Hyperhydration and Glycerol: Thermoregulatory Effects During Exercise in Hot Climates

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Abstract/Résumé

Hyperhydration or increasing body water content above normal (euhydration) level was thought to have some benefit during exercise heat-stress; however, attempts to overdrank have been minimized by a rapid diuretic response. The perception that hyperhydration might be beneficial for exercise performance and for thermoregulation arose from the adverse consequences of hypohydration. Many studies had examined the effects of hyperhydration on thermoregulation in the heat; however, most of them suffer from design problems that confound their results. The design problems included control conditions not representing euhydration but hypohydration, control conditions not adequately described, cold fluid ingestion that reduced core temperature, and/or changing heat acclimation status. Several investigators reported lower core temperatures during exercise after hyperhydration, while other studies do not. Some investigators reported higher sweating rates with hyperhydration, while other studies do not. Recent research that controlled for these confounding variables reported that hyperhydration (water or glycerol) did not alter core temperature, skin temperature, whole body sweating rate, local sweating rate, sweating threshold temperature, sweating sensitivity, or heart rate responses compared to euhydration trial. If euhydration

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is maintained during exercise-heat stress then hyperhydration appears to have no meaningful advantage.

Selon des études, l’hyperhydratation ou l’accroissement du contenu corporel d’eau au-dessus de la normale (euhydration) avait pour but de favoriser la thermorégulation à l’effort ; cependant, les tentatives de boire un excès de liquide ont été contrées par une vive diurèse. L’effet bénéfique de l’hyperhydratation en termes de performance physique et de thermorégulation a été déduit des conséquences néfastes de l’hypohydration. De nombreuses études ont analysé les effets de l’hyperhydratation sur la thermorégulation par temps chaud ; la plupart de ces études présentent des problèmes méthodologiques qui mettent en doute les résultats. Parmi les problèmes associés au protocole expérimental, les groupes témoins ne sont pas dans un état d’euhydration mais d’hypohydration ou ne sont pas bien décrits et la consommation de boisson froide réduit la température centrale et/ou modifie le niveau d’acclimatation. Quelques chercheurs ont observé une plus basse température centrale au cours d’un exercice en condition d’hyperhydratation mais d’autres chercheurs n’ont pas confirmé ces observations. En condition d’hyperhydratation, des chercheurs ont observé un plus haut taux de sudation, mais d’autres chercheurs n’ont pas observé ce phénomène. D’après des études récentes ayant exercé un contrôle des variables confusionnelles, l’hyperhydratation (eau ou glycérol), comparativement à l’euhydration, ne modifie pas les températures centrale et cutanée, les taux de sudation global et local, la température au seuil de sudation, la sensibilité de la sudation et la fréquence cardiaque. Si l’euhydration est assurée au cours de l’exercice thermogène, l’hyperhydratation ne semble pas procurer de bénéfice.

**Introduction**

Athletes often do not drink sufficient amounts of fluid to replace sweat losses during prolonged physical activities and incur fluid deficits that can impair their performance and temperature regulation. A fluid deficit as little as 1% of body weight has been reported to decrease work capacity (Sawka et al., 1996). Maintaining euhydration in prolonged events has been shown to improve exercise performance in the heat and thermoregulation as compared to subjects that are allowed to dehydrate. Therefore, it is important to initiate exercise in a euhydrated state; however, another approach in preventing or delaying hypohydration has been to attempt hyperhydration prior to prolonged exercise.

While many studies have attempted to induce hyperhydration and increase total body water by overdrinking water or water-electrolyte solutions, these approaches have produced only transient expansion of total body water. Hyperhydration is not easy to achieve since overdrinking produces a fluid overload that is rapidly excreted by the kidneys (Freund et al., 1995). Evidence has accrued that greater fluid retention can be achieved by drinking an aqueous solution containing glycerol (Freund et al., 1995; Riedesel et al., 1987). It was first reported (Riedesel et al., 1987) that following hyperhydration with a glycerol solution compared to water alone, subjects excreted significantly less of the water load. More recent studies (Freund et al., 1995) confirmed Riedesel’s findings in that greater fluid retention can be achieved by drinking an aqueous solution containing glycerol while resting in temperate conditions for up to 3 hr. They reported (Freund et al., 1995) that glycerol hyperhydration increases fluid retention by
reducing free water clearance as compared to water hyperhydration in temperate conditions while at rest.

Hyperhydration results in an increased total body water (TBW), and a few studies have reported an increase blood/plasma volume (Freund et al., 1995) as shown in Figure 1. Hyperhydration should elicit a small plasma volume expansion that is proportionate to the increase in TBW (Freund et al., 1995; Latzka et al., 1997). However, since only 7.5% of TBW is in plasma, a TBW increase of 600 ml would increase plasma volume by approximately 45 ml (if it were equally distributed between intracellular and extracellular fluid). Thus any increase in plasma

![Graph showing change in total body water and plasma volume over time.](image)

**Figure 1.** The top plot presents the change in total body water following the hydration period. The lower plot presents the change in plasma volume for glycerol hyperhydration trial (filled circles), water hyperhydration trial (open circles), and control trial (filled triangle). (Modified from Freund et al. 1995)
volume would likely exceed the measurement’s resolution especially if the volume is changing, such as when subjects are exposed to high ambient temperatures and/or exercise.

**Hyperhydration and Thermoregulation**

Several studies have investigated the effects of hyperhydration on thermoregulation and exercise performance. Table 1 provides a chronological presentation of studies evaluating hyperhydration effects on thermoregulation. Briefly, six of the fifteen studies observed lower core temperature increases during exercise in the hyperhydration trials. Three of the fifteen studies examining sweating rates observed higher rates during exercise with hyperhydration. Together, these studies support the notion that hyperhydration might provide a thermoregulatory benefit; however, nine other studies report no thermoregulatory advantage with hyperhydration during exercise. In addition many of the studies reporting a thermoregulatory advantage had confounding variables, such as control conditions that did not represent euhydration, as the subjects were allowed to dehydrate during exercise. It is well known that dehydration results in a higher core temperature and heart rate and lower sweat rate during exercise as compared to euhydrated subjects.

**Table 1** Studies Evaluating the Effects of Hyperhydration on Temperature Regulation and Performance

<table>
<thead>
<tr>
<th>Study</th>
<th>Temperature</th>
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<tbody>
<tr>
<td></td>
<td>Core</td>
<td>Skin</td>
<td>Sweat rate</td>
</tr>
<tr>
<td>(Blyth &amp; Burt, 1961)</td>
<td>nc</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>(Moroff &amp; Bass, 1965)</td>
<td>↓</td>
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<td>↑</td>
</tr>
<tr>
<td>(Greenleaf &amp; Castle, 1971)</td>
<td>nc</td>
<td>nc</td>
<td>nc</td>
</tr>
<tr>
<td>(Nielsen et al., 1971)</td>
<td>↓</td>
<td>—</td>
<td>—</td>
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<tr>
<td>(Nielsen, 1974)</td>
<td>↓</td>
<td>—</td>
<td>↑</td>
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<tr>
<td>(Gisolfi &amp; Copping, 1974)</td>
<td>↓</td>
<td>—</td>
<td>nc</td>
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<tr>
<td>(Nadel et al., 1980)</td>
<td>nc</td>
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<tr>
<td>(Grucza et al., 1987)</td>
<td>↓</td>
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<tr>
<td>(Candas et al., 1986)</td>
<td>nc</td>
<td>nc</td>
<td>—</td>
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<tr>
<td>(Lyons et al., 1990)</td>
<td>↓</td>
<td>nc</td>
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<tr>
<td>(Montner et al., 1996)</td>
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<td>(Latzka et al., 1997)</td>
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<td>(Greenleaf et al., 1998)</td>
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<td>(Inder et al., 1998)</td>
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<tr>
<td>(Hitchens et al., 1999)</td>
<td>nc</td>
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</tr>
</tbody>
</table>

nc = no significant change, ↑ = significant increase, ↓ = significant decrease.
Of the six studies reporting lower core temperature with hyperhydration, four of the studies used a control trial that allowed the subjects to dehydrate and two reported using cold water in the hyperhydration trial. The dehydration in the control group and the cold fluid ingestion in the hyperhydration group can account for the lower core temperatures reported in the hyperhydration trials.

**Glycerol Hyperhydration**

Most studies evaluating glycerol's effect on hyperhydration have used 1 g of glycerol per kg body weight with or followed by a large volume (~2 L) of fluid. A few studies (Freund et al., 1995; Latzka et al., 1998; Latzka et al., 1997) provided glycerol and fluid dose relative to the subjects' total body water or lean body mass. Providing the fluid dose and glycerol relative to TBW or body mass decreases the variability of the responses. These volumes and glycerol doses are similar to values used in other studies (Lyons et al., 1990; Montner et al., 1996; Riedesel et al., 1987). At rest in temperate conditions, both glycerol hyperhydration and water hyperhydration have a similar fluid retention at 1 hr post drink (see Figure 1); however, at 2 hr post drink the glycerol hyperhydration has a greater (400 to 600 ml) fluid retention than the water hyperhydration trial when subjects are at rest. At 3 hr post drink about 60% of the glycerol hyperhydration fluid was retained and about 30% was retained in the water hyperhydration trial. The difference in TBW between glycerol and water hyperhydration trials at 3 hr of rest is about 600 ml.

The results of several studies have lead to the development of commercial products espousing the benefits of glycerol for providing hyperhydration and ergogenic advantages (Lyons et al., 1990; Montner et al., 1996). Lyons and colleagues (1990) examined whether glycerol-mediated hyperhydration improved thermoregulatory responses to exercise-heat stress. These subjects were unfit and non-heat acclimated men and women. They completed three trials in which they exercised (60% VO\(_{2\text{max}}\)) in the heat (42 °C, 25% rh). During one trial, fluid ingestion was restricted (ad libitum intake), and in the other two trials subjects hyperhydrated with water or with glycerol and water. Ninety minutes after this hyperhydration period, subjects initiated 90 min of treadmill exercise, which they all completed. Glycerol ingestion increased fluid retention compared to drinking water alone. During exercise, glycerol hyperhydration produced a higher sweating rate (33%) and substantially lower core temperatures (0.7 °C) compared to control conditions and water hyperhydration. No differences were found between water hyperhydration and control. The investigators concluded that glycerol hyperhydration improved thermoregulation in the heat. Subsequent research from that laboratory reported that when used in temperate climates, glycerol hyperhydration may extend endurance but did not demonstrate any thermoregulatory advantage (Montner et al., 1996).

Two recent studies (Latzka et al., 1998; Latzka et al., 1997) were conducted to determine if glycerol hyperhydration provides a thermoregulatory and ergogenic advantage during exercise in the heat. Subjects were males of moderate fitness who were heat acclimated. Body hydration status was carefully controlled. The glycerol hyperhydration procedures were similar to those employed in other studies (Lyons et al., 1990; Montner et al., 1996). In the first study (Latzka et al., 1997), subjects performed treadmill exercise (45% VO\(_{2\text{max}}\)) in heat (35 °C, 45% rh)
when euhydrated and when hyperhydrated with water or with glycerol, both with and without rehydration during exercise. As shown in Figure 2, the change in TBW was similar in the hyperhydration trials at the onset of exercise. Compared to euhydration (where fluid intake during exercise matched the fluid loss), hyperhydration did not alter core temperature (Figure 3), skin temperature, whole-body sweating, or local sweating responses. Similarly, no differences in these variables were found between water and glycerol hyperhydration. These investigators concluded that neither glycerol nor water hyperhydration provided any thermoregulatory advantage over euhydration.

In their second study (Latzka et al., 1998), subjects were exposed to uncompensable heat stress, thus they could not achieve heat balance and steady-state body temperatures. The subjects exercised to exhaustion after water hyperhydration, water-glycerol hyperhydration, or after euhydration using the same hydration procedures as used in their first study. No rehydration trials were performed in this study because of the short duration of uncompensable heat stress. Water and glycerol hyperhydration elicited similar core temperature, skin temperature, whole-body sweating, cardiac output, total peripheral resistance, systolic blood pressure responses, and exercise endurance times.

**Figure 2.** Changes in total body water over time during uncompensable exercise-heat stress trials. Values are means ± SE; Eu (filled triangles) = euhydration, GD (filled square) = glycerol hyperhydration with no rehydration, GR (open square) = glycerol hyperhydration with rehydration, WD (filled circles) = water hyperhydration with no rehydration, WR (open circle) = water hyperhydration with rehydration. *Significantly (P < .05) different from Eu trial. **Significantly (P < .05) different from GD and WD.
Figure 3. Rectal temperatures during compensable exercise-heat stress trials. Values are means ± SE; Eu (filled triangles) = euhydration, GD (filled square) = glycerol hyperhydration with no rehydration, GR (open square) = glycerol hyperhydration with rehydration, WD (filled circles) = water hyperhydration with no rehydration, WR (open circle) = water hyperhydration with rehydration.

The few studies reporting thermoregulatory differences between water and glycerol hyperhydration had their subjects wait several hours after the glycerol ingestion before starting the exercise trial. These methods allowed the glycerol hyperhydrated subjects a greater fluid retention, and therefore they start the exercise with about a 500 ml greater TBW than water hyperhydrated subjects. If these subjects do not drink during exercise or drink ad libitum, they will likely become dehydrated and the water hyperhydration trial will be more dehydrated earlier in the exercise than the glycerol hyperhydration trial. If euhydration were maintained throughout the exercise, it would be unlikely that either hyperhydration method would show any thermoregulatory advantage (Latzka et al., 1998; Latzka et al., 1997).

Hyperhydration and Performance

Few studies have examined whether hyperhydration improves exercise performance or heat tolerance. Blythe and Burt (1961) were the first to report on the effects of hyperhydration and performance during exercise-heat stress. Their subjects ran (3.13 m · s⁻¹, 8.6% grade) to exhaustion in a hot climate (49 °C) following ad libitum fluid intake and 30 min after drinking 1 L of isotonic saline and 1 L of water. Exhaustion time was not different between the hyperhydration (17.3 min) and control (16.9 min) trials. They also reported no difference in core (rectal) temperature or water loss between trials. But when they separated the subjects between
athletes and nonathletes, they reported that the endurance times of the athletes were greater in the hyperhydration trial compared to the control, 18.9 min and 17.1 min, respectively, and reported no differences in changes of core temperature or water loss between the trials.

Montner and colleagues (1996) reported positive effects of glycerol hyperhydration on exercise performance in a temperate environment. In trials without rehydration, endurance time was greater in the glycerol hyperhydration than water hyperhydration trials, 94 min vs. 77 min, respectively. In the trials with rehydration (replaced 60% of sweat loss during exercise), the corresponding values were 123 min and 99 min. However, they reported no difference in core temperature, sweat rate, or perceived exertion between trials.

A recent study (Hitchens et al., 1999) reported that hyperhydration with glycerol improved endurance cycling performance in a maximal 60-min laboratory time trial in hot, humid conditions. Their subjects were hyperhydrated with a glycerol/carbohydrate sports drink or a carbohydrate sports drink 2.5 hr prior to exercise. Glycerol hyperhydration resulted in a 600 ml increase in total body water over the control group before exercise, and total amount of work performed was 2.4% greater. The time trial involved a 30-min fixed power output phase followed by a 30-min variable power phase. However, they reported no difference in heart rate, metabolic rate, lactate concentration, sweat rate, or core temperature between the groups.

Latzka and colleagues (1998) reported the effects of hyperhydration on exercise performance during uncompensable heat stress. They had the subjects walk on a treadmill until exhaustion during uncompensable heat stress. They found that glycerol hyperhydration extended endurance time (from 30 to 34 min) beyond the control trial (euhydration at the beginning of exercise) but was not different than water hyperhydration trial. By the end of the trial the subjects in the control trial finished the exercise 2% dehydrated. Dehydration of this magnitude will increase physiologic strain during exercise heat stress and could result in decreased exercise performance.

**Conclusion**

The exercise start time following the hyperhydration is a factor that often varies between studies. The timing is an important consideration when comparing glycerol hyperhydration to water hyperhydration, because the hydration status at the start of exercise will vary with different hyperhydration periods. If exercise is started at 1 hr post drink, the hydration status at the start of exercise will be similar between glycerol and water hyperhydration. However, if the exercise start time is at 3 hr post drink the glycerol hyperhydration trial will begin exercise with about 600 ml greater TBW.

If rehydration is applied with hyperhydration, then elevated TBW can be maintained throughout exercise in the heat (Latzka et al., 1997). These studies demonstrate that total body water can be increased by ~1.5 L with hyperhydration (Freund et al., 1995; Latzka et al., 1998; Latzka et al., 1997). Glycerol hyperhydration provides no hydration advantage over water hyperhydration when euhydration is maintained during exercise - heat stress (Latzka et al., 1998; Latzka
et al., 1997). Both exercise and heat stress decrease renal blood flow and free water clearance and therefore negate glycerol's effectiveness as a hyperhydrating agent if ingested shortly before exercise or during exercise (Latzka et al., 1997; Latzka et al., 1998).

Hyperhydration studies reporting either thermoregulatory or performance advantages can be accounted for by the hydration status. In controlled studies, hyperhydration increases TBW when subjects are resting for approximately 2 hr after drinking the solution, and glycerol hyperhydration results in a greater fluid retention by about 500 to 600 ml. However, during exercise the sweat loss in glycerol hyperhydration trials and water hyperhydration trials is similar. If euhydration is maintained during exercise then the individuals starting at a greater hyperhydration level will have an advantage of delaying hypohydration later in the event. However, if euhydration is maintained during the exercise then there appears to be no thermoregulatory or performance advantage for hyperhydration. If the hydration status is the same at the start of the exercise then glycerol hyperhydration will have no advantage over plain water hyperhydration. The advantages of hyperhydration that are reported in the literature are usually due to the fact that by the end of the exercise the control group is more dehydrated.

References


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