

Effect of Overhydration on Time-Trial Swim Performance

CARL M. MARESH,^{1,2,3} MICHAEL E. BERGERON,¹ ROBERT W. KENEFFICK,¹
JOHN W. CASTELLANI,¹ JAY R. HOFFMAN,¹ AND
LAWRENCE E. ARMSTRONG^{1,2,3}

The Human Performance Laboratory, ¹Department of Kinesiology, ²Department of Physiology and Neurobiology, and ³Department of Nutritional Sciences, University of Connecticut, Storrs, Connecticut 06269.

ABSTRACT

The effect of hydration status on performance has not been adequately emphasized or examined in swimmers. Theoretically, moderate overhydration might reduce the proportionate fluid loss from the circulation during exercise of this nature. To explore this issue, 11 (5 women, 6 men) collegiate swimmers swam 2 183-m (200-yd) time trials (3 days apart) in alternate, randomized euhydrated (EUH) and overhydrated (OH) states. Pre-exercise plasma osmolality (EUH: 288.5 ± 2.5 and OH: 284.6 ± 3.3 mOsmol·kg⁻¹; $p < 0.001$), urine specific gravity (EUH: 1.022 ± 0.003 and OH: 1.012 ± 0.003 ; $p < 0.001$), and body weight (EUH: 72.1 ± 9.3 and OH: 72.6 ± 9.2 kg; $p < 0.01$) values distinguished the two hydration states of the swimmers. There was no difference ($p > 0.05$) between hydration states in postexercise plasma osmolality (EUH: 312.8 ± 4.8 and OH: 307.2 ± 9.9 mOsmol·kg⁻¹), plasma volume (EUH: -16.5 ± 10.0 and OH: -17.7 ± 6.8 %Δ), plasma lactate (EUH: 18.6 ± 3.6 and OH: 17.8 ± 3.4 mmol·l⁻¹), heart rate (EUH: 167 ± 11 and OH: 166 ± 16 beats·min⁻¹), or perceived exertion (EUH: 16 ± 1 and OH: 16 ± 2) responses. Although performance time improved for 7 of the 11 swimmers during OH, there was not a statistically significant difference between the EUH (121.2 ± 8.1 seconds) and OH (120.8 ± 7.7 seconds) conditions. However, there was a modest bivariate correlation ($r = -0.602$; $p < 0.05$) between the change in body weight and change in performance time in going from the EUH to OH trials. These data demonstrated that overhydration provided no performance advantage for this group during a 183-m time-trial swim but emphasized the importance of adequate hydration in swim performance.

Key Words: plasma osmolality, plasma volume, urine specific gravity

Reference Data: Maresh, C.M., M.F. Bergeron, R.W. Kenefick; J.W. Castellani, J.R. Hoffman, and L.E. Armstrong. Effect of overhydration on time-trial swim performance. *J. Strength Cond. Res.* 15(4):514–518. 2001.

Introduction

Very limited published information is available on (a) the hydration status of swimmers during the

course of normal training and competition, or (b) the influence of hydration status on swim performance. In previous work with our own collegiate swim team we found that most of these athletes consumed inadequate fluid (frequently less than 0.24 L·day⁻¹) during their training and competitive seasons (unpublished observation). As a result, many of them often trained and competed in a relative state of dehydration. That discovery was of real concern to us because research on other exercise activities (e.g., running and cycling) has consistently demonstrated decrements in maximal aerobic power, physical work capacity, and performance when subjects were acutely hypohydrated vs. euhydrated (EUH) (15). One reason may be that with a decrease in plasma volume (as a consequence of acute hypohydration), cardiac output is compromised during maximal exercise (15). This could be an important concern for trained swimmers because their cardiac output can be quite high (e.g., >30.0 L·min⁻¹) during maximal-effort swimming (4, 7, 8), and intense swimming exercise has been shown to yield a large shift of fluid out of the vasculature (5, 11). Consultations with our swim coaches and athletes sensitized them to the importance of adequate hydration. Consequently, most of the athletes increased their daily fluid intake and were efficient at maintaining a state of EUH.

Having been successful in improving the day-to-day hydration status of our collegiate swimmers, we were interested in examining if a moderate state of overhydration (OH) might improve swim performance compared with swim performance in an EUH state. Given the large reductions in plasma volume previously observed with maximal, short-duration swimming (5, 11), we reasoned that a state of OH might reduce the proportionate fluid shift from the circulation (as indicated by a smaller relative reduction in plasma volume) during exercise of this nature. Theoretically, this could help to maintain cardiac output and improve performance. Thus, this study was de-

signed to determine if moderate OH would enhance the performance of otherwise EUH collegiate swimmers during a 183-m (200-yd) time-trial swim. This distance was used because it requires high-intensity performance and approximates a training interval and competitive distance familiar to most collegiate swimmers.

Methods

Subjects

Eleven (5 women, 6 men) division I collegiate swimmers volunteered as subjects for this study. Each subject gave written informed consent to participate in the test protocol, which was approved by the Institutional Review Board for Studies Involving Human Subjects. Subject characteristics were as follows: age, 19.1 ± 1.3 years; height, 173.8 ± 5.2 cm; weight, 72.1 ± 9.0 kg; body fat, 17.6 ± 1.5 %. The body weight values were averages of routine measures obtained during a 2-week baseline period. Both male and female swimmers comprised the study group and each subject served as his/her own control.

Baseline Measurements

Each subject was monitored during a 2-week period to obtain subject characteristics including body weight, typical daily fluid intake volume, and baseline urine specific gravity and plasma osmolality values. Body density (12) was measured 1 time for each subject before a selected afternoon workout, from which percentage of body fat was calculated (9). Before morning training sessions (0600 hours) and breakfast each subject provided a urine sample into a clean, inert plastic cup for urine specific gravity measurements. Also at that time, venous blood samples were obtained for measurement of plasma osmolality. Average fluid intake volume was determined from daily records maintained by each subject.

Experimental Design

On two occasions (randomly assigned, 3 days apart) each subject swam a 183-m (200-yd) freestyle time-trial. Water temperature was 26° C on both occasions. Testing occurred 2–3 weeks before the start of the competitive season. The subjects' average daily fluid intake, as determined from daily records, was 2.1 L. For the first time trial, 6 randomly selected swimmers consumed 1.9 additional liters of water during each of the 2 days before the time-trial swim to achieve an OH state. This amount was chosen to provide an approximate doubling of daily fluid intake, while utilizing a convenient, commercial water container. The other 5 swimmers maintained EUH by their normal fluid intake. For the second time trial, the preswim fluid consumption guidelines were reversed for the 2 groups of swimmers. Subjects were instructed to consume the extra water throughout each day and were requested

to refrain from alcohol during the time-trial week and from caffeine on both time-trial days. Subjects also were instructed to maintain consistent diets and activity levels during the entire time-trial week. Additionally, the subjects refrained from food and fluid consumption for 2 hours before each time-trial session. Performance time and selected hydration, metabolic, and perceptual indicators were monitored for the OH and EUH trials.

Time-Trial Swims

Upon arrival at the pool (1530 hours) for each time-trial swim, each subject first provided a urine sample into a clean, inert plastic cup for urine specific gravity measurements. Each subject was then weighed (to the nearest 0.1 kg) in his/her swimsuit. After 15 min in a supine posture for equilibration, a 4-ml blood sample was taken from a superficial forearm vein (pre-exercise sample). The swimmers maintained direct pressure on the blood withdrawal site with gauze for 7 minutes to ensure adequate clotting and vein closure. All subjects then stretched and completed, in a staggered fashion, a standardized 731.52-m (800-yd) warm-up. Within 5 minutes of completing their respective warm-up, groups of 3 or 4 subjects performed the 183-m time-trial swim. Swimmers started the time-trial from platform positions, in response to an electronically sounded horn, and swam freestyle in adjacent center lanes only. During both time-trials all swimmers were verbally encouraged by their coaches, other swimmers, and the research team to provide a maximal swimming effort. Experienced timers using separate handheld stopwatches for each lane measured time-trial performance. Immediately after the swim each subject was quickly assisted from the pool directly to a supine posture. A second 4-ml blood sample was taken from a superficial forearm vein within 1 min (typically under 30 s) of completing the time-trial swim (postexercise sample). While each subject was prepared for blood withdrawal, the subject's heart rate was taken by carotid artery palpation, and a rating of perceived exertion (2) was obtained.

Blood Sampling and Biochemical Analyses

All blood samples were taken while the subjects were supine. Blood was obtained with a needle (20-gauge, 3.8 cm) and plastic syringe, and immediately transferred to sodium-heparin blood collection tubes. An aliquot of the heparinized blood was used for immediate hematocrit and hemoglobin measurements. The remaining blood was centrifuged at $1,800g$ and 2° C for 15 minutes. The separated plasma was equally distributed into 1.5-ml plastic microcentrifuge tubes for prompt lactate and osmolality analyses.

Hematocrit was measured in triplicate using the microcapillary technique after sample centrifugation at $9,500g$ for 5 minutes. Hemoglobin was measured in

Table 1. Selected pre-exercise and postexercise data (mean \pm SD; $n = 11$).

	Euhydrated		Overhydrated	
	Pre	Post	Pre	Post
Body weight (kg)	72.1 \pm 9.3		72.6** \pm 9.2	
Plasma osmolality (mOsmol·kg ⁻¹)	288.5 \pm 2.5	312.8* \pm 4.8	284.6** \pm 3.3	307.2* \pm 9.9
Urine specific gravity	1.022 \pm 0.003		1.012** \pm 0.003	
Δ PV (%)		-16.5 \pm 10.0		-17.7 \pm 6.8
Plasma lactate (mmol·l ⁻¹)	1.5 \pm 0.5	18.6* \pm 3.6	1.8 \pm 0.7	17.8* \pm 3.4
Heart rate (beats·min ⁻¹)		167 \pm 11		166 \pm 16
Rating of perceived exertion		16 \pm 1		16 \pm 2

* Significantly different than corresponding pre value; ** significantly different than corresponding euhydrated value.

duplicate with a reflectance photometer (Reflotron, Boehringer Mannheim Diagnostics, Indianapolis, IN). Percentage changes in plasma volume were calculated from hematocrit and hemoglobin values (3). Plasma samples were analyzed in duplicate for lactate (Yellow Spring Instrument Co., model 2300 GL, Yellow Springs, OH). Plasma osmolality was measured in duplicate by the freezing point depression technique with a high-precision osmometer (Advanced Instruments, model 3R, Needham Heights, MA). Urine specific gravity was measured in duplicate with a hand-held refractometer (Spartan Refractometer, model A 300 CL, Japan).

Statistical Analyses

Data were analyzed with a 2-way analysis of variance (condition \times time) or paired *t*-tests where appropriate. Selected bivariate correlations were determined from Pearson product moment correlation coefficients. The 0.05 level of significance was selected for this study. Data are presented as the mean \pm SD.

Results

Pre-exercise body weight, plasma osmolality, and urine specific gravity values distinguished the hydration status (EUH and OH states) of the swimmers (Table 1). The pre-exercise values for EUH were similar ($p > 0.05$) to the baseline values determined over the 2-week period before time-trial testing. Achievement of satisfactory OH was operationally validated by the relative and significant differences in pre-exercise plasma osmolality and urine specific gravity (1), even though all values were in a clinically normal range (13). Additionally, subjects exhibited a pre-exercise increase in resting plasma volume (+7.2%, with a 95% confidence interval of -0.3 to 14.8%) in OH, compared with EUH.

The performance times for the 183-m time trials in the EUH (121.2 \pm 8.1 seconds) and OH (120.8 \pm 7.7 seconds) conditions were not significantly different. Interestingly, however, there was a significant, al-

beit modest, bivariate correlation ($r = -0.602$) between the change in body weight (0.47 \pm 0.47 kg) and change in performance time (-0.37 \pm 1.89 seconds) in going from the EUH to OH trial. There were no differences in postexercise plasma osmolality, plasma volume, plasma lactate, heart rate, or perceived exertion responses (Table 1) between the 2 hydration states.

Discussion

The present study examined performance and selected physiological responses to a 183-m time trial performed by collegiate swimmers in alternate EUH and OH states. To date, limited research has examined pre-exercise hydration status as it relates to swimming performance. This fact and the minimal daily fluid intake observed in our previous work with collegiate swimmers (unpublished observation) may share a common rationale. Swimmers train and compete in water, an environment that does not readily prompt concerns about body fluid demands and losses. Furthermore, it is important to note that water immersion has been associated with a reduction in voluntary water intake under conditions of hypohydration (14).

When comparing time-trial performances of competitive swimmers within a short period of time, differences are likely to be relatively small if efforts are truly maximal during both trials. Yet, in high-level competitive swimming small improvements in performance may be critical to success. It was our opinion, and that of the coaches, that the swimmers in the present study provided "all-out" efforts during both trials. As an example, for those swimmers who routinely competed in the 200-yd freestyle event, their time-trial and competitive meet times were quite comparable.

Competitive swimmers routinely precede all-out efforts with a warm-up period, and that occurred in the present study. In this regard, it is important to

consider that the warm-up could have interacted with the subject's hydration state, and served to compromise the effects of the hydration state on the respective time trials. The postexercise measures of plasma lactate, heart rate, and perceived exertion suggest that the physiological demands of the 183-m time trials were similar between the 2 states of hydration.

During short-distance swimming there is a large fluid shift from the vasculature (5, 11). This exercise response is likely due to an increase in capillary hydrostatic pressure, coupled with a concomitant increase in tissue osmotic pressure owing to the augmented muscle metabolism; such a cooperative influence favors net filtration of fluid from the blood (6, 10, 17). Therefore, we hypothesized that an increase in plasma volume consequent to OH might help to maintain cardiac output, thereby improving 183-m time-trial performance. Although hyperhydration has not previously been shown to improve exercise performance, especially when there is no heat problem and where performance is brief (16), the efficacy of hyperhydration or OH has not been examined with respect to swim performance.

Contrary to our hypothesis, the pre-exercise increase in plasma volume (7.2%) was not associated with improved performance times during the OH time-trial. In fact, the similar between-trial postexercise changes in plasma volume (approximately 17.0%), along with the similar postexercise plasma osmolality values, indicated that a higher absolute amount of fluid shifted from the vasculature to the interstitial and intracellular compartments during the OH (vs. EUH) time trial. Thus, cardiac output likely was not increased because of the moderate level of OH imposed in this study. Future studies should choose a time trial of longer duration that would rely to a greater extent on sustained cardiac output. Another obvious factor is the reality that an OH individual will eventually excrete the excess volume. However, the significantly greater pre-exercise body weight in the OH time trial suggests that these swimmers did possess a greater fluid volume at that time. We further suggest that future studies designed to examine the influence of hydration status on swim performance should focus on comparisons between hypohydration and EUH or between hypohydration and hyperhydration. Also, a greater level of OH should be examined. This likely would require glycerol-induced OH.

In conclusion, moderate OH achieved by consuming 1.9 L of water in addition to one's daily fluid intake during each of the 2 days before the 183-m time-trial swim provided no apparent performance advantage over EUH for this group of athletes.

Practical Applications

As in most sporting events, hydration status is an important performance-determining factor in competitive swimming. The results of the present study suggest that EUH before an intense short-duration swim is likely adequate for peak performance. Importantly, we also suspect that the poor hydration habits and, thus, diminished hydration status previously observed in collegiate swimmers by our laboratory, are not unique. This suggests that swimming coaches should encourage their athletes to regularly drink plenty of water or other appropriate hydration beverages. To ensure that their swimmers are not training and competing while dehydrated, coaches may want to track each swimmer's daily fluid intake and periodically check preswim urine specific gravity or urine color in accordance with recommended guidelines (1).

References

1. ARMSTRONG, L.E., J.A. HERRERA-SOTO, F.T. HACKER, D.J. CASA, S.A. KAVOURAS, AND C.M. MARESH. Urinary indices during dehydration, exercise, and rehydration. *Int. J. Sport Nutr.* 8:345-355. 1998.
2. BORG, G.V. *Physical Performance and Perceived Exertion*. Lund, Sweden: Gleerup, 1962.
3. DILL, D.B., AND D.L. COSTILL. Calculation of percentage change in volumes of blood, plasma, and red cells in dehydration. *J. Appl. Physiol.* 37:247-248. 1974.
4. DIXON, R.W., JR., AND J.A. FAULKNER. Cardiac outputs during maximum effort. *J. Appl. Physiol.* 30:653-656. 1971.
5. GOODMAN, C., G.G. ROGERS, H. VERMAAK, AND M.R. GOODMAN. Biochemical responses during recovery from maximal and submaximal swimming exercise. *Eur. J. Appl. Physiol.* 54: 436-441. 1985.
6. HARRISON, M.H. Effects of thermal stress and exercise on blood volume in humans. *Physiol. Rev.* 65:149-209. 1985.
7. HEIGENHAUSER, G.J.F., AND J.A. FAULKNER. Estimation of cardiac output by the CO₂ rebreathing method during tethered swimming. *J. Appl. Physiol.* 44:821-824. 1978.
8. HOLMER, I. Cardiorespiratory adjustments to swimming. In: *Proceedings—International Congress on Physical Activity Sciences*. Quebec City, 1976. pp. 45-60.
9. LAMB, D.R. *Physiology of Exercise: Responses and Adaptations* (2nd ed.). New York: Macmillan, 1984.
10. LUNDVALL, J., S. MELLANDER, H. WESTLING, AND T. WHITE. Fluid transfer between blood and tissues during exercise. *Acta Physiol. Scand.* 85:258-269. 1972.
11. MARESH, C.M., L.E. ARMSTRONG, M.F. BERGERON, C.L. GABAREE, J.R. HOFFMAN, D.R. HANNON, AND A.A. PASQUALICCHIO. Plasma cortisol and testosterone responses during a collegiate swim season. *J. Strength Cond. Res.* 8:1-4. 1994.
12. POLLOCK, M.L., D.H. SCHMIDT, AND A.S. JACKSON. Measurement of cardiorespiratory fitness and body composition in the clinical setting. *Compr. Ther.* 6:12-17. 1980.
13. ROCK, R.C., W.G. WALKER, AND C.D. JENNINGS. Nitrogen metabolites and renal function. In: *Fundamentals of Clinical Chemistry* (3rd ed.). N.W. Tietz, ed. Philadelphia: Saunders, 1987. pp. 669-704.
14. SAGAWA, S., K. MIKI, F. TAJIMA, H. TANAKA, J.K. CHOI, L.C. KEIL, K. SHIRAKI, AND J.E. GREENLEAF. Effect of dehydration on thirst and drinking during immersion in men. *J. Appl. Physiol.* 72:128-134. 1992.

15. SAWKA, M.N. Physiological consequences of hypohydration: exercise performance and thermoregulation. *Med. Sci. Sports Exerc.* 24:657-670. 1992.
16. SAWKA, M.N., S.J. MONTAINE, AND W.A. LATZKA. Body fluid balance during exercise-heat exposure. In: *Body Fluid Balance*. E.R. Buskirk and S.M. Puhl, eds. Boca Raton, FL: CRC Press, 1996. pp. 139-157.
17. SENAY, JR., L.C., AND J.M. PIVARNIK. Fluid shifts during exercise. In: *Exercise and Sport Science Reviews (Volume 13)*. R.L. Terjung, ed. New York: Macmillan, 1985. pp. 335-387.

Acknowledgments

We thank coaches Robert Goldberg and Peter Solomen, and the participating swimmers from the University of Connecticut. We also thank Catherine Gabaree, Tamara Morocco, Michael Whittlesey, Angela Pasqualicchio, Marcos Echegaray, and Andy Judelson for their assistance with the data collection.