Drink composition, voluntary drinking, and fluid balance in exercising, trained, heat-acclimatized boys

ANITA M. RIVERA-BROWN,1 RANDALL GUTIÉRREZ,1 JUAN CARLOS GUTIÉRREZ,1 WALTER R. FRONTERA,2 AND ODED BAR-OR3
1Department of Physical Medicine, Rehabilitation and Sports Medicine, Center for Sports Health and Exercise Sciences at the Alberque Olímpico, University of Puerto Rico School of Medicine, Salinas, Puerto Rico 00751; 2Department of Physical Medicine and Rehabilitation, Harvard Medical School and Spaulding Rehabilitation Hospital, Boston, Massachusetts 02114-1198; and 3Children's Exercise and Nutrition Centre, McMaster University, Hamilton, Ontario, Canada L8N 3Z5

Rivera-Brown, Anita M., Randall Gutierrez, Juan Carlos Gutierrez, Walter R. Frontera, and Oded Bar-Or. Drink composition, voluntary drinking, and fluid balance in exercising, trained, heat-acclimatized boys. J. Appl. Physiol. 86(1): 78–84, 1999.—This study examined the effects of beverage composition on the voluntary drinking pattern, body fluid balance, and thermoregulation of heat-acclimatized trained boys exercising intermittently in outdoor conditions (wet bulb globe temperature 30.4 ± 1.0°C). Twelve boys (age 13.4 ± 0.4 yr) performed two 3-h sessions, each consisting of four 20-min cycling bouts at 60% maximal aerobic power alternating with 25-min rest. One of two beverages was assigned: unflavored water (W) or flavored water plus 6% carbohydrate and 18 mmol/l Na (CNa). Drinking was ad libitum. Total intake was higher (P < 0.05) during CNa (1,943 ± 190 g) compared with W (1,470 ± 143 g). Euhydration was maintained with CNa (±0.18% body wt), but a mild dehydration resulted with W (−0.94% body wt; P < 0.05). Sweat loss, much higher than previously published for children of similar age, was similar between conditions (CNa = 1,644.7 ± 117.5 g; W = 1,750.2 ± 152.7 g). The increase in rectal temperature (CNa = 0.86 ± 0.3°C; W = 0.76 ± 0.1°C), heart rate, and all perceptual variables did not differ between conditions. In conclusion, a flavored carbohydrate-electrolyte drink prevents voluntary dehydration in trained heat-acclimatized boys exercising in a tropical climate despite their large sweat losses. Because hydration changes were minor, the thermoregulatory strain observed was similar between conditions.

LITTLE INFORMATION is available concerning the capacity of children to tolerate exercise in hot and humid environments. The majority of studies on the thermoregulatory and fluid balance responses of children during exercise in the heat have examined sedentary boys exercising in climatic chambers (5, 23, 25, 33). Little is known regarding the physiological responses of trained children during exercise in natural outdoor conditions where solar radiation contributes to the heat-stress index. This lack of information hinders the development of guidelines for exercise and athletic competition for children who live and participate in sports in tropical regions.

Several studies have demonstrated that children are less-effective thermoregulators than are adults in extreme environmental conditions (3). Children sweat less than do adults when exercising in a hot environment, which limits their reliance on evaporative heat loss (9, 22). Additionally, children, similar to adults, do not drink enough to replace sweat losses and exhibit hypohydration when water is provided ad libitum during exercise in the heat (4, 5, 28, 33). Thus children who participate in sports programs in tropical regions may be in a state of chronic hypohydration if they train and compete frequently without replenishing their fluid losses completely. Hypohydration causes greater body heat storage, decreases blood volume, and results in a reduced exercise tolerance (29) and therefore may increase children’s risk for heat-related illness. Both acclimatization and physical training improve the thermoregulatory responses to heat stress in children (19, 20, 31). Only one study has examined the thermoregulatory responses and fluid balance of heat-acclimatized children during exercise in hot outdoor conditions (28). The children demonstrated an adequate heat dissipation and a mild voluntary dehydration (1.3–2.1% fluid loss) when exposed to conditions of high climatic thermal stress while drinking water ad libitum. Heat acclimatization and training may result not only in an enhanced sweating rate, which may improve heat dissipation by evaporation, but also in greater fluid losses. The pattern of fluid loss and replacement in heat-acclimatized children who participate in structured training programs has not been examined.

Fluid temperature, flavor, and composition are important determinants of fluid intake (18, 33). Wilk and Bar-Or (33) measured the effects of drink flavor and composition on voluntary drinking and fluid balance in nontrained, nonacclimatized children exercising intermittently in a climatic chamber (35°C, 45–50% relative humidity). Results showed that flavoring of the water increased voluntary drinking by 44.5%, thus reducing children’s voluntary dehydration. The addition of 6% carbohydrate and 18 mmol/l NaCl resulted in a further increase of 45.5% in voluntary drinking, which prevented dehydration altogether. Testing in the above study took place in a Canadian winter. One can therefore assume that the boys were not acclimatized to the
heat or physically trained. As a result, their sweating rate during the chamber session was low (258 ml/h). A question remains as to whether the increase in voluntary drinking with the addition of flavor and electrolyte-carbohydrate solution would also be sufficient to prevent dehydration in children whose sweating rates are considerably higher than those in the study by Wilk and Bar-Or. Therefore, the purpose of this study was to examine the effects of beverage flavoring and composition on voluntary drinking pattern, body fluid balance, and thermoregulation in trained, heat-acclimatized children indigenous to a tropical climate during prolonged intermittent exercise in hot outdoor conditions.

MATERIALS AND METHODS

Subjects

Twelve healthy 11- to 14-yr-old trained children, who were residents of Puerto Rico, participated in this study. They were recruited from a school with a special emphasis on the development of athletic skills. All of the subjects had participated in an exercise training program for at least 6 mo before the study. Their sports specialties were tennis (n = 3), wrestling (n = 2), judo (n = 1), track and field (n = 2), boxing (n = 1), tae kwon do (n = 1), and swimming (n = 2). They had been training for a mean of 210 ± 90 (SD) min/day, 5.1 ± 0.6 days/wk, for 31.5 ± 25.1 mo, while exposed to solar radiation for 143 ± 87 min/day.

Participation in the study was on a voluntary basis. All subjects and their parents were informed of the general purpose and procedures of the study and gave written informed consent. To avoid bias, the specific purpose related to their drinking behavior was not disclosed. Mean age, height, body weight, percent body fat, and maximal aerobic power (V\textsubscript{O\textsubscript{2max}}) of the subjects were 13.4 ± 0.4 (SD) yr, 157.1 ± 7.9 cm, 45.6 ± 8.4 kg, 14.2 ± 5.0%, and 50.9 ± 7.0 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}, respectively. Their maturational level (30) ranged from pre- to midpuberty (Tanner stages I–IV).

Study Design and Procedures

Familiarization and baseline data. Each boy served as his own control. Subjects had three preparatory sessions and two experimental sessions. The first visit was designed to familiarize them with the testing center, the laboratory, and research personnel. During this visit, they underwent a general physical examination by a physician to ensure they were in good health and to assess their maturational stage, determined from pubic hair growth according to Tanner (30). During this visit, general demographic data and baseline physiological measurements were also obtained. Age, height, and weight were recorded, and skinfold thickness (subscapular and triceps) was measured for the assessment of percent body fat (6).

V\textsubscript{O\textsubscript{2max}} was determined with a metabolic cart (AMETEK, Applied Electrochemistry, model S-3A oxygen analyzer and model CD-3A carbon dioxide analyzer) during a continuous exercise test to volitional exhaustion on an electromechanical cycle ergometer (model 829E, Monark) by using the Monarch protocol (2). Heart rate (HR) was monitored and recorded every minute. The criteria for V\textsubscript{O\textsubscript{2max}} were as follows: 1) respiratory exchange ratio ≥1.0 and 2) HR ≥95% predicted maximum (220 – age). The power load required to achieve 60% of V\textsubscript{O\textsubscript{2max}} was identified for each subject for use in the heat-exposure sessions.

During a second visit to the laboratory, the subjects completed a 20-min submaximal exercise bout outdoors while they were pedaling at 60% V\textsubscript{O\textsubscript{2max}}. Oxygen consumption was measured to ensure that the load previously chosen was indeed the correct intensity for the experimental sessions. A second purpose of this exercise session was to habituate the children to the experimental procedures and to identify any with abnormal responses to exercise in hot and humid conditions.

Testing protocol. During a third visit to the laboratory, a tasting session was conducted to determine which flavor of beverage each child preferred. This individualized flavor was used during subsequent experimental sessions. Each child was tested alone while sitting in a thermoneutral room. The procedure was similar to that described by Meyer et al. (24). Eight flavors of a 6% carbohydrate (2% glucose, 4% sucrose) and 18 mmol/l NaCl beverage were presented in randomized sequence to each subject. The flavors were grape, orange, tropical burst, fruit punch, mandarin, lemon-lime, lemon ice, and orange-grapefruit. Children did not see any commercial containers of the drinks during the tasting session.

The subjects had their eyes covered so that they could not see the color of the drinks, and they were not instructed not to smell them before drinking. Drinks were served at the same temperature (8–12°C) and volume (25 ml). There was a 60-s interval between drinks, and the children ate a piece of soda cracker and drank a sip of water to clear the palate. Preference of the flavors was measured on a 5-point horizontal box scale ranging from “I dislike it very much” (1 point) to “I like it very much” (5 points). Eight subjects preferred grape flavor, three subjects preferred tropical-burst flavor, and one subject preferred orange flavor. These were the flavors that were used for each subject during the experimental sessions.

Experimental sessions. The two experimental sessions were conducted at the same time of the day (10:00 AM to 1:00 PM) 1 wk apart during the summer months (July to September). Subjects were exposed to direct sunlight during each session. One of the following beverages was assigned to each session: unflavored water (W) or flavored 6% carbohydrate and 18 mmol/l Na (CNa) solution. The sequence of these sessions was randomized. The composition of the CNa beverage is similar to that of commercially available sports drinks that are often consumed by young athletes. During all sessions, a bottle with the assigned beverage (10–17°C) was placed within arm’s reach and the subjects received the following instructions: “Here is your liquid; you can drink whenever you want.” The subjects were not informed of the content of the bottle and were not encouraged or reminded by the investigators to drink. Nor did they know that drink volume was monitored.

To increase the likelihood of full hydration before each testing session, the subjects drank at least two glasses (360–480 ml) of water, milk, or juice the night before and one glass of water (180–240 ml) at least 30 min before the start of the first exercise bout. They were asked to refrain from exercise for at least 24 h before the session and not to consume any food or beverages on the night before or the day of testing. They were also asked not to consume any food before the session because a light breakfast would be provided. A short questionnaire was administered to confirm compliance with the instructions before each exercise testing session. Two hours before the start of the testing session, subjects were given a standard breakfast: two slices of bread with strawberry jam and one bowl of corn flakes in one glass (180–240 ml) of milk.

Exercise protocol. In each experimental session, subjects completed four 20-min exercise bouts (60% V\textsubscript{O\textsubscript{2max}}) alternating with 25-min rest periods for a total exposure time of 180 min. Oxygen consumption was measured during minute 10 of bouts 2 and 4 of each session. Total mechanical work was
calculated after each exercise bout. During the resting periods, subjects sat on a chair exposed to the sun. The sessions started at 10:00 AM and ended at 1:00 PM.

Measured and Calculated Variables

Wet bulb, dry bulb, and black globe temperatures were measured by using a heat-stress monitor (model RSS-214, Imaging and Sensing Technology) during minutes 8, 10, and 18 of each exercise bout and during minutes 2, 10, and 20 of each rest period. These values were used to calculate the wet bulb globe temperature (WBGT) heat-stress index as follows: (wet bulb temperature \(\times 0.7\)) + (black globe temperature \(\times 0.2\)) + (dry bulb temperature \(\times 0.1\)). Rectal (\(T_r\)), thigh, back, and forearm temperatures and HR were determined before exercise, during minutes 4, 9, 14, and 19 of each exercise bout, and during minutes 5, 15, and 24 of each rest period by using rectal thermistors (model 702A, Yellow Springs Instruments) inserted 8 cm past the anal sphincter, an infrared skin thermometer (model M806-OCH, Mikron Instruments) inserted 8 cm past the anal sphincter, and a HR monitor (model Vantage XL, Polar), respectively. The three \(T_{sk}\) sites were weighted equally. All values for environmental temperature, \(T_r\), \(T_{sk}\), and HR were averaged to represent the total testing session. The change (\(\Delta\)) in \(T_r\) was calculated as \(T_r\) during minute 19 of the last exercise bout of each session minus \(T_r\) before exercise. The \(\Delta\) in \(T_{sk}\) was taken as an arithmetic mean of the site temperatures during minute 19 of the last exercise bout of each session minus mean \(T_{sk}\) before exercise. Metabolic heat production was calculated by using the estimated resting heat production plus the calculated exercise heat production. Heat storage (\(S\)) was calculated by using the equation of Craig et al. (8): 

\[
S = (0.8 \times \Delta T_r + 0.2 \times \Delta T_{sk}) \times 3.48 \text{kJ} \cdot \text{kg}^{-1} \cdot \text{°C}^{-1}.
\]

Body weight and clothing (shorts, shirt, shoes) weight were measured at the beginning and end of each session with an electronic scale accurate to 20 g (model UMC555, Ancaster). Bottles containing the hydrated beverage were weighed at the beginning of each exercise bout and at the end of each resting period without the child noticing. The total fluid intake for each session was calculated and expressed as a percentage of the initial body weight. Subjects emptied their bladders before the beginning of the session. Urine was collected at the end of each session after the subject was warned about it at any time during the session when the subject needed to urinate. The final body weight was calculated as body weight at the end of each testing session minus the urine output.

Sweating rate (ml/h) was calculated from the change in body weight plus the change in clothing weight plus total water intake minus urine output and respiratory water loss. Respiratory water loss was calculated according to Mitchell et al. (26). Total fluid loss was calculated as sweat loss plus urinary output minus total water intake and was expressed as a percentage of initial body weight.

Blood samples (7 ml) were drawn from an antecubital vein with the subjects in the sitting position before bout 1 and after bout 4 of every session by using lithium-heparinized collection tubes. The blood samples obtained after bout 4 were drawn 2–5 min after the end of the bout. Whole blood was delivered into three heparinized microhematocrit tubes for triple measurements. The hematocrit tubes were centrifuged for 6 min at 8,200 rpm. The average of three readings was used for hematocrit analysis. Hb and plasma Na+ and Cl− were measured by reflectance spectrophotometry with a Kodak Ektachem Analyzer (DT60). The percent changes in plasma volume were calculated by using hematocrit and Hb (10). Osmolality was measured by freezing-point depression (Wescor Vapor Pressure Osmometer 5500). The rating of perceived exertion was assessed by using the Borg Scale (7) during minutes 4 and 19 of each exercise period. The environmental thermal perception (6-point scale), thirst (11-point scale), and stomach fullness (5-point scale) were measured at the beginning and at the end of each resting period. These scales were similar to those used by Meyer et al. (25).

Statistical Analysis

Means and SEs were calculated for each variable. An analysis of variance with repeated measures was used to assess the effect of the drink and changes over time in the dependent variable. A general linear model was used when missing data occurred. If significant main effects were found, Tukey’s critical-difference procedure was used to locate differences between conditions. An \(\alpha\) level of \(P < 0.05\) was considered significant.

RESULTS

Climatic Heat Stress

The prevalent climatic heat stress during the experimental sessions is presented in Table 1. No differences were found in dry bulb, wet bulb, or black globe temperatures, the WBGT index, or relative humidity between the two experimental sessions. One should also note the consistency in climatic conditions from one day to another as judged from the means \(\pm\) SE. Such consistency is similar from that reported in studies performed in a climatic chamber (22–24, 33).

Body Fluid Balance

Cumulative drink intake is presented in Fig. 1. Total drink intake was 32% higher with CNa than with W. The difference in intake between CNa and W became significant (\(P < 0.05\)) at 110 min (after the third exercise bout) and continued for the remainder of the session. This pattern was accompanied by a progressive hypohydration with W (Fig. 2), which reached 0.94% of the initial body weight by the end of the session. In contrast, euhydration was maintained with CNa (+0.18% of initial body weight). The difference in hydration status between CNa and W became significant (\(P < 0.05\)) at 110 min.

Body fluid losses through sweat, respiration, and urine were similar between the sessions (Fig. 3). Sweating rate values (CNa = 548.2 ± 13.2; W = 583.4 ± 50.9 ml/h) were higher than those that have ever been

Table 1. Ambient heat stress components during the two experimental drinking conditions

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>CNa</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bulb temperature, °C</td>
<td>32.6 ± 0.5</td>
<td>33.3 ± 0.3</td>
</tr>
<tr>
<td>Wet bulb temperature, °C</td>
<td>26.1 ± 0.2</td>
<td>26.0 ± 0.1</td>
</tr>
<tr>
<td>Black globe temperature, °C</td>
<td>43.1 ± 1.2</td>
<td>44.8 ± 0.8</td>
</tr>
<tr>
<td>WBGT, °C</td>
<td>30.2 ± 0.4</td>
<td>30.6 ± 0.1</td>
</tr>
<tr>
<td>Relative humidity, %</td>
<td>60.6 ± 2.0</td>
<td>56.4 ± 1.9</td>
</tr>
</tbody>
</table>

Values are means ± SE. CNa, flavored water plus 6% carbohydrate and 18 mmol/l Na; W, unflavored water; WBGT, wet bulb globe temperature.
reported for children of similar age and maturational stage (14). Fluid intake with CNa was 5.5% higher than fluid losses. When the subjects drank W, a negative body fluid balance was observed. No differences were found in plasma electrolyte concentration, changes in plasma volume, or osmolality between the experimental sessions (Table 2).

Thermoregulatory Responses

Thermoregulatory responses during the two experimental sessions are presented in Table 3. Rectal temperature increased by 0.86°C with CNa and 0.76°C with W. The final mean values for $T_r$, $T_\text{sk}$, metabolic heat production and heat storage, and the changes in $T_r$ and $T_\text{sk}$ did not differ between the sessions.

Exercise Intensity and Perceptual Variables

The subjects exercised at an intensity equivalent to $60.4 \pm 0.1$ and $57.7 \pm 0.1\%$ of their $V_\text{O}_2\text{max}$ for CNa and W, respectively. Total mechanical work was $92.4 \pm 7.9$ and $92.2 \pm 7.7$ J/s during CNa and W, respectively. No differences were found in HR (CNa $= 156.7 \pm 3.2$; W $= 153.8 \pm 3.0$ beats/min), ratings of perceived exertion (CNa $= 14.3 \pm 0.49$; W $= 13.6 \pm 0.38$), thirst intensity (CNa $= 2.13 \pm 0.43$; W $= 2.0 \pm 0.48$), stomach fullness (CNa $= 0.76 \pm 0.18$; W $= 0.73 \pm 0.18$), and thermal perception (CNa $= 4.2 \pm 0.21$; W $= 4.4 \pm 0.20$) for the entire session or during any time period.

DISCUSSION

The major findings of the present study were that 1) ad libitum drinking of a flavored 6% carbohydrate and 18 mmol/l NaCl solution resulted in an increase in intake of 32% compared with water in trained heat-acclimatized boys exercising in a tropical climate and 2) the flavored carbohydrate-electrolyte solution prevented voluntary dehydration in these boys who exhibited high sweating rates when exercising in a tropical climate.

The majority of studies examining body fluid balance of children during exercise in the heat have been conducted in climatic chambers with sedentary nonacclimatized boys (4, 5, 23, 25, 33). Children who exercise outdoors are exposed to solar radiation, which contributes to the heat-stress index (28). It is most difficult to

Table 2. Plasma electrolyte concentration, plasma volume, and osmolality before and after the two experimental drinking conditions

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>CNa Before</th>
<th>CNa After</th>
<th>W Before</th>
<th>W After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺, meq/l</td>
<td>131.6 ± 1.2</td>
<td>130.0 ± 1.1</td>
<td>131.4 ± 1.8</td>
<td>128.1 ± 1.7</td>
</tr>
<tr>
<td>Cl⁻, meq/l</td>
<td>113.5 ± 1.3</td>
<td>110.5 ± 1.2</td>
<td>113.9 ± 0.9</td>
<td>112.4 ± 1.2</td>
</tr>
<tr>
<td>Osmolality, mosmol/kgH₂O</td>
<td>283.7 ± 2.6</td>
<td>281.0 ± 1.1</td>
<td>290.9 ± 4.0</td>
<td>285.8 ± 3.8</td>
</tr>
<tr>
<td>Hb, g/dl</td>
<td>13.5 ± 0.3</td>
<td>13.3 ± 0.3</td>
<td>13.2 ± 0.3</td>
<td>13.5 ± 0.3</td>
</tr>
<tr>
<td>Hct, %</td>
<td>41.4 ± 0.5</td>
<td>40.1 ± 0.6</td>
<td>40.5 ± 0.7</td>
<td>40.9 ± 0.7</td>
</tr>
<tr>
<td>PV change, %</td>
<td>1.6 ± 2.3</td>
<td>1.0 ± 4.1</td>
<td>-1.0 ± 4.1</td>
<td>-1.0 ± 4.1</td>
</tr>
</tbody>
</table>

Values are means ± SE. Hct, hematocrit; PV, plasma volume.
simulate these conditions in a dicult chamber, and therefore very little is known about children’s drinking patterns, body fluid balances, and thermoregulatory responses when they are exercising in outdoor conditions under direct sunlight. Children have a greater body surface area-to-mass ratio and will absorb heat faster than do adults from the environment in hot climates when ambient temperature exceeds Tsk (12). Thus a high level of solar radiation can be more detrimental to children than to adults. The former may be more susceptible to thermoregulatory disorders. The boys in the present study were exposed to a high climatic heat stress (WBGT), which was consistent between sessions. The mean WBGT value during the experimental sessions (30.4°C) is above the value the American College of Sports Medicine (ACSM) position stand (1) defines as “very high risk for heat illness.” However, when the boys were asked how they perceived the environment, their mean reported value for the exercise session was equivalent to a rating of “a little bit hot”. The subjects’ low thermal perceptions and their capacities to tolerate well the exercise sessions may be mostly due to the fact that they are heat acclimatized by daily exposure and exercise in a tropical climate and also due to their fitness level. Also, the ACSM position stand was developed for other climates. It is possible that these guidelines do not apply to our subjects who live and train in a tropical climate.

One of the physiological adaptations that occurs with acclimatization to humid heat is an enhanced sweating rate and an increased ability to sustain a high sweating rate during prolonged heat exposure especially in humid conditions (32). High sweating rates have also been observed in trained boys compared with untrained boys (21). Our subjects demonstrated considerably higher sweating rates (CNa = 548.2 ± 13.2; W = 583.4 ± 50.9 ml/h) than those previously reported for sedentary nonacclimatized children (~260–300 ml/h) (5, 14, 22, 33). In fact, the sweating rate found in this study is the highest ever reported for children of similar age. Dill and colleagues (11) measured the sweat rate and other variables of seven subjects, one of whom was 15 yr old. A sweating rate of ~1,100 ml/h was reported for this adolescent, which is higher than that for our 11- to 14-yr-old children, who were at Tanner stages 1–4 (pre- to midpubertal). Falk et al. (15) reported that sweating rate increases with maturational stage and not before midpuberty. Dill et al. (11) did not report the maturational stage or acclimatization state of their 15-yr-old subject. The higher sweating rate of the subject in the study of Dill et al. could be due to the fact that he was older than our subjects and possibly more biologically mature.

A high sweating rate is beneficial because it contributes to evaporative cooling, but it can also be detrimental by enhancing the likelihood of a negative fluid balance. This indeed is what happened in the present study during the W session. When the subjects were given water ad libitum, they did not drink enough, and a progressive hypohydration occurred after 90 min of exercise. We do not think the sudden downturn in hydration status was related to the urine production during the exercise session. Five subjects produced urine during the W condition and four subjects during the CNa condition. The average amount of urine produced (W = 0.131 ± 0.06; CNa = 0.135 ± 0.02 liter) was small and was not significantly different between conditions. Also, most of the subjects urinated after 110 min of exercise during both sessions. Because the drinking rate was more or less constant, the calculated sweating rate (assuming that urine output and respiratory water loss were constant) increased at ~90 min. It is difficult to provide a mechanism for this increase, but the phenomenon is not new with children (33).

The degree of hypohydration at the end of the W session (~0.94% of body weight) is mild and similar to what has been previously observed in heat-acclimatized children (28). Unlike other studies in nonacclimatized children (4, 5, 33), our subjects managed to maintain euhydration during the first 90 min of exercise when drinking water. This may be due to the fact that they have participated in sports for several years in a hot climate and are more educated about the importance of fluid replacement. The coaches reported that they emphasize the importance of adequate fluid replacement in their young athletes and that they have observed that the children drink more water when the environmental temperature and humidity are high compared with cooler conditions. They also report that the young athletes do not drink sports drinks often during training or competition. Also, heat acclimatization improves the relationship between thirst and body water needs (17). Despite this, our subjects could not maintain euhydration for the total duration of the exercise session when drinking water.

An increase in fluid intake was previously elicited in children by flavoring the hydration beverage (33). However, flavoring alone is not sufficient to prevent dehydration during prolonged exercise in children. This was demonstrated by Wilk and Bar-Or (33), who found that a grape-flavored beverage postponed but did not prevent dehydration in exercising children. The addition of sodium and carbohydrate has been suggested as a means of increasing fluid intake and absorption (16). In the present study, the increased intake of the CNa beverage may be due, in part, to

### Table 3. Thermoregulatory responses of trained boys during exercise in two experimental drinking conditions

<table>
<thead>
<tr>
<th>Experimental Conditions</th>
<th>CNa</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final T_r, °C</td>
<td>38.0 ± 0.1</td>
<td>37.9 ± 0.1</td>
</tr>
<tr>
<td>ΔT_r, °C</td>
<td>0.86 ± 0.1</td>
<td>0.76 ± 0.1</td>
</tr>
<tr>
<td>Final T_sk, °C</td>
<td>31.5 ± 0.8</td>
<td>32.6 ± 0.4</td>
</tr>
<tr>
<td>ΔT_sk, °C</td>
<td>0.5 ± 0.4</td>
<td>0.6 ± 0.5</td>
</tr>
<tr>
<td>Metabolic heat production, kJ/kg</td>
<td>51.4 ± 2.5</td>
<td>48.2 ± 2.0</td>
</tr>
<tr>
<td>Heat storage, kJ/kg</td>
<td>2.8 ± 0.4</td>
<td>2.3 ± 0.5</td>
</tr>
</tbody>
</table>

Values are means ± SE. T_r, rectal temperature; T_sk, skin temperature; Δ, change in temperature (minute 19 of the last exercise bout of each session minus temperature before exercise).
enhanced palatability resulting from the Na\(^+\) concentration. Also, the carbohydrate-Na\(^+\) combination could have accelerated the absorption of water after ingestion, preventing dehydration even though the subjects were sweating at a very high rate.

Although we cannot separate the effects of flavor from those of the composition of the beverage, this was not our purpose. The aim in this study was to examine the total effect of the beverage components on the drinking pattern of trained heat-acclimatized boys who exhibit high sweating rates. We wanted to duplicate the methodology used by Wilk and Bar-Or (33) to examine whether a drink flavor and composition that increases voluntary drinking in nonacclimatized sedentary boys would also be sufficient to prevent dehydration in heat-acclimatized and trained boys whose sweating rates are considerably higher than those of the subjects in the study of Wilk and Bar-Or. By using a similar protocol and methodology, we were able to confirm that the carbohydrate-electrolyte solution prevents voluntary dehydration in trained heat-acclimatized children exercising in tropical outdoor conditions.

Thirst perception has been related to plasma osmolality, plasma volume, and dehydration of the oropharyngeal cavity (27). In the present study, plasma osmolality, plasma volume, and plasma Na\(^+\) remained unchanged. Although these variables did not differ significantly between sessions, Na\(^+\) and osmolality tended to be better preserved in the CNa session (Table 2). This hints at the possible role of extracellular sodium and/or osmolality in triggering children's thirst.

In the present study, the change in T\(_{re}\) was similar between conditions and higher than the increase of 0.28°C for each 1% body weight loss previously reported in children (5). Such a rise in T\(_{re}\) may be due to the high thermal stress imposed by the environmental temperature, humidity, and solar radiation and the higher exercise intensity compared with those variables of previous studies (5, 23, 25, 33). Because hydration changes were minor, the thermoregulatory strain observed was similar between conditions. It has been demonstrated that beverage composition does not affect thermoregulatory variables in children as long as euhydration or a mild hyponatremia is maintained (23, 25, 33). In the present study, the CNa solution was no better than water with respect to cardiovascular stress, T\(_{sk}\), and core temperature responses to work in the heat. It is not known whether beverage composition may play a role in the prevention of thermoregulatory impairment during longer exposure times and higher intensities of exercise in outdoor conditions. Ethical constraints have prevented us and others from examining these factors in children at higher hypohydration levels. In conclusion, a carbohydrate-electrolyte solution may be recommended to prevent voluntary dehydration in heat-acclimatized boys who participate in structured training programs and exhibit very high sweating rates when exercising in a tropical climate. The ad libitum consumption of unflavored water is not enough to maintain euhydration in these children.