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ARTICLE

Effect of milk consumption on rehydration in youth following exercise in the heat

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Abstract: Low-fat milk is thought to be an effective postexercise rehydration beverage in adults; however, little is known about milk's rehydration ability in children after exercising in the heat. This study tested the hypothesis that because of its electrolyte and protein content, skim milk (SM) would be more effective than both water (W) and a carbohydrate/electrolyte solution (CES) in replacing body fluid losses in children following exercise in the heat. Thirty-eight (19 females) heat-acclimated pre- to early pubertal (PEP, aged 7–11 years) and mid- to late-pubertal (MLP, aged 14–17 years) children performed 3 sessions in 34.5 °C, 47.3% relative humidity, consisting of 2 × 20-min cycling bouts at 60% peak oxygen uptake followed by consumption of either W, CES, or SM. Each beverage was consumed immediately after exercise in a volume equal to 100% of their body mass loss during exercise. Urine samples were collected before, during, and after exercise, as well as the 2-h period following beverage consumption. On average, children dehydrated 1.3% ± 0.4%. Children ingested 0.40 ± 0.11 L (PEP) and 0.74 ± 0.20 L (MLP) of fluid. The fraction of the ingested beverage retained at 2 h of recovery was greater with SM (74% ± 18%) than W (47% ± 26%) and CES (59% ± 20%, $p < 0.001$ for both), and greater in CES than W ($p < 0.001$). All participants were in a hypohydrated state after 2 h of recovery, following the pattern SM < CES < W. In both PEP and MLP children, SM is more effective than W and CES at replacing fluid losses that occur during exercise in the heat.

Key words: protein, fluid balance, adolescents, children.

Résumé : Le lait faible en gras est apparemment une boisson de réhydratation postexercice efficace pour les adultes. Il y a peu d'études sur le potentiel de réhydratation du lait chez les enfants à la suite d'un exercice dans la chaleur. Cette étude vérifie l'hypothèse selon laquelle le lait écrémé (« SM »), en raison de son contenu en électrolytes et en protéines, serait pour les enfants une boisson de réhydratation (pour compenser les liquides corporels perdus) plus efficace que l'eau (« W ») et une solution contenant du sucre et des électrolytes (« CES ») après un exercice dans la chaleur. Trente-huit jeunes (19 filles) acclimatés à la chaleur, prépubères et au début de la puberté (« PEP », âgé de 7–11ans) et au milieu et à la fin de la puberté (MLP, âgé de 14–17 ans), participent dans un environnement chaud (34,5 °C, humidité relative : 47,3 %) à trois séances d'exercice consistant en 2 × 20 min de pédalage à une intensité sollicitant 60 % de la consommation d'oxygène de pointe puis consomment soit W, CES ou SM. La quantité de boisson consommée immédiatement après la fin de l'exercice est égale à 100 % de la masse corporelle perdue au cours de l'exercice physique. On prélève des échantillons d'urine avant, durant, après l'exercice et 2 h après la consommation de la boisson. En moyenne, les enfants perdent 1,3 ± 0,4 % de leur masse corporelle. Les enfants consomment 0,40 ± 0,11 L (PEP) et 0,74 ± 0,20 L (MLP) de liquide. La proportion de la boisson consommée et retenue 2 h après la fin de l'exercice est plus grande dans la condition SM (74 ± 18 %) que dans la condition W (47 ± 26 %) et CES (59 ± 20 %, $p < 0{,}001$ pour les deux) et plus grande dans la condition CES comparativement à W ($p < 0{,}001$). Tous les participants sont en état d'hypohydratation après 2 h de récupération, et ce, selon le degré suivant : SM < CES < W. Chez les jeunes (PEP et MLP), SM est plus efficace que W et CES pour remplacer les liquides perdus durant l'exercice physique dans la chaleur. [Traduit par la Redaction]

Mots-clés : protéine, équilibre hydrique, adolescents, enfants.

Introduction

During exercise in the heat, dehydration can lead to decrements in mental (Gopinathan et al. 1988) and physical (Sawka 1992; Cheuvront et al. 2010; Gonzalez-Alonso et al. 2008) performance. In attempts to avoid the negative effects of exercise- and heat-induced dehydration, hydration guidelines for the pediatric population have been published (American Academy of Pediatrics 2000; Meyer et al. 2007; Rowland 2011). It should be noted, however, that there are difficulties in obtaining a single common guideline, especially in the pediatric population, as individual body fluid loss (and sweating rates) are influenced by a number of factors, including pubertal status, and can vary considerably between athletes and exercise conditions. For example, estimated sweat rates have been reported to range anywhere between 0.25 L·h^{-1} (9-year-olds) (Meyer et al. 1992) to 1.8 L·h^{-1} (18-year-olds) (Palmer and Spriet 2008). These findings reinforce the importance of appropriate fluid before, during, and after sports participation, while further suggesting that both safety and performance should be improved if sufficient rehydration is achieved between the rest periods of same-day matches (Bergeron et al. 2011).

Despite access to fluids during exercise, children (aged 9 to 14 years) usually fail to consume sufficient amounts of fluid to avoid dehydration when fluid intake is driven by thirst alone (Bar-Or et al. 1980; Bar-Or et al. 1992; Rivera-Brown et al. 1999). Although this is not a universal finding (Wilk et al. 2010), the possibility makes the period after exercise critically important to replace fluid losses. Furthermore, the consistent finding that ac-

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tive or athletic youth begin their physical activities (both practices and competitions) already mildly hypohydrated suggests that a greater emphasis should be placed on the restoration of body fluid balance during the recovery period or between exercise bouts or games, particularly under warm environmental conditions (Meyer et al. 2012).

General strategies to maintain body fluid balance while exercising in the heat have resulted in a focus on the production and research of sport beverages. While sport beverages meet the basic objectives of rehydration, they contain minimal nutrient value needed for the growing child. Traditionally, the volume (to replace fluid) and sodium content (to replenish electrolytes) were considered to be 2 essential characteristics of a rehydration beverage (Shirreffs et al. 1996). In comparison with the interest in fluid intake during exercise in adults, rehydration strategies in the pediatric population have received little attention in the literature (Meyer et al. 2012).

Recently, adult research has demonstrated a role for protein in a rehydration drink to further enhance fluid balance (Shirreffs et al. 2007) and fluid retention (Seifert et al. 2006; James et al. 2011). Specifically, low-fat milk has a number of benefits as a postexercise recovery beverage. In the context of rehydration, a study from the United Kingdom found that when provided to participants in a volume equal to 150% of the volume of body mass lost during exercise in the heat, skim milk was best retained in the body over a 4-h period after exercising in the heat, compared with either water or a carbohydrate–electrolyte solution (CES) (Shirreffs et al. 2007). Whether milk would be a suitable rehydration beverage for active children has not been investigated.

A better understanding of the effectiveness of milk in replacing body fluid losses after exercise in the heat in active children is warranted, given its nutritional value. Therefore, the primary aim of this study was to examine whether skim milk could favourably impact rehydration following exercise in the heat in healthy, active 7- to 11-year-old and 14- to 17-year-old children. Our hypothesis was that because of its protein and electrolyte (Na^+ and K^+) content, skim milk would maintain a more positive fluid balance and fraction of beverage retained following exercise when compared with either water or a CES. An exploratory aim of this study was to assess the effects of puberty and sex on skim milk's ability to rehydrate.

Materials and methods

Participants

Thirty-eight (19 females, 19 males) volunteers participated in this study, which was approved by the Hamilton Health Sciences/Faculty of Health Sciences Research Ethics Board. Participants were recruited into pre- to early pubertal (PEP; aged 7–11 years) and mid- to late-pubertal (MLP; aged 14–17 years) groups. Each participant and their parents provided written informed assent and consent, respectively, prior to enrolment in the study. Inclusion criteria required participants to be healthy and physically active (as determined by medical and activity questionnaire). Participants were defined as physically active by participation in organized sports outside of school requirements more than twice per week. Exclusion criteria included obese children or elite athletes, those currently taking any medication, or presenting with any existing medical or health condition, including lactose intolerance or history of heat-related illness (heat stroke, heat exhaustion, etc.). Participant characteristics are provided in Table 1.

General overview

A randomized, repeated-measures cross-over design was incorporated so that each beverage was tested in each participant and, thus, each participant served as his or her own control. Each participant took part in an initial screening visit, followed by a series of 6 heat-acclimation sessions modified from the protocol of Inbar et al. (1981), and subsequently completed 3 experimental sessions. These 3 experimental sessions were identical, with the exception of the postexercise beverage consumed, and were performed in a counterbalanced manner with a minimum of 4 and maximum of 10 days between visits. The 3 experimental beverages consumed were (*i*) plain water (W); (*ii*) a CES, often used for the postexercise period (Powerade, Coca Cola Ltd, Toronto, Ont., Canada); and (*iii*) skim milk (SM; 0.1% Skim Milk; Beatrice, Parmalat, Toronto, Ont., Canada). All beverages were served chilled (~4 °C). To assess the rehydration potential of each beverage, the extent of rehydration was calculated as the body mass during a 2-h recovery period, expressed as a percentage of pre-exercise body mass.

Table 1. Participant characteristics.

	PEP		MLP	
	Boys (n = 10)	Girls (n = 10)	Boys (n = 9)	Girls (n = 9)
Age (y)	9.4±1.1	9.4±0.9	15.4±0.4*	14.6±0.6*
Height (cm)	137±7	135±9	169±8*	167±5*
Body mass (kg)	32.6±6.3	28.7±5.5	59.3±8.7*	57.6±9.2*
Body fat (%)[a]	13.2±6.8	13.5±5.7	18.3±9.0	22.0±5.1
Tanner stage	1.3±0.5	1.1±0.3	4.1±1.2*	3.6±0.5*

Note: MLP, mid- to late-pubertal; PEP, pre- to early pubertal.
*Significant difference from PEP, $p < 0.001$.
[a]Determined using bioelectrical impedance analysis.

Initial session

Participants came for an initial screening visit where we obtained basic anthropometric and aerobic fitness measurements. We assessed each child's height (Harpenden wall-mounted Stadiometer), body mass (Tanita BWB-800S digital scale, Tanita Corp., Japan), and body composition (InBody520 bioelectrical impedance analyzer; Biospace Co., Calif., USA). Prior to body composition measurements, participants were asked to provide a urine sample to assess hydration status measured by urine specific gravity (U_{sg}) using a handheld clinical refractometer (ATAGO, Model SUR-NE). Maturational status was self-assessed according to Tanner criteria (Tanner 1962) using pubic hair development for boys and breast development for girls.

To measure aerobic fitness, we determined peak oxygen uptake ($\dot{V}O_{2peak}$) using the McMaster All-Out Progressive Continuous Cycling Test (Bar-Or and Rowland 2004). The $\dot{V}O_{2peak}$ test was performed in a thermoneutral environment (22 ± 0.2 °C, 54% ± 1.1% relative humidity (RH)). The highest 30-s oxygen uptake was considered the $\dot{V}O_{2peak}$. Termination of the test occurred when the child could no longer maintain the pre-set cadence of 60 rpm, despite strong verbal encouragement by the investigator. Participants performed each of their sessions on the same mechanically or electromagnetically braked cycle ergometer (Fleisch-Metabo, Geneva, Switzerland, or Lode Corival, the Netherlands, respectively). Throughout the exercise, expired gases were examined over 30-s intervals in the mixing chamber setting on a calibrated metabolic cart (Vmax 29, SensorMedics, Yorba Linda, Calif., USA), with appropriately sized pediatric mouthpieces.

Heat acclimation sessions

Each participant performed 6 heat acclimation sessions that consisted of two 20-min cycling bouts at 60% $\dot{V}O_{2peak}$, separated by a 10-min rest period, inside a climatic chamber set to 34.5 °C and 47.3% RH. Successive daily sessions were used since they have proven to be effective at inducing heat acclimation (Gill and Sleivert 2001). Participants completed all trials at the same time of day (~1630 hours). To minimize dehydration, participants were given a bottle of chilled water to drink ad libitum during each session. Throughout the heat acclimation sessions, participants dehydrated an average of 0.53% ± 0.18%. Upon leaving the laboratory, participants were instructed to consume sufficient fluid (based on recommendations; Casa et al. 2000) for the remainder of the evening and prior to arrival the following day.

Experimental sessions

The first experimental session occurred 5 to 9 days after the 6-day heat acclimation protocol. To control diurnal variation, each experimental session occurred at the same time of day (~1530 hours) as the previous heat acclimation sessions (Shido et al. 1999). Parents were given a log book to record everything their child ate and drank prior to arriving to the laboratory on the first day of the experimental sessions, and each participant was then asked to replicate this information the following sessions. Participants were also asked to avoid eating at least 1 h before arriving, to avoid any strenuous physical activity on the day of the experimental sessions, and to avoid caffeine for 12 h prior to each visit.

Upon arrival to the laboratory for each experimental session, each participant was asked to empty his or her bladder and provide a spot urine sample, which was used to ascertain pre-exercise hydration status according to U_{sg}. Participants then received 5 mL·kg^{-1} of tap water, and for any participant determined to be in a hypohydrated state upon arrival to the laboratory ($U_{sg} \geq 1.020$) (Casa et al. 2000), an additional 2 mL·kg^{-1}of water was provided. To standardize pre-exercise nutrition, each participant was also given a small meal, which consisted of a piece of toast with raspberry jam, an apple, a nutrigrain bar (Nutri-Grain, Kellogg Canada Inc., Mississauga, Ont., Canada), and a boost meal replacement drink (Boost Meal Replacement, Nestle Canada Inc., North York, Ont., Canada). Each participant received the same amount of food relative to their individual body mass (i.e., g of food of fluid per kilogram of body mass). The average macronutrient and caloric content of the pre-exercise meal for the group was: 10.6% ± 1.7% protein, 76.9% ± 2.5% carbohydrates, 13.4% ± 0.6% fat, and 427.2 ± 75.4 kcal.

Participants then rested for 60 min at a thermoneutral room temperature and their nude body mass, second urine sample, and mass of their exercise clothes (including shoes) were taken after 30 min of rest. Participants were asked to wear the same exercise clothes for each experimental session, with boys exercising shirtless and wearing light shorts, and girls wearing light shorts and a bikini top/sports bra. Immediately before entering the climate chamber, participants provided another urine sample and had their clothed body mass taken.

To achieve an upper dehydration level of 2% (measured by the acute reduction in pre-exercise to postexercise body mass), each participant exercised in the climate chamber (34.5 ± 0.3 °C, 47.3% ± 1.5% RH) without fluid intake. Upon entering the chamber, participants initially rested in a seated position for 20 min to allow for passive heating. Participants then performed 2 × 20-min bouts of cycling at 60% of their previously determined $\dot{V}O_{2peak}$ (and using the same ergometer), separated by a 10-min rest period. Participants were instructed to cycle at a pre-set cadence of 60 rpm. During the rest period, each participant was asked to void their bladder, body mass was then recorded and a urine sample collected to ensure that participants did not exceed 2% dehydration.

Immediately upon exiting the chamber, participants were asked to dry any surface sweat from their bodies, and a postexercise nude body mass and urine sample were obtained. A body mass with postexercise clothes was subsequently taken. Participants then sat comfortably in a thermoneutral room (22 ± 0.6 °C, 54 ± 2.1% RH) for the remainder of the visit. Perceptions of thirst intensity and stomach fullness were assessed prior to administration of the postexercise rehydration beverage as previously described (Meyer et al. 1995). Briefly, each participant was asked "How thirsty are you?" using an analog scale and were instructed to mark an X on a corresponding horizontal line. This scale had anchor points at the extremes (left to right as not thirsty to very thirsty). Participants were also asked to rate their sensation of stomach fullness in response to the question "How full does your stomach feel now?" through a 1 to 5 category scale ranging from "not full at all" to "extremely full", respectively. Three equal aliquots of the experimental beverage, served chilled, were then ingested at 0, 15, and 30 min following the in-chamber protocol. Drink characteristics are provided in Table 2. The total volume of beverage consumed equated to 100% of the body fluid loss during exercise. Although adult recommendations suggest that to achieve complete restoration of fluid balance a volume equal to 150% of body mass loss is required (Shirreffs et al. 1996, 2004; Roy 2008), there is no evidence suggesting whether the 150% target is an appropriate recommendation for children. For this reason, we decided to match fluid losses.

Table 2. Energy density, carbohydrate content, protein content, fat content, sodium concentration, and potassium concentration of water (W), a carbohydrate–electrolyte solution (CES), and skim milk (SM).

	W	CES	SM
Energy (kcal·100 mL^{-1})	0	33	36
Carbohydrate (g·100 mL^{-1})	0	8	5.2
Protein (g·100 mL^{-1})	0	0	3.2
Fat (g·100 mL^{-1})	0	0	0
Na^+ (mmol·L^{-1})	<1	9.9	22.6
K^+ (mmol·L^{-1})	<1	3.8	41.9

To gain insight into the practical applicability of the beverages, upon tasting the beverage, participants were asked to rate the taste and overall perception of the beverage according to a 9-point hedonic category scale (Guinard 2001). Scale categories ranged from "super good" to "super bad". After ingesting the final aliquot, a urine sample and the participant's clothed body mass were collected, and to once again rate their thirst intensity and perceived intensity of stomach fullness.

Participants remained in the laboratory for 2 h following consumption of the last aliquot of their postexercise experimental beverage. During this 2-h period, participants were allowed to read, do homework, or watch movies, on the condition that they remained seated. Each participant was asked to rate thirst intensity and perceived intensity of stomach fullness at 30-min intervals. A clothed body mass was measured at 1 and 2 h after the participant had emptied his or her bladder. In cases where the participants needed to urinate before the scheduled urine collection, this sample was collected, the time was recorded, and the sample was then added to the 1- or 2-h sample.

Analysis of samples

All urine samples throughout the study were collected into labelled containers, measured to the nearest millilitre using a graduated cylinder and analyzed for U_{sg} using a handheld clinical refractometer. U_{sg} values were used only as a secondary measure of dehydration. Sweat loss (volume) was considered to be the change in body mass (kilograms) during the exercise session (assuming 1 kg = 1 L), corrected for volume of any fluid intake and volume of urine output. The contribution of respiratory water loss was considered to be negligible and consistent between trials and was, therefore, ignored. Sweating rate (L·h^{-1}) was calculated by dividing the volume of sweat loss by the duration of the observation period. Change in body mass was used as the primary indicator of dehydration, with each body mass recorded throughout each session subtracted from the pre-exercise nude body mass (30 min pre-exercise) for that session, and expressed as a percentage of the pre-exercise nude body mass. The rehydration potential of each beverage was determined by examining the fraction of the beverage retained, calculated as the volume of any urine produced following beverage consumption subtracted from the volume of the beverage consumed and expressed as a percentage of the beverage consumed. The fraction of the beverage retained was calculated for both the 1- and 2-h time points post-beverage consumption. Hourly urine output ($L \cdot h^{-1}$) was calculated as the volume of urine produced at both the 1- and 2-h time points post-beverage consumption. Cumulative urine output (in litres) was calculated by the sum of the urine samples collected immediately after beverage consumption, and at the 1- and 2-h time points post-beverage consumption. Body fluid balance over the experimental visit was calculated as the sum of the volume of sweat losses during the exercise and urine losses during the exercise and recovery periods, subtracted from the volume of experimental beverage consumed.

Statistical analysis

All data were analyzed using Statistica version 5.0. Differences in variables (spot urine U_{sg}, sweat rate, postexercise percent dehydration, fluid volume intake, perceived taste and overall preference) assessed prior to beverage completion were determined using a 3-way (puberty × sex × beverage) repeated measures (RM) ANOVA. To establish that the level of hydration was the same between trials prior to consumption of the experimental beverage, pre-exercise and exercise hydration variables (body mass, U_{sg}, and urine volume at designated time points) were assessed using a 1-way (beverage) RM ANOVA. To examine whether SM could favourably impact rehydration following exercise in the heat in healthy children, variables (cumulative urine output) collected only once following beverage consumption were analyzed using a 1-way (beverage) RM ANOVA. Variables (fraction of fluid retained, body fluid balance, percent dehydration, hourly urine output, thirst intensity, and stomach fullness) measured across the 2-h recovery period were analyzed using a 2-way (beverage × time) RM ANOVA. An exploratory aim of this study was to assess the effects of puberty and sex on SM's ability to rehydrate. To do this, variables from the SM trial were analyzed using a 2-way (puberty × sex) RM ANOVA. When main effects or interactions were significant, the source of statistically significant differences was determined using Tukey's HSD post hoc test. The significance level for all tests was set at $p < 0.05$. All data are presented as means ± SD.

Results

Pre-exercise and exercise hydration status

Spot-urine U_{sg} values were not significantly different between trials ($p = 0.17$), thus, each participant's data were averaged across experimental trials. The average spot U_{sg} during the experimental sessions was 1.021 ± 0.008, suggesting that participants arrived to the laboratory in a mild hypohydrated state. Data for body mass, U_{sg}, and urine volume collected at scheduled time points during the pre-exercise and exercise periods are presented in Table 3. There were no significant differences between trials for any of these variables, suggesting that participants were in similar states of hydration between trials prior to the consumption of the experimental beverage.

Sweat rate, dehydration and fluid intake

There was no difference in sweat rates between experimental trials ($p = 0.38$) or between sexes ($p = 0.78$). MLP children had significantly higher sweat rates (0.68 ± 0.20 $L \cdot h^{-1}$) than PEP children (0.35 ± 0.12 $L \cdot h^{-1}$, $p < 0.001$). The degree of dehydration (percentage of pre-exercise body mass) attained after the in-chamber exercise protocol (1.3% ± 0.4%) was similar among all participants (no effect of puberty ($p = 0.73$) or sex ($p = 0.89$)) and across experimental trials ($p = 0.19$). The average absolute body mass loss was 0.40 ± 0.11 kg for PEP children, and 0.75 ± 0.21 kg for MLP children ($p < 0.001$), with no difference in body mass loss between experimental trials ($p = 0.17$) or between sexes ($p = 0.54$). As a result, the volume of fluid ingested did not differ between experimental trials ($p = 0.15$) or between sexes ($p = 0.59$) but was significantly less among the PEP children (0.40 ± 0.11 L) than the MLP children (0.74 ± 0.20 L, $p < 0.001$).

Table 3. Body mass, urine specific gravity (U_{sg}) and urine volume at all trial time points prior to consumption of water (W), a carbohydrate-electrolyte solution (CES) and skim milk (SM).

	W	CES	SM	p
Body mass (kg)				
30 min pre-exercise[a]	44.6±15.9	44.6±15.8	44.7±15.9	0.725
Pre-exercise[b]	44.5±15.9	44.5±15.7	44.6±15.8	0.505
Mid-exercise[c]	44.4±15.8	44.3±15.7	44.4±15.8	0.462
Postexercise[d]	44.1±15.7	44.0±15.6	44.1±15.7	0.470
U_{sg}				
30 min pre-exercise[a]	1.016±0.010	1.018±0.009	1.020±0.011	0.112
Pre-exercise[b]	1.013±0.010	1.012±0.009	1.015±0.012	0.434
Mid-exercise[a]	1.018±0.011	1.015±0.009	1.019±0.012	0.412
Postexercise[c]	1.020±0.010	1.021±0.08	1.022±0.010	0.273
Urine volume (mL)				
30 min pre-exercise[a,b]	67.2±85.0	59.0±66.3	53.1±66.1	0.529
Pre-exercise[a]	83.2±118.2	70.9±81.9	51.8±66.6	0.149
Mid-exercise[b,c]	40.1±64.3	52.7±67.2	34.6±51.6	0.423
Postexercise[a]	37.6±57.5	34.0±46.5	34.7±50.7	0.818

Note: Data reported as means ± SD. Time points with different letters are significantly different from each other within the respective variable group, $p < 0.05$.

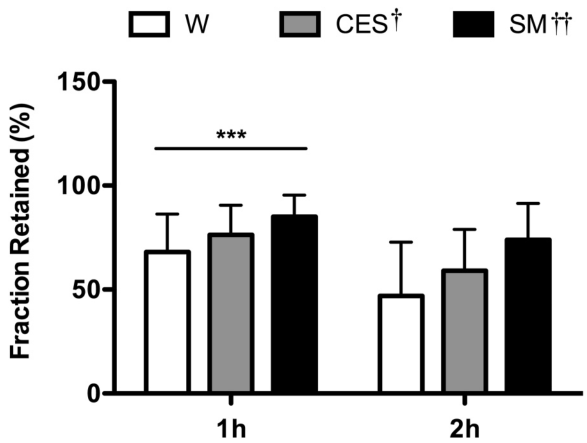
Rehydration measures

The fraction of fluid retained (Fig. 1) decreased over time, with participants retaining significantly less fluid after 2 h compared with 1 h (main effect for time, $p < 0.001$). At both 1 and 2 h of recovery, fluid retention was as follows: SM > CES > W ($p < 0.001$ for all). There was no effect of puberty ($p = 0.11$) or sex ($p = 0.82$) on the fraction of fluid retained. Body fluid balance (Fig. 2A) demonstrated a main effect for time ($p < 0.001$); values immediately postexercise and at 1 and 2 h of recovery were all significantly different from each other ($p < 0.01$ for all). Body fluid balance was negative in all trials at both 1 and 2 h of recovery. Body fluid balance also demonstrated a main effect of beverage; SM was significantly less negative compared with W ($p = 0.001$) and tended to be less negative than CES ($p = 0.09$), with no significant difference between W and CES ($p = 0.38$). There was no effect of puberty ($p = 0.59$) or sex ($p = 0.87$) on body fluid balance. Participants remained dehydrated throughout the entire protocol (Fig. 2B), and were significantly more dehydrated after 2 vs. 1 h of recovery ($p < 0.001$). The postexercise beverage consumed significantly affected changes in body mass compared with pre-exercise values whereby levels of dehydration at 1 and 2 h of recovery followed the opposite pattern as fluid retention: SM < CES < W ($p < 0.05$ for all comparisons). There was no effect of sex ($p = 0.65$) on percent dehydration throughout recovery; however, at both 1 and 2 h of recovery, PEP remained significantly more dehydrated than MLP ($p < 0.001$ for both time points).

Urinary measures

The experimental beverage consumed had a significant effect on the volume of urine produced over the 2-h recovery period (main effect of beverage, $p < 0.001$). Hourly urine volume (Fig. 3A) in SM was similar during 1 and 2 h of recovery ($p = 1.00$), whereas urine volume at 1 h was significantly greater than at 2 h for both W ($p < 0.001$) and CES ($p < 0.001$). At both 1 and 2 h of recovery, hourly urine volume was significantly less during SM than both the W ($p < 0.001$) and CES ($p < 0.01$). As a result, cumulative urine output over the recovery period (Fig. 3B) was significantly less in SM compared with both W and CES ($p < 0.001$). No difference in cumulative urine output was found between W and CES ($p = 1.00$). There were no effects of puberty or sex for hourly ($p = 0.52$ and

Fig. 1. Fraction of beverage retained during recovery after consumption of water (W), a carbohydrate–electrolyte solution (CES), and skim milk (SM). Significance was determined at $p < 0.05$. Data reported as means ± SD. ***, A main effect of time; †, significantly greater beverage retention compared with W; ††, significantly greater beverage retention compared with CES.



0.66, respectively) or cumulative (p = 0.41 and p = 0.98, respectively) urine output.

Perceptual measures

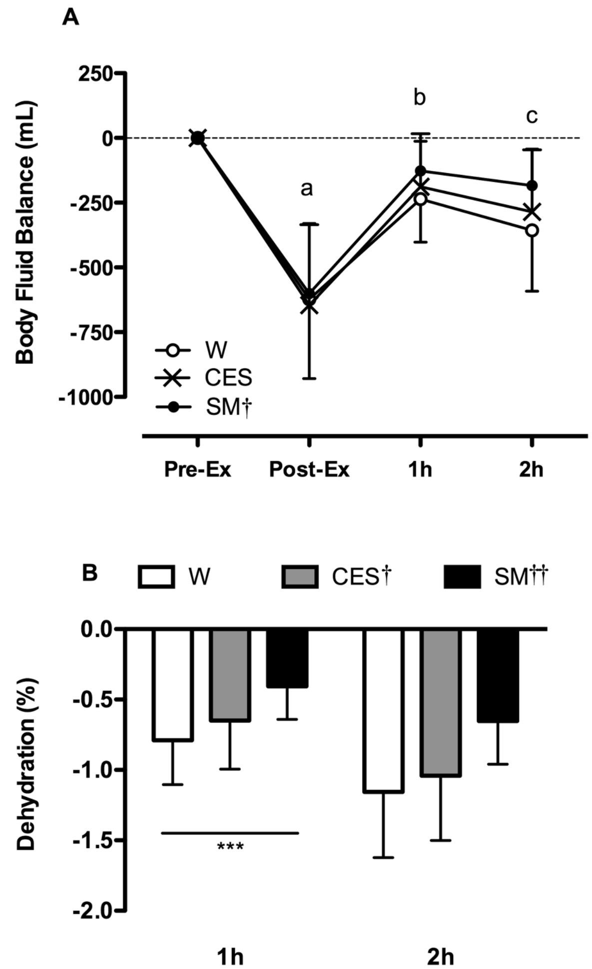
There was a main effect of beverage for both perceived taste ($p < 0.001$) and overall beverage preference ($p < 0.01$) immediately following ingestion. Participants reported that they enjoyed the taste of the CES (2.3 ± 1.5) ($p < 0.001$) more than that of the W (3.7 ± 1.7) and SM (3.4 ± 1.5) (no difference between W and SM, p = 0.72), and overall preferred the CES (2.4 ± 1.6) ($p < 0.01$) to the other 2 beverages (no difference between W (3.6 ± 1.8) and SM (3.4 ± 1.5), p = 0.93). No main effects of puberty or sex were found for either perceived taste (p = 0.84 and p = 0.42, respectively) or overall beverage preference (p = 0.72 and p = 0.17, respectively).

There was no difference between beverages for either thirst perception (Fig. 4A) (p = 0.79) or perceived intensity of stomach fullness (Fig. 4B) (p = 0.64); however, both measures had a significant effect of time ($p < 0.001$ for both). Participants were most thirsty immediately after completing the exercise and prior to beverage consumption ($p < 0.001$). Feelings of thirst subsided after consuming the experimental beverage, but as the participants continued to dehydrate over the recovery period there was a corresponding increase in thirst perception. After 2 h of recovery, participants were not as thirsty pre-beverage values ($p < 0.01$). Similarly, participants had significantly increased perceptions of stomach fullness ($p < 0.001$) immediately after consuming the experimental beverage. Throughout the recovery, the degree of stomach fullness gradually decreased. However, by 30 min post-beverage consumption, levels of stomach fullness had already returned to levels reported immediately after completing the exercise and by 90 min of recovery participants felt less full than prior to consuming the beverage ($p < 0.01$). No beverage × time interaction was found for thirst perception or perceived intensity of stomach fullness.

Discussion

The dehydration accompanying prolonged exercise, especially in warm environments, can have health implications, increasing the risk of exertional heat injury and heat-related illnesses (Bar-Or et al. 1980; Costill and Miller 1980; Convertino et al. 1996). When dehydration cannot be prevented, the role of rehydration becomes crucial. We demonstrate that postexercise SM consumption improves fluid balance and fluid retention, and improves hydration status 2 h into recovery in comparison with typical

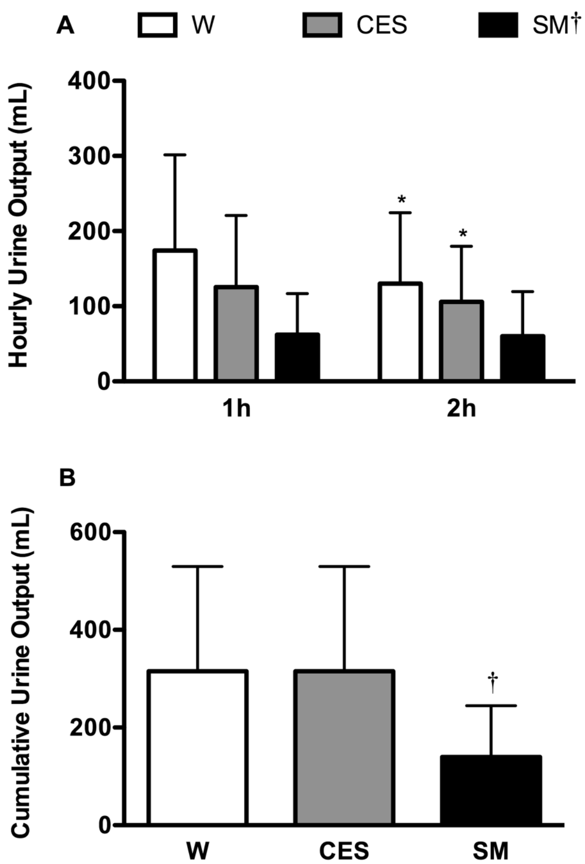
Fig. 2. (A) Body fluid balance over the course of the experimental trial: pre-exercise, immediately postexercise, and at 1 and 2 h of recovery; and (B) percent dehydration at 1 and 2 h of recovery after consumption of water (W), a carbohydrate–electrolyte solution (CES), and skim milk (SM). Significance was determined at $p < 0.05$. Data reported as means ± SD. Values with different letters differ significantly from each other. ***, A main effect of time; †, significantly less negative compared with W; ††, significantly less negative compared with CES.



postexercise beverages, including W and a CES. Despite the improvements in rehydration, it is apparent that children require a volume greater than 100% of fluid loss to completely achieve euhydration. We also highlight the importance of considering age-specific recommendations as PEP and MLP children showed differences in rehydration.

The level of dehydration experienced during exercise in the heat is affected by the level of adaptation to heat stress. In attempts to standardize the level of dehydration and physiological responses across trials, all participants underwent an initial heat acclimation protocol. While the adult literature suggests adaptations to heat acclimation are relatively short-term, vanishing only days to weeks after cessation of heat exposure (Garrett et al. 2011), there are limited data from children indicating how long the effects of acclimation last. However, it is unlikely that adaptations related to acclimation were lost in the present study given that no differences were observed in heart rate, rectal temperature, skin temperature, or perceptual measures (data not shown), or sweating rate and percent dehydration between exercise trials. The maintenance of an acclimated state in our population may be in

Fig. 3. (A) Hourly urine output during recovery; and (B) cumulative urine output at the end of recovery after consumption of water (W), a carbohydrate–electrolyte solution (CES), and skim milk (SM). Significance was determined at $p < 0.05$. Data reported as means ± SD. *, Values differ significantly from 1-h time point for corresponding beverage; †, significantly less urine produced compared with W and CES.



part related to the fact that all participants were active during the days between trials (Inbar et al. 1981).

To minimize the potentially negative effects of dehydration, sufficient fluid must be consumed to replace that which was lost, which is largely affected by the amount of sweat produced. In the present study, there was no significant difference between experimental trials with respect to the volume of sweat lost or sweating rate. This was anticipated because of the cross-over design of the study and the comparable level of acclimation among the children. Children generally have a lower sweating rate compared with adults (Meyer and Bar-Or 1994) and, thus, the volume of fluid loss incurred by a child, in absolute terms, is generally less. Therefore, it is not surprising that the PEP children had lower sweating rates and smaller absolute volume of fluid loss compared with MLP group.

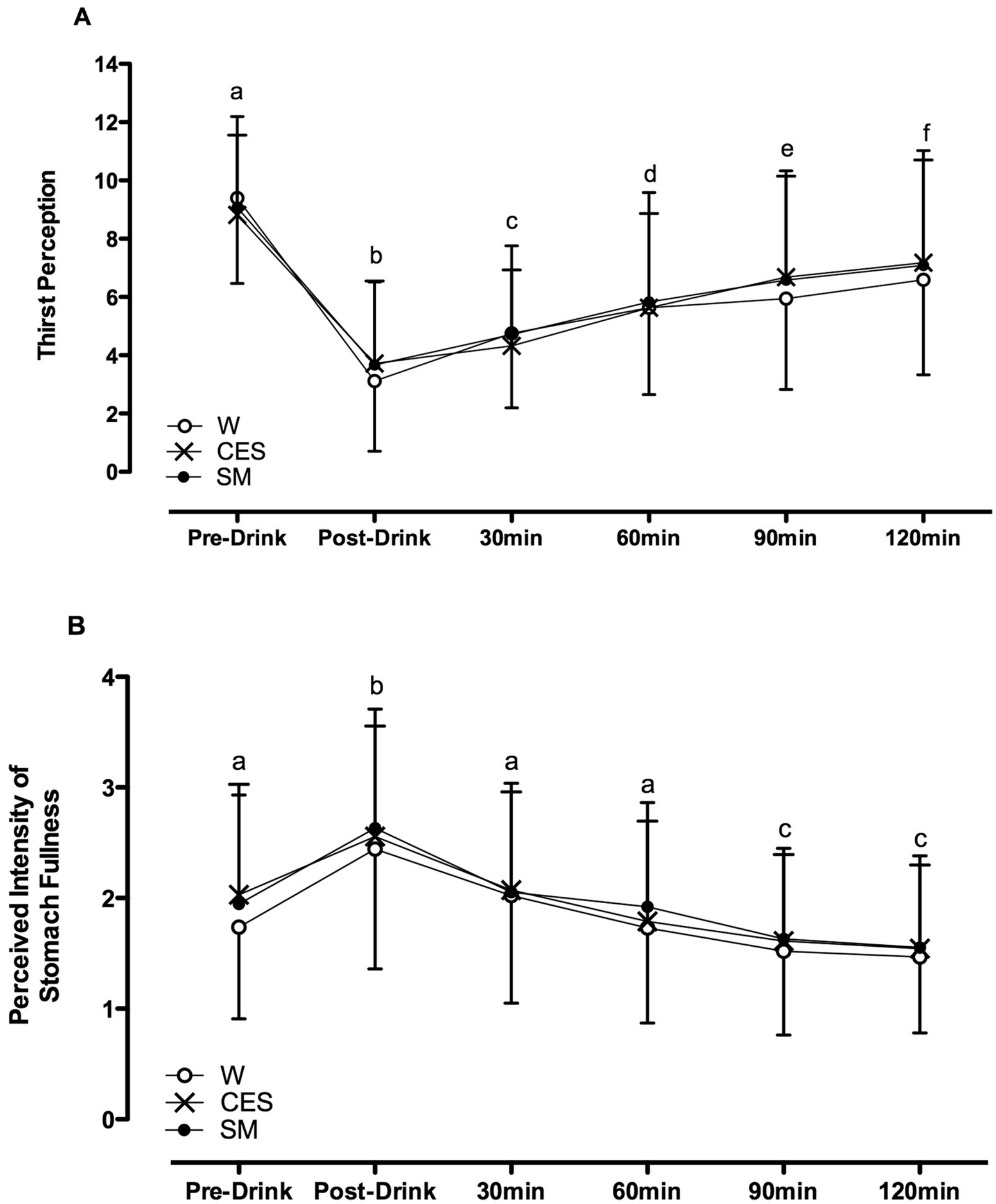
While the absolute volume of fluid ingested differed between pubertal groups (PEP consumed less fluid than MLP), the volume of fluid ingested did not differ between beverages, suggesting that any differences between subsequent measures were a result of differences in the composition of the experimental beverages consumed. SM, W, and CES differ vastly in their electrolyte composition, energy density, and macronutrient composition, making it difficult to distinguish between the effects of protein on fluid retention, and those possibly mediated by other factors. However, it was not our intention to determine which components of the beverage were most important for rehydration. SM contains a number of ingredients that have been shown to favourably affect fluid retention: a naturally high amount of electrolytes (Maughan et al. 1996; Watson et al. 2008), carbohydrates (CHO) (Roy 2008), and a higher energy-density (McHugh and Moran 1979). Interestingly, James et al. (2011) also found that the addition of milk protein to a carbohydrate solution — when controlling for energy density (kcal), sodium ion concentration and potassium ion concentration, and fat content — increased fluid retention. Although it is likely that at least some of our reported increase in fluid retention can be attributable to the milk protein, future research should investigate the importance of other compositional differences for rehydration in children.

Though ongoing urine production during the recovery period is obligatory, differences in the rehydration potentials of each beverage is likely a result of the volume of urine produced. SM has been shown to produce a lower cumulative urine volume throughout recovery from exercise in the heat compared with those of both W and a CES (Shirreffs et al. 2007; Watson et al. 2008), and to attenuate the increase in urine output often seen in the first 2 h of recovery (Roy 2008). In agreement with this, we found that the hourly urine output following SM consumption was significantly less than that following the consumption of W and CES and as a result, the cumulative volume of urine produced was greater in W and CES than in SM. The difference in urine production between beverages is likely a result of beverage composition. When large volumes of dilute solutions are consumed, a fall in serum electrolyte concentrations and osmolality occurs and urine production and excretion are stimulated (Shirreffs et al. 1996). In SM, the electrolyte concentration of the beverage was high and likely maintained plasma osmolality, preventing the excretion of dilute urine. The energy density and CHO contents of the beverage may have also been contributing factors in the difference in urine production. The presence of protein in milk, in addition to CHO, results in a higher energy density compared with those of water and a CES (Shirreffs et al. 2007), and would likely have delayed the rate at which it was emptied from the stomach (Shirreffs et al. 2007; Watson et al. 2008). Moreover, milk contains both casein and whey proteins (in a 4:1 ratio), which would further delay gastric emptying and lead to a slower rate of absorption (Maughan et al. 2004; Roy 2008; James et al. 2011). This delay in gastric emptying would slow down the entry of the fluid into the circulation and consequently inhibit the stimulation of diuresis (McHugh and Moran 1979; Watson et al. 2008). Because we did not obtain plasma samples in the present study, we cannot comment on the effects of experimental beverages on osmolality or relevant hormones that may influence rehydration.

To achieve complete rehydration after exercise and heat-induced dehydration, it has been recommended for adults that fluid volumes greater than the volume of fluid lost must be consumed to account for ongoing renal water losses (Mitchell et al. 1994; Maughan et al. 1996; Shirreffs et al. 1996). Since no specific recommendations are available for children, we decided to match fluid losses. Therefore, it may not be surprising that participants were in a state of net fluid deficit after the 2-h recovery period despite the beverage consumed. Current adult recommendations suggest that a volume equal to 150% of body mass losses is needed to achieve complete restoration of fluid balance (Shirreffs et al. 1996, 2004; Roy 2008). However, our preliminary work suggested that consuming the relatively large volume of 150% of fluid losses within the prescribed time was difficult for many participants. We do not know if the 150% target is an appropriate recommendation for children. As such, future work should examine the optimal rehydration volume for active children.

It is important to balance the composition and effectiveness of a rehydration beverage with its desirability and palatability (Meyer et al. 1994; Merson et al. 2008). Although drink preference did not affect consumption in the present study, because children were given pre-defined volumes of each beverage, the implications of

Fig. 4. (A) Thirst perception and (B) perceived intensity of stomach fullness throughout the recovery of the experimental trial: pre-drink, post-drink, and at 30, 60, 90, and 120 min following the consumption of water (W), a carbohydrate–electrolyte solution (CES), and skim milk (SM). Significance was determined at $p < 0.05$. Data reported as means ± SD. Values with different letters differ significantly from each other. No significant differences in perceptual ratings between experimental trials.



drink preferences may pose an issue when considering the practical application of a rehydration beverage wherein the drink is consumed voluntarily. Despite that both the taste and overall preferences of the CES were greater than those of W and SM, there were no perceptual differences between the latter and children in the present study described both the taste and overall desirability of the SM as "good" on the sensory analog scale. Our participants did not demonstrate the differences in stomach fullness between beverages that have been reported in adults (Shirreffs et al. 2007; Watson et al. 2008), which may be due to the smaller absolute volume of the drink consumed in the present study. Whether children would experience differences in stomach fullness or comfort when consuming larger volumes of the beverages is unknown.

In conclusion, this is the first study to investigate the effects of postexercise milk ingestion on fluid balance and fluid retention in active children. SM consumption resulted in greater fluid balance and retention compared with W and a CES and a smaller cumulative urine volume output. Following exercise in a hot environment, SM is more effective than W or a commercially available sports drink at replacing sweat losses and promoting rehydration.

Conflict of interest statement

The authors report no conflicts of interest.

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