JENB
Exercise Nutrition & Biochemistry

ORIGINAL PAPER

Effects of active drinking practices on fluid consumption and sweat rate while exercising in a hot environment

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Youn Sun Son, Bong Yeon Hwang, Dae Taek Lee and Yoon Jung Bae. Effects of active drinking practices on fluid consumption and sweat rate while exercising in a hot environment. *JENB*., Vol. 18, No. 2, pp.215-223, 2014 **[Purpose]** To examine the effects of active drinking practices on fluid consumption and sweat rate while exercising in a hot environment. **[Methods]** Nine men completed two experiments. Each consisted of 3 phases: pre-testing (pre), training period, and post-testing (post). During testing, the subjects ran on a treadmill at a moderate intensity for 90 min at $39 \pm 1\,^\circ\!C$ followed by a 3-h recovery. They drank *ad libitum*. During training, they ran for 90 min for 7 days while either drinking actively (AH, 150% of weight loss) or passively (PH, 50% of weight loss). **[Results]** The actual volume consumed in training was three times greater during AH than during PH. In post during AH, the volume of drinking was two times greater than pre (1592 ± 953 and 855 ± 551 mL, respectively; $p < 0.05$). No difference in volume consumption during PH between pre and post was found. The sweat loss during exercise was greater in post (1377 ± 956 mL) than in pre (558 ± 642 mL) during AH ($p < 0.05$), but not during PH. Rectal temperature and heart rate decreased after training. Serum osmolality following exercise were not different than the baseline or between the conditions. **[Conclusion]** Active drinking practices while exercising in a hot environment induced greater voluntary fluid intake and sweat loss. **[Keyword]** voluntary intake, rehydration, thermoregulation

INTRODUCTION

Exercise involving muscular contraction increases body heat production over the resting state. When this extra body heat is not adequately released from the body or balanced, an elevation in body temperature is inevitable. As heat accumulates, thermoregulatory responses initiate an increase in skin blood flow and sweat production [1]. Sweating is critical in managing body thermal load via evaporative cooling, especially while exercising in a hot environment.

Sweating reduces body fluid volume, resulting in dehydration, which increases physiological strain and reduces physical capacity [1,2]. These adverse effects can be greater as the fluid deficit increases over exercise intensities [3,4]. To minimize the negative effects of dehydration, voluntary drinking to ensure a hydrated state prior to and during exercise is recommended [5].

Rehydration by drinking is beneficial for reducing thermal and cardiovascular strain, stabilizing metabolic function, and decreasing fatigue [5,6]. Thus, rehydrating to maintain body fluid volume is a concern when exercising in a hot environment. Although rehydration during exercise is recommended, individual variations in volume consumption and retention exist.

To date, several factors influencing the volume of fluid consumption and volume retention have been proposed, including the contents of carbohydrates and electrolytes within the fluid [7-10], heat acclimation status [11], age [12,13], and gender [7]. However, subjects in these previous studies were tested without experiencing both exercise stress and heat acclimation at once and/or were examined only in a laboratory setting. For example, voluntary fluid intake was measured during exercise [7,9] and recovery [10], and the volume intake was not controlled [11]. These subjects were encouraged to

drink, but the volume was not manipulated. In real life, frequent drinking during exercise and heat acclimation may occur. No reported study has investigated the impact of systemic fluid consumption training during short-term exercise and heat acclimation with a prescribed volume intake. Although maintaining an adequate hydration level is believed to minimize thermoregulatory instability and maximize circulatory and metabolic capability while exercising in a hot environment, it has not been clearly demonstrated whether an active habitual drinking practice during training could modify voluntary drinking during subsequent exercise in a hot environment.

This study was designed to investigate the impact of habitual fluid drinking practices while exercising and to evaluate the impact of heat stress on subsequent drinking volume while exercising in a hot environment. It was hypothesized that an active drinking practice would elicit greater fluid consumption and sweat rate versus a non-active drinking condition when fluid intake was allowed *ad libitum*.

METHODS

Study design

A cross-over study design was used. Subjects participated in two experiments with identical procedures but different drinking interventions: 1) active hydration (AH) and 2) passive hydration (PH). Each experiment consisted of three sequential phases: 1) pre-testing, 2) 10-day training period, and 3) post-testing. Before and after the two experiments, subjects underwent a screening session (Fig. 1). In the training period, subjects ran on a treadmill in a hot environment. To achieve the study goal, they were required to drink different volume during two conditions. Subjects were required to drink 1.5 times their body weight loss while exercising during AH and 0.5 times their body weight loss during PH. The order of AH and PH was balanced. The two experiments were separated by at least 3 weeks, and the experiments were conducted during the late fall and winter.

Subjects

Nine healthy young men voluntarily participated. Based on medical history, they were considered free from any pulmonary, metabolic, and orthopedic complications and had no heat illnesses. They maintained an active lifestyle but did not engage in structured exercise programs. Full study documentation and verbal explanations about the procedures involved were provided to all subjects, and they signed informed consent forms.

Pre-screening session

The subjects' physical characteristics including age, height, weight, and body fat content were measured using the bioimpedance method (InBody 520; Biospace, Korea). During at least three separate occasions prior to the testing, the subjects were familiarized with running on a treadmill. Using the modified Bruce protocol, the maximal oxygen uptake (VO_2max) of the subjects was measured while they ran on a treadmill (Q65, Quinton Instrument Co., Bothell, WA, USA). They exercised until volitional exhaustion while breathing through a breath-by-breath gas analysis system ($K4b^2$, CosMed Srl, Rome, Italy). After completion of the VO_2max test, they rested for at least 30 min or until they returned to their resting heart rate (HR). Then, they ran once again to identify the speed of the treadmill that matched the range of each individual's exercise intensity (55-60% of the VO_2max). Initially, the speed of treadmill was set to elicit ~50% of the VO_2max prediction; additionally, it was adjusted every 3 min to match the target oxygen uptake (VO_2). When they could steadily match their target VO_2 for at least 56 min, the treadmill belt speed was recorded. That speed was used during testing and training.

Pre- and post-testing

At 3 days after the pre-screening session, pre-testing was conducted. On the day of testing, subjects reported to the laboratory after a 10-h overnight fast. They were asked to void completely, and a urine sample was collected. Their
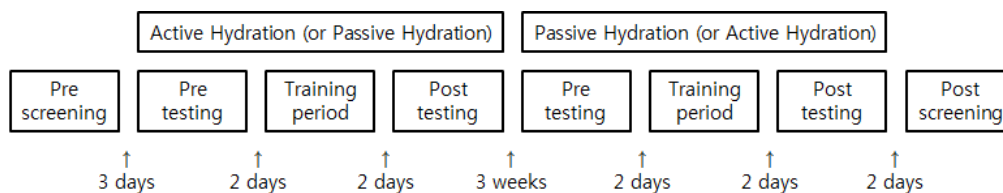

Fig. 1. Illustration of the study design

naked body weight was measured using a scale (150A, CAS, Seoul, Korea), and a rectal probe (Barnant Co., Barrington, IL, USA) was inserted 15 cm beyond the anal sphincter. Thermocouples (692-0230; Barnant Co., Barrington, IL, USA) for measuring the subjects' skin temperature were attached to three sites (chest, triceps, and thigh) using surgical tape (Micropore; 3M, St. Paul, MN, USA). An electronic HR monitor (S610; Polar Electro Oy, Finland) was strapped around the subjects' chests. Once all the equipment was adjusted, they entered a climate controlled chamber, with the temperature maintained at $39 \pm 1\,^{\circ}\!C$ with a relative humidity of $65 \pm 3\%$, and the subjects rested in a seated position for 23.3 ± 7.6 min. After they adjusted to the environment, a blood sample was taken from the antecubital vein using a disposable syringe. Then, they were asked to stand on the treadmill and begin running for 90 min at their previously determined treadmill belt speed. They were allowed to drink *ad libitum* during the testing, and they occasionally breathed through a mask for respiratory gas analysis. When they completed their exercise, all the measuring equipment was detached from their bodies, and they were dried completely. After their urine samples were collected, their naked weight was taken. Subjects walked outside the chamber and recovered for 3 h at ambient temperature $(25 \pm 2\,^{\circ}\!C)$ without any vigorous physical activity or food consumption. During recovery, their naked body weight, blood samples, and urine samples were collected during the 1st and 3rd hours. Fluid intake was allowed *ad libitum*. After testing completion, they were released from the laboratory.

Training period

Beginning 2 days after pre-testing, subjects participated in a 10-day training period where they exercised in an environment and at an exercise intensity identical to that in pre-testing. During the 90-min exercise, each subject had his own bottle filled with an assigned volume of fluid prepared by the investigators. The fluid volume to be consumed during the training period was determined during pre-testing. Subjects in AH were asked to consume a sports beverage (Gatorade Thirst Quencher) at 150% of their body weight loss while subjects in PH consumed 50% of their body weight loss. One-third of the target fluid volume was provided every 30 min of training. When they did not consume the amount provided within the time period, the leftover was discarded. Although the amount and time frame for beverage consumption was decided for each subject, they were encouraged to drink continuously. Within 2 days after training period completion, they underwent post-testing.

Post-screening session

After the experiments were completed, subjects underwent a second screening session, and the VO_2max was evaluated.

Measurements and calculations

From height and weight, the body mass index $(kg \cdot m^{-2})$ and body surface area (m^2) were calculated [14]. All body weights were measured with accuracy of 10 g. All urine samples were used for volume measurement and urine specific gravity (USG) using a digital refractometer (UG-1; Atago, Tokyo, Japan). Rectal temperature (Tre) and each skin site temperature (Tsk) were monitored continuously using a thermocouple scanner (Barnant Co., Barrington, IL, USA) and were recorded at 5-min intervals. The mean Tsk was calculated by appropriately weighing the individual's Tsk, 0.43 (chest Tsk) + 0.25 (triceps Tsk) + 0.32 (thigh Tsk) [15]. The mean body temperature (Tb) was calculated as 0.73 Tre + 0.27 mean Tsk [16]. During the testing, HRs were recorded every 5 min. The target volume of fluid consumption during the training was determined during pre-testing of each experiment. For this, the body mass difference between the baseline and at the end of the exercise was calculated with a correction for fluid volume consumed and voided. From this value, the relative amount of the individual beverage volume was calculated, and the value was considered as sweat loss. During testing, the fluid volume consumed, volume voided, and weight changes were calculated to estimate the sweat rate (SR), expressed in $mL \cdot kg^{-1} \cdot h^{-1}$.

Blood samples were collected using a 10-mL sterilized disposable plastic syringe and were immediately transferred to a clot activator tube (Green Vac-Tube; Green Cross MS Corp., Yongin, Korea). The serum was separated using a centrifuge (HA-1000-3; Hanil Science Co., Incheon, Korea) for 7 min and was analyzed for total proteins using a blood chemistry analyzer (Ektachem DT60 II; Johnson & Johnson, New Brunswick, NJ, USA). Serum osmolality was measured in triplicate by using the freeze-point depression osmometer (Micro-osmometer Model 210; Fiske Associates, Norwood, MA, USA), and the average value of the three reading was taken.

During exercise in the testing, the rating of perceived exertion (RPE; 11-point scale, 0-10), thirst sensation (11-point scale; 0: no sensation to 10: extremely thirsty), and heat sensation (11-point scale; 0: no sensation to 10: extremely hot) were asked and evaluated at the 15th and 90th minutes of exercise.

Statistical analyses

Data reduction was performed. Temperature variables were analyzed by 15-min intervals. The HR and VO_2max were analyzed at the 15th, 40th, 65th, and 90th minutes during the testing. All variables are expressed as means ± standard deviation. A comparison of values between the AH and PH was made using Student's t-test. When comparing conditions (AH vs. PH) to the testing period (pre- vs. post-testing), within-subjects factorial analysis of variance with repeated measures was employed. Statistical significance was set at $p < 0.05$.

RESULTS

All subjects completed all procedures required in the study. During testing and training, they ran at a speed of 8.0 ± 0.5 $km \cdot h^{-1}$ for a distance of 11.6 ± 1.4 km. The calculated exercise intensity during testing and training was $51 \pm 3.9\%$ of VO_2max. While subjects were requested to drink the full-strength beverage, most subjects preferred half the strength of the original beverage.

The subjects' baseline physical conditions during pre-testing in the two conditions did not differ (Table 1). Body weight and body mass index did not change between pre- and post-testing during AH and PH ($p > 0.05$), but body fat content decreased in both conditions between pre- and post-testing ($p < 0.05$, Student's t-test).

The target amount of beverage intake in training during AH was approximately three times greater than that during PH (Table 2). The average volume consumed in training during AH was short of the target amount, but it was greater than

Table 1. Subjects' physical characteristics at baseline for each condition
($n = 9$)

Age (years)		24.7 ± 3.1
Height (cm)		174.8 ± 4.6
Weight (kg)		
Active Hydration	Pre-testing	72.3 ± 6.3
	Post-testing	72.2 ± 6.8
Passive Hydration	Pre-testing	73.4 ± 6.3
	Post-testing	73.0 ± 6.9
Body Surface Area (m^2)		1.88 ± 1.00
Body Mass Index ($kg \cdot m^{-2}$)		
Active Hydration	Pre-testing	23.9 ± 1.5
	Post-testing	23.8 ± 1.6
Passive Hydration	Pre-testing	24.0 ± 1.6
	Post-testing	23.9 ± 1.8
Body Fat Content (%)		
Active Hydration	Pre-testing	$14.5 \pm 3.7^*$
	Post-testing	13.7 ± 4.3
Passive Hydration	Pre-testing	$14.4 \pm 4.1^*$
	Post-testing	13.8 ± 3.9
Maximal Oxygen Uptake (O_2 mL$\cdot kg^{-1} \cdot min^{-1}$)		
Pre-screening		51.2 ± 3.6
Post-screening		50.6 ± 4.5
Peak Heart Rate (beat$\cdot min^{-1}$)		
Pre-screening		190.1 ± 11.8
Post-screening		189.3 ± 12.2

* Significant difference between the pre- and post-testing ($p < 0.05$, Student's t-test).

100% of the subjects' body weight loss. During PH, their actual consumption was short of the target amount. When the actual beverage consumption was normalized by body weight, their consumption during AH was approximately three

Table 2. Beverage consumption levels during the testing and training periods

		Active Hydration		Passive Hydration	
Training Period	Target Volume[1] (mL)	$2,402 \pm 551$		848 ± 193	
	Actual Volume[2] (mL)	$1,986 \pm 637$		712 ± 301	
	(mL$\cdot kg^{-1}$)	27.06 ± 7.81		9.63 ± 3.68	
		Pre-testing	Post-testing	Pre-testing	Post-testing
During Testing	During Exercise (mL)	$855 \pm 551^*$	1592 ± 953	$1,050 \pm 913$	$1,166 \pm 714$
	(mL$\cdot kg^{-1} \cdot h^{-1}$)	$7.90 \pm 4.89^*$	14.62 ± 7.42	9.70 ± 8.24	10.94 ± 6.28
	During Recovery (mL)	601 ± 289	823 ± 333	1073 ± 840	866 ± 719
	(mL$\cdot kg^{-1} \cdot h^{-1}$)	2.79 ± 1.29	3.88 ± 1.57	4.80 ± 3.56	3.90 ± 3.04
	Total (mL)	$1,456 \pm 637^*$	$2,415 \pm 776$	$2,123 \pm 1107$	$2,032 \pm 1058$
	(mL$\cdot kg^{-1} \cdot h^{-1}$)	$4.44 \pm 1.83^*$	7.45 ± 1.71	6.52 ± 3.20	6.13 ± 2.81

[†] Significance between active and passive hydration conditions at $p < 0.001$ (paired t-test)
* Significant between pre- and post-testing at $p < 0.05$ (2-factor, within subjects: conditions vs. testing).
[1] The target amount was calculated from weight loss (150% for active hydration; 50% for passive hydration) according to the exercise during the first pre-testing.
[2] The actual amount was the average value of beverage consumption during exercise in the training period.
The amount of beverage consumed was expressed in absolute (mL) and relative (mL$\cdot kg^{-1} \cdot h^{-1}$) terms.
For detailed procedures, refer to the methods.

Table 3. The amount of sweat loss and sweat rate during pre- and post-testing

		Active Hydration		Passive Hydration	
		Pre-testing	Post-testing	Pre-testing	Post-testing
During Testing[1]	During Exercise (mL)	558 ± 642*	1377 ± 956	798 ± 984	900 ± 807
	(mL·kg⁻¹·h⁻¹)	5.05 ± 5.86*	12.55 ± 7.49	7.26 ± 9.06	8.27 ± 7.21
	During Recovery (mL)	1,122 ± 732*	2,114 ± 719	1,668 ± 1046*	1,780 ± 1018
	(mL·kg⁻¹·h⁻¹)	5.13 ± 3.25*	9.71 ± 2.58	7.45 ± 4.41*	8.15 ± 4.28
	Total (mL)	1,680 ± 1346*	3,491 ± 1648	2,466 ± 1879	2,679 ± 1764
	(mL·kg⁻¹·h⁻¹)	5.06 ± 4.02*	10.68 ± 4.05	7.48 ± 5.56	8.12 ± 5.06

* Significant difference between pre- and post-testing at $p < 0.05$ (2-factor, within-subjects: conditions vs. testing).
[1] Sweat loss was calculated by weight changes during the designated period corrected by the beverage intake and urine loss.

Table 4. Urine specific gravity, serum osmolality, and total protein during the pre- and post-testing

	Active Hydration				Passive Hydration			
	Pre-testing		Post-testing		Pre-testing		Post-testing	
	Base	3 h Recovery	Base	3 h Recovery	Base	3 h Recovery	Base	3 h Recovery
Urine Specific Gravity (unit)	1.017 ± 0.010	1.027 ± 0.004	1.022 ± 0.005	1.023 ± 0.011	1.021 ± 0.005	1.017 ± 0.011	1.027 ± 0.005	1.025 ± 0.010
Serum Osmolality (mOsm/kg)	295.5 ± 5.3	296.0 ± 2.7	294.1 ± 3.9	296.7 ± 5.4	296.0 ± 3.4	296.0 ± 7.5	299.3 ± 4.3	297.4 ± 6.8
Total Protein (g/dL)	7.0 ± 0.6	7.3 ± 0.7	6.7 ± 0.6	7.0 ± 0.6	7.0 ± 0.6	7.0 ± 0.8	6.8 ± 0.2	7.1 ± 0.8

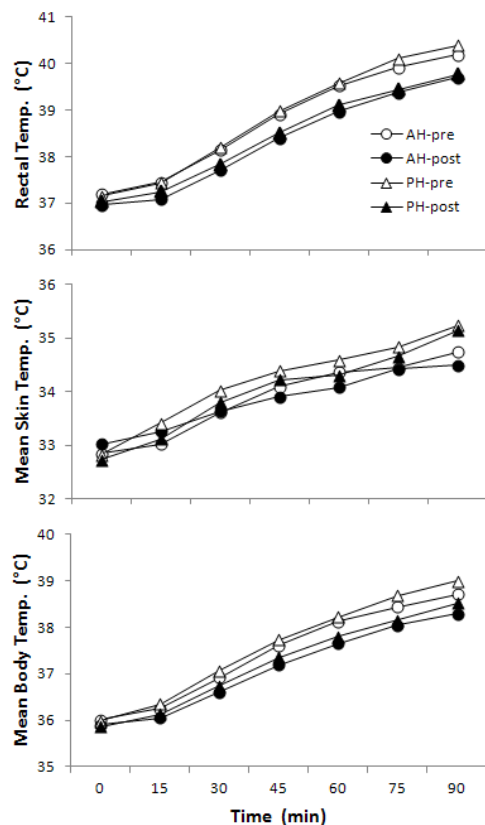**Fig. 2.** Temperature variables during pre- and post-testing in each condition (AH, active hydration; PH, passive hydration)

Fig. 3. Heart rate and oxygen uptake during pre- and post-testing in each condition (AH, active hydration; PH, passive hydration)

times greater than during PH.

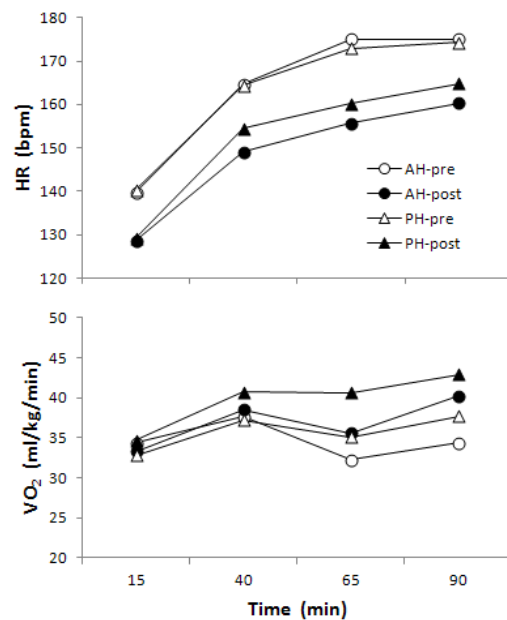While exercising in post-testing during AH, the beverage consumption was approximately two times greater than during pre-testing ($p < 0.05$, Table 2). However, the beverage consumption while exercising during PH was not statistically significantly different between pre- and post-testing. During recovery, the amount of beverage consumption was neither different between pre- and post-testing nor between the AH and PH conditions. The total amount of beverage consumption during testing was greater in post-testing than in pre-testing during AH ($p < 0.05$), but not during PH ($p > 0.05$).

Both sweat loss and sweat rate were greater in post-testing

Table 5. Psychometric variables during the pre- and post-testing

	Active Hydration				Passive Hydration			
	Pre-testing		Post-testing		Pre-testing		Post-testing	
	15th min	90th min	15th min	90th min	15th min	90th min	15th min	90th min
Rate of Perceived Exertion	1.2 ± 1.1	7.6 ± 3.4	0.9 ± 1.2	4.0 ± 2.4	1.6 ± 1.3	6.1 ± 2.1	0.8 ± 1.3	4.6 ± 2.8
Thirst Sensation	1.6 ± 1.3	6.4 ± 3.6	0.9 ± 1.2	3.3 ± 2.2	1.6 ± 1.2	5.1 ± 2.1	0.9 ± 2.0	3.4 ± 2.8
Heat Sensation	2.0 ± 1.6	7.6 ± 3.3	1.4 ± 1.1	4.7 ± 2.4	2.1 ± 1.2	6.9 ± 1.8	1.0 ± 1.4	5.1 ± 3.5

compared with pre-testing during the exercise and recovery period of AH (p < 0.05, Table 3). However, these variables were only greater in post-testing compared with pre-testing during the recovery period of PH (p < 0.05).

The final Tre during exercise in post-testing was reduced compared with that in pre-testing in both experiments, but it was not statistically significant (Fig. 2). The magnitude of the Tre elevation during exercise was $3.0 \pm 0.7℃$, $2.8 \pm 0.4℃$, $3.2 \pm 0.8℃$, and $2.8 \pm 0.8℃$ in pre-testing during AH, post-testing during AH, pre-testing during PH, and post-testing during PH, respectively, and no statistically significant difference was noted. The Tsk and Tb were also not significantly different among testing and experiments.

The HRs also decreased during exercise in post-testing compared with those in pre-testing in both experiments, but the difference was not statistically significant (Fig. 3). The magnitude of reduction of the final HR from pre-testing to post-testing was 14.7 ± 14.6 beats·min^{-1} during AH and 9.6 ± 16.4 beat·min^{-1} during PH (p > 0.05). No change was noted in the average VO$_2$max among testing and experiments.

The USG, serum osmolality, and total protein were not different at baseline or at 3 h of recovery among testing and experiments (Table 4). No psychometric variable during exercise was different among testing and experiments (Table 5).

DISCUSSION

Dehydration during exercise and heat induces performance deterioration, mainly due to thermoregulatory and cardiovascular strain. Fluid intake helps restore body fluid and fluid volume regulatory function, thereby improving physical capacity [1-3]. Thus, adequate rehydration during exercise is recommended. However, voluntary drinking during exercise, aimed at restoring fluids and regulatory function, does not always guarantee meeting the adequate volume requirement [5,22]. We hypothesized that habitual drinking practices while exercising in a hot environment may help increase voluntary volume intake during subsequent exercise and heat stress. To our knowledge, this is the first reported study examining the effects of drinking a prescribed volume during exercise with

short-term heat acclimation on fluid volume regulation. The most significant finding of the present study was that active habitual drinking practice raised the volume of voluntary drinking as well as increased the sweat rate while exercising in a hot environment. Nevertheless, no thermoregulatory or circulatory benefit from the active drinking practice compared with the non-active practice was supported statistically.

In this study, a cross-over study design was used. Subjects participated in 10 days of exercise training in a hot environment, and they ran for 90 min while being required to drink 50% (during PH) or 150% (during AH) of their body weight loss during exercise. During the 10-day program, subjects drank approximately 84% (during PH; 42% of their weight loss) and 83% (during AH; 123% of their weight loss) of their target volume. After the program, subjects were tested and allowed to drink *ad libitum* while exercising in a hot environment. The volume of voluntary drinking and the sweat rate increased significantly during AH while no change was observed during PH. In both conditions, the Tre and HR decreased, but no significant difference between the conditions was noted. Neither volume regulatory variables nor psychometric parameters differed between the conditions. Our findings suggest that short-term exercise training in a hot environment while drinking, generally, may help reduce thermoregulatory and circulatory strain. These responses were not affected by drinking volume during exercise training, at least under the conditions used in this study. However, an increased active volume drinking practice during training caused an increased voluntary drinking volume and sweat rate.

Some studies have reported that short-term heat exposure with exercise increases voluntary fluid intake [11,13]. Greenleaf *et al*. [11] reported that voluntary water intake increased from 450 mL/h on day 1 of exercise and heat stress increased to about 1,000 mL·h^{-1} on days 58. In their study, subjects were free from a target drinking volume, which was used in the present study. Zappe *et al*. [13] also reported an increased daily fluid intake while exercising in a warm environment. In the present study, subjects drank about 570 mL·h^{-1} voluntarily in pretesting and 1,061 mL·h^{-1} in post-testing during AH. By comparing the volume consumed, the active drinking practice seemed to be no more beneficial over a non-target voluntary

drinking volume. However, this previous study provided plain water for voluntary rehydration.

Although 150% of weight loss was the target volume during AH, most subjects could not meet the requirement. Despite the fact that thirst sensation increased by exercise-induced dehydration, driven by blood osmolality and angiotensin II, this may not be sufficient to promote voluntary fluid intake to match water loss [17]. Studies have shown that voluntary drinking replaced, at most, 30-70% of water loss during exercise even when fluid was readily available [9, 18-20]. One possible mechanism limiting voluntary fluid intake during exercise may be cardiopulmonary baroreceptor sensitivity [21]. The increase in volume loading due to exercising in a hot environment may stimulate the cardiopulmonary baroreceptor, resulting in suppression of the drinking desire. In his review, Noakes [22] noted that a high rate of fluid intake (> 1 L·h^{-1}) can be difficult during running and may lead to feelings of abdominal discomfort possibly due to the accumulation of unabsorbed fluid in the intestines. He also reported that most do not ingest fluid equal to the amount of fluid loss; subsequently, he proposed that drinking practices during training may reduce the severity of these symptoms. The present study supported this notion because the increased active volume drinking practice resulted in an increased volume of voluntary drinking. As mentioned above, the exercise-heat stress may have reduced cardiopulmonary baroreceptor sensitivity leading to increased fluid intake [12].

One notable observation was that subjects were reluctant to drink the full-strength sports drink while running in the heat. Numerous studies have shown that carbohydrate-electrolyte solutions are more effective than plain water for stimulating voluntary fluid intake [8,20,23,24], and promoting rapid intestinal absorption [25-27], although it is not always consistent in some populations [7,9,28]. Although a solution containing about 6% of carbohydrates is considered a sport drink, this concentration seemed to be too strong for the voluntary drinking conditions in the present study's subjects. A high concentration of a carbohydrate solution has been shown to decrease the rate of gastric emptying [29,30] and absorption [31]. Additionally, drinking the full-strength beverage might have been uncomfortable for the present study's subjects and possibly reduced gastric emptying [32]. Osterberg *et al.* [27] reported that volume retention between beverages containing 36% carbohydrate was not different. One possible factor may be drinking habits. Before the study, their usual drinking solution during exercise was plain water, instead of a full strength sports drink.

Although active drinking practices induced a higher drinking volume and sweat rate while exercising in a hot environment,

it was not advantageous over passive drinking for thermoregulatory or circulatory adjustments or psychometric responses. The general recommendation to prevent dehydration during exercise and heat stress is to prevent excessive dehydration ($> 2\%$ body water deficit) and excessive disturbance of the electrolyte balance [5]. One reason why we did not observe any difference between the two conditions may have been the severity of the dehydration. During PH, although full recovery from weight loss by exercise was not noticed, more than 40% of the subjects' body weight loss was replaced by voluntary drinking. This volume consumption may contribute to physiological and psychometric response adjustments and may subsequently allow at least a minimum adjustment to prevent dehydration. This may cause no difference between the conditions. Studies on more prolonged exercise interventions and/or severe volume restrictions during exercise may be warranted.

CONCLUSIONS

Active drinking practice while exercising in a hot environment induced greater voluntary fluid intake and sweat loss. Subjects preferred a half-strength solution of the conventional sports drink. Although they were required to drink 150% of their weight loss, they actually consumed 123% of their weight loss. There was no additional benefit from the increased volume intake in terms of thermoregulatory and circulatory adjustments or psychometric parameters, which may be due to the severity of body weight loss while exercising under the two conditions.

ACKNOWLEDGEMENTS

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