

Case report

WATER-INDUCED HYPERHYDRATION INCREASES TOTAL BODY WATER TO A GREATER EXTENT THAN GLYCEROL - INDUCED HYPERHYDRATION: A CASE STUDY OF A TRAINED TRIATHLETE

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ABSTRACT

Glycerol-induced hyperhydration (GIH) prior to endurance exercise is a strategy that is increasingly used by athletes. Compared with water-induced hyperhydration (WIH), GIH has been shown to reduce diuresis, thereby increasing total body water (TBW). It has never been demonstrated that WIH proved to be more efficient than GIH for increasing TBW. Therefore, we report the case of a trained triathlete in whom WIH, compared with GIH, increased TBW during a 110-min hydration protocol. On two separate days the subject ingested, in a randomized double blind fashion, either 26 ml·kg⁻¹ body mass (BM) of water or 26 ml·kg⁻¹ BM of water with 1.2 g glycerol·kg⁻¹ BM. Compared with GIH, WIH increased TBW by an additional 511 ml. It is proposed that WIH was effective in decreasing urine output and, therefore, in augmenting TBW, because the water ingested during this treatment was integrated into the body fluid pools relatively more slowly than that ingested during GIH. Practically, this finding implies that it could thus be possible for researchers and athletes to find out that on occasion WIH increases TBW more than GIH over a period of hydration of 2 h.

KEY WORDS: Fluid balance, gastric emptying, hydration, intestinal absorption, nutritional ergogenic aid.

SU İLE OLUŞTURULAN HİPERHİDRASYON TOPLAM VÜCUT SUYUNU GLİSEROL İLE OLUŞTURULAN HİPERHİDRASYONDAN DAHA İYİ ARTIRIR: ANTRENMANLI BİR TRIATLETİN OLGU ÇALIŞMASI

ÖZET

Dayanıklılık egzersizi öncesi gliserol ile oluşturulan hiperhidrasyon (GIH) atletler tarafından kullanımı artan bir stratejidir. Su ile oluşturulan hiperhidrasyon (WIH) ile karşılaştırıldığında GIH'in diürezis azaltarak toplam vücut suyunu (TBW) artırdığı gösterilmiştir. TBW'yi artırmak için WIH'in GIH'den çok daha etkili olduğu gösterilememiştir. Bundan dolayı GIH ile karşılaştırıldığında WIH ile 110 dak hidrasyon protokolü ile artmış TBW antrenmanlı bir triatlet olgusu ile sunulmaktadır. Denek, farklı iki günde rastgele çift kör yöntemi ile 26 ml·kg⁻¹ vücut kitlesi (BM) için su veya 26 ml·kg⁻¹ BM için su ile birlikte 1.2 g glycerol·kg⁻¹ BM aldı. GIH ile karşılaştırıldığında WIH TBW'da 511 ml ek bir artış sağladı. TBW değerlendirildiğinde WIH'in idrar çıkışını azaltmakta etkili olduğu (bu uygulama sırasında alınan su vücut sıvı havuzları ile relatif olarak GIH alımından daha yavaş bütünleştiği için) düşünülmektedir. Pratik olarak bu bulgular araştırmacılar ve

sporcular için 2 saati aşan bir hidrasyon dönemi için WIH'in GIH'den daha fazla TBW artırdığı olasılığına işaret etmektedir.

ANAHTAR KELİMELER: Sıvı dengesi, gastrik boşalma, hidrasyon, intestinal emilim, ergojenik yardım.

INTRODUCTION

In comparison to beginning an exercise euhydrated, starting an exercise while water hyperhydrated has been shown during exercise to reduce core temperature (Grucza et al., 1987; Moroff and Bass, 1965; Nielsen et al., 1971) and heart rate (Moroff and Bass, 1965; Nadel et al., 1980; Nielsen et al., 1971), and increase sweat rate (Moroff and Bass, 1965) and endurance performance (Blyth and Burt, 1961). However, the effectiveness of this hydration strategy is limited because it confers an increase in TBW that is typically only transient, as the ingested fluid is rapidly excreted through urine (Freund et al., 1995; Moroff and Bass, 1965). Because it substantially reduces diuresis, the addition of glycerol to the fluid to be ingested during hyperhydration has been shown to increase TBW compared with WIH (Robergs and Griffin, 1998). Hence, compared with WIH, GIH has been demonstrated during exercise to decrease core temperature (Anderson et al., 2001; Goulet et al., 2002; Lyons et al., 1990) and heart rate (Anderson et al., 2001; Montner et al., 1996), and increase sweat rate (Lyons et al., 1990) and endurance performance (Anderson et al., 2001; Coutts et al., 2002; Goulet et al., 2002; Hitchins et al., 1999; Montner et al., 1996). As a direct consequence of these findings, many endurance athletes nowadays use this hydration strategy during training and competitions held in hot and humid conditions (personal observation). In none of the studies on GIH has it been reported that WIH increased TBW to a greater extent than GIH. Thus, the purpose of this paper is to report the case of a trained triathlete in whom WIH increased TBW more than GIH during a hydration protocol that lasted 110 min.

METHODS

Subject

A trained male triathlete volunteered to participate in this experimental project. His physical and physiological characteristics were: age, 32 yr; height, 1.68 m; BM, 67.15 kg; maximal oxygen consumption ($\text{VO}_2 \text{ max}$), $3.7 \text{ L}\cdot\text{min}^{-1}$; ventilatory threshold 2 (VT_2), 86 % of $\text{VO}_2 \text{ max}$ and; peak power output (PPO), 310 W. At the time of the study the subject was an active member of the triathlon team of the Université de

Sherbrooke and was training an average of 14 h \cdot week⁻¹. Prior to undertaking this study, the subject completed a health history questionnaire in order to detect any medical condition that could have contraindicated exercise testing of any type. Then the subject was thoroughly explained the study's risks and procedures and written consent was obtained. The procedures were approved by the local Research and Ethics Committee of the Faculty of physical education.

Preliminary Testing

Seven days prior to the first trial, the subject underwent a measurement of $\text{VO}_2 \text{ max}$, VT_2 and PPO on an electromagnetically braked cycle ergometer (Ergoline ER900, Jaeger, Germany). For this purpose, a continuous incremental test was utilized. The subject first warmed-up by cycling for 5 min at a workload of 75 W. Then, following a 1 min rest period, he began cycling at a workload of 100 W for 2 min. Thereafter, the workload was step-incremented by $30 \text{ W}\cdot\text{min}^{-1}$. The test ceased either when the subject claimed complete exhaustion or at the moment his pedal frequency attained 59 revolutions $\cdot\text{min}^{-1}$. Parameters (average of each 15 s intervals) of VO_2 , $\text{VE}\cdot\text{VO}_2^{-1}$, $\text{VE}\cdot\text{VCO}_2^{-1}$ and $\text{P}_{\text{ET}}\text{CO}_2$ were determined using an Oxycon Pro (Jaeger, Germany) gas analyzer that was calibrated at least 20 min before the onset of the test with gases of known concentration. $\text{VO}_2 \text{ max}$ was defined as the average of the VO_2 values obtained during the last min of the test. VT_2 was determined using the criteria of an increase in both the $\text{VE}\cdot\text{VO}_2^{-1}$ and $\text{VE}\cdot\text{VCO}_2^{-1}$ and a concomitant decrease in $\text{P}_{\text{ET}}\text{CO}_2$ (Lucia et al., 2000). PPO was defined as the last workload that was maintained longer than 30 s.

Pre-Experimental Protocol

Over the study period the subject maintained his regular training routine, but refrained from any physical activity 24 h prior to each trial. Moreover, 72 h prior to each trial he stopped any form of strength training. For the last 24 and 48 h prior to the first trial, the subject kept a fluid and a diet log, respectively. He replicated these logs prior to the second trial. For the last 24 h prior to each trial he refrained from diuretic substances such as alcohol, tea, coffee, and chocolate.

Finally, in an attempt to ensure euhydration prior to each trial, the subject ingested 500 ml of water 90 min before reporting to the laboratory.

Experimental Trial

The subject performed two trials: one using GIH and the other using WIH. The trials were separated by a 7-day period and were conducted at the same time of the day. At his arrival at the laboratory the subject voided his bladder and was then weighted in the nude. Then

he rated his stomach fullness (no, light, moderate, considerable and extreme fullness corresponding to numbers 1 to 5, respectively), and finally began to hydrate. The length of the hydration protocol was 110 min. During WIH the subject ingested a total of 26 ml·kg⁻¹ BM of water. During GIH he ingested the same amount of water together with a total of 1.2 g glycerol·kg⁻¹ BM. The way the glycerol and water were administered over time is shown in Table 1.

Table 1. Hyperhydration protocols.

Time (min)	Glycerol-induced Hyperhydration	Water-induced Hyperhydration
0	0.4 g glycerol·kg ⁻¹ BM mixed with 6 ml·kg ⁻¹ BM of flavored water	6 ml·kg ⁻¹ BM of flavored water
20	4 ml·kg ⁻¹ BM of plain water	4 ml·kg ⁻¹ BM of plain water
40	0.4 g glycerol·kg ⁻¹ BM mixed with 6 ml·kg ⁻¹ BM of flavored water	6 ml·kg ⁻¹ BM of flavored water
60	4 ml·kg ⁻¹ BM of plain water	4 ml·kg ⁻¹ BM of plain water
80	0.4 g glycerol·kg ⁻¹ BM mixed with 6 ml·kg ⁻¹ BM of flavored water	6 ml·kg ⁻¹ BM of flavored water
110	End of the protocol	

BM= Body Mass.

The reason why the glycerol and water were administered in such a manner over time has been discussed elsewhere (Goulet et al., 2002). The experimental solutions (ingested at min 0, 40 and 80) were given in a randomized, double blind fashion. Both experimental solutions were served at refrigerator temperature (4 °C) and had the same color, texture and sweetness (aspartame) to mask the taste of glycerol. Plain water was served at 25 °C. Immediately after having ingested the experimental solutions, the subject rinsed his mouth for 10-15 s with 50-100 ml of warm water (37 °C), which was then spat into a sink. The goal of this procedure was to remove any possible residual taste left by the glycerol. The subject was unable to differentiate between the experimental solutions. Following the rating of stomach fullness at min 18, 38, 58, 78 and 110, the subject urinated in a graduated urinal and urine volume was measured to the nearest 5 ml. The goal of this procedure was to determine the changes in TBW, which were calculated by subtracting the accumulated volume of urine produced from the accumulated volume of water ingested. Insensible water loss was

assumed to be similar between trials. During the hydration protocols the subject stood only for voiding his bladder as well as for ingesting the experimental solutions and the plain water: the remainder of the time he remained calmly seated. The hydration protocols took place at a temperature of 25 °C with a relative humidity of 38-42%.

RESULTS

The subject started the GIH and WIH trial with a BM of 67.45 and 67.30 kg, respectively. Given the trivial (0.15 kg) difference of BM between hydration trials, and that the subject 1) refrained from diuretic substances prior to each trial and; 2) replicated his food and fluid intake from trial 1 to trial 2, we thus feel confident that he started both trials in a similar state of hydration. The subject ingested a total of 1745 ml of water in each trial. Figure 1 shows the changes in TBW and urine volumes produced over time during GIH and WIH.

In both trials the urine volumes produced at each time point increased steadily to reach a final

value at min 110 of 480 and 350 ml for GIH and WIH, respectively. At each urine collection point the urine volume produced with GIH was superior to that produced with WIH by ~ 65 -130 ml. The subject produced a total urine volume with GIH and WIH of 1310 and 799 ml, respectively. During WIH TBW increased steadily over time to reach a final value at min 110 of 946 ml. In contrast, during GIH TBW peaked at min 60, after which time it steadily decreased to attain a final value at min 110 of 435 ml. Therefore, WIH increased TBW by an additional 511 ml compared with GIH. Up until min 60, and this in both trials, the subject reported no stomach fullness. After this time, however, he reported a light (min 80) and moderate (min 110) stomach fullness with WIH compared to none with GIH.

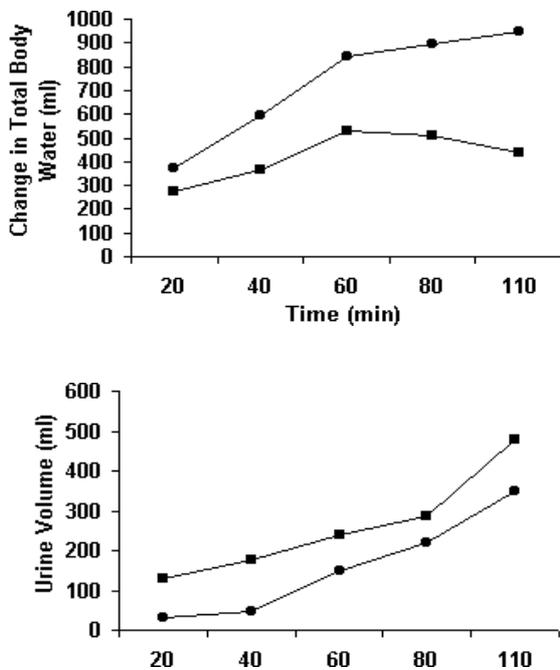


Figure 1. Changes in urine volumes produced (bottom) and total body water (top) over time during GIH (square) and WIH (circle).

DISCUSSION

This case study showed that, compared with GIH, WIH increased TBW by 511 ml in a healthy trained triathlete. This is an important finding since this is the first study to show that GIH conferred an increase in TBW that was less than that conferred by WIH. In fact, the combined results of the previous studies on

GIH demonstrate that, compared with WIH, GIH increases TBW by 100-1033 ml after 2-4 h of hydration (Goulet et al., 2002, Montner et al., 1996; Robergs and Griffin, 1998).

Many studies have observed the effect of GIH during a 2 h period. Riedesel et al. (1987), Freund et al. (1995), Hitchins et al. (1999), Anderson et al. (2001), and Coutts et al. (2002) have showed that, compared with WIH, GIH increased TBW over a 2 h period by ~ 275 , 250, 500, 385, and 360 ml, respectively. In these studies, the experimental subjects ingested, within the first 15-60 min of the hydration protocol, 1450-1955 ml of fluid with 0.9-1.2 g glycerol \cdot kg⁻¹ BM. Montner et al. (1999) used a fragmented protocol of hydration where ~ 350 ml of fluid were administered at min 0 and then every 30 min up to min 120. The glycerol, in a dose of 1 and 0.2 g \cdot kg⁻¹ BM, was ingested, along with the fluid, at min 0 and 60, respectively. With such a protocol, Montner et al. (1999) showed that GIH increased TBW by 600 ml compared with WIH. Obviously, the protocol of hydration utilized in the present study, though using a comparable quantity of glycerol and fluid, differs greatly from those that have just been described above. Nevertheless, it would be unlikely that the way we administered the fluid and glycerol over time could explain why WIH increased TBW more than GIH. Indeed, using the exact same protocol of hydration than the one used in the present study, we recently demonstrated in our laboratory that, in a highly trained triathlete, GIH increased TBW by 1033 ml compared with WIH (Goulet et al., 2002). Despite the fact that we did not measure key blood variables as well as the rate of glycerol excretion through urine, it is nevertheless possible to propose a sound explanation as to why WIH increased TBW more than GIH.

At the end of the hydration period with WIH the subject reported a moderate sensation of stomach fullness, compared to none with GIH. Moreover, it was observed that at all urine collection points the urine volumes produced with GIH were higher than those produced with WIH. The combination of these two facts suggests that the rate of integration of WIH into the body fluid pools, which is dependent on the rates of gastric emptying and intestinal absorption (Leiper, 1998), was slower than that of GIH. In comparison to WIH, it is theorized that GIH allows a better retention of fluid because the ingested glycerol, once in the renal filtrate, is reabsorbed in the distal and proximal tubules, which, consequently, creates a favorable gradient for the reabsorption of water (Freund et al., 1995; Hitchins et al., 1999; Montner et

al., 1999; Robergs and Griffin, 1998). Consequently, if the water ingested during WIH had been integrated at a rate comparable to that ingested during GIH, the volumes of urine produced at all urine collection points would have been larger, or at the very least as large, than those with GIH, which was not the case. Additionally, the sensation (rating) of stomach fullness would have been identical between trials, which, manifestly, was not the case. Thus, it is proposed that WIH was more effective than GIH for reducing diuresis, and consequently for increasing TBW, because the water ingested during this treatment was integrated into the organism relatively more slowly than that ingested during GIH. Why WIH was integrated less rapidly than GIH is not necessarily easy to explain and deserves attention.

A variety of factors can influence the rate of gastric emptying and/or intestinal absorption of an ingested fluid (Brouns, 1998; Leiper, 1998). Those of interest in the present study are fluid volume, caloric density, osmolality, temperature and psychological stress. Because of the presence of glycerol, two of the preceding factors were not held constant between trials, that is the caloric density and osmolality level of the experimental solutions. Indeed, compared with the control solutions (WIH), the glycerol solutions possessed a higher caloric density (+ 0.29 Kcal·ml⁻¹) and osmolality level (+ 726 mOsm·kg⁻¹ ([26.9/92]/403 x 1000)). Presently, it is unknown how GIH affects gastric emptying and intestinal absorption in humans. However, research on liquid carbohydrate solutions has shown that when the caloric density of a solution is increased, the rate of gastric emptying decreases proportionally (Vist and Maughan, 1994). Additionally, it is also well known that carbohydrate-induced hypertonicity decreases the rates of gastric emptying (Vist and Maughan, 1995) and intestinal absorption (Leiper, 1998). Thus, given the higher osmolality and caloric density of the glycerol solutions compared with the control solutions, it is theoretically WIH, and not GIH that should have been integrated more rapidly.

It has been shown that the rates of gastric emptying (Anderson et al., 1992; Beckers et al., 1991) and intestinal absorption are not constant from day to day but rather highly variable. For example, Beckers et al. (1991) showed that, in eight subjects, the mean within-subjects coefficient of variation for gastric emptying over four days was 29%. Beckers et al. (1991) report in their Table 1 the gastric emptying data obtained by each individual over the four testing days. Interestingly, when these data are closely examined, it can be observed that, in three individuals, the rate of

gastric emptying varied by as much as 100% over two testing days. Similarly to the rate of gastric emptying, the mean within-subjects coefficient of variation for the rate of intestinal absorption approximates 30% (personal communication, J.B. Leiper, January 28th, 2002). Thus, the reduced integration rate of WIH could be explained if, with respect to the rates of gastric emptying and intestinal absorption, the subject was on a "very bad day" during WIH (low rates of emptying and absorption) and, inversely, on a "very good day" during GIH (high rates of emptying and absorption).

The slight possibility that the subject rapidly excreted the glycerol and, therefore, free water, must not be ruled out. This would have contributed to accentuate the difference of fluid retention between the hydration trials. Finally, the influence of the anti-diuretic hormone during WIH is unlikely as the ingestion of a large quantity of water suppresses its release (Freund et al., 1995).

CONCLUSION

In summary, this case study showed that WIH increased TBW more than GIH over a period of 110 min. It is proposed that WIH decreased urine excretion, and thus increased TBW, because the water ingested during this treatment was incorporated into the body relatively more slowly than that ingested during GIH. It is suggested that the slower integration rate of WIH may be attributable to the daily variation in gastric emptying and intestinal absorption. Future studies should report any case of individual who showed more fluid retention with WIH than with GIH. Moreover, further research is required to evaluate the effect of GIH on gastric emptying and intestinal absorption.

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