mile run. Although we did not ask runners to report how much fluid they felt they drank during their runs, it is plausible that Participant X was consuming fluids in amount he believed were roughly equal to his sweat losses, as the volumes were comparable. If similar trends of vast underconsumption were continued during a longer competition or training bout, it would not be surprising if major performance decrements occurred, considering Participant X’s high sweat rate. Despite beginning his run adequately hydrated (USG = 1.012), Participant X drank the second highest total volume of water during his run, more than twice the amount of mean fluid intake for all male runners.

A limitation of Passe et al.’s (2007) investigation was that no comparison could be made between genders due to the small sample size and much lower percentage of female runners. Spontaneous USG assessed in tennis players (Armstrong et al., 1994), Division I collegiate athletes of various sports (Volpe, Poule, & Bland, 2009), and recreational exercisers entering gyms (Stover et al., 2006) and recent evidence evaluating runners (Silva et al., 2010) have shown that women begin exercise substantially more hydrated than men. Surveys of runners have found that women are more likely to intentionally increase nonexercise-environment fluid intake in warm weather than men (O’Neal et al., 2011) and are 1.6 times more likely than men to “drink as much as tolerable” during runs (Winger et al., 2011).

We hypothesized that lower relative sweat rates and possible greater concern about dehydration would result in women more accurately estimating or overestimating sweat losses than men. Such evidence could potentially elucidate some of the differences in preexercise USG between male and female athletes and explain why female runners are more prone to consume fluids in greater quantities relative to sweat losses than men during competitive runs (Almond et al., 2005; Chorley, Cianca, & Divine, 2007). However, no differences between sweat-loss-estimation errors by percentage (Figure 1) or prerun USG (Table 1) were found between genders. There was also no evidence of individual outliers who overestimated sweat losses to a great extent to balance out Participant X and several other runners who exhibited vast underestimations of sweat loss.

Nine runners (5 female and 4 male) reported on a postrun questionnaire that they had weighed themselves before and after a run in the previous month. Seven of the nine runners reported assessing weight changes nearly every run or three times a week or more. It is surprising that runners who reported using this technique in the previous month were no more accurate estimators than their peers who had not (Figure 4). Two explanations for the poor estimation accuracy are that the runners had difficulty in translating the weight of the cups from the metric system to change in body weight assessed in pounds, to which they were likely more accustomed, or the investigation run was conducted in hotter or cooler temperatures than those in which the runners typically trained. However, conversations with participants revealed that they commonly made mistakes when determining sweat losses that would lead to lower than actual sweat-loss calculations, such as not considering weighing in the nude or in the same pair of dry clothes or not accounting for fluid intake during their runs.

The term voluntary dehydration describes the phenomenon in which individuals replace their fluid losses at a slower rate than losses are incurred. Great efforts have been made to understand the physiological basis for thirst and responses to thirst stimuli (for excellent reviews see Greenleaf, 1992; Johnson, 2007). However, it is apparent that physiological mechanisms alone do not result in behavior that tightly controls fluid homeostasis when substantial short-term alterations occur. The runners in Passe et al.’s study (2007) replaced ~30% of their sweat losses during a 75-min run. It is interesting that Passe et al. focused most of their discussion on the voluntary-dehydration aspect of their findings. They stated that they recruited veteran runners who they anticipated “would be astute about their fluid needs, would be experienced at drinking during running, and would drink accordingly during exercise” (Passe et al., p. 291). This remark suggests that the authors were baffled that the runners did not consume the readily available sport beverages at a greater rate. This comment would be appropriate if the authors speculated that their participants would drink according to guidelines proposed by the ACSM (Convertino et al., 1996) at the time this study was conducted, which promoted aggressively replacing all fluid losses. An alternate interpretation of these data would be that if the runners were drinking to their perceived sweat losses, they were close to replacing most of their estimated sweat losses.

The runners in the current study only replaced around 15% (Table 3) of their sweat losses while running, but we did not interpret this finding as novel or perplexing considering the hot and humid environmental conditions, the duration of the run (~1 hr), and our personal experiences with runners. Drinking while running requires coordination and may lead to stomach discomfort, and carrying large volumes of fluid during training runs presents obvious logistical problems. Based on these factors, it is likely that our participants were accustomed to experiencing voluntary dehydration on a regular basis while successfully completing their training runs. It should also be noted that most runners in the current and Passe et al. (2007) studies were able to minimize body-weight loss to less than the recommended 2% marker at which performance decrements are expected to be manifested (Sawka et al., 2007).

Myhre, Hartung, Nunneley, and Tucker (1985) found that male and female runners replaced a little over 40% of their sweat losses during a temperate-environment-condition marathon. Cheuvront and Haymes (2001) reported that women completing 30-km runs in 25, 17, and 12 °C replaced 63%, 68%, and 73% of their sweat losses, respectively. These volumes of voluntary fluid replacement minimized sweat losses to <3% body weight and kept rectal temperature below 39 °C in all environments.
Examination of Cheuvront and Haymes’s participants’ fluid intake in 5-km intervals reveals that under hot conditions the runners began drinking early, with little change in fluid-intake volume in the later stages of the run even though they began their run hyperhydrated (USG = 1.003 ± 0.002). We propose that this behavior represents preemptive hydration for expected fluid deficit that is not based on immediate thirst but on expectations of fluid needs to complete the longer running task. Similarly, we suggest that the runners in Passe et al. (2007) and the current investigation drank at a minimal, not maximal, rate needed to complete their running bout based on experience. The male and female runners consumed 3 times as much water in the hour after their run as during their 1-hr run, suggesting that the low fluid consumption during the run was not based on a lack of thirst. Again, we contend that these were psychological, not physiological, influences dictating fluid-intake behavior and that thirst stimulus was not attended to as a priority during the run.

Despite being given instructions to hydrate as if they were preparing for an organized race, half the runners did not report in a euhydrated status based on USG (Casa et al., 2000; Sawka et al., 2007: Table 1). After a 90-min run in temperate conditions, the runners in Wong, Williams, Simpson, and Ogaki’s study (1998) consumed 70% of their fluid in the first hour of a 4-hr recovery period followed by a subsequent run to exhaustion with minimal levels of fluid intake in Hours 2, 3, and 4. Despite replacing just under 100% of their sweat losses, the runners only retained 43% ± 8% of the fluids they ingested during the 4-hr recovery period. This resulted in their beginning the subsequent exercise bout hypohydrated compared with their initial trial (~1.5% less body mass than first trial). Our runners replaced just under 70% (Table 1) of their fluid losses including run and 1-hr-postrun fluid losses similar to the results reported by Wong et al. (1998). If thirst drive diminished in a similar pattern and urinary losses were similar to those in Wong et al. (1998) it would not be surprising that runners often begin exercise in a hypohydrated state with satiated thirst. Ad libitum fluid ingestion postexercise has received less attention than fluid intake during exercise, and it is plausible that runners also give less consideration to postrun fluid needs. These results provide additional evidence that accurate estimates of sweat losses are critical in enabling runners to determine their fluid needs between exercise bouts, particularly for triathletes, who are likely to undertake multiple training bouts in a single day. In addition, the combined results of Wong et al. (1998) and the current study suggest that ecological validity (i.e., runners’ much lower postexercise ad libitum fluid-intake habits) should be considered when designing methodologies for future studies examining between-bouts rehydration strategies, as previous studies have often incorporated fluid intake at rates of 150–200% of sweat loss in the first hour of recovery, which appears to be 2–3 times greater than runners voluntarily consume (Merson, Maughan, & Shirreffs, 2008; Shirreffs, Aragon-Vargas, Keil, Love, & Phillips, 2007; Wong, Williams, & Adams, 2000).

The primary intention of this study was to determine how accurately runners estimate their sweat losses. The impetus for the investigation was based on the premise that runners’ experience of negative events from vast amounts of over- or underconsumption of fluid stems from poor estimation of individual hydration needs or inaccurate perceptions of fluid losses. Our findings confirm those of Passe et al. (2007) that most runners underestimate their sweat losses, with no differences between genders. This is likely due to runners only considering sweat losses retained in clothing and on the skin’s surface and not accounting for evaporated sweat. One of the most important findings of this study was that more than 75% of our runners did not consider or were unaware that changes in body mass could be used to determine sweat loss. Of equally important note, runners who reported frequently monitoring their sweat losses using this technique failed to more accurately estimate their sweat losses than those who did not. Conversations with runners revealed that these errors were likely due to errors made when calculating sweat losses, such as not considering fluid intake during runs and postrun weight measurements taken in sweaty clothing. Greater awareness and dissemination of information on how to accurately assess sweat losses could lead to development of more appropriate hydration strategies, giving runners objective numbers on which to base their during- and between-bouts fluid-intake goals. Future research is warranted to determine if sweat-loss estimations would differ for runners in arid or cold climates and for other athletic populations.

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References


