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Review/Commentary

PRE-EXERCISE HYPERHYDRATION: COMMENTS ON THE 2007 ACSM POSITION STAND ON EXERCISE AND FLUID REPLACEMENT

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ABSTRACT

Goulet EDB. Pre-Exercise Hyperhydration: Comments on the 2007 ACSM Position Stand on Exercise and Fluid Replacement. ***JEPonline*** 2008;11(2):**64-74.** In the latest hydration guidelines of the ACSM (February 2007), two paragraphs are dedicated to the effects of pre-exercise hyperhydration (PEH) on exercise endurance performance (EEP) and physiological functions. With respect to its ergogenic potential, the Position Stand of the ACSM concluded that PEH only occasionally improves EEP, or offers no clear performance advantage. These conclusions are, in my opinion, not a perfect reflection of what is really known about the ergogenic value of PEH, as they were derived from results of studies whose experimental designs are inadequate to determine the ergogenic property of PEH. In this opinion/review article, I will provide an alternative view of the effect of PEH on EEP using newly published, as well as results not discussed by the ACSM Position Stand. When the literature is carefully reviewed, one finds out that only few investigations provide clues about the effect of PEH on EEP, and collectively their results suggest a performance-enhancing effect in athletes. On the other hand, the Position Stand judged that this strategy provides no thermoregulatory or other clear physiological advantages, and that it increases the risk of hyponatremia and of having to void during competition. I am not in total agreement with these conclusions and here I will present evidence suggesting otherwise. I believe that it is important to provide an alternative view of the effects of PEH on EEP and physiological functions than that given by the ACSM's Position Stand due to the influential role of this organization within the exercise science community.

Key Words: Fluid overloading, Exercise capacity, Heart rate, Rectal temperature, Hyponatremia.

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INTRODUCTION

In February 2007, the American College of Sports Medicine (ACSM) released the first update of their Position Stand on exercise and fluid replacement (1) that was first published in 1996. Clearly, this update was much needed since over this interval of time important advancements have been made in some hydration-related research areas.

Pages 381 and 384 of the Position Stand each contain a paragraph devoted exclusively to the effects of pre-exercise hyperhydration (PEH) (a state of elevated body water induced acutely prior to exercise by means of fluid ingestion with or without water-binding agents (glycerol, sodium, etc.)) on exercise endurance performance (EEP) and physiological functions. The ACSM Position Stand concludes that PEH can occasionally be responsible for small performance benefits or provides no clear performance advantage. An important problem with these statements is that both are based on results of studies using experimental designs that are not appropriate to draw conclusions about PEH's ergogenic value during normal, out-of-doors exercise situations. Therefore, it is important to provide a clear picture of what is known (and unknown) about the effect of PEH on EEP. This opinion/review article will be based on newly published results, as well as on an analysis of results not taken into consideration by the Position Stand.

Although the Position Stand of the ACSM adequately reported some of the known physiological effects of PEH, in other instances it is my belief that it failed to appropriately do so. For example, the Position Stand concluded that PEH provides no thermoregulatory or other clear physiological advantages, increases the risk of dilutional hyponatremia during exercise, and greatly augments the risk of having to void during competition. I do not completely agree with these statements, and this paper will provide scientific evidence suggesting that, compared with pre-exercise euhydration (PEE), the use of PEH provides cardiovascular and thermoregulatory advantages during prolonged exercise where athletes dehydrate (lose body water as a result of not entirely replacing their sweat losses through fluid intake), does not increase the risk of dilutional hyponatremia when athletes dehydrate during exercise, and does not greatly increase the risk to void during competition, i.e., during moderate- to high-intensity exercises.

Globally, the ACSM guidelines on exercise and fluid replacement judges that PEH provides equivocal benefits and has several disadvantages (see Table 6., page 385). Unfortunately, these conclusions are drawn from a limited and, in my view, simplistic evaluation of the existing literature. In this paper, I will discuss each issue raised by the Position Stand of the ACSM with which I do not agree and provide counterevidence to support my position. A short discussion on the possible side-effects of PEH is added at the end of my argumentation. Finally, a paragraph will briefly discuss under what particular exercise conditions athletes should use PEH. Due to the significant impact that the ACSM guidelines on exercise and fluid replacement has in the research field of hydration and exercise, it is important to provide an alternative view of the effects of PEH on EEP and physiological functions.

Throughout this article, the term euhydration refers to a ‘’normal’’ body water content, while the terms hypohydration and hyperhydration refer to a body water content below euhydration and above euhydration, respectively. The term dehydration refers to the dynamic loss of body water during exercise that can occur from the hyperhydrated state to euhydration and continue downward to hypohydration.

Issue 1

As previously indicated, the Position Stand of the ACSM arrives at two conclusions concerning the ergogenic potential of PEH. The conclusions were based on the results provided by three studies (2,3,4). The first one is found on page 381 and suggests that PEH ‘’… can delay the onset of dehydration, which may be responsible for any small performance benefits that are occasionally reported (2,3).’’, whereas the second one is found on page 384 and suggests that PEH ‘’… provides no clear physiologic or performance advantage over euhydration (4).’’

It is my position that the use of these studies for drawing conclusions about the effect of PEH on EEP is inappropriate, and this, independently of their outcomes. In fact, when each study is examined with scrutiny, it is apparent that none used an adequate methodological design to satisfactorily and validly answer the question ‘’Can PEH improve EEP compared with PEE, during normal, out-of-doors exercise situations?’’ Now let’s examine what I believe are the methodological inadequacies of these studies.

Greenleaf et al. (2) compared the effect of PEE to that of two PEH solutions (solution 1 contained sodium (55 mEq $\cdot$ L^{-1}), potassium (5.3 mEq $\cdot$ L^{-1}), glucose (20.5 g $\cdot$ L^{-1}) and sodium citrate (4.2 g $\cdot$ L^{-1}); solution 2 contained sodium (164 mEq $\cdot$ L^{-1}), a trace of potassium, a trace of glucose and sodium citrate (8.5 g $\cdot$ L^{-1})) on endurance capacity during a constant power output cycling test to exhaustion that was conducted at 87-91% VO_{2max} and 21ºC. Only drink 2 improved performance compared with PEE. There are two major methodological problems with this study. The first one is that both drinks contained sodium citrate, a substance which has been shown to improve EEP in some (5,6,7), but not all studies (8,9). Greenleaf et al. (2) indicated that the doses of sodium citrate they administered were higher than those reported in the previously cited studies. It is therefore possible that the ergogenic effect of drink 2 was due to the presence of sodium citrate, and not because of the excess volume of fluid ingested. The second one is that subjects ingested too little fluid (10 ml $\cdot$ kg $bodyweight^{-1}$) too early (from min -105 to min -45) before commencing exercise. Due to the obligatory production of urine that took place as a result of the excess fluid ingested, it is possible that subjects started the exercise only euhydrated or with an increase in total body water insufficient to meaningfully affect performance. Unfortunately, the authors did not report the extent to which the drinks enhanced total body water before exercise, or the effect they had on dehydration levels during exercise. The lack of hyperhydration prior to exercise may explain why drink 1 did not provide any ergogenic effect compared with PEE, but it is also possible that the reduced amount of sodium citrate in this drink may also have played a role. The presence of sodium citrate in the hyperhydration drinks, coupled with the likely low hyperhydration levels induced in this study and the non-reporting of those levels (a very important data in this type of study), render the interpretation of results difficult and therefore their generalization hazardous.

The reason the study of Kavouras et al. (3) is inadequate to conclude about the effect of PEH on EEP is straightforward because it examined the rehydrating, not hyperhydrating effectiveness of this strategy. In fact, no hyperhydration was induced in any of the trials this study contained. Subjects were first dehydrated by 4% of their bodyweight, then they ingested either nothing or enough water (with or without glycerol) to replace 3% of their bodyweight loss, and finally, they completed a cycling test to exhaustion (74% VO_{2peak}) in the heat (37 ºC). The glycerol trial was associated with an improvement in fluid retention and an increase in EEP that was significantly greater than in the two other trials. By definition PEH refers to an enhanced body water status and, consequently, it would be unfair to conclude anything about this strategy's ergogenic potential from a study whose results were obtained from an experimental design where all subjects started each exercise condition dehydrated.

Finally, the study of Latzka et al. (4) was used to support the second conclusion of the Position Stand. This study euhydrated or hyperhydrated (water-induced hyperhydration (WIH) and glycerol-induced hyperhydration (GIH)) subjects who then had to complete a treadmill test to exhaustion (55% VO_{2max} and 35 ºC) while wearing chemical protective clothing, thereby simulating conditions where it is extremely difficult for the body to thermoregulate efficiently. Glycerol-induced hyperhydration, but not WIH, improved EEP compared with PEE. Why GIH but not WIH improved endurance capacity is unclear because the changes in total body water throughout the hyperhydration and exercise periods were similar between groups. No matter the outcomes of this study, the fact that it was conducted in exercise conditions where athletes were wearing chemical protective clothing makes the generalization of their results to any real-world exercise condition imprudent.

If, according to me, the authors of the Position Stand failed to adequately report on the effect of PEH on EEP, then one may ask whether there is any valid, published scientific evidence that provides clues about PEH's ergogenic property. The answer is yes. In truth, only one study can be found in the literature that directly compared the effect of PEH and PEE on EEP (10). It is a difficult study to find, since it was published in 1961 and is not indexed in PubMed. However, Latzka and Sawka reported its existence in 2000 in an excellent review paper examining the thermoregulatory effects of PEH during exercise in hot climates (11). The study of Blyth and Burt (10) compared the effect of PEH (water + saline, 23 ml $\cdot$ kg bodyweight^{-1} ingested 30 min before exercise) and PEE on endurance capacity during a constant-speed treadmill test to exhaustion (11.3 km $\cdot$ h^{-1} with a 8.6% grade) conducted at a temperature of 49 ºC. Subjects ingested no fluid during exercise. The authors reported that PEH improved endurance capacity by 10% in athletes. This was not the case in non-athletes, however. These discrepant results are important, in that they may indicate that PEH could only improve EEP in trained athletes. Since PEH is a strategy mostly known and used by trained athletes (personal observations) this was a relevant distinction made by authors.

Since the natural behavior of athletes is to start exercise in a euhydrated state, then it follows that the only studies that can provide a direct information about the effectiveness of PEH on EEP are those comparing PEH with PEE with or without fluid consumption during exercise. Although to date only one study has directly and validly compared the effect of PEH and PEE on EEP (10), there are many reports that have been published over the past 10 years which compared the effect of GIH to that of WIH on EEP (12,13,14,15,16,17,18). These studies, when properly analyzed, can provide evidence about PEH's ergogenic effectiveness compared with PEE. Strangely, none of these studies included a PEE condition. Therefore, they were completed without the researchers really knowing whether or not PEH was providing any ergogenic benefit over PEE. As those particular studies compare two states of hyperhydration, one must consider that nothing can be concluded about PEH's ergogenic value (compared with PEE) from those investigations failing to demonstrate performance differences between GIH and WIH. Although in this particular scenario both conditions similarly affect EEP, it is possible that both or one of them would confer an increase in performance if they would also be compared with PEE. It must be remembered that the only true control group in research on PEH is PEE. On the other hand, in studies where one hyperhydration condition improves EEP over the other then it is reasonable to assume that this particular condition would also improve EEP over PEE if this latter condition would also be included in the study. In fact, if a hyperhydration state shows to be capable of improving EEP over another hyperhydration state of a lesser magnitude, then it is relatively safe to assume that, at least, the best hyperhydration state would improve EEP compared with a normal state of hydration (PEE). Now let's examine what the literature says about those studies comparing the effectiveness of GIH and WIH on EEP.

In a recent meta-analysis, Goulet et al. (19) reported that, compared with WIH, GIH significantly improves EEP by 2.6% during prolonged exercise in a hot or temperate climate. Hence, from these results one can reasonably assume that GIH would likely improve EEP compared with PEE and the gain in performance would be of at least 2.6%. This is a very reasonable assumption that will need to be tested in future studies. Studies comparing GIH with WIH have important limitations that need to be considered in that they provide no information as to the magnitude of the performance effect PEH may provide over PEE and, very importantly, preclude precise determination of the physiological effects of PEH compared with PEE. As a final note, it must be indicated that the salutary effect of GIH on EEP is unlikely to result from it modifying metabolism, as the turnover rate of this neoglucogenic precursor in the liver is not rapid enough to significantly serve as an energy source during exercise (20). Hence, the ingestion of glycerol alone has been shown not to improve EEP (21,22).

From what has been reported above, four conclusions can be drawn. First, PEH has the potential for improving EEP compared with PEE, at least during short-term exercise conducted in the heat. Second, GIH can enhance EEP during long-term exercise in a hot and temperate climate compared with WIH. Although still not proven scientifically, on the basis of the explanations given previously, GIH is very likely to improve EEP compared with PEE during prolonged exercise performed in the heat and a temperate climate as well. Third, there has been an overemphasis placed on research comparing the effect of GIH and WIH on EEP, while studies that would have had the most impact in the field and provided the most useful information about PEH (i.e., those comparing the effect of PEH and PEE on EEP) were left aside. And fourth, it is clear that there is a paucity of direct evidence of the effect of PEH on EEP in comparison with PEE and, therefore, scientists are encouraged to undertake studies in this particular direction.

Issue 2

On page 381 of the Position Stand it is stated that PEH ''does not provide any thermoregulatory advantages… .'' To support this statement, the authors used the results found in the investigation of Latzka et al. (23). Additionally, on page 384 it is mentioned that PEH ''… provides no clear physiologic or performance advantage over euhydration.'' and this statement is based on results found in three studies (3,4,23). As explained before, two of these studies (3,4), for methodological reasons, cannot be used to infer about the physiological effect of PEH. Thus, there is really only one study from those cited by the Position Stand that can be utilized to conclude about the physiological effectiveness of PEH over PEE (23). In this study, five experimental conditions were compared during 2 h of treadmill exercise conducted at 45% VO_{2max} and 35 ℃. 1) GIH with full fluid replacement during exercise (enough to replace sweat losses); 2) WIH with full fluid replacement during exercise; 3) GIH with no fluid intake during exercise; 4) WIH with no fluid intake during exercise and; 5) no PEH with the maintenance of euhydration during exercise. Results of this study showed that conditions 1 and 2 did not decrease heart rate nor rectal temperature during the treadmill runs compared to condition 5. However, condition 5 decreased heart rate and esophageal temperature compared with conditions 3 and 4. The authors concluded that PEH provides no thermoregulatory advantage over the maintenance of euhydration during exercise. The interpretation of these results is problematic given that the conditions which were compared did not represent the typical hydration practices of athletes in the field. In fact, it has long been recognized that endurance athletes do not drink sufficient fluid during exercise to replace sweat losses and finish exercise in a hypohydrated state (24). Yet, the study of Latzka et al. (23) contained three trials where athletes totally replaced their sweat losses during exercise. This understanding renders the results of Latzka et al. (23) of little utility to infer about the physiological effect of PEH in situations where athletes do not fully replace their sweat losses during exercise, which represents the natural behavior of most endurance athletes.

Based on what has just been said, then the question of interest for the field athletes becomes, ‘’Are there any published studies that compared PEE and PEH when athletes do not fully replace their sweat losses during exercise?’’ The answer is yes, and, clearly, the interest of researchers has been centered on how PEH modulates cardiovascular and thermoregulatory function during exercise. During exercises ≥ 45 min, numerous studies have shown that PEH ≥ 1000 ml reduces cardiovascular (↓ heart rate and/or ↑ increase stroke volume) (25,26,27) and thermoregulatory (↓ rectal or esophageal) (25,26,27,28,29) strain compared with PEE, and this, apparently in both a temperate and hot climate. During exercises ≤ 30 min, the effects of PEH on cardiovascular and thermoregulatory functions are unclear, compared with PEE (10,30). This may be due to the length of the exercise period, which is too short to pick up any substantial effect that PEH may have on regulatory functions. The effect of PEH on sweat rate during exercise ≥ 45 min is as of now unclear, with studies showing an increase (25,26) or decrease (29), while no difference has been observed between PEH and PEE in others (23,28). PEH has been shown to improve plasma volume during resting condition, compared with PEE (31). To my knowledge, there is no study that determined whether PEH improves plasma volume over PEE when athletes dehydrate during exercise. Although the effect of PEH on sweat rate regulation during exercise is unclear, that this hydration strategy improves thermoregulatory and cardiovascular functions is quite important as the impairment of these systems has been shown to play a substantial role in the exercise-induced dehydration mediated decrease in EEP (1).

The ability of PEH to reduce cardiovascular and thermoregulatory strain in the above cited studies likely resulted from the fact that, compared with PEE, it attenuated hypohydration (26,28) or completely prevented it (25,27,29). Also, the use of PEH can decrease rectal temperature before exercise (26,27,28,29), which also may contribute in reducing the increase in core temperature during the subsequent exercise period.

Compared with PEE, PEH has been shown to improve cardiovascular and thermoregulatory functions in situations where athletes dehydrate during exercise. An important question that needs to be answered is how much hypohydration is required during PEE before PEH can improve physiological function. Results of Grucza et al. (29), Lyons et al. (25), and Moroff and Bass (26) showed that at a hypohydration level as low as 0.5-1% bodyweight during PEE the beneficial effects of the accrued body water level provided by PEH are already perceptible and significant. Such a level of hypohydration is reached relatively rapidly during prolonged exercise when athletes start an exercise euhydrated, thereby indicating that the beneficial effect of PEH operates relatively early after the start of exercise.

Two conclusions can be drawn about the physiological effects of PEH from what has been said above. First, if with PEE euhydration is maintained during exercise, i.e., athletes drink at a rate sufficient to replace all sweat losses, then using PEH will confer no thermoregulatory and cardiovascular advantages. Second, if with PEE athletes do not totally replace sweat losses during exercise through fluid ingestion, then using PEH in this circumstance should improve thermoregulatory and cardiovascular functions (in both a temperate and hot climate).

Issue 3

On page 381 the Position Stand states that with PEH ''… there is a risk of dilutional hyponatremia.'' In support of this statement they cite a chapter that is within the 2005 ACSM's Advanced Exercise Physiology book (32). The primary cause of hyponatremia is over consumption of fluid during exercise (33). Symptomatic hyponatremia can occur when plasma sodium levels drop rapidly below 130 mmol $\cdot$ L^{-1} (1). Because the use of PEH substantially enhances body water level, the issue of whether PEH can cause symptomatic hyponatremia during the procedure *per se* and the ensuing exercise period is therefore relevant. The question of interest now is ''Are there any scientific data showing that PEH may cause symptomatic hyponatremia?

Evidence indicates that the ingestion of 20-25 ml of water $\cdot$ kg $bodyweight^{-1}$ within 15-150 min does not reduce plasma sodium levels to values < 133 mmol $\cdot$ L^{-1} (12,15,23,31,34,35), thereby suggesting that symptomatic hyponatremia is unlikely to develop during the PEH procedure *per se*. This statement is supported by the fact that there are no studies that reported symptoms of hyponatremia with PEH when quantities of fluid of the order of 1-2 L were administered. The use of PEH is unlikely to cause symptomatic hyponatremia during the subsequent exercise period when athletes are not fully replacing their sweat losses through fluid ingestion. In fact, none of the studies who had subjects exercise after PEH demonstrated sodium levels below 136 mmol $\cdot$ L^{-1} when athletes were losing body water during exercise (12,15,23,25,34). However, as carefully pointed out by the Position Stand on page 384, it is not impossible that when PEH is combined with full fluid replacement during exercise that symptomatic hyponatremia could develop if the exercise period is long enough (23). In any case, athletes should never resort to the use of PEH when their intake of fluid during exercise is sufficient to totally replace sweat losses, as this will cause prolonged fluid overloading. First, prolonged overhydration may cause gastrointestinal distress that may, if severe enough, decrease EEP (36). Second, combining PEH with full fluid replacement during exercise appears to provide no physiological advantage compared with maintaining euhydration during exercise (23). And third, acting this way will confer a peace of mind, as it has been demonstrated on more than one occasion that prolonged fluid overloading is the cause of hyponatremia (33**).**

Two conclusions can be drawn in regards to Issue 3. First, there is no scientific evidence supporting the concept that PEH can cause symptomatic hyponatremia when athletes are not consuming enough liquid during exercise to totally replace their sweat losses. Second, the use of PEH is discouraged when it is intended by an athlete to totally replace sweat losses during exercise.

Issue 4

On page 384 of the Position Stand it is stated that the use of PEH ''… greatly increases the risk of having to void during competition… .'' The authors support this point by citing two papers that evaluated the effect of PEH on urine production during resting conditions, not during exercise (31,35). It is intuitive to believe that because PEH substantially enhances body water level before exercise that a part of this excess fluid would need to be excreted as urine during exercise, thereby forcing the athlete to stop, and as a result, possibly impairing performance in continuous-type sports. However, an important point to bear in mind is that during exercise (especially during intense exercise) and heat-stress renal blood flow and glomerular filtration rate are both markedly reduced, which decreases the ability of the kidneys to excrete any excess volume of water ingested before and/or during exercise. This raises the question: ''Is there any evidence that suggests that PEH would augment the chance of having to urinate during competition (moderate- to high-intensity exercise)? Only one study has compared and documented the effect of PEH and PEE on the production of urine during exercise of moderate intensity or higher. Lyons et al. (25) hyperhydrated (GIH and WIH) subjects before 90 min of running (60% VO_{2max}) in the heat (42℃) and found that at the end of exercise urine production with PEE amounted to 85 ml, compared with 240 ml and 95 ml for the WIH and GIH trials, respectively.

Interestingly, a study (37) can be found in the literature which documented that Alberto Salazar, winner of three New York City Marathons and one Boston Marathon, hyperhydrated with 1000 ml of water immediately before the start of the 1984 Olympic marathon. Salazar ran the marathon at an average intensity of ~ 85% VO_{2max} and at an ambient temperature of ~ 24-28 °C. He finished in 15th position overall. Although no mention was made about it in the article, it is more than reasonable to assume that he did not have to stop to urinate during the race.

Although not an ideal experimental design to provide an answer to the question of whether or not PEH may increase the chance of voiding during competition, the study of Wingo et al. (18) nevertheless offers interesting insights. This study compared the effect of three hydration regimens on EEP during a mountain-bike race (mean intensity of ~81% of maximal heart rate) in the heat (30-31°C). During the non-fluid trial (NFT), athletes hyperhydrated with 2300 ml of water before the race while consuming no fluid during exercise. In the fluid trials, athletes first hyperhydrated with 2300 ml of water alone (FTW) or with water + glycerol (FTG) and then drank ~ 2300 ml of water during exercise. Despite no difference in overall finishing time among trials, and although during FTG and FTW total consumption of fluid was twice that observed during NFT, there was no difference in urine production between NFT and FTW, whereas urine production was significantly lower with FTG than with NFT and FTW. If PEH would greatly increase the chance to void during competition, then theoretically urine output during FTG and FTW should have been greater than with NFT. However, it must be made clear that when exercise intensity and/or heat-stress is not important that the use of PEH (WIH and GIH) is very likely to increase the chance of having to urinate during exercise (23). This is an important factor to take into account when using PEH during low heat-stress or exercise intensity situations.

Thus, from what has just been reported above, there are no data in the literature yet suggesting that PEH greatly augments the chance to void during competition, especially if glycerol is present in the hyperhydration drink. However, further studies on the topic are needed before more definitive conclusions can be drawn. Of importance, nevertheless, is that the chances of having to void during exercise increase as the exercise intensity and/or ambient temperature becomes lower.

HYPERHYDRATION-RELATED UNTOWARD EFFECTS

An issue not addressed by the Position Stand, but that is highly relevant for athletes, is whether the use of PEH is associated with unwanted side-effects that may impair EEP. Most studies that have observed the possible side-effects associated with PEH are those comparing the effects of GIH to those of WIH on fluid retention and/or EEP. Collectively, they demonstrate that PEH is associated with a very low prevalence of side-effects (< 10%) (Eric Goulet, unpublished observations). Undesirable effects were observed only during the PEH periods; none were reported during the exercise periods. The nature of the experienced problems was gastro-intestinal discomfort (13,25), nausea (4,23) and vomiting (4). It is noteworthy to point out that nausea and vomiting were reported only when glycerol was present in the solution and not when water alone was consumed. Therefore, it appears not to be the hyperhydration (volume effect) procedure *per se* that is responsible for the side-effects, but rather the foreign substances that may be added into the mix. Or alternately, it may be because the studies (4,23) where nausea and vomiting were observed administered a very concentrated glycerol solution first followed by the bolus of water a couple of minutes later. For minimizing the incidence of side-effects during GIH it is recommended to dilute the quantity of glycerol in the total quantity of fluid to be ingested. Finally, it is also important to mention that the feeling of gastro-intestinal discomfort lasts for about only 15 min after the end of fluid ingestion (25).

WHEN TO USE PEH?

It has been reported in the Position Stand on exercise and fluid replacement that exercise-induced dehydration starts to impair EEP at a body mass loss > 2% (1). Hence, in real-world conditions, athletes should only be encouraged to use PEH when it would be impossible for them to prevent a loss of body mass > 2% through voluntary fluid intake during exercise.

CONCLUSIONS

This paper demonstrated that PEH apparently has more advantages than disadvantages. In fact, it was demonstrated that PEH improves EEP compared with PEE, at least during short-term exercise in the heat; that GIH improves EEP during long-term exercise in a temperate and hot climate compared with WIH; and that, based on a very reasonable assumption, GIH likely has the capability of improving EEP compared with PEE, although this still has to be demonstrated scientifically. Results were presented demonstrating that compared with PEE, PEH improves thermoregulatory and cardiovascular functions during exercise ≥ 45 min when athletes do not fully replace their sweat losses during exercise. There is no evidence in the literature suggesting that PEH can increase the risk of dilutional hyponatremia when the body is dehydrating during exercise, or that PEH greatly augments the risk of having to void during competition (i.e., during moderate- to high-intensity exercise), especially if glycerol is present in the hyperhydration solution. Importantly, the use of PEH is associated with a very low prevalence of side-effects, making it a relatively safe hydration strategy. Individuals are encouraged to use PEH only when it will be impossible for them to prevent a loss of bodyweight > 2% through voluntary intake of fluid during exercise. It is obvious that there is a lack of studies comparing the effectiveness of PEH and PEE on EEP; researchers are therefore encouraged to pursue such studies so that in the near future a good picture of its ergogenic effect can be presented to the public. For increasing the ability to generalize results, future studies on PEH should provide fluid during exercise at a rate replicating that of athletes during out-of-doors exercise.

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REFERENCES

1. Sawka MN, Burke LM, Randy Eichner, E, Maughan RJ, Montain SJ and Stachenfeld NS. American College of Sports Medicine Position Stand. Exercise and fluid replacement. ***Med Sci Sports Exerc*** 2007;39:377-390.

2. Greenleaf JE, Looft-Wilson R, Wisherd JL, McKenzie MA, Jensen CD and Whittam JH. Pre-exercise hypervolemia and cycle ergometer endurance in men. ***Biol. Sport*** 1997;14:103-114.

3. Kavouras SA, Armstrong LE, Maresh CM, Casa DJ, Herrera-Soto JA, Scheett TP, Stoppani J, Mack GW and Kraemer WJ. Rehydration with glycerol: endocrine, cardiovascular, and thermoregulatory responses during exercise in the heat. ***J Appl Physiol*** 2006;100:442-450.

4. Latzka WA, Sawka MN, Montain SJ, Skrinar GS, Fielding RA, Matott RP and Pandolf KB. Hyperhydration: tolerance and cardiovascular effects during uncompensable exercise-heat stress. ***J Appl Physiol*** 1998;84:1858-1864.
5. Potteiger JA, Nickel GL, Webster MJ, Haub MD and Palmer RJ. Sodium citrate ingestion enhances 30 km cycling performance. ***Int J Sports Med*** 1996;17:7-11.
6. Shave R, Whyte G, Siemann A and Doggart L. The effects of sodium citrate ingestion on 3,000-meter time-trial performance. ***J Strength Cond Res*** 2001;15:230-234.
7. Oöpik V, Saaremets I, Medijainen L, Karelson K, Janson T and Timpmann S. Effects of sodium citrate ingestion before exercise on endurance performance in well trained college runners. ***Br J Sports Med*** 2003;37:485-489.
8. Schabort EJ, Wilson G and Noakes TD. Dose-related elevations in venous pH with citrate ingestion do not alter 40-km cycling time-trial performance. ***Eur J Appl Physiol*** 2000;83:320-327.
9. Potteiger JA, Webster MJ, Nickel GL, Haub MD and Palmer RJ. The effects of buffer ingestion on metabolic factors related to distance running performance. ***Eur J Appl Physiol Occup Physiol*** 1996;72:365-371.
10. Blyth CS and Burt JJ. Effect of water balance on ability to perform in high ambient temperatures. ***Res Quart*** 1961;32:301-307.
11. Latzka WA and Sawka MN. Hyperhydration and glycerol: thermoregulatory effects during exercise in hot climates. ***Can J Appl Physiol*** 2000;25:536-545.
12. Anderson MJ, Cotter JD, Garnham AP, Casley DJ and Febbraio MA. Effect of glycerol-induced hyperhydration on thermoregulation and metabolism during exercise in heat. ***Int J Sport Nutr Exerc Metab*** 2001;11:315-333.
13. Coutts A, Reaburn P, Mummery K and Holmes M. The effect of glycerol hyperhydration on olympic distance triathlon performance in high ambient temperatures. ***Int J Sport Nutr Exerc Metab*** 2002;12:105-119.
14. Goulet ED, Robergs RA, Labrecque S, Royer D and Dionne IJ. Effect of glycerol-induced hyperhydration on thermoregulatory and cardiovascular functions and endurance performance during prolonged cycling in a 25 degrees C environment. ***Appl Physiol Nutr Metab*** 2006;31:101-109.
15. Hitchins S, Martin DT, Burke L, Yates K, Fallon K, Hahn A and Dobson GP. Glycerol hyperhydration improves cycle time trial performance in hot humid conditions. ***Eur J Appl Physiol Occup Physiol*** 1999;80:494-501.
16. Marino FE, Kay D and Cannon J. Glycerol hyperhydration fails to improve endurance performance and thermoregulation in humans in a warm humid environment. ***Pflugers Arch*** 2003;446:455-462.
17. Montner P, Stark DM, Riedesel ML, Murata G, Robergs R, Timms M and Chick TW. Pre-exercise glycerol hydration improves cycling endurance time. ***Int J Sports Med*** 1996;17:27-33.
18. Wingo JE, Casa DJ, Berger EM, Dellis WO, Knight JC and McClung JM. Influence of a pre-exercise glycerol hydration beverage on performance and physiologic function during mountain-bike races in the heat**.** ***J Athl Train*** 2004;39:169-175.
19. Goulet EDB, Aubertin-Leheudre M, Plante GE and Dionne IJ. A meta-analysis of the effects of glycerol-induced hyperhydration on fluid retention and endurance performance. ***Int J Sport Nutr Exerc Metab*** 2007;17:391-410.
20. Massicotte D, Scotto A, Peronnet F, M'kaouar H, Milot M and Lavoie, C. Metabolic fate of a large amount of (13)C-glycerol ingested during prolonged exercise. ***Eur J Appl Physiol*** 2006;96:322-329.
21. Miller JM, Coyle EF, Sherman WM, Hagberg JM, Costill DL, Fink, WJ, Terblanche, SE and Holloszy, JO. Effect of glycerol feeding on endurance and metabolism during prolonged exercise in man. ***Med Sci Sports Exerc*** 1983;15:237-242.
22. Gleeson M, Maughan RJ and Greenhaff PL. Comparison of the effects of pre-exercise feeding of glucose, glycerol and placebo on endurance and fuel homeostasis in man. ***Eur J Appl Physiol Occup Physiol*** 1986;55:645-653.

23. Latzka WA, Sawka MN, Montain SJ, Skrinar GS, Fielding RA, Matott RP and Pandolf KB. Hyperhydration: thermoregulatory effects during compensable exercise-heat stress. ***J Appl Physiol*** 1997;83:860-866.
24. Noakes TD. Fluid replacement during exercise. ***Exerc Sport Sci Rev*** 1993;21:297-330.
25. Lyons TP, Riedesel ML, Meuli LE and Chick TW. Effects of glycerol-induced hyperhydration prior to exercise in the heat on sweating and core temperature. ***Med Sci Sports Exerc*** 1990;22:477-483.
26. Moroff SV and Bass DE. Effects of overhydration on man's physiological responses to work in the heat. ***J Appl Physiol*** 1965;20:267-270.
27. Nielsen B, Hansen G, Jorgensen SO and Nielsen E. Thermoregulation in exercising man during dehydration and hyperhydration with water and saline. **Int J Biometeorol** 1971;15:195-200.
28. Gisolfi CV and Copping JR. Thermal effects of prolonged treadmill exercise in the heat. ***Med Sci Sports*** 1974;6:108-113.
29. Grucza R, Szczypaczewska M and Kozlowski S. Thermoregulation in hyperhydrated men during physical exercise. ***Eur J Appl Physiol Occup Physiol*** 1987;56:603-607.
30. Nadel ER, Fortney SM and Wenger CB. Effect of hydration state of circulatory and thermal regulations. ***J Appl Physiol*** 1980;49:715-721.
31. Freund BJ, Montain SJ, Young AJ, Sawka MN, DeLuca JP, Pandolf KB and Valeri CR. Glycerol hyperhydration: hormonal, renal, and vascular fluid responses. ***J Appl Physiol*** 1995;79:2069-2077.
32. Zambraski EJ. ***The renal System: In: ACSM's Advanced Exercise Physiology***. Baltimore, MD: Lippincott, Williams & Wilkins, pp. 521-532, 2005.
33. Noakes TD and Speedy DB. Case proven: exercise associated hyponatraemia is due to overdrinking. So why did it take 20 years before the original evidence was accepted? ***Br J Sports Med*** 2006;40:567-572.
34. Magal M, Webster MJ, Sistrunk LE, Whitehead MT, Evans RK and Boyd JC. Comparison of glycerol and water hydration regimens on tennis-related performance. ***Med Sci Sports Exerc*** 2003;35:150-156.
35. O'Brien C, Freund BJ, Young AJ and Sawka MN. Glycerol hyperhydration: physiological responses during cold-air exposure. ***J Appl Physiol*** 2005;99:515-521.
36. Robinson TA, Hawley JA, Palmer GS, Wilson GR, Gray DA, Noakes TD and Dennis SC. Water ingestion does not improve 1-h cycling performance in moderate ambient temperatures. ***Eur J Appl Physiol Occup Physiol*** 1995;71:153-160.
37. Armstrong LE, Hubbard RW, Jones BH and Daniels JJ. Preparing Alberto Salazar for the heat of the 1984 Olympic marathon. ***Physician Sportsmed*** 1986;14:73-81.