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ORIGINAL RESEARCH

Effect of Drinking Rate on the Retention of Water or Milk Following Exercise-Induced Dehydration

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This study investigated the effect of drinking rate on fluid retention of milk and water following exercise-induced dehydration. In Part A, 12 male participants lost 1.9% ± 0.3% body mass through cycle exercise on four occasions. Following exercise, plain water or low-fat milk equal to the volume of sweat lost during exercise was provided. Beverages were ingested over 30 or 90 min, resulting in four beverage treatments: water 30 min, water 90 min, milk 30 min, and milk 90 min. In Part B, 12 participants (nine males and three females) lost 2.0% ± 0.3% body mass through cycle exercise on four occasions. Following exercise, plain water equal to the volume of sweat lost during exercise was provided. Water was ingested over 15 min (DR15), 45 min (DR45), or 90 min (DR90), with either DR15 or DR45 repeated. In both trials, nude body mass, urine volume, urine specific gravity and osmolality, plasma osmolality, and subjective ratings of gastrointestinal symptoms were obtained preexercise and every hour for 3 hr after the onset of drinking. In Part A, no effect of drinking rate was observed on the proportion of fluid retained, but milk retention was greater ($p < .01$) than water (water 30 min: 57% ± 16%, water 90 min: 60% ± 20%, milk 30 min: 83% ± 6%, and milk 90 min: 85% ± 7%). In Part B, fluid retention was greater in DR90 (57% ± 13%) than DR15 (50% ± 11%, $p < .05$), but this was within test–retest variation determined from the repeated trials (coefficient of variation: 17%). Within the range of drinking rates investigated the nutrient composition of a beverage has a more pronounced impact on fluid retention than the ingestion rate.

Keywords: fluid balance, hypohydration, nutrition, rehydration

Individuals typically do not consume enough fluid during exercise to counteract sweat losses, producing a postexercise state of body water deficit (i.e., dehydration; Garth & Burke, 2013). As a result, individuals are encouraged to drink fluid during recovery to reinstate total body water balance prior to recommencing physical activity (Evans et al., 2017; Sawka et al., 2007). However, rapidly consuming large volumes of hypotonic fluid has the potential to reduce plasma osmolality (P_{OSM}), resulting in increased urinary output (i.e., "fluid-induced diuresis"), potentially delaying a return to euhydration (Mitchell et al., 1994; Robertson, 1974). Hence, there is considerable scientific interest in understanding factors that enhance fluid retention and assist with rehydration after exercise.

When consumed without food and matched for volume, nutrient-dense beverages (e.g., milk and milk-based beverages) appear to promote greater fluid retention compared with water and carbohydrate–electrolyte solutions (Desbrow et al., 2014; Seery & Jakeman, 2016; Shirreffs et al., 2007; Watson et al., 2008). The effectiveness of milk as a rehydration solution has been attributed to a number of its constituents (i.e., sodium [Merson et al., 2008; Shirreffs & Maughan, 1998], carbohydrate [Evans, Shirreffs, & Maughan, 2009; Osterberg et al., 2009], and protein [Hobson & James, 2015; James et al., 2012, 2014]), which are believed to delay gastric emptying and/or attenuate changes in P_{OSM}, reducing the degree of fluid induced diuresis (Baker & Jeukendrup, 2014; Calbet & MacLean, 1997; Clayton et al., 2014; Murray et al., 1999; Vist & Maughan, 1995).

Typically, postexercise rehydration studies control drinking rate by prescribing fixed volumes of beverages within standardized time periods. In contrast, active individuals may consume fluids at different rates, which is likely to influence nutrient delivery and consequently, fluid retention. To date, only two studies have investigated the influence of drinking rate on fluid recovery (Jones et al., 2010; Kovacs et al., 2002). The initial investigation failed to detect differences in fluid retention when a carbohydrate–electrolyte beverage was consumed over 3 hr (79% ± 6%) compared with 5 hr (82% ± 5%) following exercise-induced dehydration (3.0% body mass [BM] loss). In contrast, Jones et al. (2010) reported significantly greater retention when water was consumed over a 4-hr drinking period (75% ± 12%) compared with a 1-hr drinking

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period (55% ± 18%) following an exercise-induced 2.0% BM loss. The explanation for the equivocal findings may relate to the subtle differences in the drinking rates and/or the use of beverages with different nutrient profiles (and hence osmolalities). Furthermore, when consumed ad libitum, individuals typically ingest the largest volume of fluid within the first 30 min following exercise (Baguley et al., 2016). To date, the effect of drinking rate on the retention of fluid from beverages with contrasting nutrient profiles has not been systematically examined. In addition, no previous investigation has compared a conservative drink pattern to a rapid ingestion rate (e.g., large volumes consumed in ~30 min), which may reflect the actual behavior of individuals following exercise.

Therefore, the aim of this study was to investigate the effect of rapid versus slower drinking rates on fluid retention using beverages with contrasting nutrient profiles (milk vs. water). It was hypothesized that the fluid retained from the consumption of a nutrient-dense beverage would be unaffected by drinking rate and that slower intake of a hypotonic beverage would enhance subsequent fluid retention.

Methods

Overview of Study Designs

This investigation was intended to systematically explore the effect of drinking rate on subsequent fluid recovery. The investigation was conducted in two parts, with the results from Part A used to inform the design of Part B. Part A explored the impact of drinking rates of different beverages (milk and water) on fluid retention. In Part B, further exploration of different drinking rates was performed. In addition, the trials were conducted in separate laboratories (Part A: Australia and Part B: Scotland). All participants were fully informed of the nature and possible risks of the investigations before providing written informed consent. The investigation was approved by the Griffith University and University of Stirling's Human Ethics Committees, and the procedures were conducted in accordance with the principles outlined by the Declaration of Helsinki.

Participant Characteristics

In Part A, 13 healthy males volunteered to take part. However, one participant was unable to continue with the study after completing the first trial for reasons unrelated to the study (i.e., work commitments). Consequently, 12 male participants (age: 23.5 ± 5.3 years; height: 179 ± 6 cm; BM: 77.3 ± 9.6 kg; maximal oxygen consumption [VO_2peak]: 43.1 ± 6.4 ml·kg^{-1}·hr^{-1} [mean ± *SD*]) completed four experimental trials.

In Part B, 14 healthy participants volunteered to take part. However, one participant withdrew from the study due to external factors, and one participant's data was excluded because they could not achieve the required level of dehydration. Consequently, 12 (nine males and three females) participants (age: 28.3 ± 6.3 years; height: 176 ± 11 cm; BM 74.0 ± 10.2 kg; VO_2peak: 50.6 ± 7.6 ml·kg^{-1}·hr^{-1}) completed four experimental trials.

Study Designs

A schematic representation of the experimental protocols is displayed in Figure 1. Both parts utilized a repeated-measures experimental design, involving four experimental trials; each separated by a minimum of 5 days. For all trials, participants lost ~2.0% BM through intermittent cycle exercise before cooling down and beginning a rehydration period in which different treatment interventions were examined (Part A, water or milk ingested over 30 or 90 min; Part B, water ingested over 15, 45, or 90 min with either the 15- or 45-min trial repeated). An incomplete Latin square design was used to counterbalance the order of treatments.

Preliminary Requirements

Participants undertook an incremental test to exhaustion on a cycle ergometer. The protocol began at 100 W and increased in 50 W increments every 2.5 min until volitional exhaustion with participant's breath sampled continuously via a calibrated gas analysis system (Part A: Medgraphics Ultima, Saint Paul, MN; Part B: Servomex Group Ltd., Crowborough, United Kingdom). The test was used to determine VO_2peak and maximum heart rate; these values used to guide the prescription of exercise intensity for the experimental trials.

Participants were instructed to abstain from caffeine (12 hr), alcohol (24 hr), and moderate to strenuous exercise (12 hr) before all trials. During the 24-hr period preceding the first trial, individuals completed a food and beverage diary. They were also instructed to drink 500 ml of water at least 2 hr before arrival at the laboratory (to assist with hydration) and to abstain from all food and fluid (excluding water) after 21:00. Individuals were then instructed to repeat these behaviors prior to all subsequent experimental trials.

Experimental Procedures

Participants arrived at the laboratory between 05:30 and 08:00 and verbally acknowledged compliance to the preexperimental conditions. A urine sample was taken for determination of hydration status (Part A: urine specific gravity [U_{SG}; Palette Digital Refractometer; ATAGO, Seattle, WA] and Part B: urine osmolality [U_{OSM}; Löser Osmometer; Camlab, Cambridgeshire, United Kingdom]). If participants recorded a U_{SG} ≥1.024 (Sommerfield et al., 2016) or U_{OSM} >700 mOsm/kg (Sawka et al., 2007), they were considered hypohydrated. In Part A, hypohydrated participants were required to consume 600 ml of plain water over 5 min, before providing a second urine sample 30–60 min later. If this urine sample achieved the thresholds for euhydration, the participants continued with the trial. (This practice was then replicated on all subsequent trials.) If the threshold value was not reached within the 60-min period, the trial was rescheduled. Participants then rested in a seated position for 5 min prior to venipuncture of a forearm vein. Following this initial blood collection, participants were provided with a standardized breakfast in a quantity relative to BM (20 kJ/kg and 1 g carbohydrate/kg) that consisted of raisin toast, strawberry jam, and fruit juice (200 ml), before completing a questionnaire on gastrointestinal subjective symptoms, voiding their bladder and obtaining a baseline nude BM measurement (Part A: A&D Company Ltd., Tokyo, Japan, to nearest 20 g; Part B: Marsden, Rotherham, United Kingdom, to nearest 10 g).

Exercise-Induced Dehydration

After completing a brief standardized warm-up, participants began cycling in a warm environment (Part A: 25.2 ± 0.8 °C and 84% ±11% relative humidity; Part B: 26.4 ± 0.7 °C and 38% ± 5% relative humidity). Individuals commenced exercise at a workload corresponding to ~65% of maximum heart rate. Intensity was recorded by an investigator and replicated on all subsequent trials. Following 50 min of cycling, participants'

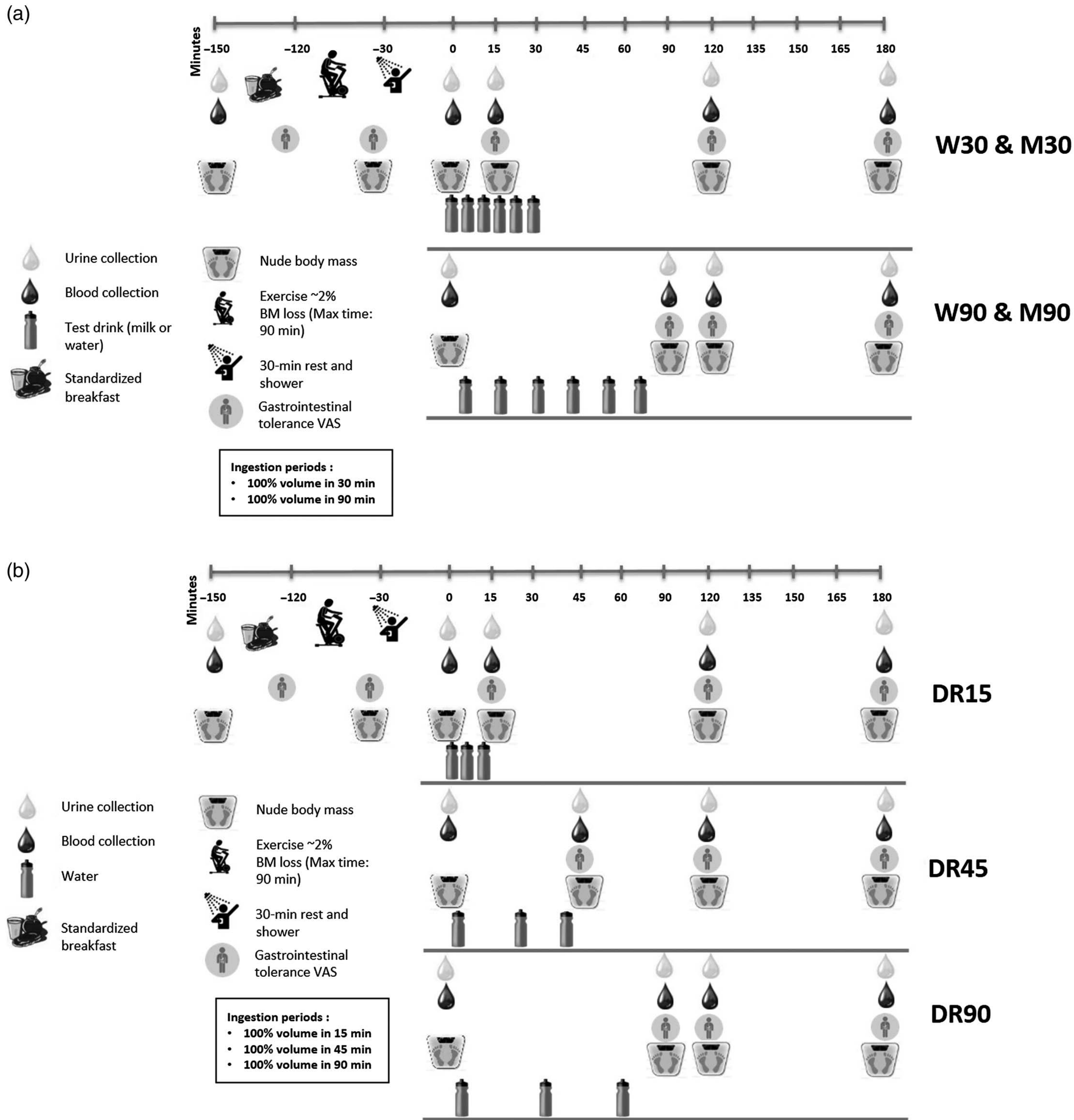

Figure 1 — Schematic of experimental protocol investigating the effect of drinking rate on fluid retention following exercise. (a) Part A—water or milk ingested over 30 or 90 min (water 30 min [W30], water 90 min [W90], milk 30 min [M30], and milk 90 min [M90]). (b) Part B—water ingested over 15 min (DR15), 45 min (DR45), or 90 min (DR90).

BM was measured. A BM loss of <1.8% from baseline required participants to continue exercising in 10-min bouts until a BM loss of ≥1.8% was achieved. Following exercise, dehydrated participants rested in a seated position for 15 min prior to having a cool shower. Afterward, participants dried themselves thoroughly before a cannula was inserted into a forearm vein and a blood sample was obtained. Participants then emptied their bladder and provided a urine sample before a final nude BM measure was recorded to determine total fluid loss (30 min postexercise).

Postexercise Fluid Replacement

In Part A, water or low-fat cow's milk (Maleny Dairies, Maleny, Queensland, Australia; 210 kJ energy, 5.3 g carbohydrate, 4.0 g protein, 1.4 g fat, 48 mg Na^+/100 ml) were ingested in a quantity equal to 100% of the volume of sweat lost during exercise. The fluid volume was ingested in six equal aliquots spread evenly over either a 30- or 90-min period, resulting in the beverage treatments: water 30 min (W30), water 90 min (W90), milk 30 min (M30), and milk 90 min (M90). Participants were instructed to consume each aliquot at an even pace over 5 or 15 min according to the relevant drinking rate. In Part B, water in a quantity equal to 100% of the volume of sweat lost during exercise was ingested. The volume was provided in three aliquots spaced evenly over either a 15-, 45-, or 90-min drinking period, resulting in the following beverage treatments: water 15 min (DR15), water 45 min (DR45), and water 90 min (DR90). To assess within individual variation, participants in Part B repeated either the DR15 or the DR45 trial. To assess intersite variation, W90 (Part A) was compared with DR90 (Part B).

A 3-hr rehydration monitoring period (from the commencement of drinking) was applied to all trials. Observations were made every hour and included measures of nude BM, urine, and plasma measures of hydration status. In addition, subjective measures of bloatedness, fullness, and thirst were recorded. All measurements were obtained while participants remained seated.

BM and Fluid Retention

The BM change (estimate of fluid loss) was calculated by subtracting the postexercise BM (postvoid) from the preexercise BM. Net BM change was calculated by subtracting the 3-hr BM measurement from the preexercise BM. Percent fluid retention at the conclusion of the observation period was calculated by the following equation:

$$\text{Fluid retained}\,(\%) = 100 \times \frac{\text{Total beverage ingested}\,(\text{g}) - \text{Total urine output}\,(\text{g})}{\text{Total beverage ingested}\,(\text{g})}.$$

Urine and Blood Collection, Storage, and Analysis

Additional urine sampling was performed at preexercise, postexercise (immediately predrinking), immediately postdrinking, and then at 120 and 180 min after the start of drinking. At each of these urine collection points, participants completely voided their bladder into an empty container for subsequent measures of urine volume. Total urine loss was calculated from the accumulated urine output in the period from the commencement of drinking until the end of the observation period. A sample of urine was retained for determination of U_{OSM}. Blood sampling was performed at preexercise, postexercise (immediately predrinking), immediately postdrinking, and then at 120 and 180 min after the start of drinking for the determination of P_{OSM}. Participants remained seated prior to a 5-ml blood sample being drawn from an antecubital vein. All samples were collected into ethylenediaminetetraacetic acid-pretreated vacutainers and centrifuged at room temperature for 10 min at ~1,350*g*. Plasma was analyzed in duplicate on a calibrated freezing-point depression osmometer (Part A: Osmomat 030-D; Gonotec, Berlin, Germany and Part B: Löser osmometer, Camlab). Cannulas were kept patent by flushing sterile saline (2 ml of 0.9% NaCl; Becton Dickinson, Macquarie Park, New South Wales, Australia) on completion of each sample (with an equivalent volume of blood initially discarded before collection of subsequent samples).

Subjective Measures

Subjective ratings of bloatedness, fullness, and thirst were recorded on separate 100-mm visual analog scales, with 0 mm representing *not at all* and 100 mm representing *extremely much*. Scales were administered via a computerized modifiable software program (Marsh-Richard et al., 2009).

Statistical Analyses

Statistical analyses were performed using SPSS Statistics for Windows (version 22; SPSS Inc., Chicago, IL). All measures were examined for normality and sphericity using the Shapiro–Wilk test ($p > .05$) and Mauchly test ($p > .05$), respectively. Where assumptions of sphericity in repeated-measures analyses were violated, the Greenhouse–Geisser statistic was applied. One-way repeated-measures analysis of variance (ANOVA) was performed to verify that pretrial conditions and exercise-induced fluid loss did not differ across trials. For Part A, a three-factor (i.e., Beverage × Rate × Time) repeated-measures ANOVA was used to compare main outcomes; two-factor (i.e., Beverage × Rate) repeated-measures ANOVA was conducted to compare total fluid retention and net BM changes across treatments. Pairwise comparison (Bonferroni) were performed where significant main effects were present. For Part B, two-factor (i.e., Rate × Time) repeated-measures ANOVA was used to compare outcomes between the different beverage ingestion rates. Paired *t* tests or Wilcoxon tests were used where appropriate to conduct post hoc comparisons on significant interaction effects. An adjusted alpha (i.e., $p = .05$ divided by the number of tests performed) was used to account for multiple comparisons. The test–retest reliability was calculated as a coefficient of variation (CV%) using the traditional method, and any difference in responses between sites was assessed using an unpaired *t* test. Statistical significance was accepted at $p < .05$. All data are reported as mean ± *SD*, unless stated as mean ± *SEM*.

Results

Standardization Procedures

All participants reported compliance with the standardization procedures in the 24 hr prior to arriving at the laboratory. In Part A, two participants were administered water (600 ml) due to a preexercise U_{SG} ≥1.024 on Trial 1; this practice was repeated on all subsequent trials to ensure consistency. The remaining participants had a U_{SG} <1.024 at the commencement of each trial. Exercise duration and preexercise values for BM, U_{SG}, and P_{OSM} were similar across all treatments and did not differ significantly by trial order ($p > .05$). Exercise-induced BM loss differed significantly ($p < .01$) by trial order (Trial 1: 1.54 ± 0.26 kg, Trial 2: 1.44 ± 0.28 kg, Trial 3: 1.41 ± 0.31 kg, and Trial 4: 1.38 ± 0.32 kg); however, counterbalancing ensured that BM loss was similar across treatment conditions (Table 1).

In Part B, exercise duration and preexercise values for BM, U_{OSM}, P_{OSM}, and exercise-induced BM loss were similar across all treatments (Table 1) and did not differ significantly by trial order ($p > .05$).

Urine Output and Fluid Retention

In Part A, cumulative urine output was greater with water than with milk at 120 min (398 ± 190 vs. 139 ± 44 g) and 180 min (592 ± 248 vs. 224 ± 70 g) after the start of drinking ($p < .01$; Figure 2a).

Table 1 Pretrial Conditions and Impact of Exercise-Induced Dehydration

Part A	W30	W90	M30	M90	*p* value
Pre-Ex U_{SG}	1.015 ± 0.006	1.015 ± 0.007	1.013 ± 0.005	1.014 ± 0.005	.35
Pre-Ex P_{OSM} (mOsm/kg)	290 ± 4	292 ± 5	290 ± 6	289 ± 5	.67
Pre-Ex BM (kg)	77.10 ± 9.67	77.27 ± 9.78	76.77 ± 9.73	76.57 ± 9.52	.28
Ex duration (min)	70 ± 14	70 ± 13	70 ± 13	70 ± 12	.86
BM loss (kg)	1.46 ± 0.28	1.42 ± 0.30	1.43 ± 0.32	1.46 ± 0.29	.79
BM loss (%)	1.9 ± 0.3	1.9 ± 0.4	1.9 ± 0.4	1.9 ± 0.3	.82
Part B	**DR15**	**DR45**	**DR90**		***p* value**
Pre-Ex U_{OSM}	477 ± 218	474 ± 178	443 ± 185		.76
Pre-Ex P_{OSM} (mOsm/kg)	303 ± 5	302 ± 3	302 ± 5		.36
Pre-Ex BM (kg)	71.60 ± 9.90	71.54 ± 10.15	71.31 ± 10.08		.39
Ex duration (min)	79 ± 12	81 ± 13	80 ± 11		.62
BM loss (kg)	1.46 ± 0.35	1.51 ± 0.33	1.45 ± 0.32		.30
BM loss (%)	2.0 ± 0.4	2.1 ± 0.2	2.0 ± 0.3		.61

Note. Values are presented as mean ± *SD*. Water or milk ingested over 30 or 90 min: water 30 min (W30), water 90 min (W90), milk 30 min (M30), and milk 90 min (M90). Water ingested over 15 min (DR15), 45 min (DR45), or 90 min (DR90). Ex = exercise; U_{SG} = urine specific gravity; P_{OSM} = plasma osmolality; BM = body mass; U_{OSM} = urine osmolality.

A significant effect of beverage was observed on fluid retention (W30: 56.5% ± 16.1%, W90: 59.7% ± 19.9%, M30: 82.9% ±6%, and M90: 84.9% ± 7%) with the proportion of ingested fluid retained lower with water than milk (58.1% ± 15.6% vs. 83.9% ±6.1%, $p < .01$). No other significant differences were observed in either analysis.

In Part B, a similar cumulative urine output response was observed when water was ingested at DR15, DR45, and DR90 rates. Three hours after the start of the drinking period, cumulative urine output was lower for the DR90 trial (602 ± 183 g) compared with the DR45 (750 ± 373 g) and DR15 (754 ± 230 g) trials, but this did not reach statistical significance ($p > .05$). The mean difference (95% confidence interval) between DR15 and DR90 was 7.4% (1.2–13.6%), equivalent to 152 ml (43–260 ml) (Figure 2b). Fluid retention was significantly higher ($p < .05$) on the DR90 trial (57.1% ± 12.9%) compared with the DR15 trial (49.7% ± 11.0%), but these trials were not different ($p > .05$) to DR45 (51.6% ±19.8%).

Net Fluid Balance

In Part A, all experimental trials concluded with participants in a state of negative net fluid balance 180 min after the ingestion period started (Part A: W30: –0.68 ± 0.31 L; W90: –0.61 ± 0.25 L; M30: –0.27 ±0.07 L; M90: –0.28 ± 0.08 L; Figure 3a). Post hoc comparisons revealed that milk ingestion led to less negative fluid balance compared with water at 120 min (–0.40 ± 0.19 vs. –0.14 ± 0.04 L, $p = .001$) and 180 min (–0.64 ± 0.27 vs. –0.28 ± 0.07 L, $p < .001$) after drinking started. Fluid balance was also less negative immediately postdrinking for the 30-min drinking trial compared with the 90-min drinking trial (–0.14 ± 0.08 vs. 0.04 ± 0.03 L, $p < .001$), as participants had less time to produce urine on these trials.

In Part B, all experimental trials concluded with participants in a state of negative net fluid balance (DR15: –0.75 ± 0.23 L; DR45: –0.75 ± 0.37 L; DR90: –0.60 ± 0.18 L; Figure 3b). No differences were observed between trials.

Plasma Osmolality

In Part A, the consumption of water decreased P_{OSM} compared with milk at the cessation of drinking (291 ± 4 vs. 298 ± 5 mOsm/kg, $p < .001$), but this effect was not evident by 180 min (water: 290 ± 2 mOsm/kg and milk: 293 ± 4 mOsm/kg, $p = .033$). P_{OSM} did not differ significantly as a result of the fluid ingestion rate at any point ($p > .05$).

In Part B, a drinking rate by time interaction was not evident for P_{OSM}. Plasma osmolality 180 min after start of drink ingestion did not differ significantly as a result of the fluid ingestion rate (DR15: 304 ± 2 mOsm/kg, DR45: 302 ± 3 mOsm/kg, and DR90: 303 ± 5 mOsm/kg, $p > .05$).

Subjective Measures

In Part A, analysis for bloatedness, fullness, and thirst ratings identified a significant effect of time on each variable ($p < .01$). A significant effect of beverage was also observed for fullness ($p = .022$). For bloatedness and fullness, there were significant Time × Beverage interaction effects (bloatedness: $p = .014$; fullness: $p < .01$). Post hoc comparisons revealed that the 30-min drinking protocol increased feelings of bloatedness ($p < .01$) and decreased feelings of thirst ($p < .01$) immediately after drinking compared with the 90-min protocol. The consumption of milk increased feelings of fullness immediately after drinking ($p < .01$) and at 120 min ($p < .01$), compared with the consumption of water. No other significant differences were observed.

In Part B, perceived bloatedness and fullness were significantly higher immediately after drinking on the DR15 trials compared with the DR45 and DR90 drinking rates ($p < .01$) but were not different at subsequent time points up to 180 min. No other significant differences were observed at any other time point (Figure 4).

Reliability and Inter-Lab Repeatability

The CV% of test–retest reliability between duplicate trials on DR15 and DR45 ingestion rates (Part B) was 17%. Data from repeated trials were not significantly different (Table 2). The fluid retention on 90-min water rate trials (Part A: W90 and Part B: DR90) was not significantly different between testing sites (W90: 59.7% ± 19.9% and DR90: 57.1% ± 12.9%, $p = .73$).

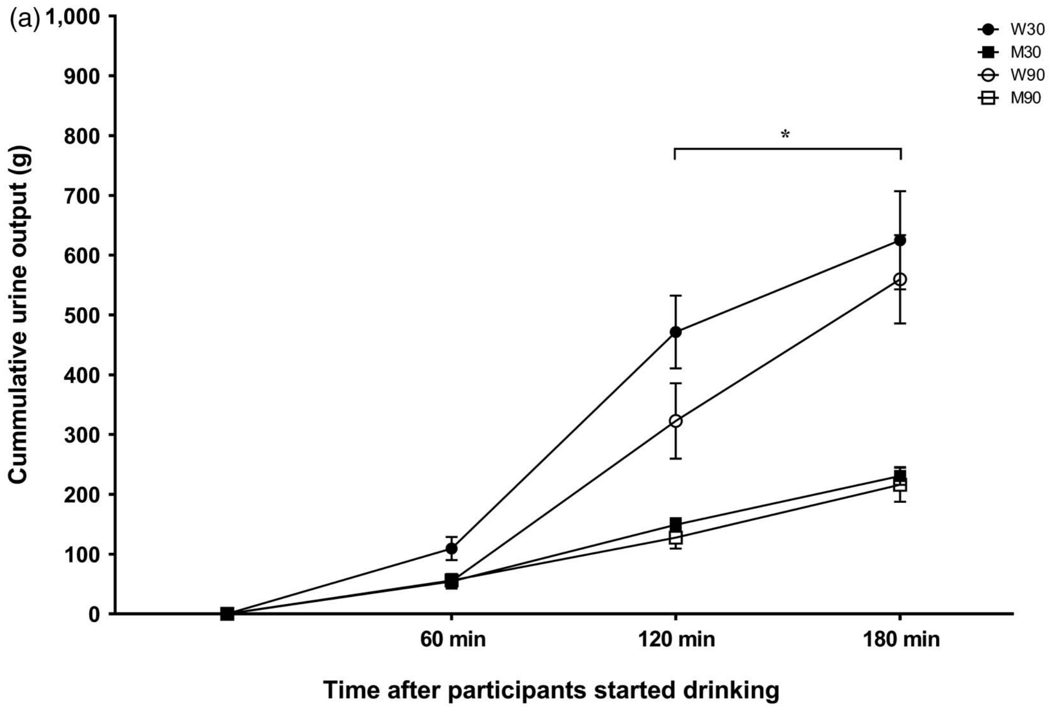

Figure 2 — Cumulative urine output before and after the test drink ingestion equal to the volume of sweat lost during exercise. (a) Part A—water or milk ingested over 30 or 90 min (water 30 min [W30], water 90 min [W90], milk 30 min [M30], and milk 90 min [M90]). (b) Part B—water ingested over 15 min (DR15), 45 min (DR45), or 90 min (DR90). Values are presented as mean ± *SD*. *Milk significantly different to water.

Discussion

This two-part study explored the effect of drinking rate on fluid retention of different beverages following exercise-induced dehydration. In keeping with our hypothesis, Part A observed that drinking milk resulted in greater fluid retention than water during a 3-hr recovery period. This effect was not influenced by drinking rate (i.e., 30 vs. 90 min). Consequently, Part B assessed retention of water consumed over alternative drinking rates (i.e., 15 vs. 45 vs. 90 min), as well as the day-to-day variation in postexercise fluid retention. Part B indicated that the 15-min drinking protocol led to a significant reduction in fluid retention compared with the 90-min drinking protocol. However, the magnitude of the effect was within the CV% of the repeated

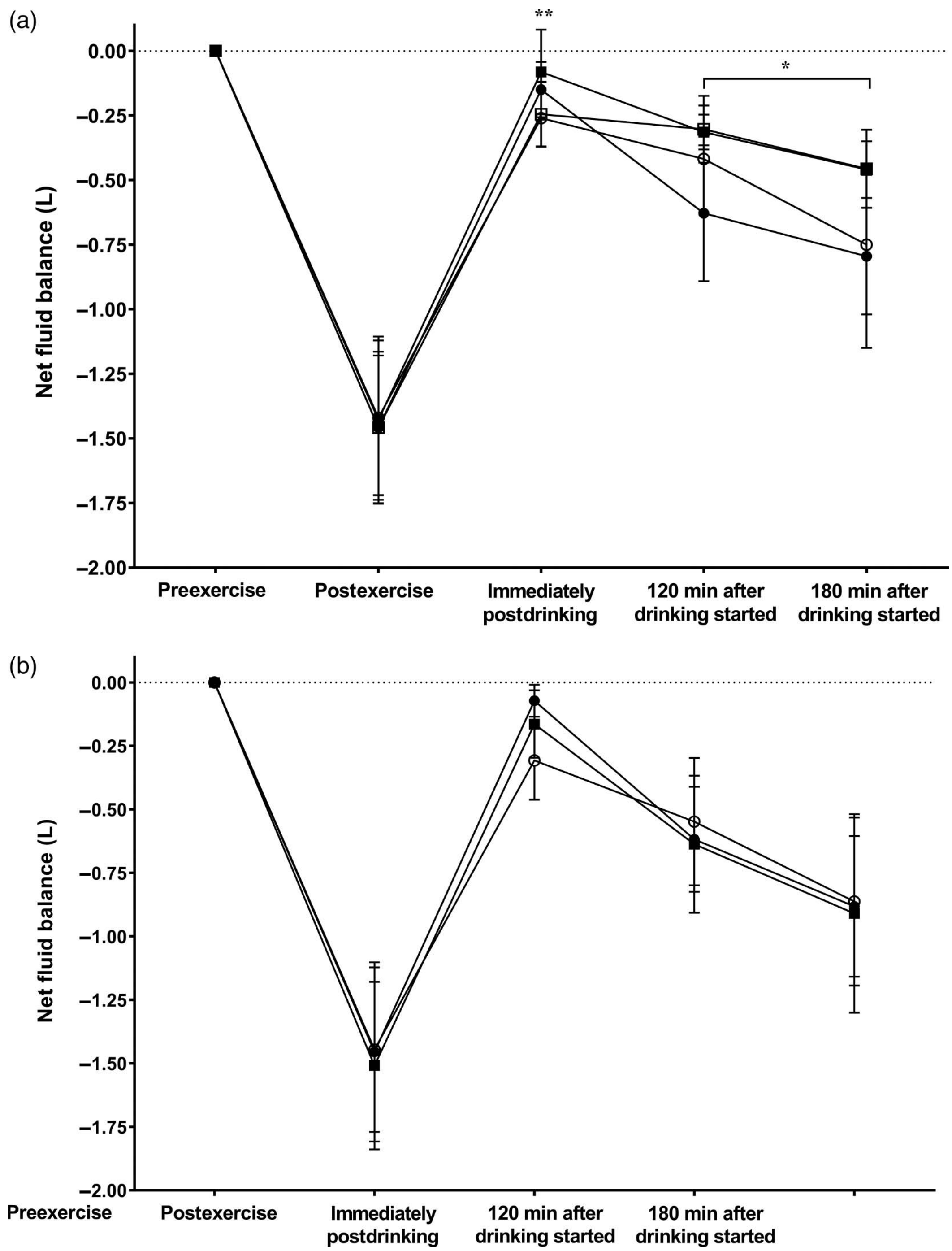

Figure 3 — Net fluid balance responses before and after the test drink ingestion equal to the volume of sweat lost during exercise. (a) Part A—water or milk ingested over 30 or 90 min (water 30 min [W30], water 90 min [W90], milk 30 min [M30], and milk 90 min [M90]). (b) Part B—water ingested over 15 min (DR15), 45 min (DR45), or 90 min (DR90). Values are presented as mean ± *SD*. *Milk significantly different to water. **Rapid drinking significantly different to metered drinking.

trials (17%). Thus, findings from this study suggest that the influence of drinking rate on postexercise fluid recovery is small and that the nutrient composition of a beverage has a more pronounced impact on fluid retention than the beverage ingestion rate.

Only two studies have previously investigated the influence of drinking rate on fluid recovery (Jones et al., 2010; Kovacs et al., 2002). Results from these studies are contradictory, with only one investigation (Jones et al., 2010) identifying an influence of drinking rate on fluid retention. Jones et al. (2010) had participants ingest water at 1.61 versus 0.40 L/hr. Kovacs et al. (2002) had participants ingest a carbohydrate–electrolyte sports drink at a maximum rate of 1.32 L/hr in the first hour, with an average rate over 3 hr of 0.77 L/hr and compared this to fluid retention with a slow drinking rate of 0.53 L/hr over 5 hr. These fluid consumption patterns are slower than those observed when

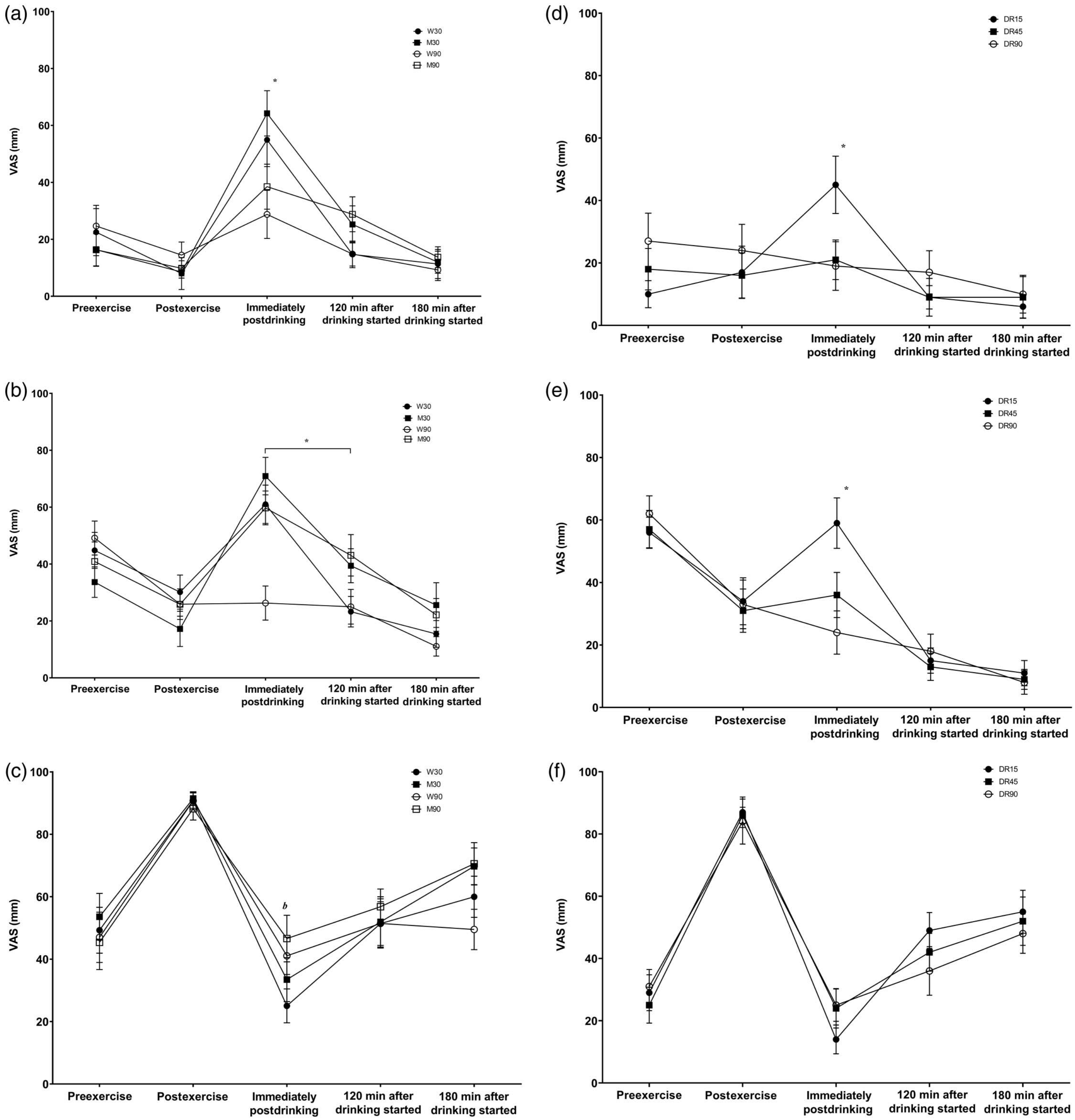

Figure 4 — Subjective gastrointestinal ratings of bloatedness, fullness, and thirst before and after test drink ingestion equal to the volume of sweat lost during exercise. Part A = panels a, b, and c. Part B = panels d, e, and f. Values are presented as mean ± *SEM*, where 0 represents *not at all*, and 100 represents *extremely much* for each subjective feeling. *Milk significantly different to water. **Rapid drinking significantly different to metered drinking. ***Fast ingestion rate significantly different to slow ingestion rate.

individuals drink ad libitum postexercise (e.g., with drinking rates in the first 30 min exceeding 2 L/hr; Baguley et al., 2016). This study attempted to assess drinking rates across a broader range (5.84 L/hr [1.46 L in 15 min] to 0.95 L/hr [1.42 L in 90 min]) to elucidate effects on fluid retention. We observed little impact of contrasting drinking rates on fluid retention with water. In fact, the only difference noted in Part B (DR15 vs. DR90) was within the CV% of the method.

The current findings suggest that the nutrient profile of different beverages have a greater impact on fluid retention than

Table 2 Test–Retest Trial Data (Part B: Pooled From DR15 and DR45)

Measure	Initial trial	Repeat trial	*p* value
Pretrial conditions			
Pre-Ex U_{OSM}	483 ± 197	479 ± 197	.30
Pre-Ex P_{OSM} (mOsm/kg)	307 ± 5	307 ± 7	.81
Pre-Ex BM (kg)	72.56 ± 11.10	72.38 ± 10.94	.30
Ex duration (min)	80.0 ± 13.5	80.8 ± 13.1	.34
BM loss (kg)	1.43 ± 0.32	1.39 ± 0.39	.62
Fluid retention data			
Cumulative urine output (g)	792 ± 280	704 ± 175	.07
U_{OSM} 180 min after drinking started (mOsm/kg)	297 ± 75	281 ± 127	.69
P_{OSM} 180 min after drinking started (mOsm/kg)	303 ± 4	302 ± 4	.38
Fluid retention (%)	52.8 ± 7.0	55.0 ± 7.5	.21

Note. Values are presented as mean ± *SD*. Water ingested over 15 min (DR15) or 45 min (DR45). Ex = exercise; U_{OSM} = urine osmolality; P_{OSM} = plasma osmolality; BM = body mass.

ingestion rate. Indeed, when consumed exclusively and matched for volume, milk beverages promote greater fluid retention than water at rest (Maughan et al., 2016) and during the postexercise period (Seery & Jakeman, 2016; Shirreffs et al., 2007; Watson et al., 2008). These effects may be mediated by the composition of milk (whey/casein protein), electrolyte content, and insulin response to carbohydrate/protein delivery. In addition, the electrolyte content of milk (Shirreffs et al., 2007) and insulin-mediated impacts on renal water transport (Magaldi et al., 1994) both have the potential to enhance fluid retention.

In a practical sense postexercise, athletes typically consume fluids ad libitum, and the beverage choice, drinking rate, and total volume consumed are determined by many factors, including prior exercise (intensity, duration, and type); environmental conditions; thirst; palatability; gastrointestinal tolerance; drink availability; exercise commitments; and other, unrelated dietary goals (Minehan et al., 2002; Passe et al., 2000). The rapid consumption of large volumes of milk or water during the immediate postexercise period may be poorly tolerated by some individuals. However, the range of subjective responses to our most rapid drinking rates highlights individual differences in tolerance. For those who drink beverages rapidly in the immediate postexercise period, the rates examined in this study do not appear to compromise fluid retention when a fixed volume is provided and may facilitate the consumption of other fluids after completing a “prescribed” volume of a beverage. Conversely, it is not known whether rapid beverage ingestion compromises subsequent voluntary fluid consumption in ad libitum drinking scenarios due to an action on thirst response mediated via the gut–brain axis (Zimmerman et al., 2019).

Several methodological limitations require acknowledgment. First, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during milk trials, the physiological distribution of the retained fluid (e.g., within gastrointestinal tract as opposed to vascular space) remains unknown. In addition, the recovery period for this study (3 hr from the start of drinking) was shorter than previous work in this area (typically ≥ 4 hr), which may have resulted in small volumes of uncaptured fluid losses in response to the differences in drinking strategy. The decision to shorten the duration of the observation was based on a number of factors: (a) the relatively small volumes of urine seen beyond 90 min following the cessation of drinking in our previous study (Desbrow et al., 2014); (b) the smaller volume of fluid being ingested (100% vs. 150% fluid replacement); (c) the practical relevance of 4 hr observation, given that many individuals are likely to eat/drink within this period of time; and (d) our previous study (Maughan et al., 2016) demonstrated that the pattern of response in cumulative urine output and calculated hydration index to ingested drinks was observed to be similar at 2 hr and 4 hr postdrinking.

Conclusion

This study suggests that drinking more rapidly does not compromise postexercise fluid retention following moderate-intensity exercise in recreationally active participants. This observation was consistent between different testing sites and across different drinking rates. Laboratory informed findings suggest that beverage composition is more influential than fluid ingestion rate in determining postexercise fluid retention.

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