Consistency in Preventing Voluntary Dehydration in Boys Who Drink a Flavored Carbohydrate-NaCl Beverage During Exercise in the Heat

Boguslaw Wilk, Susi Kriemler, Heidemarie Keller, and Oded Bar-Or

Twelve 10- to 12-year-old healthy boys performed six 70-min intermittent exercise sessions (three 20-min cycling bouts at 50% VO₂ max with 5 min rest in between) over a 2-week period at 35 ± 1 °C, 50 ± 5% or 60 ± 5% relative humidity. Subjects drank grape-flavored solution with 6% carbohydrate (2% glucose, 4% sucrose) and 18.0 mmol·L⁻¹ NaCl ad libitum. Body weight (BW), heart rate, rectal temperature, thirst, and stomach fullness perception were monitored periodically. There were no differences among the six sessions in voluntary drink intake (765–902 g), hydration level (+0.75 to +1.07 %BW), sweating rate (245–263 g·m⁻²·hr⁻¹), and the other physiological and perceptual variables. A positive fluid balance was achieved in 67 out of 72 sessions. Voluntary drink intake of grape-flavored carbohydrate-NaCl beverage was consistently sufficient to prevent dehydration in 10- to 12-year-old boys during repeated exposures of exercise in the heat. This effect is likely to be achieved through a combination of physiological and behavioral mechanisms.

Key Words: rehydration, hypohydration, electrolytes, fluid intake, sweating

Voluntary dehydration in adults (9, 21) and in children (3, 4, 23) exercising in hot environments has been observed when unflavored water was given ad libitum. Several studies with adults have indicated the importance of drink content, flavor, and temperature in determining voluntary fluid consumption during exercise (1, 5, 22). In our recent study with prepubertal boys (23), ad libitum drinking of unflavored water resulted in progressive voluntary dehydration over a 3-hr period of intermittent exercise in 35 °C, 45–50% relative humidity (RH). Grape-flavored water increased the voluntary fluid intake and reduced the degree of hypohydration. Furthermore, grape-flavored beverage with 6% carbohydrate and 18 mmol·L⁻¹ NaCl increased the voluntary drinking volume by 91%, compared with unflavored water, and totally prevented voluntary dehydration.

It is unclear, however, whether the children’s voluntary drinking pattern observed in the above study was a one-time response or would remain consistent.

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during repeated sessions of exercise in the heat. There are two possible factors that might affect consistency in drinking pattern and body fluid balance. One is the process of acclimation, during which there are shifts in body fluid compartments and an increase in exercise-induced sweat losses (8, 10, 18, 19). The other potential factor is that once the novelty of a new beverage as provided in the Wilk and Bar-Or study (23) diminishes, voluntary drinking volume of the beverage might decrease.

This study, therefore, was undertaken to find out whether providing the child with a flavored carbohydrate-NaCl solution would induce a drinking volume sufficient to consistently prevent voluntary dehydration during repeated sessions of exercise in the heat. We hypothesized that, with the repeated exposures, fluid intake would become insufficient to prevent voluntary dehydration. The composition of the solution (4% sucrose, 2% glucose, 18 mmol·L⁻¹ NaCl) was similar to that found in commonly used sports drinks.

Methods

Subjects

Twelve 10- to 12-year-old healthy boys volunteered for this study. Their self-assessed pubertal rating (pubic hair) was Stage 1, 6 subjects; Stage 2, 5 subjects; and Stage 4, 1 subject. This self-assessment method was validated recently (11). All subjects were habitually involved in recreational sports, but only three boys (2 swimmers and 1 cyclist) were competitive athletes. Their morphological and physiological characteristics are presented in Table 1. The project was approved by the Ethics Research Board of the Faculty of Health Sciences.

Study Design, Protocol, and Procedures

The study, which consisted of seven visits to the laboratory, took place during the winter season. A preliminary visit was intended to explain the general purpose and procedures to the children and their parents and to obtain background information. However, the main goal of monitoring voluntary drinking was not disclosed to either child or parent. They were only told that we wanted to study the effect of repeated exposure to the heat on the child’s responses to exercise in a warm climate.

Written informed consent was obtained from the parents after the child had given verbal consent. A medical questionnaire was administered and health status

<table>
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<th>Table 1</th>
<th>Age, Morphological Characteristics, and Maximal Oxygen Uptake of the Subjects</th>
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<td>Age (year)</td>
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<tr>
<td>Mean</td>
<td>11.17</td>
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<td>SD</td>
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Note. BSA = body surface area; BW = body weight. *According to Dubois and Dubois (6).
was confirmed through an interview. Anthropometric measurements were then taken: height with a Harpenden wall-mount Stadiometer (2109 CMS Weighing Equipment, London, UK), body weight (BW) with an Ancker electro scale model UMC-600 (Ancker Scale Co., Brantford, ON, 20-g accuracy), and adiposity with a bioelectrical impedance analyzer (BIA-101A RJL Systems Inc., Clinton, MN). Maximal oxygen uptake (VO\textsubscript{max}) was assessed by an open-circuit system (Horizon Metabolic Measurement Cart, Beckman Instruments Inc., Anaheim, CA), using an all-out continuous progressive cycling test, 2 min per stage, on a cycle ergometer (Fleisch-Ergostat Universal, Metabo, Switzerland) (2). The test was terminated upon the subject’s volitional exhaustion or when he could not maintain the 50 rpm cadence, despite encouragement by the investigator. The metabolic cart was gas- and volume-calibrated prior to and following each exercise test.

The above preliminary visit was followed by six chamber-based sessions (Sessions I–VI) at 35±1°C, 50±5% RH (for some children 60±5% RH). Each 70-min session consisted of three 20-min cycling bouts at 50% VO\textsubscript{max} with 5 min rest in between. Sessions were repeated three times per week for 2 weeks. Two to 3 days separated each testing session. To decrease the likelihood of circadian variation, each child performed all sessions at approximately the same time of the day. The choice of six sessions for this study was based on a previous observation (10) that six exposures of exercise in the heat were sufficient to induce partial acclimation in children. The subjects drank grape-flavored solution with 6% carbohydrate (2% glucose, 4% sucrose) and 18.0 mmol·L\textsuperscript{-1} NaCl ad libitum in all six sessions. Grape flavor was selected based on a previous study (12) in which children of a similar cultural and geographic background preferred grape to other flavors.

On the day of each chamber session, subjects arrived at the laboratory 2 hr after a light meal. They were also asked to eat and drink regularly but to avoid salty, sweet, or caffeine-containing food or drinks on the day of the experiment. Upon their arrival to the laboratory, a short questionnaire was administered to confirm compliance with these instructions. Subjects were dressed in athletic shoes and shorts. A rectal thermistor (YSI 400 series) was inserted 8-10 cm beyond the anal sphincter (Visits I and VI only). A Sport Tester PE3000 was used to monitor heart rate (HR). The clothes and the Sport Tester were weighed just before chamber entry (Accuba scale 1200, Ancker Scale Co., Brantford, ON; 200-mg accuracy), at which time the subjects emptied their bladders.

Upon entering the chamber, subjects were shown an opaque bottle containing a beverage and were told, “This is your drink. You can drink whenever you want.” From that moment on there was no more mention of drinking or water. The bottle was positioned such that the subject could reach it easily during rest and while cycling. Drinks were served cool at the same temperature range (8–10°C) throughout the session. The volume of fluid intake was monitored periodically with an Accuba scale, although the children did not know this.

During the first 2 min in the chamber, baseline BW, HR, and (in Visits I and VI only) rectal temperature (T\textsubscript{re}) were measured. T\textsubscript{re} was taken with a Doric digital bridge system model 450 (Doric Scientific, San Diego, CA; ±0.1°C accuracy). At that stage, the initial level of two subjective variables was assessed: thirst intensity (analog scale) and perceived intensity of stomach fullness (5-category scale ranging from 1 = not full at all to 5 = extremely full). A similar approach to assessing these perceptions has been reported (13, 18). Physiological and perceptual variables were then periodically monitored throughout the chamber session. BW, thirst, and
perceived intensity of stomach fullness were measured at the beginning and at the end of each resting period. HR and \( T_e \) were measured in the middle of exercise and at the end of each exercise bout and rest period.

After the subject left the chamber, his clothes were weighed again. He voided and the urine was weighed.

**Calculations and Statistical Analysis**

The level of hydration was calculated as a percentage change from initial BW, corrected for urine output and the increase in weight of the clothes. Total sweat volume was calculated as drink intake minus net BW changes, urine output, and respiratory water loss. The latter was calculated according to Mitchell et al. (14).

The results were analyzed by a two-factor (visit, time during the session) repeated-measures ANOVA. Tukey’s HSD post hoc test was used to determine significance among mean values. A probability of .05 was taken as significant. Results are presented as mean ± SEM.

**Results**

Voluntary drink intake at each stage of the session was at a similar rate during all six visits. Total drink intake by the end of the session ranged from 765 g (Visit II) to 902 g (Visit I) with no significant differences among visits (Figure 1A). As shown in Figure 1B, BW increased progressively in the first 25 min and then leveled off at a slight overhydration state. The hydration level at the end of the session was not different among the six visits, ranging from +0.75% BW (Visit V) to +1.07% BW (Visit I).

Body fluid losses through sweat, respiration, and urine were not different among the sessions (Figure 2). On each occasion, fluid losses were lower than fluid intake, which resulted in a positive body fluid balance during all six sessions. Averaged for the session, whole body sweating rate was not different (245–263 g \( \cdot m^{-2} \cdot hr^{-1} \)) among the six sessions, nor were HR and \( T_e \) different among sessions. Initial HR was at a narrow range of 83–88 beats \( \cdot min^{-1} \). It ranged between 94 and 102 beats \( \cdot min^{-1} \) at the end of the rest periods and from 147 to 152 beats \( \cdot min^{-1} \) during the last exercise bout. \( T_e \) followed the same pattern: 37.4°C to 37.7°C at the start of the session and 38.0°C and 38.1°C at the end of the exercise bouts.

Perception of thirst intensity (Figure 3A) and stomach fullness (Figure 3B) did not differ among sessions. Thirst intensity progressively decreased over the session from 49–57% at the beginning to 31–36% at the end. This decrease in Visits I, II, III, and V was statistically significant \( (p < .05) \). Stomach fullness perception remained unchanged over each session at around Level 2 (somewhat full).

**Discussion**

This study confirms our previous observation (23) that a grape-flavored beverage with carbohydrate-NaCl content, when given ad libitum, prevents voluntary dehydration in children exercising in the heat. Furthermore, it shows that such a response is consistent when exposure to the heat is repeated several times over 2 weeks. A mild positive fluid balance was achieved in 67 out of 72 sessions. These findings did not confirm our hypothesis that, with repeated sessions, fluid intake would diminish
and not fully replenish fluid losses. The voluntary drink intake of 765–902 g per session was lower than the 1,167 g reported by Wilk and Bar-Or (23). This difference reflects the shorter duration of the sessions in the present study (3 × 20-min exercise bouts during 70 min vs. 4 × 20-min exercise bouts during 180-min sessions in the previous study). Irrespective of the protocol, however, drink intake was sufficient to prevent dehydration in these boys.

The mechanism for enhanced voluntary drinking of flavored carbohydrate-NaCl beverage compared with unflavored water may be both physiological and behavioral. The most likely physiological mechanism is that the added NaCl may have ameliorated the fall in body fluid osmolality often seen when water is used as a beverage. This, in turn, may have provided a greater stimulus to hypothalamic
osmoreceptors that triggered thirst. Such a mechanism was postulated in previous studies with adults (15, 20) and with children (3, 23). For ethical reasons, we did not obtain blood samples in the present study and therefore were not able to directly assess this effect.

As suggested by Greenleaf (7), since humans drink sometimes with no apparent physiological stimulus, a behavioral component should be sought as well. A perceptual factor that most probably played a role in this study is drink palatability. We did not monitor drink palatability per se, but our previous study (23) showed that flavoring of water, in itself, increased voluntary drinking volume 45% compared to unflavored water. The current study indicates that there was no diminution in palatability from one session to the next. We therefore suggest that novelty of the drink played no role in the high consumption reported in our previous study.

It is hard to tell whether the slightly excessive fluid consumption in the current study (yielding a 0.75–1.0% positive fluid balance) is a real “overhydration.” An alternative possibility might be that some of the beverage remained in the gastrointestinal lumen. There are no data available regarding the rates of gastric emptying and intestinal fluid absorption in exercising children. Our subjects consumed 665–773 g/hr of the drink, which is well below the maximal rate of gastric emptying and intestinal absorption in young adults (900–1,200 ml/hr) (16). Moreover, perceived stomach fullness remained low throughout each session (Figure 3). We therefore suggest that most, if not all, of the consumed beverage was probably absorbed from the gastrointestinal tract.

In conclusion, voluntary intake of grape-flavored carbohydrate-NaCl beverage was consistently sufficient to prevent voluntary dehydration in 10- to 12-year-old
Figure 3 — The perception of thirst intensity (A) and of stomach fullness (B) throughout the six sessions. *p < .05 between the initial value and at the end of the session in Visits I, II, III, and V. Vertical lines denote SEM.

boys during repeated exposures of exercise in the heat. More research is needed on the voluntary drinking patterns of girls, as well as of children who are habitually acclimatized to the heat and therefore respond to exercise with greater fluid losses than did the boys in this study.

References


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