View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by TopSCHOLAR

International Journal of EXERCISE SCIENCE

ORIGINAL RESEARCH

Hot Training Conditions Inhibit Adequate Ad Libitum Recovery Fluid Intake of Runners

BRETT A. DAVIS†‡[1,2], ERIC K. O'NEAL‡[3], SAMANTHA L. JOHNSON†‡[1], and RICHARD S. FARLEY‡[1]

[1]Department of Health and Human Performance, Middle Tennessee State University, Murfreesboro, TN, USA; [2]Department of Kinesiology, Auburn University at Montgomery, Montgomery, AL, USA; [3]Department of Health, Physical Education and Recreation, University of North Alabama, Florence, AL, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 12(6): 1322-1333, 2019. This study examined voluntary fluid intake, hydration descriptors, and sweat loss estimation accuracy following runs in wet bulb globe temperatures of 18 (TEMP) and 26 °C (HOT). Twelve male runners completed 1-h runs at 65% of $VO_{2\,max}$ with access to water during runs and a variety of beverages for the following 24-h. Urine specific gravity (USG), body mass, fluid intake, and urine output were assessed at 12 and 24-h. Runners lost 1.355 ± 0.263 and 1.943 ± 0.485 L during TEMP and HOT, respectively. Sweat loss volume was underestimated by approximately one-third during both conditions. Cumulative fluid intake from start until 1-h post-run was greater in HOT, but not at 12-h (2.202±0.600 vs 2.265±0.673 L) or 24-h (3.602±0.807 vs 3.742±1.205 L). Runners replaced a lower percentage of sweat losses and displayed higher USG ($p < 0.001$) for HOT (119±34%; 1.027±0.004) versus TEMP (166±51%; 1.018±0.004) at 12-h while exhibiting repeatable rehydration patterns within runners (ICC = 0.89) between trials. Absolute body mass was unable to differentiate the substantial differences in fluid replacement percentage. Seven runners replaced <125% of sweat losses (3 replaced < 90%) at 12-h. All seven of these runners had USG levels exceeding 1.025 at 12-h post-run. This data provides additional confirmation that most runners will underestimate sweat loss volume, but ad libitum fluid intake between runs is likely sufficient for most runners. The exception may be runs in the heat with ≤ 12 h recovery. Repeated pre-run USG values that meet or exceed 1.025 may help identify runners that chronically fail to rehydrate effectively and need structured fluid replacement strategies.

KEY WORDS: running, thirst, hydration, urine specific gravity

INTRODUCTION

Runners experience considerable sweat losses during training, but the nature of distance running makes both transporting and consuming fluids challenging. As such, runners tend to drink minimally during runs even in hot environments (6, 14, 18). This factor makes restoration of fluid balance between exercise bouts crucial for maintaining optimal performance when runners train in the heat. To promote pre-exercise euhydration, the current American College of

Sports Medicine (ACSM) guidelines (25) recommend beverage fluid replacement equaling 150% of sweat losses during recovery if training bouts are separated by less than 12 h.

Multiple investigations have documented ad libitum fluid intake patterns and changes in hydration status among elite East African runners training multiple times per day in cool to temperate (16 - 20 °C) environments (1, 9, 10, 22). The general consensus of these investigations was that the elite runners maintained day-to-day hydration status during training with ad libitum food and fluid consumption. Both Leiper et al. (15) and O'Neal et al. (18) also found voluntary fluid intake was sufficient to maintain total body water or meet ACSM recovery fluid replacement guidelines for non-elite runners training in cool to temperate conditions. In contrast, Davis and colleagues (5) reported 10 of 13 participants considered fluid replacement equaling 150% of sweat losses incurred during a 75 min run in hot and humid conditions (WBGT ~26 °C) over a 12-h recovery period to be considerably greater fluid consumption than they would choose to drink ad libitum.

Together this evidence suggests current guidelines (25) promoting recovery fluid replacement equaling 150% of sweat loss volume are likely adhered to with ad libitum fluid intake for runners training in cool environments, but that natural thirst stimulus may not promote this level of beverage consumption when training occurs in the heat. Therefore, the focus of the current investigation was to describe voluntary fluid intake behavior patterns at 12 and 24-h following 1 h runs in temperate and hot environments. It was hypothesized that natural thirst stimulus of runners would fail to elicit a beverage fluid consumption volume equaling 150% of sweat losses as currently suggested (25) following runs in the hot condition by 12 hours post-run. Secondary aims of this study were to determine if urine specific gravity (USG) could detect runners with inadequate recovery fluid intake and assess if runners estimate their sweat losses differently based on training environment.

METHODS

Participants

Twelve recreationally competitive male runners (22 ± 2 y) completed all study procedures. All participants reported regularly competing in organized recreational races and reported completing ≥ 3 training sessions per week lasting one hour or longer. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (17). This project was approved by the Middle Tennessee State University Institutional Review Board. Experimental procedures were explained thoroughly to participants and written consent was obtained prior to testing.

Protocol

Participation entailed completion of a screening visit and completion of two experimental trials in a counterbalanced order. All trials were performed on separate days. During both experimental trials participants completed 1 h of treadmill running at wet bulb globe temperatures (WBGT) of 18 °C (TEMP) or 26 °C (HOT). Ad libitum fluid intake volume, body mass, urine production, and USG were assessed at 12 and 24 h after each running bout.

Upon arrival to the laboratory for the screening visit all participants completed an informed consent, a pre-participation health screening, and a training history questionnaire. Height (176 ± 5 cm) (Model 222, SECA Corporation, Hamburg, Germany) and body mass (77.8 ± 6.6 kg) (Health-o-Meter, Professional Model 770, Hamburg, Germany) were measured, and percent body fat (12.3 ± 2.2%) was estimated using the 3-site (chest, abdomen, thigh) skinfold (Lange, Cambridge, MD) method (12) during the initial session. Participants then completed a $VO_{2\,max}$ test. Maximal oxygen consumption ($VO_{2\,max}$ = 52.1 ± 3.6 ml.kg-1.min-1) was assessed via indirect calorimetry (MOXUS system, Applied Electrochemistry, Pittsburgh, PA) during an incremental treadmill test to volitional exhaustion (11).

All experimental trials were completed between September and January in the Southeastern United States. Each treatment session was separated by a minimum of 5 days but no more than 14 days. Participants were instructed to avoid alcohol consumption and strenuous physical activity for 24 h prior to each laboratory visit. Participants were also instructed to consume 500 mL of water 2 h before and 500 mL of water 1 h before each visit to ensure arrival in a euhydrated state. Upon arrival to the laboratory investigators verbally confirmed that participants had consumed these prescribed volumes of water and abstained from exercise the previous day. Participants arrived at the laboratory between 4:00 and 6:00 pm for their treatment sessions and provided a urine sample for the assessment of pre-exercise USG via an automated refractometer (PEN-Urine S.G., Atago, Tokyo, Japan). Nude body mass was then measured, and participants changed into their running attire. A heart rate monitor (RS 800, Polar Electro Kempele, Finland) was fitted to each participant and recorded heart rate continuously.

Environmental chamber temperature (Model HT30 Heat Stress Meter, Extech Instruments, Waltham, MA) was recorded every 15 min with the intentions of maintaining WBGT of ~18 °C and 26 °C for TEMP and HOT respectively. The HOT WBGT was selected to replicate local early morning or late evening summer environmental conditions (5, 19). Each running session lasted 60 min with a running pace (9.5 ± 0.8 km/h) selected that would elicit 65% of $VO_{2\,max}$. One-minute breaks were given at minutes 15, 30, and 45. Participants were offered a 250 mL aliquot of chilled water during each break. The treadmill was stopped to reduce risk of falling and allow for easier fluid consumption breaks that might be taken during a non-competition run in a hot environment. Upon completion of exercise participants exited the environmental chamber and sat quietly for 10 min to allow for post-exercise sweat losses to attenuate. No fluids were provided to participants during this 10 min period. Participants then undressed, removed instrumentation, and toweled off before a second nude body mass assessment. Sweat loss was calculated as the difference between pre and post-exercise body mass with adjustment for fluid volume consumed during the run and voids made following first body mass assessment.
Following these procedures, participants were asked to make an estimation of their sweat loss volume. Participants were presented with two, 3.79 L containers of water and a large stack of 237 mL paper cups. Participants were instructed to fill the cups, using the larger containers, with a volume of water believed to be equivalent to the volume of sweat lost during the run. After filling the cups, participants placed the cups on a digital scale (KD-200, Tanita Corporation, Tokyo, Japan) and were informed of their estimated sweat loss volume. If desired, participants were allowed one opportunity to adjust their estimated sweat loss volume.

Following attainment of all post-exercise measurements, participants were presented with a variety of pre-weighed, chilled beverages including: sodas, sport drinks, juices, and water. All bottled beverages were manufacturer sealed. A variety of beverages, rather than a standardized rehydration beverage, were provided to participants to enhance ecological validity. Participants were allowed to take as many bottled beverages as they thought they would consume before arriving back at the laboratory the next morning (i.e. 12-h post-exercise). Participants were not restricted to selecting only one beverage type and were instructed to not be conservative when choosing number of bottles. Additionally, investigators emphasized that runners could consume as much beverage from each bottle as desired and were not expected to finish a bottle just because it was opened. Participants were provided a labeled bag and asked to place the bottles of all drinks consumed within the first hour post-exercise in the labeled bag so that fluid consumption during the first hour of recovery could be assessed. Participants were instructed to place the bottles of all drinks consumed between 1-h and 12-h post-exercise into a separate bag so that fluid consumption between 1-h and 12-h post-exercise could be assessed. Change in bottle mass upon return to the laboratory was used to quantify fluid intake volume.

Participants were instructed to consume only fluids provided by investigators. The consumption of coffee, tea, milk and alcohol were prohibited as investigators could not account for their consumption. Participants were also provided a food log and asked to document all foods consumed over the 24 h following exercise. To control for dietary intake participants were instructed to consume the same diet over the 24 h following each running session. Urine collection containers were also provided to participants so that urine void volume could be calculated.

Participants returned to the laboratory the following morning post-breakfast (7:00 - 9:00 am) for assessment of ~12 h post run change in body mass, urine voids, and fluid consumption volume. Upon arrival participants completed a form stating only fluid provided by investigators was consumed, all food consumed was documented, all urine voids were collected, and no strenuous activity was performed during the 0–12 h time period. Prior to measurement of nude body mass, a non-first morning urine sample was collected for assessment of USG and weighed for consideration in total urine losses. Change in urine collection containers and drink bottles mass was assessed for determination of 12 h post-run urine losses and fluid intake volume. Before leaving the laboratory, participants chose a new set of chilled drink bottles to consume during the 12 h to 24 h post-exercise time period. Participants were to collect the bottles of all drinks consumed between 12 h and 24 h post-exercise so that fluid consumption during this time period could be assessed. Participants were provided with a new urine collection container to use until returning to the laboratory approximately 24 h after initiation of their running session the previous day. The same procedures were performed.

Statistical Analysis

All data was analyzed using International Business Machines Corp. Statistical Packages for the Social Sciences (Version 19.0) software. Paired samples t-tests were used to determine if differences existed for dependent variables between TEMP and HOT trials during the same time points (e.g. body mass for TEMP versus HOT at hour 12). Intraclass correlation (ICC) was used to assess the relationship between fluid intake volume by percentage at 12 and 24 hours. All data are presented as mean ± SD. An alpha level of 0.05 was used for all analyses.

RESULTS

All runners reported with a pre-exercise USG < 1.020 with no differences (p = 0.62) between treatments. The average wet bulb globe temperature (TEMP = 18.1 ± 0.2 °C; HOT = 25.5 ± 0.4°C) and average heart rate (TEMP = 157 ± 9 bpm; HOT = 168 ± 9 bpm) both differed between treatments (p < 0.001). Absolute sweat losses incurred during the 1 h running bout equaled 1.355 ± 0.263 L (1.73 ± 0.27% body mass) for TEMP and 1.943 ± 0.485 L (2.47 ± 0.50% body mass) for HOT (p < 0.001). Despite significant differences in sweat losses, cumulative fluid consumption only differed during the running bout and at 1-h post run but not at 12 or 24 hours (Figure 1).

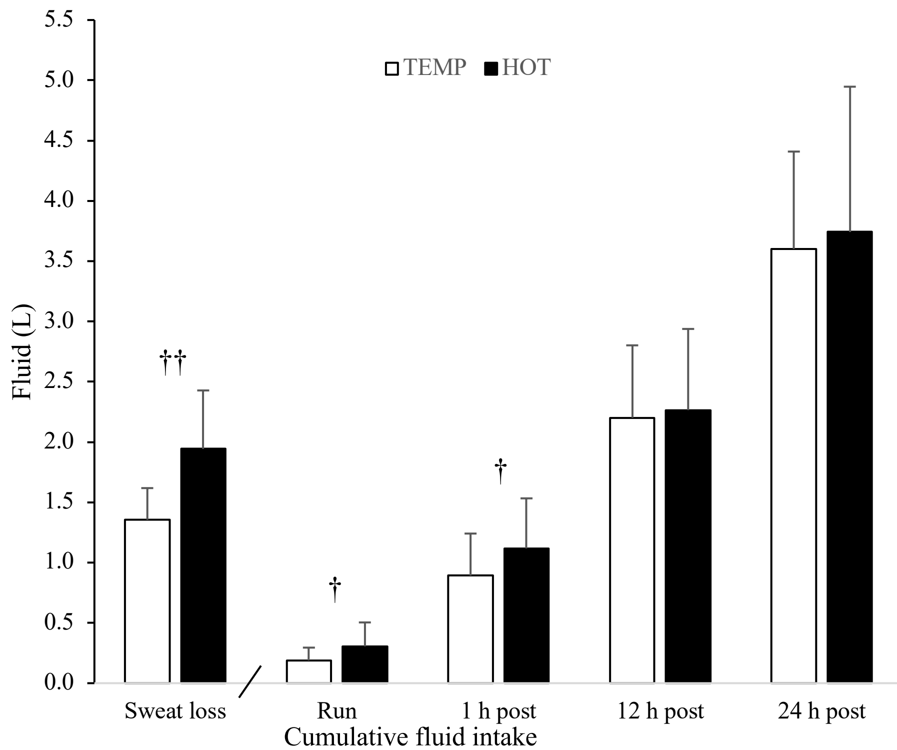

Figure 1. Cumulative absolute fluid intake volume by time point. Exercise induced sweat loss data has been included for comparison. † = p < 0.05. †† = p < 0.001.

Body mass differed at no time points between treatments, and urine volumes were similar at 12 and 24-h (Table 1). When change in total body water was calculated based on sweat loss, urine production, and fluid intake, both treatment means were negative at 12 hours with HOT resulting in a lesser return to pre-exercise levels (p = 0.005), but no difference at 24 hours (p = 0.21) (Table 1). Cumulative fluid replacement did not differ during the run (p = 0.44) but was greater (p < 0.001) at 12 and 24 hours for TEMP (Table 1). Fluid preference was nearly identical between trials with water, soda, juice, and sports drinks accounting for 35%, 15%, 10%, and 40% during TEMP and 36%, 16%, 9%, and 39% during HOT, respectively. While there were great inter-individual differences in ad libitum fluid intake, runners displayed a strong relationship between percent of sweat loss replaced between trials at both 12-h (ICC = 0.89; $p < 0.001$; Figure 2) and 24-h (ICC = 0.84; $p = 0.003$; Figure 3). USG increased in both groups with greater differentiation for HOT versus TEMP at 12-h ($p = 0.001$) versus 24-h ($p = 0.014$) (Table 1).

Table 1. Hydration marker shifts across time ($n = 12$; mean ± SD).

	Pre-run	12-hours	24-hours
USG			
TEMP	1.009 ± 0.006	1.018 ± 0.004††	1.017 ± 0.006†
HOT	1.007 ± 0.004	1.027 ± 0.004	1.021 ± 0.004
Body mass (kg)			
TEMP	78.2 ± 6.8	77.9 ± 6.8	78.2 ± 6.6
HOT	78.2 ± 6.7	77.6 ± 6.7	78.0 ± 6.7
Urine voids (L)			
TEMP	--	0.936 ± 0.353	1.601 ± 0.644
HOT	--	0.898 ± 0.332	1.453 ± 0.430
Fluid replacement (%)			
TEMP	15 ± 10**	166 ± 51††	271 ± 64††
HOT	16 ± 11**	119 ± 34	198 ± 57
Change in TBW* (L)			
TEMP	--	-0.167 ± 0.541††	0.761 ± 0.839
HOT	--	-0.582 ± 0.298	0.345 ± 0.702

*TBW = change in total body water based on sweat loss, beverage fluid intake, and urine losses. Respiratory tract evaporation, fecal matter water losses, and moisture contained in foods are not considered in this calculation.
**This data represents sweat loss fluid replacement percentage from water consumed during the run.
†† = comparisons of the same timepoint with $p < 0.001$; † = comparisons of the same timepoint with $p < 0.05$.

There were no differences in sweat loss estimation accuracy based on percentage when comparisons were made between running trials ($p = 0.77$). Runners displayed trends of underestimating their sweat losses following running in both TEMP (818 ± 307 mL; 62 ± 25% of actual losses) and HOT (1,198 ± 550 mL; 65% ± 35% of actual sweat losses) trials. There was no difference between estimation accuracy by percentage between treatments ($p = 0.83$). Two runners (different runners in each treatment) overestimated their sweat losses in each treatment, while 7 and 8 participants underestimated their sweat losses by 40% or greater during TEMP and HOT respectively.

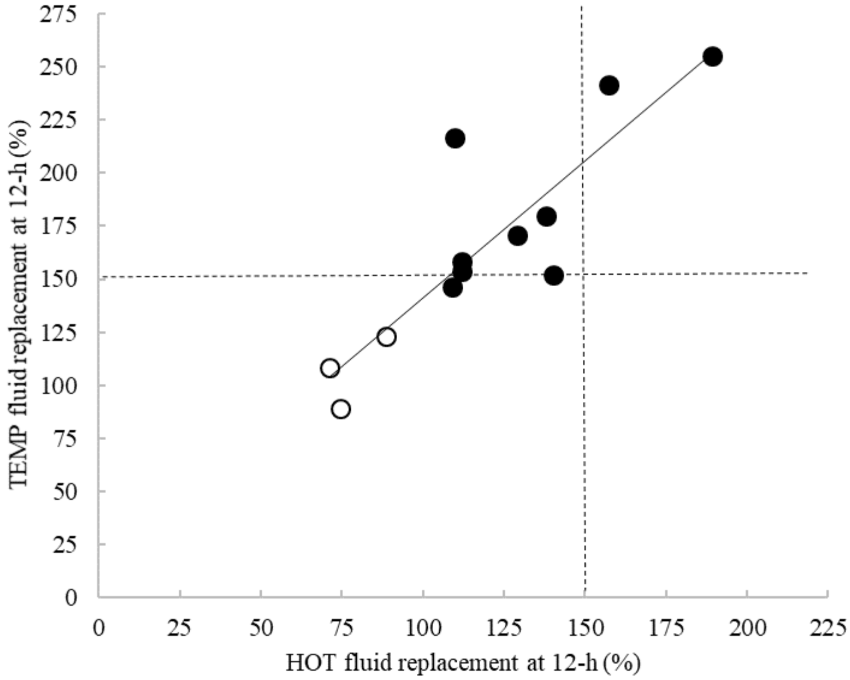

Figure 2. Scatterplot for fluid replacement volume by percentage of sweat loss at 12 hours (intraclass correlation = 0.89; $p < 0.001$). Markers with no fill represent the 3 participants who failed to adequately rehydrate. Dashed lines represent 150% fluid replacement as suggested by ACSM guidelines (25).

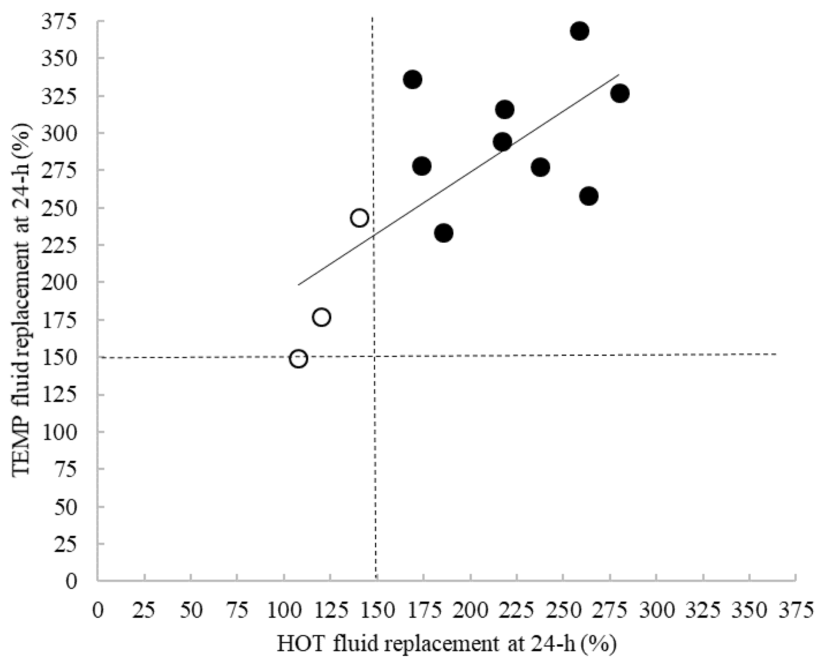

Figure 3. Scatterplot for fluid replacement volume by percentage of sweat loss at 24 hours (intraclass correlation = 0.84; $p = 0.003$). Markers with no fill represent the 3 participants who failed to adequately rehydrate. Dashed lines represent 150% fluid replacement as suggested by ACSM guidelines (25).

DISCUSSION

It is well established that male runners drink minimally during both training and competition regardless of environmental conditions. However, the focus of most past studies regarding runners' hydration behaviors have centered on fluid intake during running alone (7, 14, 26). Additionally, when post-run hydration behavior studies have been conducted, observation windows have typically only lasted 1-6 h and often include unrealistic bolus fluid intake volumes (8). The primary objective of this investigation was to evaluate voluntary fluid intake behavior and fluid retention of recreational runners over ~24 h following 1 h runs of the same pace in TEMP versus HOT environments that would result in greater sweat losses. This is the first study the current authors are aware of that has examined ad libitum intake across environmental training conditions and included a within subject design. Special consideration was given to the 12-h time period as it is common for runners training twice per day to complete runs in the morning and evening. The main finding of this study was that despite a short-term period of increased fluid intake during and immediately after exercise in HOT, runners failed to increase absolute fluid intake over levels consumed during TEMP at either 12 or 24-h (Figure 1). This data indicates a considerable percentage of male runners training in the heat for 1 hour will not meet ACSM (25) recommendations of replacing 150% of sweat loss volume with fluid from beverages if training bouts are separated by 12 h or less. The sweat losses and subsequent fluid intake of runners in this study also indicate that current recommendations (25) to maintain less than 2% loss in body mass will not be achieved during runs of ≥ 1-h in hot environments even under ideal circumstances (i.e. runners were allowed multiple 1-min breaks to consume chilled water that did not have to be transported). More importantly, the strong correlations between sweat loss replacement percentage following TEMP versus HOT at both 12 and 24 hours suggests that runners' recovery fluid intake behavior is predictable, and runners that fail to rehydrate consistently between training bouts (Figure 2) may be identifiable using simple and cheap USG assessments.

A key point of contention is that for the most part, conclusions concerning hydration behavior have often been drawn from group, not individual data, excluding the most critical information for the smaller percentage of outliers that are actually affected by poor hydration habits. Three participants (25% of sample), represented by unfilled markers in Figures 2 & 3, demonstrate some runners will fail to match sweat losses with fluid intake during HOT (89%, 71%, and 75% of sweat losses replaced) 12-h post-exercise. All three runners had fluid deficits of > 0.85 L at 12 hours based on fluid intake and urine production volume. This trend was replicated during TEMP with the same runners again exhibiting the three lowest replacement volumes (123%, 108%, and 89% of sweat losses replaced). Previous evidence confirms that these individuals are a minority, but not an anomaly, in the running community (5, 18). Recognition of this population of "chronic hypo-hydraters" are likely to go undetected when only central tendency data is reported. Inadequate recovery fluid intake levels replicated by nearly a quarter of the participants in the current study suggest hindered subsequent training capacity is likely (5).

The basic components of thirst, salt appetite, and fluid retention following intracellular dehydration are well understood. Loss of intracellular osmolality and hypovolemia serve as the primary and secondary signals for release of arginine vasopressin, aldosterone, and angiotensin II resulting in an increased drive to both consume and retain fluids and sodium, while temporarily increasing vasoconstriction until a return to homeostasis is reached. More detailed explanations for the mechanisms involved with thirst and salt appetite are available (3, 13); however, why such variance in fluid intake patterns exists between athletes is unknown but tangibly evident in Figures 2 & 3. Only recently have investigators examined possible dipsogenic-related polymorphisms influence on voluntary fluid intake. Unfortunately, these studies have only observed fluid replacement during exercise and do not give any confirmation on recovery fluid intake behavior responses. Saunders et al. (24) separated finishers of Ironman distance triathlons by race body weight loss and found mixed results concerning genotype expression and fluid intake behavior. However, the authors of this study question that pre-planned hydration strategies (21) versus simple ad libitum fluid intake likely make it difficult to determine if genotype expression alone can explain differences in fluid intake or if the triathletes were drinking to schedule versus ad libitum. An additional investigation found no influence of angiotensin converting enzyme or bradykinin receptor β2 genotype expression on fluid intake during 1-h of cycling in the heat (28).

Although chilled fluids were offered at multiple short breaks during the running session, participants only consumed fluid at a volume equal to roughly 15% of their sweat losses during exercise (Figure 1). This data supports two separate investigations in which non-elite runners consumed similar volumes of water during 1-hour outdoor runs with similar drinking opportunities in temperate (18) or hot (19) environments and matches fluid intake rate in relation to body mass losses for male half-marathon runners competing in hot and humid race conditions (14). Elite African runners are unlikely to drink at all during training (1, 9, 22), and elite male marathoners are estimated to lose as much as 10% body mass during competition (2). Cumulatively, these findings help reinforce our position that between running bouts fluid consumption, not fluid consumption during running, is the most critical time phase for optimizing hydration status of runners. The percentage of sweat loss replaced following TEMP at 12-h (Table 1) was nearly identical to the 171 ± 40% reported under similar conditions by our research group in the past (18), suggesting that even when twice-a-day training is occurring no intervention is likely needed for runners training for 1 h or less in environments without significant heat stress.

It has been contended (3, 4) that traditional urinalysis techniques used by athletes and practitioners in the field (e.g. USG or urine color) lack validity in identifying hydration status unless first morning voids are used. However, Wilcoxson, Johnson, Pribyslavska, Green and O'Neal (27) reported mean USG differed by ~0.010 units for both waking and post-breakfast voids following an evening run that induced 3% body mass when low versus moderate recovery fluid intake strategies were incorporated. Combining data from multiple studies where USG was assessed 10 - 14 hours post runs in the heat, USG displayed excellent diagnostic accuracy at detecting adequate recovery fluid replacement intake when sweat losses exceeded 3% body mass (20). The outcomes in the current study provide additional support that USG can be useful in identifying runners that begin subsequent training bouts with inadequate recovery fluid intake. It is important to note that the 12-h urine specimens presented in the current study were intentionally collected after participants' self-selected breakfast and were not first morning voids (i.e. more likely to be considered less valid than a first morning void). Mean values in Table 1 clearly reflect the fluid intake and concomitant USG responses of the runners, but examination of individual data is required to display the true utility of spontaneous USG sample analysis. Eleven participants were able to provide urine specimens at all time-points. Of those, 9 replaced 140% or less of their sweat losses following HOT at 12 hours. All 9 of these runners exhibited USG values ≥ 1.025. The runners with the three lowest fluid replacement volumes by percentages at each time point and described above exhibited USG of 1.029, 1.029, and 1.031 during HOT and 1.023, 1.026, and 1.024 during TEMP. Furthermore, the participant with the lowest fluid intake by percentage at all measurement points had a USG of 1.029 at 24-h during TEMP after replacing only 149% of total sweat losses. All other participants had USG values below 1.025 at 24-h following TEMP.

It is well established that change in pre to post-exercise body mass is the most accurate method of determining post-exercise fluid needs. However, without a relatively accurate estimation of sweat loss through acute change in body mass assessment, current fluid intake guidelines (16, 25) are of little value to runners. Despite the importance of this fact, and that previous investigations have shown runners overwhelmingly underestimate their sweat losses under hot (19) or temperate conditions (18, 23), we are unaware of these observations being considered in any major hydration guidelines including the most recent by the National Athletic Trainer's Association (16). Poor perception of sweat loss volume is not surprising as O'Neal and colleagues (21) found less than 3% of 276 non-elite half- or full-marathon runners reported assessing change in body mass as a measure to determine hydration status. The current findings continue to support these past investigations with most runners underestimating their sweat losses by more than half. The current investigation is unique in that it is the first to confirm these findings while using a within-subject design while training environment served as the independent variable. The three runners that were least effective at rehydrating adequately underestimated their sweat losses by 45 - 83% during HOT. This is important as all three runners met or approached their recommended fluid replacement needs based on their perceived, but not actual, sweat loss volumes.

Despite great inter-individual differences, the percentage of sweat loss runners will replace during recovery is repeatable across environments, and an ad libitum fluid intake threshold will result in a contingency of runners failing to rehydrate effectively when training is separated by 12 hours or less in hot environments. Runners and coaches may utilize repeated USG measures and incorporate a pre-run goal USG of < 1.025 to determine which athletes' natural thirst drives do not promote adequate recovery fluid intake volume. For at risk runners, assessments in acute body mass change and a physical representation of sweat losses may help increase awareness of their true fluid needs. The study has multiple limitations. Only recreationally competitive trained male runners were evaluated, and coffee, tea, milk, and other commonly consumed fluids were not provided as beverage options. Additionally, participants may have potentially increased their fluid intake if they were actually running at 12 and 24 hours. However, it should also be noted that recovery fluid intake may have also been mitigated by the required 1-liter water consumption commenced in the 2 hours prior to running. Future research warrants examining if female athletes and individuals who spend extended periods of time in the heat (e.g. military personnel, wildland firefighters, and industrial workers) exhibit similar fluid replacement threshold patterns following significant sweat losses.

REFERENCES

1. Beis LY, Willkomm L, Ross R, Bekele Z, Wolde B, Fudge B, Pitsiladis YP. Food and macronutrient intake of elite ethiopian distance runners. J Int Soc Sports Nutr 8:7, 2011.

2. Beis LY, Wright-Whyte M, Fudge B, Noakes T, Pitsiladis YP. Drinking behaviors of elite male runners during marathon competition. Clin J Sport Med 22(3):254-261, 2012.

3. Cheuvront SN, Kenefick RW. Dehydration: Physiology, assessment, and performance effects. Compr Physiol 4(1):257-285, 2014.

4. Cheuvront SN, Kenefick RW, Zambraski EJ. Spot urine concentrations should not be used for hydration assessment: A methodology review. Int J Sport Nutr Exerc Metab 25(3):293-297, 2015.

5. Davis BA, Thigpen LK, Hornsby JH, Green JM, Coates TE, O'Neal EK. Hydration kinetics and 10-km outdoor running performance following 75% versus 150% between bout fluid replacement. Eur J Sport Sci 14(7):703-710, 2014.

6. Dion T, Savoie FA, Asselin A, Gariepy C, Goulet ED. Half-marathon running performance is not improved by a rate of fluid intake above that dictated by thirst sensation in trained distance runners. Eur J Appl Physiol 113(12):3011-3020, 2013.

7. Dion T, Savoie FA, Asselin A, Gariepy C, Goulet ED. Half-marathon running performance is not improved by a rate of fluid intake above that dictated by thirst sensation in trained distance runners. Eur J Appl Physiol 2013.

8. Evans GH, James LJ, Shirreffs SM, Maughan RJ. Optimizing the restoration and maintenance of fluid balance after exercise-induced dehydration. J Appl Physiol 122(4):945-951, 2017.

9. Fudge BW, Easton C, Kingsmore D, Kiplamai FK, Onywera VO, Westerterp KR, Kayser B, Noakes TD, Pitsiladis YP. Elite kenyan endurance runners are hydrated day-to-day with ad libitum fluid intake. Med Sci Sports Exerc 40(6):1171-1179, 2008.

10. Fudge BW, Westerterp KR, Kiplamai FK, Onywera VO, Boit MK, Kayser B, Pitsiladis YP. Evidence of negative energy balance using doubly labelled water in elite kenyan endurance runners prior to competition. Br J Nutr 95(1):59-66, 2006.

11. Hanson NJ, Berg K, Deka P, Meendering JR, Ryan C. Oxygen cost of running barefoot vs. Running shod. Int J Sports Med 32(6):401-406, 2011.

12. Jackson A, Pollock ML. Practical assessment of body composition. Phys Sport Med 13:76-90, 1985.

13. Johnson AK. The sensory psychobiology of thirst and salt appetite. Med Sci Sports Exerc 39(8):1388-1400, 2007.

14. Lee JK, Nio AQ, Lim CL, Teo EY, Byrne C. Thermoregulation, pacing and fluid balance during mass participation distance running in a warm and humid environment. Eur J Appl Physiol 109(5):887-898, 2010.

15. Leiper JB, Carnie A, Maughan RJ. Water turnover rates in sedentary and exercising middle aged men. Br J Sports Med 30(1):24-26, 1996.

16. McDermott BP, Anderson SA, Armstrong LE, Casa DJ, Cheuvront SN, Cooper L, Kenney WL, O'Connor FG, Roberts WO. National athletic trainers' association position statement: Fluid replacement for the physically active. J Athl Train 52(9):877-895, 2017.

17. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1):1-8, 2019.

18. O'Neal EK, Caufield CR, Lowe JB, Stevenson MC, Davis BA, Thigpen LK. 24-h fluid kinetics and perception of sweat losses following a 1-h run in a temperate environment. Nutrients 6:37-49, 2014.

19. O'Neal EK, Davis BA, Thigpen LK, Caufield CR, Horton AD, McIntosh JR. Runners greatly underestimate sweat losses before and after a 1-hr summer run. Int J Sport Nutr Exerc Metab 22(5):353-362, 2012.

20. O'Neal EK, Johnson SL, Davis BA, Pribyslavska V, Stevenson-Wilcoxson MC. Urine specific gravity as a practical marker for identifying suboptimal fluid intake of runners approximately 12-hr postexercise. Int J Sport Nutr Exerc Metab 29:32-38, 2019.

21. O'Neal EK, Wingo JE, Richardson MT, Leeper JD, Neggers YH, Bishop PA. Half-marathon and full-marathon runners' hydration practices and perceptions. J Athl Train 46(6):581-591, 2011.

22. Onywera VO, Kiplamai FK, Boit MK, Pitsiladis YP. Food and macronutrient intake of elite kenyan distance runners. Int J Sport Nutr Exerc Metab 14(6):709-719, 2004.

23. Passe D, Horn M, Stofan J, Horswill C, Murray R. Voluntary dehydration in runners despite favorable conditions for fluid intake. Int J Sport Nutr Exerc Metab 17(3):284-295, 2007.

24. Saunders CJ, de Milander L, Hew-Butler T, Xenophontos SL, Cariolou MA, Anastassiades LC, Noakes TD, Collins M. Dipsogenic genes associated with weight changes during ironman triathlons. Hum Mol Genet 15(20):2980-2987, 2006.

25. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American college of sports medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 39(2):377-390, 2007.

26. Tam N, Nolte HW, Noakes TD. Changes in total body water content during running races of 21.1 km and 56 km in athletes drinking ad libitum. Clin J Sport Med 21(3):218-225, 2011.

27. Wilcoxson MC, Johnson SL, Pribyslavska V, Green JM, O'Neal EK. Fluid retention and utility of practical hydration markers to detect three levels of recovery fluid intake in male runners. Int J Sport Nutr Exerc Metab 27(2):178-185, 2017.

28. Yau AM, Moss AD, James LJ, Gilmore W, Ashworth JJ, Evans GH. The influence of angiotensin converting enzyme and bradykinin receptor b2 gene variants on voluntary fluid intake and fluid balance in healthy men during moderate-intensity exercise in the heat. Appl Physiol Nutr Metab 40(2):184-190, 2015.