Journal of Athletic Training 2014;49(5):624–631
doi: 10.4085/1062-6050-49.3.85
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original research

Drinking to Thirst Versus Drinking Ad Libitum During Road Cycling

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Context: The sensation of thirst is different from the complex behavior of drinking ad libitum. Rehydration recommendations to athletes differ, depending on the source, yet no previous researchers have systematically compared drinking to thirst (D_{TT}) versus ad libitum drinking behavior (D_{AL}).

Objective: To compare 2 groups of trained cyclists (D_{TT} and D_{AL}) who had similar physical characteristics and training programs ($P > .05$). The D_{TT} group (n = 12, age = 47 ± 7 years) drank only when thirsty, whereas the D_{AL} group (n = 12, age = 44 ± 7 years) consumed fluid ad libitum (ie, whenever and in whatever volume desired).

Design: Cohort study.

Setting: Road cycling (164 km) in the heat (36.1°C ± 6.5°C).

Patients or Other Participants: Ultraendurance cyclists (4 women, 20 men).

Intervention(s): We recorded measurements 1 day before the event, on event day before the start, at 3 roadside aid stations, at the finish line, and 1 day after the event.

Main Outcome Measure(s): Body mass, urinary hydration indices, and food and fluids consumed.

Results: No between-groups differences were seen on event day for total exercise time (D_{TT} = 6.69 ± 0.89 hours, D_{AL} = 6.66 ± 0.77 hours), urinary indices (specific gravity, color), body mass change (D_{TT} = –2.22% ± 1.73%, D_{AL} = –2.29% ± 1.62%), fluid intake (D_{TT} = 5.63 ± 2.59 L/6.7 h, D_{AL} = 6.04 ± 2.37 L/6.7 h), dietary energy intake, macronutrient intake, ratings of thirst (D_{TT} start = 2 ± 1, D_{TT} finish = 6 ± 1, D_{AL} start = 2 ± 1, D_{AL} finish = 6 ± 1), pain, perceived exertion, or thermal sensation. Total fluid intake on recovery day +1 was the primary significant difference (D_{AL} = 5.13 ± 1.87 L/24 h, D_{TT} = 3.13 ± 1.53 L/24 h, $t_{18} = 2.59$, $P = .02$).

Conclusions: Observations on event day indicated that drinking to thirst and drinking ad libitum resulted in similar physiologic and perceptual outcomes. This suggests that specific instructions to "drink to thirst" were unnecessary. Indeed, if athletes drink ad libitum, they can focus on training and competition rather than being distracted by ongoing evaluation of thirst sensations.

Key Words: rehydration, fluids, electrolytes, urine, sport nutrition

Key Points

- Drinking to thirst (ie, focusing on the presence of thirst as the only stimulus to drink) is different from ad libitum drinking (ie, consuming fluid whenever and in whatever volume desired).
- Ultraendurance nonelite cyclists who drank to thirst or ad libitum during a 164-km event in the heat had similar physiologic and perceptual outcomes.
- These athletes can be encouraged to drink ad libitum and focus their attention on training and competition.

In recent years, the National Athletic Trainers' Association[1] and other professional organizations[2,3] have published position statements regarding fluid replacement during and after exercise. These documents uniformly agree that the goal of drinking during exercise is to prevent excessive dehydration and avoid body weight loss of ≥2% and excessive changes in electrolyte balance, which compromise performance.[1,2] However, concerns about exertional hyponatremia secondary to consuming a large volume of water have prompted some authorities[4–6] to recommend that athletes rely on their sensory perceptions and "drink to thirst." These authors assert that increased extracellular concentration triggers thirst to naturally protect athletes from the negative consequences of both excess fluid and severe dehydration.[7] In contrast to this advice, the current National Athletic Trainers' Association position statement[1] recommends that athletes drink more than thirst dictates and develop an individual plan: "Individual containers permit easier monitoring of fluid intake. Clear water bottles marked in 100-mL (3.4-fl oz) increments provide visual reminders to athletes to drink beyond thirst satiation or the typical few gulps."[1] The current American College of Sports Medicine position stand[2] also mentions nothing about drinking to thirst but states that athletes may benefit from drinking ad libitum, assuming that they begin competition euhydrated. This underscores the variability of advice that is given to athletes, depending on the source.

Although drinking to thirst (ie, using the sensation of thirst as the only stimulus to drink) is quite different from ad libitum drinking (ie, consuming fluid whenever and in whatever volume desired),[8–10] authorities[1–15] have not recognized these as distinct behaviors. For example, terminology varies among authors who publish in the field of rehydration. Some experts use the phrase *drink to thirst* synonymously with *ad libitum*[7,11,12] or a preestablished drinking plan,[6] whereas others use *ad libitum* to refer to a preestablished drinking plan.[13] Furthermore, the sensation of thirst, the desire to seek water, and the volume consumed are complex entities that are influenced by physiologic responses, sensations, preferences, cultural influences, learned behaviors, fluid characteristics, and environmental factors.[15–17] This complexity explains, in part, the present debate among experts[1–15] and suggests that instructing athletes to "drink to thirst" may or may not result in identical outcomes as advising athletes to drink ad libitum. Further complicating this debate, thirst ratings were neither measured nor reported in any of the studies cited earlier.

In an attempt to clarify rehydration advice to athletes, our research team conducted a field investigation during a summer ultraendurance cycling event in the southwestern United States, because no previous field investigators have systematically investigated differences between drinking to thirst and ad libitum drinking. We proposed 3 hypotheses: (1) the ad libitum drinking group (D_{AL}) would consume a larger fluid volume than the drinking-to-thirst group (D_{TT}) during the 164-km cycling event; (2) the D_{AL} would complete this event with a superior hydration status, as indicated by urinary hydration indices and body-mass changes; and (3) the D_{AL} would consume less fluid than D_{TT} on the day after this event (day +1). If we detected a difference between D_{TT} and D_{AL}, the rehydration advice offered by athletic trainers, coaches, and dietitians could be updated and clarified to recommend a specific method of drinking that results in a superior hydration status.

METHODS

Our research team selected the 164-km Hotter 'n Hell Hundred (HHH) event in 2011 because it presents to athletes unique nutritional and physiologic stresses. The HHH is held during the last week of August in Wichita Falls, Texas, when the average high temperature exceeds 35°C; also, the HHH is one of the largest single-day ultraendurance cycling events in the world. We recruited cyclists as they visited the Exposition Hall 1 day and 2 days before the HHH.

Before giving informed written consent, each cyclist attended a meeting and received written and oral descriptions of all procedures, measurements, time commitments, benefits, and risks, as approved by the university's Institutional Review Board for Human Studies. Athletes were not paid but were promised a detailed written explanation of their own data after analysis, which they subsequently received. During this meeting, test participants declared that they routinely consumed fluid using 1 of 2 methods (D_{TT} or D_{AL}, as defined above). Each participant determined which group (D_{TT} or D_{AL}) matched his or her ordinary drinking behavior and self-selected the group to join after careful discussion with the principal investigator. This allowed our research team to conduct observations without changing the preexisting drinking behaviors of either D_{TT} or D_{AL}. Because our goal was to observe the habitual drinking behaviors of cyclists as they usually occur, we did not randomly assign cyclists to D_{AL} or D_{TT}. Cyclists agreed to drink using only 1 method (D_{TT} or D_{AL}) during the 164-km cycling event, and they were reminded on event day (prerace and at each aid station) to follow this method. Cyclists were asked not to participate in the study (ie, as unpaid volunteers) if they felt that it would be impossible or very inconvenient to consume fluids using 1 technique (D_{TT} or D_{AL}) throughout the entire event.

Of the 5441 registered entrants, 74% were men and 26% were women; >99% of all starters completed the entire 164-km distance. The characteristics of the 24 participants appear in Table 1. The D_{TT} group consisted of 11 men and 1 woman; the D_{AL} group consisted of 9 men and 3 women. Times to complete 164 km did not differ ($D_{TT} = 6.69 \pm 0.89$ hours, $D_{AL} = 6.66 \pm 0.77$ hours) and demonstrated that the participants were very fit but not elite competitors. The range of ground speeds (calculated) was 20.6 to 34.2 km/h.

Participants completed a medical history questionnaire and a 30-day exercise recall, which subsequently were screened by the event medical director and the responsible investigator before event day. The 30-day exercise questionnaire surveyed the number of training sessions, as well as the exercise intensity and the duration of each session. Exclusionary criteria were inadequate recent training, current musculoskeletal injury, or a history of either exertional heat stroke or exercise heat intolerance. All persons enrolled in this study had previously completed at least one 160-km cycling event.

After providing written informed consent, each cyclist also completed a questionnaire that assessed fluid-consumption behaviors and hydration plans for the event. We designed this novel paper questionnaire (Table 2) specifically for the field study and required participants to circle 1 of the 5 responses: 1, *strongly disagree*; 2, *disagree*; 3, *neutral*; 4, *agree*; 5, *strongly agree*. Based on the question "I drink only when I am thirsty" and a discussion with an investigator, each cyclist agreed to consume fluid during the 164-km endurance event using 1 of 2 methods: drinking either only when thirsty or ad libitum. During this discussion, each cyclist verified which method he or she habitually used during previous ultraendurance cycling events. The D_{TT} group was instructed and agreed to rely solely on the sensation of thirst to dictate fluid consumption. The D_{AL} group was not given any instructions regarding drinking behavior.

We did not provide food or water to participants or offer advice or instructions to participants about planning or execution of race strategies or food and fluid intake. However, on event day, athletes were reminded to drink only when thirsty (D_{TT}) or ad libitum (D_{AL}), as they previously had agreed. The D_{TT} group agreed to rely solely on the sensation of thirst to dictate fluid consumption. In

Table 1. Participants' Characteristics

Characteristic[a]	Group Drink to Thirst (n = 12)	 Drink Ad Libitum (n = 12)
Men/women	11/1	9/3
Age, y	44 ± 7	47 ± 7
Height, cm	174.8 ± 7.0	175.0 ± 8.1
Pre-event body mass index[b]	26.1 ± 3.1	28.0 ± 4.5
Body fat, %	16.1 ± 4.3	18.2 ± 5.9
Training time in past 30 d (h/wk)	6.8 ± 4.3	8.7 ± 4.5
Training sessions in past 30 d (rides/wk)	3.0 ± 1.5	3.3 ± 1.2
Rating of perceived exertion during training in past 30 d	14 ± 2	14 ± 2
Event-day total exercise time, h[c]	6.69 ± 0.89	6.66 ± 0.77
Average ground speed, km/h[c]	24.96 ± 3.74	24.95 ± 2.93
Event-day (6.7-h) energy expenditure[d]		
MJ	10.7 ± 1.5	10.8 ± 1.3
Kcal	2547 ± 366	2576 ± 310

[a] The groups were similar for all demographic characteristics ($P > .05$).
[b] Body mass values appear in Table 3.
[c] Total finish time minus time at aid stations, estimated as 30-min total.
[d] Using the overground cycling method of Swain et al.[19] Oxygen consumption was calculated from the ground speed and body mass of each rider and then was converted to energy expenditure (Kcal = L/min × 5) by considering the total exercise time for each participant.

contrast, the D_{AL} group was instructed to consume fluids as desired and in the quantity desired.

Physiologic Variables

On day –1, we recorded each participant's age to the nearest year. We measured each person's height by having him or her stand against a tape measure that was attached to a wall. Body mass was measured with a floor scale, accurate to ±100 g. Body mass index was calculated as body mass (kg) divided by height squared (m^2). Body fat was estimated by using skinfold calipers to measure the thickness at 3 sites (men: quadriceps, chest, abdomen; women: quadriceps, suprailiac, triceps); we applied prediction formulas that were appropriate for sex and age.[18]

We calculated energy expenditure during exercise using an overground cycling method[19] that incorporated the ground speed (km/h) and body mass of each cyclist to derive the rate of oxygen consumption (L/min). Considering the elapsed time, oxygen consumption was then converted to Kcal (MJ). Because all participants stopped at 3 aid stations along the course, the calculations for ground speed and energy expenditure incorporated an estimated 10 minutes for rehydration and data collection at each aid station.

Diet Records

During the 24 hours before the event (day –1), cyclists recorded all food and fluid that were consumed during meals and snacks, using written and oral instructions that a registered dietitian provided at the preparticipation briefing. Cyclists recorded details such as the number, volume, size, brand, manufacturer, and method of preparation; they submitted nutrition labels and packages when possible. On the morning of the HHH, an investigator reviewed the day –1 diet records (plus the morning meal and pre-event snacks) for completeness in the presence of each cyclist. During the event, at the 3 aid stations (52 km, 97 km, and 136 km), and at the finish line (164 km), an investigator interviewed each cyclist to verify individual foods and fluids consumed between aid stations. We provided each cyclist with 2 plastic bottles (known capacity of 592 mL each) that were labeled with external volume-demarcation lines. When a cyclist arrived at each aid station, the investigator visually examined his or her plastic bottle to determine the amount consumed to the nearest 3 mL (0.1 ounce); this volume and all gels, bars, and solid foods the cyclist reported ingesting were recorded. An investigator then refilled each bottle to capacity and returned it to the cyclist. After riding the entire event, cyclists recorded all fluids and solid foods consumed during the remainder of the day. On day +1, each cyclist again recorded all food and fluids consumed and then mailed the record to an investigator. Dietary records were analyzed by selecting individual food items from a commercial software database (version 1.2; Nutritionist Pro, N-Squared Computing, Salem, OR).

Table 2. Athletes' Responses Regarding Drinking Behaviors and Hydration Planning on Day –1

Questionnaire Item[a]	Group Drink to Thirst (n = 12)	 Drink Ad Libitum (n = 12)
I have an established drinking plan.	3.8 ± 1.0	4.0 ± 0.7
I usually drink as much as I can.	2.5 ± 0.8	3.2 ± 1.3
I drink when I sense that I am dehydrated.	3.3 ± 1.4	3.5 ± 1.3
I drink only when I am thirsty.[b]	4.0 ± 0.9	1.8 ± 0.6

[a] 1 = *Strongly disagree*, 2 = *disagree*, 3 = *neutral*, 4 = *agree*, 5 = *strongly agree*.
[b] Between-groups difference (t_{11} = –7.38, $P < .001$).

Table 3. Body Mass and Urinary Variables, Mean ± SD[a]

Variable	Group	Prerace (0 km)	Aid Station 1 (52 km)[b]	Aid Station 2 (97 km)	Aid Station 3 (136 km)	Finish (164 km)
Body mass, kg[c]	D_{TT}	81.52 ± 11.64[d]	80.49 ± 11.85	80.69 ± 12.02	80.61 ± 12.14[e]	79.74 ± 11.75[e]
	D_{AL}	87.45 ± 16.83[d]	86.71 ± 16.75	85.45 ± 17.30	86.01 ± 16.54[e]	85.42 ± 16.81[e]
Urine volume, mL[f]	D_{TT}	144 ± 46	166 ± 97	196 ± 129	134 ± 47	91 ± 42
	D_{AL}	170 ± 100	228 ± 84	170 ± 61	133 ± 56	164 ± 52
Urine specific gravity[c]	D_{TT}	1.018± 0.007	1.014 ± 0.008[f]	1.017 ± 0.007	1.019 ± 0.007[g]	1.022 ± 0.007[d]
	D_{AL}	1.022 ± 0.008	1.016 ± 0.010[f]	1.019 ± 0.008	1.021 ± 0.008[g]	1.026 ± 0.009[d]
Urine color[c]	D_{TT}	3 ± 1	4 ± 2	4 ± 2	5 ± 1[h]	6 ± 2[h]
	D_{AL}	4 ± 2	4 ± 2	4 ± 2	5 ± 2[h]	6 ± 2[h]

Abbreviations: D_{AL}, drink ad libitum group; D_{TT}, drink to thirst group.

[a] No between-groups differences were detected for any variable.

[b] Participants voluntarily stopped at 3 aid stations for research measurements, elimination, drinking, and eating.

[c] Main effect of time ($P < .001$) but no main effect of group or significant interaction.

[d] Different from all other means (within-group P values = .01 to .00005).

[e] Different from 0 km and 52 km ($P = .04$ to $P < .001$).

[f] Different from 0 km ($P = .01$ to $P = .006$).

[g] Different from 52 km ($P = .01$).

[h] Different from 0 km, 52 km, and 97 km ($P = .02$ to $P < .001$).

Data-Measurement Sites

On day −1, each participant received written and oral instructions regarding the procedures and measurements that would occur at 5 data-collection points. Measurements were taken at the same 5 locations for all cyclists: at the main medical tent (0 km, before the event), at 3 aid stations on the course (52, 97, and 136 km), and at the finish line (164 km) in the same medical tent used before the race started. Data sheets and rating scales were identical at all sites.

On event day before the 7:00 AM start, participants reported to a medical tent near the starting line, located in the center of Wichita Falls, Texas, where investigators recorded baseline measurements of body mass and perceptual ratings. Digital floor scales (model DS44L; Ohaus Corporation, Florham Park, NJ) had a precision of ±100 g. A urine sample was collected in a clean, transparent sample cup and analyzed for specific gravity (handheld refractometer, model 300CL; Atago Co, Ltd, Tokyo, Japan) and urine color (ie, the sample was held over a sheet of white paper and compared with a color chart[20]). An investigator then gave participants an oral description of the physiologic and perceptual measurements that would be taken that day at each data-collection site.

At the aid stations (52, 97, and 136 km), located on rural roads surrounding Wichita Falls, Texas, investigators measured body mass (with the participants wearing the same clothing as at the starting line), urine specific gravity, urine color, and 4 perceptual ratings. Investigators requested that cyclists provide a urine sample at each observation point, but some were unable to do so. Body weight scales at all locations were newly purchased and manufactured by the same company. All scales were compared before the event to ensure consistency (±200 g). Urine color was evaluated as described above. Investigators used identical refractometers at each aid station to assess specific gravity; refractometers were calibrated before the event, using distilled water, per the manufacturer's instructions. When urinating, cyclists counted the duration to completely empty the bladder in seconds for an estimate of urine volume; this method was developed by Peterson and Webster.[21] Immediately before they mounted bicycles and proceeded toward the next data-collection site, cyclists were instructed to remember all food and fluid they consumed during the next event stage and to drink according to the prearranged method (D_{TT} or D_{AL}).

The investigators administered 4 perceptual scales (all relevant to prolonged endurance exercise in a hot environment) at the starting line, at 3 aid stations on the course, and at the finish line. These consisted of an 8-category rating of thermal sensation,[22] a 9-point rating of thirst,[23] a 6- to 20-point rating of perceived exertion,[24] and a 10-category pain rating scale.[25]

After completing the entire 164-km distance, cyclists reported to the medical tent near the finish line. Urine was collected and analyzed as described above. All other physiologic and perceptual variables (which had been measured previously at the starting line), including diet records, were repeated.

Statistical Analyses

All data are presented as mean ± SD. Analysis of variance (ANOVA; group × data-collection point) with repeated measures on data-collection point were applied to all variables that were measured on event day at the starting line, the 3 aid stations, and the finish line on day −1, event day, and day +1. We used a *t* test for noncorrelated samples to compare group means (D_{TT} or D_{AL}) of variables measured once (eg, personal characteristics, training history, total ride time; Table 1). Although we believe that separating the data on the basis of sex is informative and unique, we did not compare data for the men and women across data-collection points or between sexes, due to the small number of women participants.

Sample size was calculated before the study on the basis of the variability in body mass loss. We conservatively estimated that the variation in body mass loss was approximately 10% and that the day-to-day between-subjects variation was approximately 50%. Subsequently, the retest correlation (r) or reliability of our outcome measure was calculated as $50^2 - 10^2 / 50^2$ or $2500 - 100 / 2500$ or 0.96. For this experimental design, which involves pre-event and postevent measurements for each person, the minimal sample size to detect a significant difference ($P < .05$) was calculated using the following equation: $n = (1 - r)$

Table 4. Total Fluid, Energy, and Electrolytes Cyclists Consumed on 3 Consecutive Days[a]

			Event Day			
Dietary Component	Group	All Meals on Day −1	Early Morning, Before Event	During 164-km Ride	After Event	All Meals on Day +1
Total fluid intake, mL[b]	D_{TT}	5005 ± 1999	761 ± 834	5630 ± 2585	2114 ± 802	3127 ± 1526[c]
	D_{AL}	6025 ± 2742	853 ± 573	6041 ± 2371	2949 ± 981	5137 ± 1860[c]
Total energy intake						
MJ	D_{TT}	9.7 ± 1.8[d]	2.8 ± 1.4	6.7 ± 3.4	7.3 ± 2.0	10.0 ± 3.0
	D_{AL}	13.2 ± 2.4[d]	3.0 ± 1.1	6.7 ± 3.2	9.2 ± 3.2	12.8 ± 4.3
Kcal	D_{TT}	2324 ± 438[d]	660 ± 323	1608 ± 803	1729 ± 440	2390 ± 719
	D_{AL}	3157 ± 568[d]	676 ± 287	1598 ± 761	2199 ± 773	3059 ± 1035
Carbohydrate, g	D_{TT}	343 ± 82	99 ± 61	346 ± 189	186 ± 63	279 ± 80
	D_{AL}	380 ± 114	112 ± 42	315 ± 145	203 ± 82	349 ± 128
Sodium, mg	D_{TT}	3465 ± 1228[e]	687 ± 316	2841 ± 1520	2489 ± 1221	3057 ± 1185
	D_{AL}	5218 ± 1248[e]	762 ± 406	4579 ± 2841	2756 ± 1281	4299 ± 1591
Potassium, mg	D_{TT}	1804 ± 673[f]	978 ± 692	1836 ± 1118	1752 ± 907	2401 ± 973
	D_{AL}	3320 ± 971[f]	1312 ± 863	1391 ± 963	2273 ± 1445	3314 ± 1430

Abbreviations: D_{AL}, drink ad libitum group; D_{TT}, drink to thirst group.

[a] Computed using commercial nutrition analysis software (see Methods section).

[b] Total fluid consumed as water, beverages, and in solid foods.

[c] Between-groups difference ($t_{18} = 2.59$, $P = .019$).

[d] Between-groups difference ($t_{18} = 3.71$, $P = .002$).

[e] Between-groups difference ($t_{18} = 3.15$, $P = .005$).

[f] Between-groups difference ($t_{18} = 4.12$, $P < .001$).

N / 2 or n = (1 − 0.96) 400 / 2 = 8, where N = (32 / effect size^2) / 2, and effect size was 0.2.

RESULTS

The local meteorologic station reported environmental conditions on event day each hour from 7:00 AM to 5:00 PM. The mean dry-bulb temperature was 35.5°C ± 6.5°C, ranging from 25.6°C at 7:00 AM to 42.2°C at 5:00 PM. The mean relative humidity was 29% ± 16%; it ranged from 17% at 3:00 PM to 58% at 8:00 AM. The mean wet-bulb globe temperature was 30.8°C ± 1.9°C, with a range from 27.8°C at 7:00 AM to 32.7°C at 12:00 PM. Cloud cover throughout the event day was 0% to 5%.

Responses regarding drinking behaviors and hydration plans of both groups are shown in Table 2. Only 1 item distinguished D_{AL} from D_{TT} ($t_{11} = -7.38$, $P < .001$): the practice of drinking only when thirsty. This finding verifies that the method of drinking, before this investigation, was different in D_{TT} and D_{AL}.

The following variables (seen in Table 3) exhibited a main effect of time but no main effect of group and no significant interaction, as indicated by ANOVA: urine specific gravity ($F_{1,4} = 12.41$, $P = .01$), urine color ($F_{1,4} = 11.22$, $P < .001$), and body mass ($F_{1,4} = 23.81$, $P < .001$). Thus, urine concentration and water loss increased during the 6.7-hour event. The mean (±SD) body masses of D_{TT} and D_{AL} decreased similarly from the start to the finish ($D_{TT} = -1.78 \pm 1.47$ kg, $D_{AL} = -2.03 \pm 1.36$ kg). All participants lost less than 3.8% of body mass except 2 in D_{TT} (–4.7%, –5.3%) and 1 in D_{AL} (–6.5%). Estimated urine volume[21] showed a similar trend ($F_{1,4} = 2.30$, $P = .08$) but no significant effect of time or group or significant interaction (Table 3).

The ANOVA of the 4 perceptual ratings, all relevant to endurance exercise performance, revealed main effects of time during the 6.7 hours of exercise in a hot environment, as expected: thermal rating[22] ($F_{1,4} = 23.81$, $P < .001$), thirst rating[23] ($F_{1,4} = 23.81$, $P < .001$), rating of perceived exertion[24] ($F_{1,4} = 23.81$, $P < .001$), and pain rating[25] ($F_{1,4} = 23.81$, $P < .001$). The values at the starting line (0 km) and the finish line (164 km), respectively, were $D_{TT} = 4.5 \pm 1.0$ and 6.5 ± 0.5 and $D_{AL} = 4.5 \pm 0.5$ and 6.5 ± 0.5 for thermal rating, $D_{TT} = 2 \pm 1$ and 6 ± 1 and $D_{AL} = 2 \pm 1$ and 6 ± 1 for thirst rating, $D_{TT} = 7 \pm 2$ and 16 ± 3 and $D_{AL} = 7 \pm 1$ and 16 ± 2 for rating of perceived exertion, and $D_{TT} = 0 \pm 0$ and 2 ± 3 and $D_{AL} = 0 \pm 0$ and 3 ± 3 for pain rating. All intermediate values measured at 3 aid stations along the course (52, 97, and 136 km) increased progressively. The D_{TT} and D_{AL} groups rated all perceptual sensations similarly at all time points ($P > .05$).

Quantities of fluid, energy, and electrolytes consumed on 3 consecutive days are presented in Table 4. On day –1, food energy (MJ and Kcal) consumed by D_{AL} was greater ($t_{18} = 3.71$, $P = .002$) than that consumed by D_{TT}. Similarly, on day –1, D_{AL} ingested more sodium ($t_{18} = 3.15$, $P = .005$) and potassium ($t_{18} = 4.12$, $P < .001$) than D_{TT}. On event day and day +1, D_{TT} and D_{AL} consumed similar amounts ($P > .05$) of all fluid, energy, and electrolytes except that total fluid intake on day +1 (ie, the day after exercise) was greater for D_{AL} (5137 ± 1860 mL) than for D_{TT} (3127 ± 1526 mL; $t_{18} = 2.59$, $P = .02$).

DISCUSSION

In recent years, authorities[4–7,26] have recommended that athletes drink to thirst to avoid illness related to the fluid overload that could occur with ad libitum drinking while claiming no effect on exercise performance. However, this advice may be oversimplified or invalid because (1) no previous authors have systematically investigated physiologic or performance differences between drinking to thirst and ad libitum drinking, (2) these behaviors are not identical,[8–10] and (3) the sensation of thirst, the drive to seek water, and drinking behavior are complex entities that are influenced by many intrinsic and extrinsic factors.[9,15–17,23] In consideration of these facts, we observed 2 groups of ultraendurance cyclists (D_{TT} n = 12, D_{AL} n =

12) during a 164-km road event in a 36.1°C ± 6.5°C environment. These groups were similar in personal characteristics, 30-day training history, and exercise performance (Table 1) but were different in their usual, preferred method of drinking (Table 2). We hypothesized that D_{AL} (versus D_{TT}) would consume more fluid on event day, finish with a better hydration status, and consume less fluid on the day after the HHH (day +1). Our field observations (Tables 3 and 4) indicated that these 3 hypotheses were not supported.

Variables that have been used by numerous investigators to assess hydration status and perception are shown in Table 3.[1,2,20] Although we found no between-groups differences, we detected main effects of time for body mass, urine specific gravity, and urine color. This indicated that D_{TT} and D_{AL} had similar hydration states throughout the 164-km event. Ratings of thirst, thermal sensation, perceived exertion, and pain also increased across time.

Dietary constituents that are relevant to physiologic function, optimal hydration, and exercise performance appear in Table 4. On event day, both groups of cyclists consumed similar quantities of fluid, energy, and electrolytes during the pre-exercise early morning hours, the entire "century ride" (100 mi [164 km]), and the hours after the event. The fact that participants carried items on their bicycle frames and in jersey pockets ensured consistent and free access to fluids, gels, and solid food for both groups of cyclists.

On day +1, contrary to our third hypothesis, D_{AL} consumed 2 L more fluid than D_{TT}. We believe it is unlikely that plasma osmolality differences (not measured) stimulated this greater fluid intake because thirst ratings ($D_{TT} = 2 \pm 1$ pre-event and 6 ± 1 postevent, $D_{AL} = 2 \pm 1$ pre-event and 6 ± 1 postevent), body mass changes (Table 3), and fluid intakes (Table 4) were similar for D_{TT} and D_{AL} on event day. Instead, we interpret this finding to represent a difference in volitional-hedonic drinking behavior; that is, cyclists in the D_{AL} group perceived that they should drink more on day +1 and did so. This agrees with measurements taken on the day before the 164-km ride (day –1) in that the food energy (MJ and Kcal) consumed by D_{AL} was greater than the energy consumed by D_{TT} (Table 4). The D_{AL} also ingested more sodium and potassium than D_{TT} on day –1. Thus, although D_{TT} and D_{AL} had similar demographic characteristics and 30-day training programs, D_{AL} volitionally consumed more food and fluids on the day before and the day after riding 164 km.

Comparison of Different Cycling Events

Our research group[27] recently published the results of field observations at the 2008 HHH event. The men who participated in that study were nonelite cyclists who rode the same course in a similar environment (temperature = 34.4°C ± 5.0°C, cloud cover 0% to 5%) but at a slower pace (2008: 17.9 km/h, 2011: 24.96 km/h). The findings of the 2008 study indicated that 33 men underconsumed food energy (2.2 MJ or 521 Kcal, representing an energy deficit of 10.9 MJ or 2594 Kcal), carbohydrate (106 g), and sodium (852 mg) before and during the event (5:30 AM to 4:00 PM). In contrast, Table 4 shows that the 24 cyclists who rode the 2011 HHH consumed approximately 4.3 times more energy (9.5 MJ or 2265 Kcal) and carbohydrate (427–445 g), as well as approximately 4 to 6 times more sodium (3528 to 5341 mg) and potassium (2703 to 2914 mg) during a similar segment of the day (5:30 AM to 2:00 PM). Furthermore, the total volume of water consumed in 2008 (5.91 L/9.1 h, n = 33) was similar to the fluid intakes of D_{TT} (5.63 L/6.7 h, n = 12) and D_{AL} (6.04L/6.7 h, n = 12) in 2011, even though the latter athletes accomplished this in 2.4 hours less. Thus, the cyclists who rode 164 km at a slower pace in 2008 consumed a similar volume of fluid but less energy, carbohydrates, sodium, and potassium, perhaps because faster competitors developed a prerace nutritional plan to optimize performance. This also supports the concept of Robins and Hetherington[28] that faster recreational cyclists have better nutrition knowledge and superior on-course nutritional provisions than slower competitors. It also suggests that the fluid and food consumption of cyclists within a large field of competitors varies with experience and race pace. For example, elite cyclists in the Tour of Spain consumed an average of only 1.3 L/d of fluid while covering 500 km across terrain that included 2 mountain stages in 3 days.[29] Clearly, the elucidation of these differences among cyclists of varying abilities deserves future research.

By their very nature, field studies usually contain more limitations than controlled laboratory experiments. We acknowledge the following limitations in our investigation. First, because we took our measurements during the HHH event, the external validity of these findings is limited to ultraendurance cyclists. Second, because cyclists traversed a 164-km road course, it was impossible for us to inquire about the motivation and method of drinking after each aliquot consumed. We took each cyclist at his or her word, using an honor system. Nevertheless, it is possible that some individuals did not follow the pre-established drinking instructions (ie, appropriate to their group) at all times. Third, the use of archived meteorologic data from 1 location in Wichita Falls, Texas, did not represent the exact environmental conditions at all points along the 164-km road course. Fourth, urine volume was estimated by instructing cyclists to count the seconds required to empty the bladder. Although this method has been validated via videographic analysis,[21] the error of the method is undoubtedly greater than that of volumetric or gravimetric methods. Fifth, we could not control the temporal proximity of fluid intake to measurements of thirst. Sixth, cyclists experienced mean body mass losses of 2.22% (D_{TT}) and 2.29% (D_{AL}) at the finish line. These levels of dehydration are minor compared with some sporting activities. It is possible that the responses of groups D_{TT} and D_{AL} would be different at greater levels of body water loss. Seventh, the mean age of test participants was 44 ± 7 years and 47 ± 7 years for the D_{TT} and D_{AL} groups, respectively. Advanced age may influence the sensitivity to thirst, as observed in adults who were older than 65 years.[30] However, several groups[31–34] have reported no influence of age on thirst or ad libitum water intake. Thus, our results may or may not be relevant to considerably older or younger athletes. Eighth, D_{TT} and D_{AL} were predominantly men. A few publications suggest that the drinking behavior of women differs from that of men in subtle ways,[35] in part due to differences in reproductive hormones.[36] But, because few previous authors[27] have focused on women during ultraendurance exercise, the influence of sex in the present investigation is unknown.

CONCLUSIONS

Our field observations demonstrated few differences between drinking to thirst (ie, using the sensation of thirst as the only stimulus to consume fluid) and ad libitum drinking (ie, consuming fluid whenever and in whatever volume desired) during ultraendurance cycling in a hot environment. Statistical comparisons included performance time and average ground speed, hydration markers, dietary intake, and perceptual ratings. Relevant to the primary research question of this investigation, thirst ratings were similar for both groups of cyclists on day −1, at the starting line, and at the finish line. These findings demonstrate that instructions to drink when thirsty or to drink ad libitum resulted in very similar physiologic and perceptual responses in fit but nonelite recreational cyclists. This insight can be used by athletic trainers, coaches, and dietitians in that specific instructions to drink to thirst apparently are unnecessary; drinking ad libitum frees athletes to focus on training and competition rather than being distracted by regular or continuous thoughts about sensations of thirst.

It is important to note that these findings neither support nor dispute statements about the effects of drinking to thirst or drinking ad libitum (ie, compared with no drinking and drinking to maintain a euhydrated condition) on exercise performance. In fact, published data from the 2008 HHH event[27] and elite cyclists and marathon runners[12,29] suggest that the similarities of D_{TT} and D_{AL} in our investigation may not apply to slower cyclists. We recommend additional studies during competition and in other groups of athletes. For example, the relative difficulty runners experience in accessing fluids during exercise (ie, cyclists carry large fluid bottles in jersey pockets or on their bicycle frames, runners receive fluids by hand in small cups), as well as differences between ultraendurance cycling and team sports such as soccer and American football, indicate that our findings may not apply to all modes of exercise or competition.

ACKNOWLEDGMENTS

We gratefully recognize the technical contributions of Sean D. Wallace, MA, and Paula Y. S. Poh, MA. Amy McKenzie, MS, ATC, PES, provided useful suggestions regarding planned fluid consumption by athletes.

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