Effect of drinking rate on the retention of water or milk following exercise-induced dehydration.

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Introduction

Individuals typically do not consume enough fluid during exercise to counteract sweat losses, producing a post-exercise 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 (POSM), 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 to 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 (Osterberg et al., 2009), and protein (Hobson & James, 2015; James et al., 2014; James et al., 2012)), which are believed to delay gastric emptying and/or attenuate changes in \( P_{\text{OSM}} \), reducing the degree of fluid induced diuresis (Calbet & MacLean, 1997; Clayton et al., 2014; Murray et al., 1999; Vist & Maughan, 1995).

Typically, post-exercise rehydration studies control drinking rate by prescribing fixed volumes of beverages within standardised 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 h (79±6%) compared to 5 h (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 h (75±12%) compared to a 1 h
(55±18%) drinking period 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 the current study was to investigate the effect of rapid vs 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, 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 thirteen 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, twelve male participants (age: $23.5\pm5.3$ y; height: $179\pm6$ cm; BM: $77.3\pm9.6$ kg; maximal oxygen consumption ($V\text{O}_2\text{peak}$): $43.1\pm6.4$ mL·kg$^{-1}$·h$^{-1}$ (Mean±SD)) completed four experimental trials.

In Part B fourteen 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, twelve (9 males and 3 females) participants (age: $28.3\pm6.3$ y; height: $176\pm11$ cm; BM $74.0\pm10.2$ kg; $V\text{O}_2\text{peak}$: $50.6\pm7.6$ mL·kg$^{-1}$·h$^{-1}$) completed four experimental trials.

Study designs

A schematic representation of the experimental protocols is displayed in Figure 1. Both parts utilised a repeated-measures experimental design, involving 4 experimental trials; each separated by a minimum of 5 d. For all trials, participants lost $\sim2.0\%$ 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, USA; Part B: Servomex Group Ltd, United Kingdom). The test was used to determine $V\text{O}_2\text{peak}$ and maximum heart rate ($HR_{\text{max}}$), with these values used to guide the prescription of exercise intensity for the experimental trials. Participants were instructed to abstain from caffeine (12 h), alcohol (24 h) and moderate to strenuous exercise (12 h) before all trials. During the 24 h period preceding the first trial, individuals completed a
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They were also instructed to drink 500 mL of water at least 2 h before arrival at the laboratory (to assist with hydration) and abstain from all food and fluid (excluding water) after 21:00 h. 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 h and verbally acknowledged compliance to the pre-experimental conditions. A urine sample was taken for determination of hydration status (Part A: urine specific gravity ($U_{SG}$) (Palette Digital Refractometer, ATAGO, USA) and Part B: urine osmolality ($U_{Osm}$) (Löser Osmometer, Camlab, UK). If participants recorded a $U_{SG} \geq 1.024$ (Sommerfield et al., 2016) or $U_{Osm}$ of $>700$ mOsm·kg$^{-1}$ (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 venepuncture of a forearm vein. Following this initial blood collection, participants were provided with a standardised breakfast in a quantity relative to BM (20 kJ·kg$^{-1}$ and 1 g CHO·kg$^{-1}$) that consisted of raisin toast, strawberry jam and fruit juice (200 mL), before completing a questionnaire on GI 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 standardised warm up, participants began cycling in a warm environment (Part A: 25.2±0.8 °C and 84±11% RH, Part B: 26.4±0.7°C and 38±5% RH). Individuals commenced exercise at a workload corresponding to ~65% of HR$_{max}$. Intensity was recorded by an investigator and replicated on all subsequent trials. Following 50 min of cycling, participants BM was measured. A BM loss of <1.8% from baseline required participants to continue exercising in 10 min bouts until a BM loss $\geq$ 1.8% was reached.
achieved. Following exercise, dehydrated participants rested in a seated position for 15 min prior to
having a cool shower. Afterwards, participants dried themselves thoroughly, before a cannula was
inserted into a forearm vein and a blood sample 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 post-exercise).

*Post-exercise fluid replacement*

In Part A, water or low fat cow’s milk (Maleny Dairies, Queensland, Australia; 210 kJ Energy, 5.3 g
CHO, 4.0 g Protein, 1.4 g Fat, 48 mg Na\(^+\)·100 mL\(^{-1}\)) 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 DR45 trial. To
assess inter-site variation W90 (Part A) was compared to DR90 (Part B).

A 3 h 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.

*Body mass and fluid retention*

BM change (estimate of fluid loss) was calculated by subtracting the post-exercise BM (post-void) from
the pre-exercise BM. Net BM change was calculated by subtracting the 3 h BM measurement from the
pre-exercise BM. Percent fluid retention at the conclusion of the observation period was calculated by the following equation:

\[
\text{Fluid Retained (％) = 100} \times \frac{\text{Total beverage ingested (g) – Total urine output (g)}}{\text{Total beverage ingested (g)}}
\]

126

127 *Urine and blood collection, storage and analysis*

128 Additional urine sampling was performed at pre-exercise, post-exercise (immediately pre-drinking), immediately post-drinking and then at 120 min 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 urine osmolality. Blood sampling was performed at pre-exercise, post-exercise (immediately pre-drinking), immediately post-drinking and then at 120 min 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 EDTA pre-treated vacutainers and centrifuged at room temperature for 10 min at ~1350×g. Plasma was analysed in duplicate on a calibrated freezing-point depression osmometer (Part A: Osmomat 030, Germany and Part B: Löser osmometer, Camlab, UK). Cannulas were kept patent by flushing sterile saline (2 mL of 0.9% NaCl; Becton Dickson, NJ, USA) on completion of each sample (with an equivalent volume of blood initially discarded before collection of subsequent samples).

142 *Subjective measures*

143 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’. 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., IBM, Chicago, IL). All measures were examined for normality and sphericity using the Shapiro-Wilk test ($p>0.05$) and Mauchly’s test ($p>0.05$), 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) were performed to verify that pre-trial conditions and exercise-induced fluid loss did not differ across trials. For Part A, a three-factor (i.e. Beverage x Rate x Time) repeated-measures ANOVA was used to compare main outcomes; two-factor (i.e. Beverage x Rate) repeated-measures ANOVA were 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 x Time) repeated-measures ANOVA were 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. $p=0.05$ 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 $p<0.05$. All data are reported as Mean±SD, unless stated as Mean±SEM.

**Results**

**Standardisation procedures**

All participants reported compliance with the standardisation procedures in the 24 h prior to arriving at the laboratory. In Part A, two participants were administered water (600 mL) due to a pre-exercise USG $\geq 1.024$ 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 pre-exercise values for BM, $U_{SG}$ and $P_{OSM}$ were similar across all treatments, and did not differ significantly by trial order ($p>0.05$). Exercise-induced BM loss differed significantly ($p<0.01$) by trial order (Trial 1:...
171 1.54±0.26 kg; Trial 2: 1.44±0.28 kg; Trial 3: 1.41±0.31 kg; Trial 4: 1.38±0.32 kg); however, 
172 counterbalancing ensured that mass loss was similar across treatment conditions (Table 1). 
173 In Part B, exercise duration and pre-exercise values for BM, U_{OSM}, P_{OSM}, and exercise induced 
174 BM loss were similar across all treatments (Table 1); and did not differ significantly by trial order (p>0.05).

175 **Urine output and fluid retention**

176 In Part A, cumulative urine output was greater with water than with milk at 120 min (398±190 vs. 139±44 
177 g) and 180 min (592±248 vs. 224±70 g) after the start of drinking (p<0.01; Figure 2A). A significant 
178 effect of beverage was observed on fluid retention (W30: 56.5±16.1%; W90: 59.7±19.9%; M30: 
179 82.9±6%; M90: 84.9±7%) with the proportion of ingested fluid retained lower with water than milk 
180 (58.1±15.6 vs. 83.9±6.1%, p<0.01). No other significant differences were observed in either analysis.

181 In Part B, a similar cumulative urine output response was observed when water was ingested at DR15, 
182 DR45 and DR90 rates. Three hours after the start of the drinking period, cumulative urine output was 
183 lower for the DR90 trial (602±183 g) compared to the DR45 (750±373 g) and DR15 (754±230 g) trials, 
184 but this did not reach statistical significance (p>0.05). The mean difference (95% CI) between DR15 and 
185 DR90 was 7.4(1.2-13.6)%, equivalent to 152 (43-260) mL (Figure 2B). Fluid retention was significantly 
186 higher (p<0.05) on the DR90 trial (57.1±12.9%) compared to the DR15 trial (49.7±11.0%), but these 
187 trials were not different (p>0.05) to DR45 (51.6±19.8%).

188 **Net fluid balance**

189 In Part A, all experimental trials concluded with participants in a state of negative net fluid balance 180 
190 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 
191 L, M90: -0.28±0.08 L; Figure 3A). Post hoc comparisons revealed that milk ingestion led to less negative 
192 fluid balance compared to water at 120 min (-0.40±0.19 vs. -0.14±0.04 L, p=0.001) and 180 min (- 
193 0.64±0.27 vs. -0.28±0.07 L, p<0.001) after drinking started. Fluid balance was also less negative
immediately post-drinking for the 30 min compared to the 90 min drinking trials (-0.14±0.08 vs. 0.04±0.03 L, p<0.001), since 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 to milk at the cessation of drinking (291±4 vs. 298±5 mOsm·kg\(^{-1}\), p<0.001), but this effect was not evident by 180 min (Water: 290±2 mOsm·kg\(^{-1}\); Milk: 293±4 mOsm·kg\(^{-1}\), p=0.033). P_{OSM} did not differ significantly as a result of the fluid ingestion rate at any point (p>0.05).

In Part B, a drinking rate by time interaction was not evident for P_{OSM}. Plasma osmolality 180 minutes after start of drink ingestion did not differ significantly as a result of the fluid ingestion rate (DR15: 304±2 mOsm·kg\(^{-1}\); DR45: 302±3 mOsm·kg\(^{-1}\); DR90: 303±5 mOsm·kg\(^{-1}\), p>0.05).

**Subjective measures**

In Part A, analysis for bloatedness, fullness, and thirst ratings identified a significant effect of time on each variable (p<0.01). A significant effect of beverage was also observed for fullness (p=0.022). For bloatedness and fullness there were significant time x beverage interaction effects (bloatedness: p=0.014; fullness p<0.01). Post hoc comparisons revealed that the 30 min drinking protocol increased feelings of bloatedness (p<0.01) and decreased feelings of thirst (p<0.01) immediately after drinking compared to the 90 min protocol. The consumption of milk increased feelings of fullness immediately after drinking (p<0.01) and at 120 min (p<0.01), compared to 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 to the DR45 and DR90 drinking rates (p<0.01), 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 re-test reliability between duplicate trials on DR15 and DR45 ingestion rates (Part B) was 17%. Data from repeated trials was 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%; DR90: 57.1±12.9%, p=0.73).

**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 h 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 post-exercise fluid retention. Part B, indicated that the 15 min drinking protocol led to a significant reduction in fluid retention compared to the 90 min drinking protocol. However, the magnitude of the effect was within the CV% of the repeated trials (17%). Thus, findings from this study suggest the influence of drinking rate on post-exercise 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 L h⁻¹ vs. 0.40 L h⁻¹. Kovacs et al., (2002) had participants ingest a carbohydrate-electrolyte sports drink at a maximum rate of 1.32 L h⁻¹ in the first hour, with an average rate over 3 hours of 0.77 L h⁻¹ and compared this to fluid retention with a slow drinking rate of 0.53 L h⁻¹ over 5 h. These fluid consumption patterns are slower than those observed when individuals drink ad...
libitum post-exercise (e.g. with drinking rates in the first 30 min exceeding 2 L h⁻¹, Baguley et al., 2016).

The present study attempted to assess drinking rates across a broader range (5.84 L h⁻¹ (1.46 L in 15 min) to 0.95 L h⁻¹ (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 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 post-exercise 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 post-exercise, 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 post-exercise 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 post-exercise period, the rates examined in the present 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 acknowledgement. Firstly, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during Milk trials, the distribution of the retained fluid (e.g. within the GI tract as potentially indicated by higher “fullness” ratings as opposed to vascular space) and therefore physiological relevance of this fluid retention remains unknown. In addition, the recovery period for this study (3 h from the start of drinking) was shorter than previous work in this area (typically ≥4 h), 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; (1) the relatively small volumes of urine seen beyond 90 min following the cessation of drinking in our previous study (Desbrow et al 2014), (2) the smaller volume of fluid being ingested (100% vs. 150% fluid replacement), (3) the practical relevance of 4 h observation, given that many individuals are likely to eat/drink within this period of time and (4) our previous study (Maughan et al., 2016) demonstrated the pattern of response in cumulative urine output and calculated hydration index to ingested drinks was observed to be similar at 2 h post-drinking and 4 h post-drinking.

**Conclusion**

This study suggests that drinking more rapidly does not compromise post-exercise 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 post-exercise fluid retention.

**Acknowledgments**

The authors declare no conflicts of interest.

Giustiniani conducted the research and analysed the samples. B. Desbrow, S. D. R. Galloway, C. Irwin, N. Rodriguez-Sanchez, D. McCartney and L. Sayer performed the statistical analysis. B. Desbrow, S. D. R. Galloway, C. Irwin, N. Rodriguez-Sanchez, D. McCartney, P. Rodriguez-Giustiniani and L. Sayer wrote the paper. All the authors approved the final version of the paper.

References


and Metabolism, 34(4), 785-793.


Figure legends and footnotes

Figure 1. Schematic of experimental protocol investigating the effect of drinking rate on fluid retention following exercise.

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 (W30); Water 90 (W90); Milk 30 (M30); and Milk 90 (M90)), B = Part B (Water ingested over 15 (DR15), 45 (DR45) or 90 (DR90) mins). a, milk significantly different to water. Values are Mean±SD.

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 (W30); Water 90 (W90); Milk 30 (M30); and Milk 90 (M90)), B = Part B (Water ingested over 15 (DR15), 45 (DR45) or 90 (DR90) mins). a, milk significantly different to water; b, rapid drinking significantly different to metered drinking. Values are Mean±SD.

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 and Part B = Panels D, E and F. a, milk significantly different to water; b, rapid drinking significantly different to metered drinking; c, fast ingestion rate significantly different to slow ingestion rate. Values are Mean±SEM, where 0 represents ‘not at all’ and 100 represents ‘extremely much’ for each subjective feeling.
Table 1. Pre-trial conditions and impact of exercise-induced dehydration

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<td>Pre-Ex $U_{SG}$</td>
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<td>Pre-Ex BM (kg)</td>
<td>77.10±9.67</td>
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<td>Ex Duration (min)</td>
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<td>BM Loss (kg)</td>
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<td>Pre-Ex $U_{OSM}$</td>
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<td>Pre-Ex BM (kg)</td>
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<td>Ex Duration (min)</td>
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<td>BM Loss (%)</td>
<td>2.0±0.4</td>
<td>2.1±0.2</td>
<td>2.0±0.3</td>
<td>0.61</td>
</tr>
</tbody>
</table>

BM: Body mass; Ex: Exercise; $P_{OSM}$: Plasma osmolality; $U_{SG}$: Urine specific gravity; $U_{OSM}$: Urine osmolality.
Values are Mean±SD.
Table 2. Test-retest trial data (Part B: pooled from DR15 and DR45)  

<table>
<thead>
<tr>
<th>Pre-Trial Conditions</th>
<th>Initial Trial</th>
<th>Repeat Trial</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Ex U\text{OSM}</td>
<td>483±197</td>
<td>479±197</td>
<td>0.30</td>
</tr>
<tr>
<td>Pre-Ex P\text{Osm} (mOsm·kg\text{-1})</td>
<td>307±5</td>
<td>307±7</td>
<td>0.81</td>
</tr>
<tr>
<td>Pre-Ex BM (kg)</td>
<td>72.56±11.10</td>
<td>72.38±10.94</td>
<td>0.30</td>
</tr>
<tr>
<td>Ex Duration (min)</td>
<td>80.0±13.5</td>
<td>80.8±13.1</td>
<td>0.34</td>
</tr>
<tr>
<td>BM Loss (kg)</td>
<td>1.43±0.32</td>
<td>1.39±0.39</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**Fluid Retention Data**

<table>
<thead>
<tr>
<th></th>
<th>Initial Trial</th>
<th>Repeat Trial</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative urine output (g)</td>
<td>792±280</td>
<td>704±175</td>
<td>0.07</td>
</tr>
<tr>
<td>U\text{OSM} 180 min after drinking started (mOsm·kg\text{-1})</td>
<td>297±75</td>
<td>281±127</td>
<td>0.69</td>
</tr>
<tr>
<td>P\text{Osm} 180 min after drinking started (mOsm·kg\text{-1})</td>
<td>303±4</td>
<td>302±4</td>
<td>0.38</td>
</tr>
<tr>
<td>Fluid retention (%)</td>
<td>52.8±7.0</td>
<td>55.0±7.5</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Values are mean±SD.
Figure 1

A

- Urine collection
- Blood collection
- TEST drink of milk (400 mL) or water (400 mL)
- Standardized breakfast

B

- Urine collection
- Blood collection
- Water
- Standardized breakfast

Measures

W30 & M30

- Node body mass
- Exercise 12% BM loss (Max time: 60 min)
- 10-min rest and shower
- Gastrintestinal symptoms

W90 & M90

- DR15

- DR45

- DR90
Figure 2

A

Cumulative urine output (g)

Time after participants started drinking

B

Cumulative urine output (g)

Time after participants started drinking
Figure 3

**A**

- **W30**
- **W90**
- **M30**
- **M90**

**B**

- **DR15**
- **DR45**
- **DR90**

Net fluid balance (L)

<table>
<thead>
<tr>
<th>Time</th>
<th>Pre-exercise</th>
<th>Post-exercise</th>
<th>Immediately post-drinking</th>
<th>120 min after drinking started</th>
<th>180 min after drinking started</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-exercise</td>
<td>-2.00</td>
<td>-1.75</td>
<td>-1.50</td>
<td>-1.25</td>
<td>-1.00</td>
</tr>
<tr>
<td>Post-exercise</td>
<td>-1.75</td>
<td>-1.50</td>
<td>-1.25</td>
<td>-1.00</td>
<td>-0.75</td>
</tr>
<tr>
<td>Immediately post-drink</td>
<td>-1.50</td>
<td>-1.25</td>
<td>-1.00</td>
<td>-0.75</td>
<td>-0.50</td>
</tr>
<tr>
<td>120 min after drinking started</td>
<td>-1.25</td>
<td>-1.00</td>
<td>-0.75</td>
<td>-0.50</td>
<td>-0.25</td>
</tr>
<tr>
<td>180 min after drinking started</td>
<td>-1.00</td>
<td>-0.75</td>
<td>-0.50</td>
<td>-0.25</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Figure 4

A

B

C

D

E

F

Human Kinetics, 1607 N Market St, Champaign, IL 61825
Figure 2

A

B

Cummulative urine output (g)

Time after participants started drinking

Cumulative urine output (g)

Time after participants started drinking
Figure 3

A

Net fluid balance (L)

Pre-exercise  Post-exercise  Immediately post-drinking  120 min after drinking started  180 min after drinking started

B

Net fluid balance (L)

Pre-exercise  Post-exercise  Immediately post-drinking  120 min after drinking started  180 min after drinking started
Figure 4

A

B

C

D

E

F

Human Kinetics, 1607 N Market St, Champaign, IL 61825
Table 1. Pre-trial conditions and impact of exercise-induced dehydration

<table>
<thead>
<tr>
<th>Part A</th>
<th>W30</th>
<th>W90</th>
<th>M30</th>
<th>M90</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Ex $U_{SG}$</td>
<td>1.015±0.006</td>
<td>1.015±0.007</td>
<td>1.013±0.005</td>
<td>1.014±0.005</td>
<td>0.35</td>
</tr>
<tr>
<td>Pre-Ex $P_{OSM}$ (mOsm·kg⁻¹)</td>
<td>290±4</td>
<td>292±5</td>
<td>290±6</td>
<td>289±5</td>
<td>0.67</td>
</tr>
<tr>
<td>Pre-Ex BM (kg)</td>
<td>77.10±9.67</td>
<td>77.27±9.78</td>
<td>76.77±9.73</td>
<td>76.57±9.52</td>
<td>0.28</td>
</tr>
<tr>
<td>Ex Duration (min)</td>
<td>70±14</td>
<td>70±13</td>
<td>70±13</td>
<td>70±12</td>
<td>0.86</td>
</tr>
<tr>
<td>BM Loss (kg)</td>
<td>1.46±0.28</td>
<td>1.42±0.30</td>
<td>1.43±0.32</td>
<td>1.46±0.29</td>
<td>0.79</td>
</tr>
<tr>
<td>BM Loss (%)</td>
<td>1.9±0.3</td>
<td>1.9±0.4</td>
<td>1.9±0.4</td>
<td>1.9±0.3</td>
<td>0.82</td>
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<table>
<thead>
<tr>
<th>Part B</th>
<th>DR15</th>
<th>DR45</th>
<th>DR90</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Ex $U_{OSM}$</td>
<td>477±218</td>
<td>474±178</td>
<td>443±185</td>
<td>0.76</td>
</tr>
<tr>
<td>Pre-Ex $P_{OSM}$ (mOsm·kg⁻¹)</td>
<td>303±5</td>
<td>302±3</td>
<td>302± 5</td>
<td>0.36</td>
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<tr>
<td>Pre-Ex BM (kg)</td>
<td>71.60±9.90</td>
<td>71.54± 10.15</td>
<td>71.31± 10.08</td>
<td>0.39</td>
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<tr>
<td>Ex Duration (min)</td>
<td>79±12</td>
<td>81±13</td>
<td>80± 11</td>
<td>0.62</td>
</tr>
<tr>
<td>BM Loss (kg)</td>
<td>1.46±0.35</td>
<td>1.51± 0.33</td>
<td>1.45±0.32</td>
<td>0.30</td>
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<td>BM Loss (%)</td>
<td>2.0± 0.4</td>
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Values are mean±SD.
Response to peer review comments

Manuscript ID IJSNEM. 2019-0176 entitled
“Effect of drinking rate on the retention of water or milk following exercise-induced dehydration.”

We thank the editor and reviewers for the detailed review, and believe the edits strengthen our manuscript. Please note that as an Original Research manuscript, we have addressed reviewer concerns (and made appropriate manuscript amendments) while being respectful of the word limit specified by the journal.

Reviewer: 1

Recommendation: Minor Revision

Comments:
This paper titled ‘Effect of drinking rate on the retention of water or milk following exercise-induced dehydration’ includes data from 2 separate studies undertaken in Scotland and Australia. The studies are well-conceived and answer relevant research questions with a clear link between the two studies that justifies their inclusion in the same paper. Given that the studies employ methods that have been often used in previous studies in this area, they are generally sound. Overall, the work highlights that varying the duration in which a drink is ingested from 15-90 min post-exercise has little (small effect on drink retention between 15 and 90 min) effect on the amount of drink retained, but that milk was better retained than water.

The authors thank reviewer #1 for the generally complimentary response to the investigation.

Major Points

Whilst there is relatively few issues with the studies presented and the authors have generally done a good job, there are some caveats that should be covered in the discussion in more detail, in my opinion. Firstly, the duration of follow up was relatively short (i.e. total of 3 h from the start of drinking). This is shorter than the vast majority of previous work in the area and may influence the results in a number of ways. If urine volume was not back down to near basal values, then there may be uncaptured fluid losses in response to the differences in drinking strategy that have not been accounted for. In reality, this is unlikely to represent a large amount of fluid, but should be mentioned as it is particularly pertinent when you consider it in the context of the difference drinking durations as in the shorter trials (e.g. 15 min drinking) there will be a longer time from the end of drinking for the drink to be excreted (i.e. 2 h 45 min in this case) compared to the slower drinking trials. This is particularly pertinent since the only other study I’m aware of in this area (published as an abstract; Archer DT, Shirreffs SM. Effect of fluid ingestion rate on post-exercise rehydration in human subjects. Proc Nutr Soc 60: 200A, 2001) followed for 4 h after the start of drinking and saw no difference between drinking over 30 min and 90 min at 3 h, but a significant difference at 4 h. The difference was, however, small. The other difference between the study of Archer and Shirreffs and this one was that they provided a drink volume equal to 150% of the subjects’ sweat loss during exercise. Maybe this also accounts for the difference in observation?

The authors thank the reviewer for these detailed comments and suggestions. In response to these comments (and the concerns of Reviewer #2), we have added a limitations paragraph to the Discussion. The paragraph reads as follows:

“Several methodological limitations require acknowledgement. Firstly, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during Milk trials, the distribution of the retained fluid (e.g. within the GI tract (as potentially indicated by higher “fullness” ratings) as opposed to vascular space) and therefore physiological relevance of this fluid retention remains unknown. In addition, the recovery period for this study (3 h from the start of drinking) was shorter than previous work in this area (typically ≥4 h), 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: (1) the relatively small volumes of urine seen beyond 90 min following the cessation of drinking in our previous work (Desbrow et al, 2014), (2) the smaller volume of
fluid being ingested (100% v’s 150% fluid replacement), (3) the practical relevance of 4 h observation, given that many individuals are likely to eat/drink within this period of time and (4) a previous study (Maughan et al 2016) demonstrated the pattern of response in cumulative urine output and calculated hydration index to ingested drinks was observed to be similar at 2 h post-drinking and 4 h post-drinking.”

We were aware of the Archer et al study, but have avoided direct reference to it in the manuscript, as the information was available in abstract form (as mentioned) only and involved a small participant pool (n=6).

The discussion lacked a little in depth and I certainly would liked to have seen more on the points above and also the practical relevance of the finding, particularly given that in the real world food would also be consumed alongside the drinks, which might change the effects reported. Also, from a practical perspective, drinking more quickly might offer an advantage given that other fluids might then be ingested sooner after completing the ‘prescribed rehydration’. Could the methods be shortened to allow more space for discussion of these points?

The authors thank the reviewer for this comment. We agree that the practical aspects of rehydration warrant consideration. Indeed, we have attempted to understand the interaction between food and fluid in our recent studies (1-3). However, for this investigation, food was removed to avoid further influences on gastric emptying rate. We acknowledge the suggestion of reducing the methods section, however, the current level of information has been significantly reduced while ensuring the reader is provided with adequate detail to understand the study design, experimental protocol and standardisation procedures employed for scientific rigor and enhanced confidence in the reported data. Thus, for the methods section, we have opted to retain the current level of detail.

As mentioned, a potential practical benefit of rapid drinking has been added to the Discussion. This section reads as follows:

“In a practical sense post-exercise – as an alternative to “In the sporting post-exercise context”, 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/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 post-exercise 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 post-exercise period, the rates examined in the present 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).”

Minor Points

Line-by line comments:

5: Evans et al. (J Appl Physiol 122: 945–951, 2017) provides a more up to date overview of post-exercise rehydration that might be relevant here.

The Evans et al reference has now been included.

14: Interestingly, the study of Shirreffs et al (2007) and Watson et al. (2008) are the only studies in the literature (or information from historic nutrition composition tables, nutrition information etc.) to report
such high levels of sodium in milk. Typically (historic nutrition composition tables/ nutrition information etc.), milk is considered to have a sodium concentration in the region of 20 mmol/L, which generally seems to be ineffective at promoting better rehydration.

The authors agree that the sodium content of milk is interesting in that some varieties appear to differ (regionally / seasonally) in amounts that may influence fluid retention. In fact, our original study design was to have milk trials completed at both study sites with the sodium content of the different milks being an important consideration. However, results from the initial trials lead to a change in experimental treatments for Part B. That said, it is also important to recognise that a combination of nutrients within milk may play a role in either delaying gastric emptying and/or attenuating changes in plasma osmolality.

17: The references here are of less relevance given the exercise/dehydration scenario discussed. Perhaps Clayton et al. (Int J Sport Nutr Exerc Metab 24: 79–89, 2014) or even Evans et al. (Br J Nutr 106: 1732-1739) given they deal with dehydration and/or exercise and repeated drink ingestion.

The Clayton et al. reference has been added to provide further support to this section.

56: Great that females were included, but can you add reference here that supports the lack of any menstrual cycle effects on the measured outcomes?

Unfortunately, there remains a limited amount of research in this area. However, a recent review concluded “most research indicates that the differences caused by hormonal fluctuations in women do not appear to affect performance, fluid regulation, or health risks during exercise” (4). Our recent study (5) confirmed that in eumenorrheic females (n=10) there was no difference in fluid balance outcomes post-exercise heat stress when assessed in late follicular and mid-luteal menstrual cycle phases. In the current study we confirmed that all female participants (n=3) had regular menstrual cycles as part of the pre-screening questionnaire and none were taking any oral contraceptive medication.

73-74: Is this correct? Given the effects of strenuous exercise on fluid balance, might a longer standardisation period have been appropriate? By this, they could have done 3 h cycling in the heat 4-7pm if arriving for an 8am trial. Further, it is not mentioned whether any activity done on the day before trials was standardised? As per the food/beverage diary? If so, please can you provide a bit more detail here?

The pre-trial procedures are consistent with those previously reported by our laboratory. The participants in our trial were recreationally active and not trained athletes. As such, we were interested in standardising the pre-trial conditions without being unnecessarily restrictive. All participants reported nil strenuous exercise was performed 12 h prior to the commencement of the experiment.

To clarify, the following sentence has been added to the Results. This section reads as follows:

“All participants reported compliance with the standardisation procedures in the 24 h prior to arriving at the laboratory. In Part A, two participants....”

90: What was the volume of fluid ingested here (i.e. fruit juice).

The authors thank the reviewer for highlighting this omission. The paragraph has been edited and reads as follows:

“Following this initial blood collection, participants were provided with a standardised breakfast in a quantity relative to BM (20 kJ·kg-1 and 1 g CHO·kg-1) that consisted of raisin toast, strawberry jam and fruit juice (200 mL), ...”
106-110: Was the volume of milk adjusted for the volume of water present since 1000 mL milk does not provide 1000 mL water due to the presence of other nutrients?
The authors thank the reviewer for this important comment. The volume of milk was not adjusted for the water present. This was due to our focus being on the applied context of drinking common beverages at different rates on fluid retention. If the volume of milk was increased to account for its water content (i.e. maintaining water intake rates), the participants would have been required to ingest larger (~10%) volumes of milk at a similar rate, creating inconsistencies across key parameters such as GI ratings.

137-141: What was the anticoagulant added to the blood to yield plasma? Was this consistent between sites?
The authors thank the reviewer for highlighting this omission. An indication of the specific anticoagulant has been added to the Method. This was consistent between sites. The section reads as follows:

“All samples were collected into EDTA pre-treated vacutainers and centrifuged at room temperature for 10 min at ~1350×g.”

155: Presumably this pair-wise comparison was a t-test, which was adjusted for multiple comparisons using the Bonferroni adjustment?
Correct. This information is included within the Methods “statistical analysis” section.

169-170: Any ideas on why this trial order effect occurred? After the first trial, did you standardise the exercise duration? Or did you always proceed until the same degree of body mass loss. If the latter, then it seems particularly peculiar.
The authors thank the reviewer for this comment. As mentioned, our participants were recreationally active, therefore our trial order effect is likely due to participant’s significant adaptation to the exercise protocol. The protocol was set based on the initial trial and then largely replicated. However, there were a small number of occasions when a participant reached fatigue (following slightly longer exercise duration) yet had less fluid loss than on a previous trial.
Reviewer: 2

Recommendation: Minor Revision

Comments:
Many thanks for the opportunity to read this manuscript. Please see my comments below.

The authors thank reviewer #2 for the positive comment and excellent suggestions.

Introduction:

Line-by-line comments:

7: what is meant by "delaying euhydration"? Surely for the diuresis to occur, participants would be hyperhydrated and then return to a hypohydrated state?
The authors thank the reviewer for identifying this source of ambiguity. To clarify, the Introduction has been edited. This section reads as follows:

“However, rapidly consuming large volumes of hypotonic fluid has the potential to reduce plasma osmolality (POSM), resulting in increased urinary output (i.e. “fluid induced diuresis”), potentially delaying a return to euhydration (Mitchell et al., 1994; Robertson, 1974).”

10 (onwards): I understand the focus on milk as a rehydration solution given the nature of the study in question however I believe some further discussion is warranted on the efficacy of these solutions. In particular, studies that have demonstrated milk is an effective rehydration solution rely on calculations of net fluid balance/cumulative urine output. In turn, this assumes that all of a solution has been emptied from the stomach and absorbed from the intestine. Studies looking at high carbohydrate solutions (Clayton et al. & Evans et al.) have suggested that nutrient dense solutions result in slow gastric emptying rates that effect the calculation of net fluid balance. Consequently, "greater fluid retention" may simply be the result of the calculations being used rather than any physiological relevance.
The authors thank the reviewer for this comment. In order to address the concerns of both reviewers we have added a section to the Discussion which incorporates the limitation of the past (and current) milk-based rehydration research. This section reads as follows:

“Several methodological limitations require acknowledgement. Firstly, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during Milk trials, the distribution of the retained fluid (e.g. within the GI tract (as potentially indicated by higher “fullness” ratings) as opposed to vascular space) and therefore physiological relevance of this fluid retention remains unknown.”

Methods:

Given it was only measured on one occasion, perhaps VO2max should be referred to as VO2peak
VO2_{\text{max}} has been replaced with VO2_{\text{peak}} throughout the manuscript.

I really like the assessment of inter-site variation - more studies should do this!
The authors thank the reviewer for the positive response to this assessment.
Why was a 3 hour recovery period employed? Given that some of these trials involve 90 minute drinking protocols, monitoring recovery for a further 90 minutes seems on the short side. Particularly as it involves ingesting milk and it is likely that this will have reduced gastric emptying etc.

Further details regarding concerns over the 3 h recovery period have been incorporated into the Discussion. This section reads as follows:

“Several methodological limitations require acknowledgement. Firstly, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during Milk trials, the distribution of the retained fluid (e.g. within the GI tract (as potentially indicated by higher “fullness” ratings) as opposed to vascular space) and therefore physiological relevance of this fluid retention remains unknown. In addition, the recovery period for this study (3 h from the start of drinking) was shorter than previous work in this area (typically ≥4 h), 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; (1) the relatively small volumes of urine seen beyond 90 min following the cessation of drinking in our previous study (Desbrow et al 2014), (2) the smaller volume of fluid being ingested (100% v’s 150% fluid replacement), (3) the practical relevance of 4 h observation, given that many individuals are likely to eat/drink within this period of time and (4) a previous study (Maughan et al 2016) demonstrated the pattern of response in cumulative urine output and calculated hydration index to ingested drinks was observed to be similar at 2 h post-drinking and 4 h post-drinking.”

Why are some data reported as mean (SD) and others as mean (SEM)? I would suggest choosing one (preferably mean and SD).

The authors would generally agree with this comment. However, in this instance, only the subjective data (presented as a six figure panel) has used SEM (for error bars). On attempting to provide SD error bars the figure becomes difficult to format with consistency. Thus, for this figure only, we have opted to retain SEM.

Discussion:

As above, I think more attention could be given to some mechanistic detail. In particular, while you haven't measured gastric emptying or stomach volumes, you do have some proxy markers of this i.e. bloatedness/fullness. Given that there are some differences in these markers (particularly when milk was ingested) this might indicate some differences in availability of ingested fluid (though, interestingly, POsm doesn't appear to be different at the end of 3h). While not a major issue, I think it is worth discussing in more detail.

The authors thank the reviewer for this comment. An additional comment has been added within the new limitations section of the Discussion to accommodate this point. This section reads as follows:

“Several methodological limitations require acknowledgement. Firstly, this study did not employ a direct measure of gastric emptying. Hence, while greater fluid retention was achieved during Milk trials, the distribution of the retained fluid (e.g. within the GI tract (as potentially indicated by higher “fullness” ratings) as opposed to vascular space) and therefore physiological relevance of this fluid retention remains unknown. In addition, the recovery period for this study (3 h from the start of drinking) was shorter than previous work in this area (typically ≥4 h), 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; (1) the relatively small volumes of urine seen beyond 90 min following the cessation of drinking in our previous study (Desbrow et al 2014), (2) the smaller volume of fluid being ingested (100% v’s 150% fluid replacement), (3) the practical relevance of 4 h observation, given that many individuals are likely to eat/drink within this period of time and (4) a previous study (Maughan et
al 2016) demonstrated the pattern of response in cumulative urine output and calculated hydration index to ingested drinks was observed to be similar at 2 h post-drinking and 4 h post-drinking.”

References:


