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POST-EXERCISE REHYDRATION: NO CHANGE IN DIURESIS FROM WATER INGESTED AT DIFFERENT TEMPERATURES

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Abstract

Aim: to assess the effect of water temperature on post-rehydration urine output and fluid retention

Methods: on three different days, one week apart, 11 physically active men (24±4 years old, 1.73±0.05 m and 70.2±9.0 kg) ($\bar{x}$ ± S.D.) exercised intermittently in a temperature-controlled room (Dry bulb temperature = 30-32°C, relative humidity = 50-60%) until dehydrated to 1.96±0.2% of body mass (BM) on three separate occasions. They were rehydrated in random order with cold (4-6°C), ambient (23-25°C) or warm (38-40°C) water, equivalent in volume to 120% of weight loss. Fluid was consumed in one hour in 6 equal aliquots, one every 10 minutes. Following rehydration, urine samples were collected every 30 minutes for 4 hours, analyzing volume and Urine Specific Gravity (USG).

Results: no interaction was found between water temperature (TEMP) and diuresis (*P*=.726), or USG (*P*=.140) over time. There was no significant effect of TEMP on the total volume of urine eliminated (882±380, 973±341, and 1006±407 mL for cold, ambient, and warm water, respectively; *P*=.541), or on fluid retention (45.0±22, 41.9±14 and 37±28%; *P*=.588).

Conclusion: when men are rehydrated with a volume of water equivalent to 120% of weight loss, after dehydration to 2% BM, water temperature (within this range) has no effect on diuresis or fluid retention.

Key words: *recovery, hydration, urine, drinking, water intake*

Introduction

Numerous studies show the importance of maintaining adequate hydration before, during, and after physical activity. Beverage characteristics may influence voluntary fluid intake, tolerance of drinking large volumes, retention and even sports performance [1-4]. Often times it is not possible to compensate fluid losses during exercise, and post-exercise rehydration becomes essential, particularly when a new exercise bout will be performed shortly thereafter.

It is common for athletes not to drink enough during rehydration. As an alternative to using forced rehydration protocols based on individual needs, coaches and nutritionists can resort to stimulating voluntary fluid ingestion. Voluntary post-exercise fluid ingestion is influenced by thirst and in general terms by fluid palatability. Fluid flavor and temperature are important, and it is well-accepted that colder fluids (between 7 and 15°C) will have a positive influence on voluntary intake, stimulating rehydration [5]. Even when fluid intake is sufficiently high, however, there may be a waste of fluid if a large proportion of ingested liquids is quickly eliminated by the kidneys, as is the case when rehydration is aggressive and ingested fluids contain little or no sodium [6, 7].

Well-formulated sports drinks capitalize on both the enhancement of flavor to stimulate voluntary ingestion, supported by the carbohydrates, and on improved fluid retention thanks to the presence of electrolytes [8]. Beverage temperature, however, may not necessarily work totally in favor of rehydration: while colder fluids will stimulate intake, there is a perception that cold drinks, and a cold environment in general, may induce a higher diuresis, resulting in more fluid waste (unpublished observation). This perception possibly derives from the well-known fact that cold-water immersion stimulates diuresis (9). It is important to understand, therefore, if there is an effect of ingested beverage temperature on post-exercise fluid retention.

Many hydration studies have looked at beverage temperature, but focusing on its effect on sports performance or body core temperature regulation [3, 10-12) or on the effect of food and drink temperature on gastric emptying and absorption of fluid [13, 14], or on beverage acceptance and perception at different temperatures [5, 15]. To the best of our knowledge, the effect of beverage temperature on rehydration efficiency has not been addressed.

Therefore, this post-exercise rehydration study evaluated the diuresis response to the ingestion of a controlled volume of water at different temperatures, following mild dehydration in the heat (2% body mass). We hypothesized that diuresis would be higher at lower water temperatures.

Materials and Methods

Participants: 11 healthy, physically-active males, 24±4 years old, 1.73±0.05 m tall and weighing 70.2±9 kg ($\bar{x}$±S.D.), signed a consent form and provided general health and exercise information. The study was approved by the University's Ethics and Science Committee.

Each participant was evaluated on three different occasions, the same day of the week, on consecutive weeks, drinking water at a different temperature each time. The order of water temperatures was randomized for each participant.

Preparation for the study. On the day before each test, participants registered all food and beverage consumption. They were requested to eat the same foods prior to each test and to drink five extra glasses of water throughout the day, and to avoid (or when part of the regular diet, not to modify) the intake of alcoholic and caffeinated beverages (energy drinks, coffee, tea, caffeinated soft drinks). No use of diuretics, laxatives or antihistamines was permitted. Finally, they were asked to refrain from participating in strenuous exercise at least 24 hours before each test.

Participants arrived after an overnight fast, provided a urine sample (to assess approximate hydration status upon arrival), and were weighed nude to the nearest 10 grams. They received a standardized breakfast providing 775±25 kcal. No other food was ingested until the end of the experiment.

Dehydration protocol. One hour after finishing their breakfast, the participants initiated their exercise in the heat in a controlled environment chamber maintained at a temperature between 30 and 32°C, with a relative humidity between 50 and 60%. They alternated between jogging on a *Sports Art®* 3250 treadmill and pedaling on a *Monark®* 818c cycle ergometer, at a moderate intensity of 80-85% of maximum heart rate, as calculated using Gellish et al.'s equation: FCmax = 207-(0.7 x age in years) (16). Heart rate was monitored with a *Polar®* S120.

After each 20 minutes of exercise (alternating between 10 minutes on the treadmill and another 10 min on the cycle ergometer), they rested for 5 minutes and were weighed nude on a *Ballar®* scale, Model DSB921, with a capacity of 250 kg and a resolution of 10 g. They continued to exercise this way until they achieved a dehydration close to 2% body mass (BM). At this point, they showered and emptied their bladders, and a nude post-exercise body weight was recorded for calculation of weight loss.

Rehydration and follow-up. Participants were rehydrated with a volume equivalent to 120% of weight loss, distributed in 6 equal portions, one every 10 minutes; they drank cold (4-6°C), ambient (23-25°C) or warm (38-40°C) water, in sessions one week apart. Water for consumption was kept in thermal containers, controlling their temperature with calibrated alcohol thermometers.

Urine was collected in plastic labeled containers immediately upon completing the rehydration protocol and every 30 minutes thereafter, for 4 hours. Participants were requested to completely empty the bladder each time. Each sample was discarded immediately after recording its volume and USG. After the last urine sample, a final nude body weight was obtained.

Both water and urine volumes were measured by weighing the containers on a *DHAUS®* scale, Model CS-2000, with a capacity of 2000 g and a resolution of 1 gram. Urine specific gravity (USG) was measured using a hand-held refractometer, *ATAGO®* model URC-NE, with a range between 1.000 and 1.050. Euhydration was defined as USG ≤ 1.020 (4).

Statistical analysis: descriptive statistics were performed on measured variables to check for normality of the distribution. A one-way analysis of variance (ANOVA) was performed to compare each of the baseline variables among the three water temperatures. In addition, a repeated-measures two-way ANOVA was performed for each dependent variable (urine volume, urine specific gravity, percent weight loss recovered, and percent fluid retained), with water temperature and time of measurement as independent variables (3 temperatures X 9 measurements). When an overall difference was identified, a Bonferroni Post Hoc test was used to identify the specific difference. In addition, a repeated-measures two-way ANOVA was performed for body weight (3 temperatures X 4 measurements). Statistics were performed using SPSS version 15.0 for Windows.

Results

Baseline and preparatory stage results were not significantly different among the three water temperature conditions: initial body weight, USG upon arrival, exercise time to achieve desired dehydration, dehydration achieved, and volume of water ingested, were all the same (*Table 1*). Overall, average heart rate was 156 bpm during the exercise period; the lowest value was 148 bpm and the highest was 165 bpm. At the end of the exercise period, participants achieved a dehydration of 1.96±0.2% of initial body weight.

Figure 1 shows the partial urine collection volumes at each point in time. There was no interaction between the three water temperature conditions and time of measurement regarding urine elimination (P = .726), although there was a main effect of time (P <.0001); Post Hoc analysis showed that the largest volumes

Table 1. *Initial conditions*

WATER TEMPERATURE							
	COLD (4-6°C)		AMBIENT (23-25°C)		WARM (38-40°C)		
Variable	$\overline{x}$	S.D.	$\overline{x}$	S.D.	$\overline{x}$	S.D.	*p*
INITIAL USG	1.013	0.006	1.012	0.008	1.013	0.005	.442
INITIAL WEIGHT (Kg)	70.10	9.15	70.15	9.01	70.36	8.94	.328
POST-EXERCISE WEIGHT (Kg)	68.72	8.91	68.76	8.79	68.97	8.72	.330
EXERCISE TIME (min)	46.8	6.4	46.4	5.5	47.3	6.5	.490
DEHYDRATION (%BM)	1.95	0.20	1.98	0.20	1.97	0.17	.889
FLUID INTAKE (mL)	1647	343	1666	306	1674	304	.915

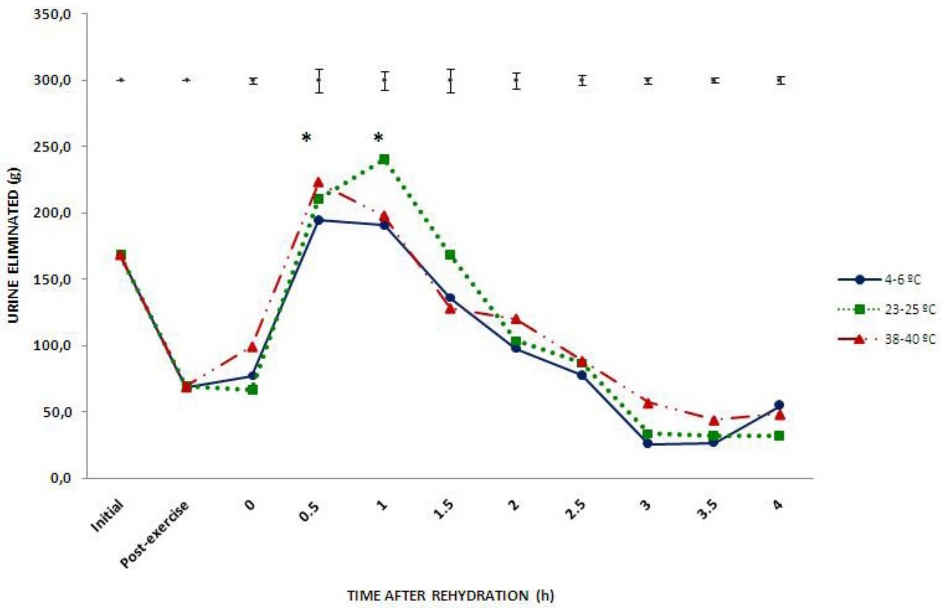

Figure 1. *URINE ELIMINATION vs. TIME. Interaction between water temperature and time: P=.726. (*) P < .05 vs. urine volume at time = 0.*

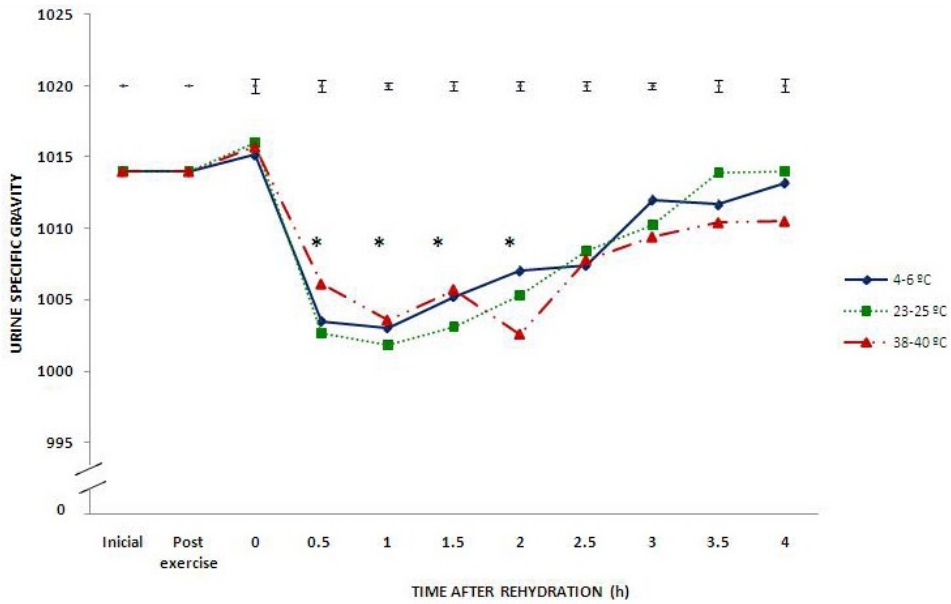

Figure 2. *URINE SPECIFIC GRAVITY. Interaction between water temperature and time: P=.140. (*) P < 0.05 vs. urine specific gravity at time = 0.*

were eliminated between 1/2 hour and 1 hour after the rehydration period finished, for all three temperatures (*P*<.05). After the first hour there was no difference with respect to urine eliminated at time = 0.

Urine specific gravity showed an inverted but similar pattern to the urine collection volumes in all conditions: the interaction between water temperature and time was not significant (*P*=.140, *Figure 2*), but there was a main effect of time (*P* <.0001). Post Hoc analysis showed that urine specific gravity at hour 0 was different from USG at 1/2 hour, 1 hour, 1 1/2 hour and 2 hours (*P*<0,05); after that time, there were no differences.

Figure 3 shows the changes in body weight resulting from our protocol of dehydration, rehydration, and continued urine loss; these were significant (*P* < .05) but the same for all conditions, as no interaction was found between time of measurement and water temperature (*P*= .694**,** *Figure 3*). When water temperature was analyzed as the independent variable, it had no effect on final body weight (*P*=.726), (*Figure 3*).

Finally, *Figure 4* shows that water temperature did not have a significant effect on fluid retention (*P*=.588), or on its mirror variable, total urine collected over four hours relative to ingested fluid (*P*=.541).

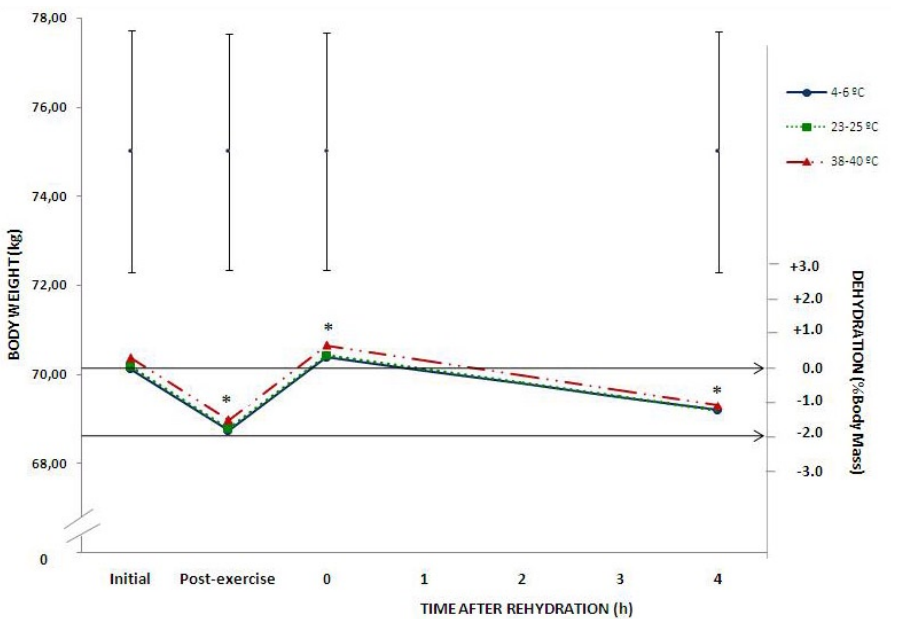

Figure 3. *BODY WEIGHT vs. TIME. The upper horizontal line represents initial body weight, considered euhydration; the lower horizontal line shows 2% BM dehydration. (*) P < 0.05 vs. initial body weight.*

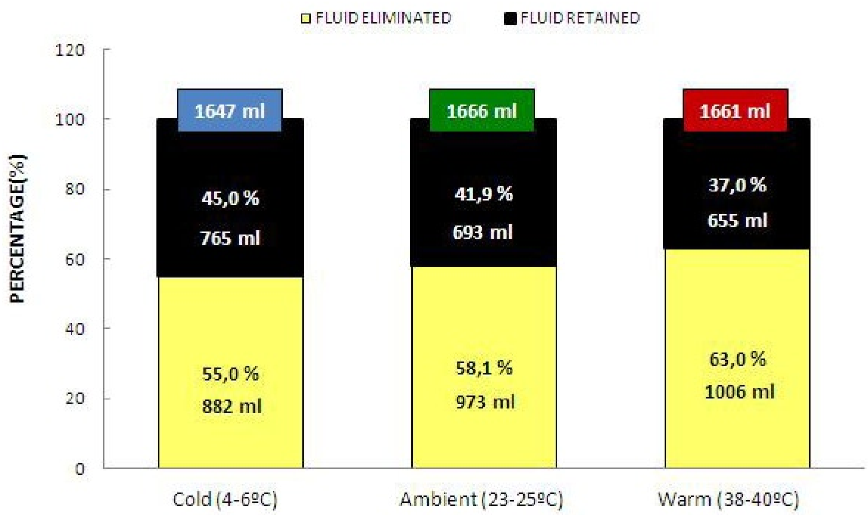

Figure 4. *TOTAL FLUID INTAKE, RETENTION, AND ELIMINATION. Colored insets show the total volume of fluid ingested for each water temperature. Comparison among water temperatures: fluid retention, p=.588; fluid elimination, p=.541.*

Discussion

Contrary to the belief that cold beverages promote a greater diuresis, our results showed no statistically significant differences in elimination of urine after replacing 120% of weight loss (mostly from sweat losses) with cold, ambient, or warm water. From the point of view of fluid retention, it is not necessary to modify the normal recommendation to consume cold or cool water to stimulate voluntary intake [5, 15, 17-19]; the benefit of a better palatability with cold water was not undermined by greater diuresis.

Similar results have been reported in a hospital setting in Costa Rica for a clinical, not exercise in the heat, situation. An oral rehydration solution was administered to breastfeeding-age babies suffering from diarrhea, at either 23°C (100 babies) or 37°C (100 babies). The study reported no difference between groups in weight gain, speed of rehydration, vomiting frequency or general efficacy of the treatment [20].

Factors such as voluntary intake, gastric emptying, and intestinal absorption, all play important roles in the efficacy of oral rehydration. While we acknowledge we did not measure either gastric emptying or absorption, and we held voluntary intake constant, those processes may offer an explanation for the results we obtained.

Bateman [21] compared gastric emptying for two fluid volumes (200 and 500 mL) at two different beverage temperatures. He found that drinking 500 mL at 12°C resulted in faster emptying than the same volume at 37°C, during the first five minutes. After that time, however, there were no differences between conditions. The findings of Bateman [21] are consistent with the finding in the present study that the temperature of ingested water has no effect on urine elimination.

McArthur & Feldman [14] evaluated whether fluid temperature had an effect on intragastric temperature, HCl secretion, gastrin release or gastric emptying in healthy humans. They found no effect of temperature on any of the variables. Furthermore, they noted that the coffee (360 mL) they infused at 4, 37, or 58°C with a nasogastric tube was back to normal body temperature after 17 minutes (hot coffee) and 24 minutes (cold coffee). They concluded that fluid temperature has little effect on gastric function in humans.

Considering that gastric emptying must occur before fluid absorption and urine production and elimination, it may be speculated that in the absence of an effect on gastric function, and with fluid temperature reaching core body temperature within a relatively short time [22], differences in the subsequent steps, including diuresis, might be minimal. The results observed in the present study, while contrary to our hypothesis, provide empirical evidence to support this, even after ingestion of larger fluid volumes of about 1650 ml, on average.

For better efficacy of oral rehydration, fluid composition seems much more important than its temperature. Studies have repeatedly shown that the use of carbohydrate-electrolyte solutions, or even milk, result in better fluid retention than pure water. The large volumes of pure water used in the present study, regardless of its temperature, could not prevent development of progressive dehydration during post-rehydration resting period [6, 23- 26].

One particular anecdotal finding from this study warrants a little discussion: some of the participants reported nausea when drinking the warm water, making the cold water option even more attractive. It is speculated that a slower gastric emptying with warm water may have resulted in higher nausea, in line with the results of Van Nieuwenhoven et al. [27]; it is not possible at this point, however, to conclude if the significantly lower voluntary fluid intake observed in previous studies with warm drinks is due to the reduced palatability alone or to a combination of palatability and nausea [28,29]. What is clear is that warm water reduces voluntary fluid intake which, in turn, may result in greater dehydration and negative consequences.

It is worth noting that the present results are relevant to future studies on post-exercise rehydration using fixed fluid intake protocols; researchers can be confident that under similar conditions to our study, beverage temperature should not impact diuresis.

In summary, in this group of men who exercised in the heat to reach a dehydration of 2% BM and then replaced 120% of their weight loss with cold, ambient, or warm water, the water temperature had no effect on diuresis: urine volume, urine specific gravity, and fluid retention were all the same among conditions.

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