Abstract Whether the use of pre-exercise hyperhydration could improve the performance of athletes who do not hydrate sufficiently during prolonged exercise is still unknown. We therefore compared the effects of pre-exercise hyperhydration and pre-exercise euhydration on endurance capacity, peak power output and selected components of the cardiovascular and thermoregulatory systems during prolonged cycling. Using a randomized, crossover experimental design, 6 endurance-trained subjects underwent a pre-exercise hyperhydration (26 ml of water·kg body mass\(^{-1}\) with 1.2 g glycerol·kg body mass\(^{-1}\)) or pre-exercise euhydration period of 80 min, followed by 2 h of cycling at 65% maximal oxygen consumption (\(\dot{V}O_2\max\)) (26–27°C) that were interspersed by 5, 2-min intervals performed at 80% \(\dot{V}O_2\max\). Following the 2 h cycling exercise, subjects underwent an incremental cycling test to exhaustion. Pre-exercise hyperhydration increased body water by 16.1 ± 2.2 ml·kg body mass\(^{-1}\). During exercise, subjects received 12.5 ml of sports drink·kg body mass\(^{-1}\). With pre-exercise hyperhydration and pre-exercise euhydration, respectively, fluid ingestion during exercise replaced 31.0 ± 2.9% and 37.1 ± 6.8% of sweat losses (p<0.05). Body mass loss at the end of exercise reached 1.7 ± 0.3% with pre-exercise hyperhydration and 3.3 ± 0.4% with pre-exercise euhydration (p<0.05). During the 2 h of cycling, pre-exercise hyperhydration significantly decreased heart rate and perceived thirst, but rectal temperature, sweat rate, perceived exertion and perceived heat-stress did not differ between conditions. Pre-exercise hyperhydration significantly increased time to exhaustion and peak power output, compared with pre-exercise euhydration. We conclude that pre-exercise hyperhydration improves endurance capacity and peak power output and decreases heart rate and thirst sensation, but does not reduce rectal temperature during 2 h of moderate to intense cycling in a moderate environment when fluid consumption is 33% of sweat losses. J Physiol Anthropol 27(5): 263–271, 2008

Introduction

Dehydration >2% body mass impairs exercise endurance performance (Sawka et al., 2007). Physiological factors contributing to this decrease in performance include increased body core temperature, cardiovascular strain, glycogen utilization and altered metabolic and central nervous system functions (Cheuvront et al., 2003). Considerable efforts have been spent by scientists within the past decade in trying to educate endurance athletes about the importance of maintaining adequate hydration during exercise (Sawka et al., 2007). Yet, recent research shows that athletes still routinely dehydrate by more than 2% body mass during prolonged exercise (Daries et al., 2000; Dugas et al., 2006), thereby rendering them vulnerable to dehydration-mediated decrement in physical performance.

Because it appears difficult for athletes to drink sufficiently during exercise to maintain exercise endurance performance, one may wonder whether starting a prolonged exercise while hyperhydrated, as opposed to only euhydrated, could contribute in improving performance as a result of delaying dehydration. It has been shown that pre-exercise hyperhydration can improve endurance capacity during short-term aerobic exercises, compared with pre-exercise euhydration (Blyth and Burt, 1961; Greenleaf et al., 1997; Latzka et al., 1998). However, whether pre-exercise hyperhydration can also improve performance during prolonged exercise has not been yet tested and still remains unknown. Although it appears

Pre-Exercise Hyperhydration Delays Dehydration and Improves Endurance Capacity during 2 h of Cycling in a Temperate Climate

Eric D.B. Goulet\(^1,\)\(^2\)*, Stéphane F. Rousseau\(^1\), Cédric R. H. Lamboley\(^2\), Gérard E. Plante\(^2\) and Isabelle J. Dionne\(^1,\)\(^2,\)\(^3\)

1) Research Centre on Aging, University of Sherbrooke, Sherbrooke, P.Q., Canada
2) Department of Physiology and Biophysics, University of Sherbrooke, Sherbrooke, P.Q., Canada
3) Faculty of Physical Education and Sports, University of Sherbrooke, Sherbrooke, P.Q., Canada

* E Eric D. B. Goulet is now with the McGill Nutrition and Food Science Centre, McGill University Health Centre, Royal Victoria Hospital, Montréal, P.Q., CAN., H3A 1A1.

Keywords: fluid overloading, exercise capacity, moderate ambient condition, heart rate, rectal temperature

http://www.jstage.jst.go.jp/browse/jpa2
[DOI: 10.2114/jpa2.27.263]
intuitive to believe that as a result of retarding dehydration during prolonged exercise pre-exercise hyperhydration should improve performance, a rigorous test of this hypothesis as yet to be carried out.

Research has shown that during aerobic exercises of 45–120 min, pre-exercise hyperhydration ≥1000 ml reduces cardiovascular (decreased heart rate and/or increased stroke volume) and thermoregulatory (reduced rectal or esophageal temperature) strain (Moroff and Bass, 1965; Nielsen et al., 1971; Gisolfi and Copping, 1974; Gruczka et al., 1987; Lyons et al., 1990), compared with pre-exercise euhydration. As pre-exercise hyperhydration appears to offer a physiological advantage during short- and long-term aerobic exercises, then it is reasonable to believe that this strategy could confer an increase in exercise endurance performance, compared with pre-exercise euhydration.

An important amount of studies hitherto have been conducted which compared the effect of water-induced hyperhydration to that of glycerol-induced hyperhydration on performance and physiological functions during prolonged exercise. Surprisingly, none of those studies included a pre-exercise euhydration group (Goulet et al., 2007). Not having included a pre-exercise euhydration group represents an important limitation of those studies, as the natural behavior of athletes is to start an exercise euhydrated. Hence, although these studies provide information as to how those hyperhydration techniques affect exercise endurance performance and physiological functions compared to one another, they fail to indicate how pre-exercise hyperhydration affects exercise endurance performance and physiological functions compared with pre-exercise euhydration, which is an essential piece of information for coaches, practitioners and athletes.

Therefore, the goal of this study was to determine whether pre-exercise hyperhydration, compared with pre-exercise euhydration, could improve endurance capacity, peak power output and selected physiological functions of the cardiovascular and thermoregulatory systems during 2 h of moderate to intense cycling conducted in a moderate environment when the rate of fluid intake is substantially less than sweat rate. It was hypothesized that, as a result of delaying dehydration, pre-exercise hyperhydration would decrease cardiovascular and thermoregulatory strain during the 2 h cycling period and improve endurance capacity and peak power output, compared with pre-exercise euhydration.

Methods

Subjects

Six lean, endurance-trained athletes (5 men and 1 woman) were recruited to participate in this study. Their mean (±SEM) age, body mass, height, maximal oxygen consumption (VO2max), maximal heart rate and peak power output were 36.5±5.5 yrs, 68.3±4.9 kg, 174±2 cm, 59.1±4.7 ml·kg⁻¹·min⁻¹, 173±6 beats·min⁻¹ and 341±36 W, respectively.

With the exception of the woman who reported to be amenorrheic, all subjects were healthy at the time of the study as determined with the aid of a health history questionnaire. De Souza et al. (1990) demonstrated that menstrual status (eumenorrheic vs. amenorrheic) does not alter nor limit exercise performance in female athletes. Based on this finding, we therefore decided to keep the results of the female subject. Subjects were thoroughly explained the procedures and risks of the study and informed written consent was obtained from each of them. Because of the impossibility to blind subjects from the experimental trials they would undergo, it must be noted that they were not explained the specific goals of the study nor the hypotheses that were tested. The study received the approval of the Research and Ethics Committee of the Faculty of Physical Education and Sports of the University of Sherbrooke.

Overview of the experimental trials

Subjects underwent two experimental trials, one with pre-exercise hyperhydration and the other with pre-exercise euhydration, which were conducted one week apart, at the same time of the day, and administered in a randomized, crossover fashion. After their arrival at the laboratory, and following the measurement of several parameters, subjects had to wait (pre-exercise euhydration) or hyperhydrate (pre-exercise hyperhydration) during an 80 min period. Then, after these periods had been completed, subjects cycled for 2 h at an ambient temperature of 26–27°C and a relative humidity of 55%. Following the 2 h cycling bout, and without any interruption in exercise, subjects completed an incremental cycling test to exhaustion.

Preliminary testing

Four to 6 days before the first experimental trial, subjects underwent a measurement of height, body mass, VO2max, maximal heart rate and peak power output. Body mass was determined to the nearest 100 g with an electronic scale (Detecto, USA) after subjects voided their bladder. Maximal oxygen consumption, maximal heart rate and peak power output were measured on a computerized, speed-independent cycle ergometer (Ergoline ER 900, Jaeger, Germany), using a test and procedures that have been fully described elsewhere (Goulet et al., 2006). This ergometer was also used for the two experimental trials.

Familiarization Trial

Approximately 15 min after the completion of the VO2max test, subjects underwent a familiarization trial consisting of 40 min of cycling in an ambient temperature of 26–27°C, with a relative humidity of 50–55%. During this exercise session the workloads to be used in the upcoming experimental trials, i.e., those corresponding to 65 and 80% of VO2max were determined. For our subjects, the workloads which elicited 65% and 80% of VO2max were, respectively, 168±24 W and 221±24 W, corresponding to a VO2 of 2661±302 ml·min⁻¹ and 3274±373 ml·min⁻¹, and a percentage of peak power
output of 49±1.0% and 65.0±0.4%.

Subjects were not familiarized with the endurance capacity test, which consisted of a step-incremented test to exhaustion. Such a decision was made because of the nature of the test, which was until complete exhaustion. However, although not exactly identical, the nature (step-incremented test), intensity (up to exhaustion and peak power output) and length (8 to 14 min) of the VO_{2max} test adequately prepared the subjects for the endurance capacity test used in the present study.

Pre-experimental protocol

Over the study period, subjects were allowed to continue their usual training routine, but were asked to refrain from any physical activity 24 h prior to each trial. Additionally, they refrained from any lower leg strength training and dietary supplements 48 h prior to each trial. For the last 24 h prior to the first trial, subjects kept a fluid and a diet log. They were asked to replicate these logs over the last 24 h prior to the second trial. For 24 h before each trial, subjects refrained from any diuretic substances such as alcohol and caffeine. On the day of each trial, subjects were asked to drink 10 ml of water·kg body mass⁻¹ and eat a white bagel (200 kcal) 120 min prior to reporting to the laboratory and then to abstain from any food and fluid ingestion.

Pre-exercise hyperhydration and euhydration periods

Upon arrival at the laboratory, subjects provided a urine sample, voided their bladder, were weighed in the nude and instrumented with a Polar electrode (Polar USA, USA) for the measurement of heart rate. After this measure, subjects rated on a scale of 1 (none) to 5 (extreme) different side-effect parameters (abdominal bloating, cramp, nausea, headache and dizziness). Then the 80-min long pre-exercise hyperhydration or pre-exercise euhydration period began. No fluid was given to subjects during the pre-exercise euhydration period. During pre-exercise hyperhydration, subjects drank a total of 26 ml of fluid·kg body mass⁻¹ together with 1.2 g glycerol·kg body mass⁻¹. At min 0 and 20, subjects respectively ingested 9 and 6 ml of aspartame-flavoured beverage (Crystal Light, USA)·kg body mass⁻¹ with 0.6 g glycerol·kg body mass⁻¹. At min 40 and 60, 6 and 5 ml of plain water·kg body mass⁻¹ were respectively ingested by subjects. The aspartame-flavoured beverage containing glycerol was served at 4°C to improve its taste, whereas plain water was served at 37°C. Heart rate and side-effect parameters were measured at min 18, 38, 58 and 78, followed by urine volume (graduated urinal) measurements. At min 70 subjects were instrumented with a rectal probe to measure rectal temperature. At 82 min a measurement of body mass was taken. The changes in body mass from before to after pre-exercise hyperhydration and pre-exercise euhydration were taken as a reflection of the changes in body water. Insensible water loss was not measured and was assumed to be similar between trials.

Glycerol was provided with the excess fluid having to be ingested because it has been shown to substantially enhance fluid retention compared with water-induced hyperhydration (Goulet et al., 2007). The oral ingestion of glycerol has been shown not to improve endurance capacity (Miller et al., 1983; Gleeson et al., 1986). Hence, the presence of glycerol into the hyperhydration solution should not be perceived as a factor that could confound the effects of hyperhydration per se on exercise endurance performance.

2 h cycling periods

Before the start of exercise, exactly 10 min after the onset of pre-exercise hyperhydration and pre-exercise euhydration, measures of rectal temperature, heart rate, perceived exertion (Borg scale, 20-point scale, 6: very, very light; 20: very, very hard), perceived thirst (11-point scale, 1: none; 11: extreme), perceived heat-stress (5-point scale, 1: none; 5: extreme) and abdominal discomfort (5-point scale, 1: none; 5: extreme) were taken. Subjects cycled for 2 h at 65% VO_{2max}, which were interspersed by 5, 2-min intervals at 80% VO_{2max} performed at min 12, 32, 52, 72 and 92. These intervals were included to increase thermal stress and, therefore, sweat production and dehydration level. Oxygen consumption was continuously measured and monitored over the first 14 min of each trial to ensure that subjects exercised at a similar intensity between trials. A fan located 2 m in front of the bike circulated air at the subjects’ head and chest level at a low velocity and identical speed between trials. Measures of perceived exertion, thirst, heat-stress and abdominal discomfort were taken at 18, 38, 58, 78, 98 and 118 min, followed by heart rate and rectal temperature, 2 min later. During the 2 min intervals conducted at 80% VO_{2max}, heart rate was measured at the 2 min mark (end of the intervals). Every 20 min, up until min 100, subjects drank 2.5 ml of a 6% sports drink solution·kg body mass⁻¹ (Gatorade, USA), which was given at room temperature. For our subjects, this quantity corresponded to a total average of 853±49 ml, or 427±60 ml·h⁻¹. This rate of fluid intake (500 ml·70 kg body mass⁻¹·h⁻¹) is representative of the hourly amount of fluid drank by endurance athletes during exercise (Noakes et al., 1993), is substantially lower than the typical sweat rate observed during moderate to intense exercise performed in a temperate climate (McConell et al., 1997; Buono and Wall, 2000; Goulet et al., 2006; Passe et al., 2007) and is unlikely to be sufficient to prevent a loss of body mass <2% over a period of exercise >2 h (McConell et al., 1997; Passe et al., 2007). Subjects were free to stop at any time during exercise for urine voiding, except when the next collection of measures was within the next 10 min.

Incremental test to exhaustion

At the end of the 2 h cycling exercise, subjects performed an incremental test to exhaustion. This particular test was chosen because of its high reliability. In fact, Hopkins et al. (2001) reported that the peak power output measured during such a test displays a test-retest coefficient of variation of 0.9% and 1.2% with subjects being familiarized and non-familiarized with the test, respectively. The test started at the workload used
during the 2 h cycling bout plus 25 W. The workload was subsequently increased by 25 W every 3 min until exhaustion or a pedaling frequency <55 revolutions·min⁻¹. Measures of heart rate and rectal temperature were taken at the end of the tests. For the endurance capacity test, peak power output was computed using the following formula: last workload completed for the entire 3 min+((total time (s) in the last workload which was not entirely completed/180 s)×25 W). Within 2–3 min following the endurance capacity test, subjects towelled dry, provided a urine sample, voided their bladder as completely as possible and were weighted in the nude.

Heart rate and rectal temperature
Heart rate was measured using a Polar heart rate monitor (Polar Advantage, USA). Rectal temperature was measured with a rectal probe (Yellow Springs Instrument (YSI), USA) inserted 15-cm beyond the anal sphincter, which was connected to a YSI tele-thermometer (Model 43TA).

Urine osmolality
Urine osmolality was measured in duplicate with the freezing point method (Fiske Model 210 Micro-Osmometer, USA).

Sweat loss
Sweat loss was computed from the before and after exercise change in body mass, corrected for fluid intake and urine loss during exercise. No correction was made for insensible water loss and the loss of mass associated with the respiratory exchange of O₂ and CO₂, and all were assumed to be similar between trials.

Statistical analysis
Data are expressed as means±SEM. All data were tested for normality of distribution and equality of variances. Data were analyzed using either paired sample t-tests or two-way (treatment×time) analyses of variance (ANOVA). When significant main or interaction effects were found, follow-up tests were performed using paired sample t-tests with Bonferonni corrections. Significance was defined as p<0.05. An effect size was calculated to determine the magnitude of the effect of pre-exercise hyperhydration on peak power output (Thomas and Nelson, 2001) and interpreted according to Cohen (1988). The clinical significance of the effect of pre-exercise hyperhydration on peak power output was calculated using the spreadsheet developed by Hopkins et al. (2002). A statistical analysis (α=0.05, β=0.2) indicated that 6 subjects would provide sufficient power to detect a 2.5% change in peak power output with the type of test we used which has a coefficient of variation of 1.2% (Hopkins et al., 2001). All statistics were performed using the SPSS software for Windows (version 9.0, USA).

Results

Pre-exercise hyperhydration and euhydration periods
State of hydration of subjects at the arrival at the laboratory
Subjects were similarly hydrated before pre-exercise hyperhydration and pre-exercise euhydration, as indicated by a urine osmolality level of 233±57 mosmol·kg⁻¹ with pre-exercise hyperhydration and 373±93 mosmol·kg⁻¹ with pre-exercise euhydration (p=0.17). Equality in hydration was further confirmed by the non-significant difference in body mass (pre-exercise hyperhydration: 68.6±4.1 kg; pre-exercise euhydration: 68.8±4.4 kg (p=0.57)), urine production (pre-exercise hyperhydration: 275±34 ml; pre-exercise euhydration: 198±47 ml (p=0.09)), and heart rate (pre-exercise hyperhydration: 53±2 beats·min⁻¹; pre-exercise euhydration: 54±3 beats·min⁻¹ (p=0.92)) between trials upon arrival at the laboratory.

Amount of fluid and glycerol (pre-exercise hyperhydration trial) ingested
During pre-exercise hyperhydration subjects ingested 1776±102 ml of fluid, together with 82.0±4.7 g of glycerol.

Fluid balance
Figure 1 shows the changes in body mass during pre-exercise hyperhydration and pre-exercise euhydration, whereas Fig. 2 shows the accumulated urine production over time during those two periods. As was to be anticipated during pre-exercise hyperhydration, the subjects’ total production of urine (636±90 ml or 9.2±2.7 ml·kg body mass⁻¹) was less than the total quantity of fluid that had been ingested and, as a result, an increase in body mass of 1.1±0.12 kg was observed. This therefore indicates that pre-exercise hyperhydration increased body water by 1100±120 ml (16.1±2.2 ml·kg body mass⁻¹). During pre-exercise euhydration, the subjects’ total production of urine was of the order of 253±64 ml (9.2±2.8 ml·kg body mass⁻¹), and despite this decrease in body water, subjects were still in an euhydrated state at the end of the pre-exercise euhydration trial, as reflected by a urine osmolality level of
368±108 mosmol·kg⁻¹, which was not significantly different from the value observed at the start of the trial. The change in body mass from before to after pre-exercise euhydration was −0.37±0.07 kg. Based on the changes in body mass during pre-exercise hyperhydration and pre-exercise euhydration, it can be indicated that the use of pre-exercise hyperhydration allowed subjects to start the exercise period with 1450±70 ml (21.7±2.10 ml·kg body mass⁻¹) more fluid compared with pre-exercise euhydration. The total quantity of urine produced during pre-exercise hyperhydration was significantly higher than during pre-exercise euhydration. The quantity of urine produced was significantly higher during pre-exercise hyperhydration than pre-exercise euhydration from 60 min to the end of the trials. At the end of the pre-exercise hyperhydration and pre-exercise euhydration trials the body mass of subjects was 69.7±4.1 kg and 68.4±4.4 kg, respectively (p=0.01).

Heart rate and side effects
From min 0 to min 80, heart rate significantly decreased during both pre-exercise hyperhydration and pre-exercise euhydration, but at no time points did heart rate values differ significantly between trials. Subjects reported no untoward effects during either pre-exercise hyperhydration or pre-exercise euhydration.

Exercise periods
Heart rate and rectal temperature during the 2 h exercise periods
Heart rate and rectal temperature data measured immediately prior, during and at the end of exercise are shown in Fig. 3. A significant main (p=0.02) and interaction (p=0.02) effect was noted for heart rate at 65% VO₂max. At 80% VO₂max, a significant main treatment effect was observed in heart rate (p=0.03). No significant main or interaction effect was noted for rectal temperature.

Perceived heat-stress, exertion and thirst during the 2 h exercise periods
Perceived heat-stress and exertion values were not different at any time points between trials (p>0.05). Figure 4 depicts the perceived thirst values observed over time during pre-exercise hyperhydration and pre-exercise euhydration. At all time points perceived thirst values were significantly lower with pre-exercise hyperhydration than with pre-exercise euhydration.

Side effects during the 2 h exercise periods
No subjects reported untoward effects in any of the trials.

Fluid balance during the entire exercise periods
Total sweat loss and hourly sweat rate (pre-exercise hyperhydration: 2904±367 ml (1304±161 ml·h⁻¹); pre-exercise euhydration: 2736±491 ml (1246±224 ml·h⁻¹) did not differ significantly between trials. The percentage of sweat loss replaced by fluid intake during exercise was 31.0±2.9% with pre-exercise hyperhydration and 37.2±6.8% with pre-exercise euhydration, which was not significantly different between trials.

During pre-exercise euhydration none of the subjects passed
urine during exercise. One subject during pre-exercise hyperhydration had to stop exercising to void urine (210 ml). Total and hourly rates of urine production during exercise were significantly different between pre-exercise hyperhydration (262±32 ml (117.7±14.3 ml·h⁻¹)) and pre-exercise euhydration (100±40 ml (45.3±18.3 ml·h⁻¹)) (both p<0.01).

Subjects terminated the pre-exercise hyperhydration and pre-exercise euhydration trial with a loss of body mass amounting to 1.2±0.2 kg and 2.4±0.4 kg, respectively, corresponding to a loss of 1.7±0.3% body mass with pre-exercise hyperhydration and 3.3±0.4% body mass with pre-exercise euhydration (p<0.001).

Heart rate and rectal temperature during the incremental cycling test to exhaustion

Heart rate reached a final value of 169.3±4.2 beats·min⁻¹ with pre-exercise hyperhydration and 169.8±3.7 beats·min⁻¹ with pre-exercise euhydration (p=0.75). These heart rate values represented 91.8±1.2% (pre-exercise hyperhydration) and 93.4±1.2% (pre-exercise euhydration) of the maximal heart rate reached during the VO₂max test. Rectal temperature reached a final value of 38.1±0.2°C with pre-exercise hyperhydration and 38.2±0.2°C with pre-exercise euhydration (p=0.22).

Peak power output and time to exhaustion during the incremental cycling test to exhaustion

There was no trial order effect (p=0.45), suggesting that the practice effect was negligible between trials. Figure 5 depicts the peak power output and time to exhaustion reached by each subject under each experimental condition during the incremental tests to exhaustion. Pre-exercise hyperhydration increased peak power output (pre-exercise hyperhydration: 280±19 W; pre-exercise euhydration: 266±18 W (p=0.048), effect size: 0.31 (small but substantial effect)) and time to exhaustion (pre-exercise hyperhydration: 13.6±1.7 min; pre-exercise euhydration: 11.9±1.4 min (p=0.047)) compared with pre-exercise euhydration. Pre-exercise hyperhydration increased peak power output and time to exhaustion in 5 of the 6 subjects. Considering that the smallest worthwhile change in peak power output provided by pre-exercise hyperhydration that would matter to athletes is 1% (Hopkins et al., 1999), the present results suggest that 95% of the time the true effect of pre-exercise hyperhydration should be above this threshold.

Discussion

The goal of this study was to determine whether the use of pre-exercise hyperhydration could improve exercise endurance performance, peak power output and selected components of the cardiovascular and thermoregulatory systems during 2 h of cycling in a temperate climate when the rate of fluid intake during exercise was substantially lower than sweat rate and insufficient to prevent a loss of body mass <2% with pre-exercise euhydration. Within this research context, results of this investigation showed for the first time that, compared with pre-exercise euhydration, pre-exercise hyperhydration...
improves endurance capacity and peak power output and decreases heart rate and perceived thirst, but has no effect on rectal temperature during 2 h of moderate to intense cycling in a 26–27°C environment when 33% of sweat losses are replaced.

Pre-exercise hyperhydration improved peak power output and time to exhaustion by 5 and 14%, respectively. The magnitude of improvement in endurance capacity provided by pre-exercise hyperhydration in this study is relatively in line with that provided by the strategy during short-term aerobic exercises. In fact, during 20–30 min exercises Blyth and Burt (1961), Greenleaf et al. (1997) and Latzka et al. (1998) showed a gain in endurance capacity of 11–25% with pre-exercise hyperhydration compared with pre-exercise euhydration. The improvement in peak power output corresponded to a small, but nevertheless significant increase in performance. Moreover, if the smallest worthwhile change in peak power output provided by pre-exercise hyperhydration that would matter to athletes is 1% (Hopkins et al., 1999), the present results suggest that 95% of the time the true effect of pre-exercise hyperhydration should be above this level. These results are therefore suggestive that the use of pre-exercise hyperhydration is capable of offering to endurance athletes a real and meaningful improvement in exercise endurance performance compared with commencing an exercise euhydrated.

The difference in performance between trials was associated with a loss of body mass at the end of exercise amounting to 1.7% with pre-exercise hyperhydration and 3.3% with pre-exercise euhydration. Most of the difference in body mass between conditions can be accounted for by the surplus of water provided by pre-exercise hyperhydration. Our results are therefore consistent with the interpretation of the literature suggesting that exercise endurance performance is hampered when the loss of body mass is >2% (Sawka et al., 2007). Hence, as we hypothesized, the use of pre-exercise hyperhydration allowed decreasing the level of dehydration incurred by exercise which consequently enabled athletes to improve their exercise endurance performance, compared with pre-exercise euhydration.

Over the past few years, several studies have compared the effect of glycerol-induced hyperhydration to that of water-induced hyperhydration on exercise endurance performance and thermoregulatory and cardiovascular functions (Goulet et al., 2007). Their combined results indicate that glycerol-induced hyperhydration has an equivocal effect on cardiovascular and thermoregulatory functions, compared with water-induced hyperhydration. With respect to exercise endurance performance, a recently published meta-analysis by our research group showed an ergogenic effect of glycerol-induced hyperhydration over water-induced hyperhydration (Goulet et al., 2007). Unfortunately, none of these studies used a control group, that is a pre-exercise euhydration group, thereby rendering any comparison between our results and theirs difficult. Moreover, the fact that these studies did not include a control group makes it difficult to apply their findings to real-world conditions where athletes start an exercise euhydrated. More studies comparing the effect of pre-exercise hyperhydration and pre-exercise euhydration on exercise endurance performance must definitely be conducted.

The improvement in endurance capacity with pre-exercise hyperhydration was associated with a decreased heart rate during the 2 h cycling period. This finding is in agreement with those of Lyons et al. (1990), Nielsen et al. (1971) and Moroff and Bass (1965), who showed a lower heart rate with pre-exercise hyperhydration compared with pre-exercise euhydration during exercises of 60–120 min. The observed decrease in heart rate in the present study represents a physiological change that may have contributed in improving performance. It has been shown that reducing exercise-induced dehydration during prolonged cycling in a temperate climate, as pre-exercise hyperhydration allowed in the current study, is associated with a reduction in heart rate and an increase in plasma volume, stroke volume and cardiac output (Hamilton et al., 1991; Nassis et al., 2002). If in the present study cardiac output was indeed enhanced with pre-exercise hyperhydration, then it could have contributed to the increase in endurance capacity by improving oxygen and nutrient delivery to the muscle, waste removal and buffering capacity (Casa, 1999).

No change in rectal temperature was observed between trials. Although no difference was detected, rectal temperature was systematically lower at all time points during exercise with pre-exercise hyperhydration. These results contrast with those of other studies which showed that pre-exercise hyperhydration reduces rectal temperature, compared with pre-exercise euhydration (Moroff and Bass, 1965; Gisolfi and Copping, 1974; Gruczka et al., 1987; Lyons et al., 1990). The discrepancy between findings may be related to the difference in ambient temperature, the quantity of fluid given during pre-exercise hyperhydration or the administration of fluid during exercise. Nevertheless, the reduction in rectal temperature observed in the current study with pre-exercise hyperhydration is unlikely to have played a role in the improvement in endurance capacity. In fact, the rectal temperature values observed during and at the end of both trials indicate that thermal strain was below the threshold shown to be performance-limiting (Gonzalez-Alonso et al., 1999).

Subjects were not blinded from the treatments they received, which may have confounded the endurance capacity test results. Although this possibility cannot be completely ruled out, we believe that it nevertheless did not affect the validity of results since subjects were not explained the goals of the study nor the hypotheses which were tested. Second, heart rate values at the end of the endurance capacity test were similar between trials and as elevated as those observed during the VO2max test performed during their first visit at the laboratory, indicating that subjects provided a maximal effort in each test. Finally, one subject had a decrease in endurance capacity with pre-exercise hyperhydration; had the effect of a lack of blinding been strong, then it would have been surprising to observe
such a result.

In conclusion, as a result of delaying dehydration the use of pre-exercise hyperhydration during 2 h of moderate to intense cycling conducted in a temperate environment when fluid consumption is low (33% of sweat losses) improves endurance capacity and peak power output and decreases heart rate and thirst sensation, but does not reduce rectal temperature. Studies must be conducted to compare the effect of pre-exercise hyperhydration and pre-exercise euhydration on performance during prolonged exercise in the heat when fluid consumption during exercise is sub-optimal.

Acknowledgements We are indebted to the subjects who agreed to participate in this study. We thank Dr. Paul Pape for having lent us the osmometer and provided the equipments necessary for the urine osmolality analyzes. At the time of conducting this study EDBG was financially supported by the Canadian Institutes of Health Research (CIHR) and is now supported by the Fonds de Recherche en Santé du Québec (FRSQ). IJD holds a salary grant from the CIHR.

References

Nassis GP, Geladas ND (2002) Effect of water ingestion on


Received: January 11, 2008
Accepted: July 26, 2008
Correspondence to: Eric Goulet, McGill Nutrition and Food Science Centre, McGill University Health Centre, Royal Victoria Hospital, 687 Pine Ave., West, Room H6.61, Montréal, Quebec, H3A 1A1, Canada
Phone: +514–934–1934 (ext. 36350)
Fax: +514–843–1706