Effects of Fluid Ingestion During Intermittent High Intensity Swimming Exercise on Thermoregulatory Responses and Performance

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Abstract: High intensity exercise in the heat causes major alterations in the circulatory and thermoregulatory functions resulting in reduced athletic performance. We investigated whether fluid ingestion during intermittent high intensity swimming exercise in warm water can mitigate adverse thermoregulatory and cardiovascular responses, and improve athletic performance. To do this, eight male college swimmers aged 22.8 ± 1.0 yr, body weight 66.72 ± 1.63 kg and height 171.7 ± 0.7 cm were used. In a cross-over design, all eight subjects performed 20 sessions of intermittent 50 m swims with a 1 min interval between each session when they were water replete (WR) or water deprived (WD). Oral temperature (To), heart rate (HR), plasma osmolarity (Posm), sweat water loss (SWL) and rating of perceived exertion (RPE) as well as swimming velocities (SV) were measured. No difference were observed in To, HR, SWL, and Posm between WR and WD conditions. However, WR maintained higher SV and lower RPE. In a second experiment involving a second set of college swimmers, a strong positive correlation was observed between SV and SWL ($r = 0.881$, $p < 0.05$). These findings reveal that during short duration high intensity intermittent swimming exercise lasting $\sim$ 12 mins, fluid intake did not influence cardiovascular and thermoregulatory responses, but improved athletic performance.

Key words: Fluid ingestion, Thermoregulation, Swimming, Osmoregulation, Hyperthermia.

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INTRODUCTION

Exercise patterns involving the performance of intermittent work having bursts of high-intensity, punctuated with intervals of rest are associated with high rates of metabolic heat production, significant loss of body water and hyperthermia (Burke and Hawley, 1997; Maughan and Leiper, 1994). Athletes involved in these activities can lose up to 3 L of fluid per hour (Horswill, 1998) and, as a consequence, a reduction in exercise performance results (Maughan and Leiper, 1994). Hyperthermia appears to be the critical determinant of exercise performance in the heat (Burke and Hawley, 1997; Hargreaves and Febbraio, 1998) and, furthermore, the increased evaporative water loss required to offload exercise metabolic heat is a major factor in reducing cardiovascular filling.

In order to prevent dehydration and its adverse effects, fluid replacement is practiced to maintain hydration and allow athletes to perform optimally (Horswill, 1998). Investigations involving exercise dehydrations in athletes on land suggested that adequate hydration prior to exercise and ingestion of fluids during exercise delayed fatigue, blunted body temperature rise and improved athletic performance (Gisolfi and Duchman, 1992 ; Hargreaves and Febbraio, 1998 ; Maughan and Noakes, 1991 ; Millard-Stafford *et al.,* 1992). Comparative studies involving swimmers are scanty or lacking. Our previous investigations which examined the effect of fluid ingestion on thermoregulation in swimmers centered on sweat water loss (Taimura and Sugahara, 1994 ; Taimura *et al.,* 1995).

We now compared the thermoregulatory and cardiovascular responses as well as exercise performance in water replete and water deprived college swimmers. The data could constitute a basis for strategies that can be implemented to minimize the impact of metabolic heat on high intensity swimmers.

MATERIALS AND METHODS

Experimental subjects

Two sets of experiments were performed. In the first set of the experiment which investigated the effect of fluid ingestion on thermoregulation and exercise performance, subjects were eight male college swimmers (CS I) aged 22.8±1.0 yr, body weight 66.72±1.63 kg, height 171.7±0.7 cm and percentage body fat 15.9±1.63 %. Their average competitive experience was 9.3±1.5 years. In a second set of experiments which investigated the correlation between swimming velocity and sweat water loss as well as body temperature, 6 male college swimmers (CS II), 24.2±1.2 years old, 171.8±2.2 cm in height and 69.70±5.04 kg in weight were used. All the subjects trained regularly for 2–3 hours a day, 5–7 times in a week. They were informed of the aims, risks, and benefits of this investigation both verbally and in writing prior to signing an informed consent document.

Experimental protocol/measurements

In a cross-over design, the subjects used in the investigation of the effect of fluid ingestion on thermoregulation and exercise performance (CS I) performed 20 sessions of intermittent 50 m swims with a 1 min interval between each session when they were water replete (WR) or water deprived (WD). Firstly, one group of four subject were maintained on *ad libitum* 15 ℃ water ingestion for water repletion (WR) before and during the exercise bouts, while the other group of four subject was water deprived (WD). After an interval of 3 days the same two groups of subject repeated the same exercise sessions, while the water repletion and deprivation treatment were reversed.

Pool water temperature was measured every 30 min during swimming exercise and the mean (29.95±0.05 ℃) was taken as the exposure temperature. Mean ambient temperature where the pool was situated was 31.18±0.31 ℃.

Oral temperature (To), heart rate (HR), sweat water loss (SWL), plasma osmolarity (Posm), rating of perceived exertion (RPE) and mean swimming time were measured, before and after the 20 swimming sessions. Blood samples were also taken and used for the determination of plasma volume. To was measured using a clinical thermometer C102 (TERUMO Co. Ltd., Japan). HR was measured by palpation. Changes in plasma volumes were assessed as routinely done, from the changes in haematocrit and haemoglobin, details of which are available from Dill and Costill (1974). Posm was measured by freezing-point depression (OM-6030 KDK Corp., Japan). SWL was determined gravimetrically by weighing each subject before and after the 20 swimming sessions (Digital Scale UC-300 A&D Co. Ltd., Japan). Blood lactate concentrations were measured by ACCUSPORT (Boehringer Mannheim, Germany). Water for ingestion was contained in a graduated water bottle. Water ingested was measured each time a subject had taken water by weighing the water bottle. Total water ingested was calculated at the end of the event by subtracting the water remaining in the bottle from the initial volume.

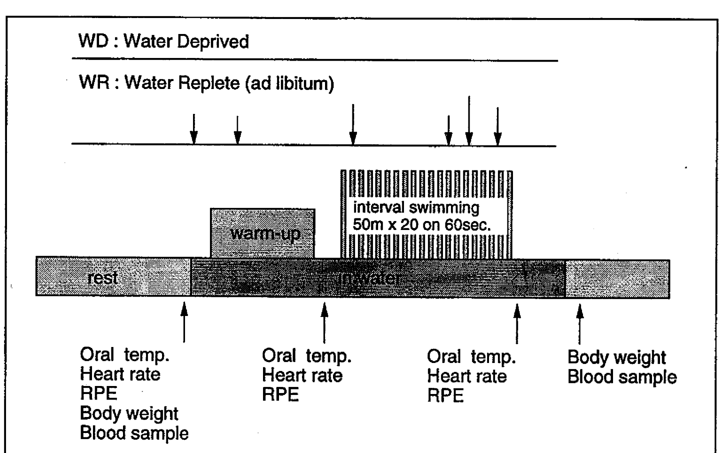

Fig. 1. Experimental protocol (CS I)

In the second set of experiments, the 6 male college swimmers (CS II) having free access to water performed at submaximal velocity for a 1500 m free style swimming exercise in warm (30.4±0.2 ℃) water. Swimming time, body temperature (oral temperature), heart rate, and sweat water loss were measured. Body temperature, heart rate and body weight were measured before and after swimming. Changes in To and SWL were measured in the same manner as for the first set of experiments (CS I).

Statistical analysis

All data are expressed as means±SEM. Analysis of variance for repeated measurements was used for comparison of swimming time (CS I), and other parameters were tested by Student's paired t-test. For all statistical procedures the significance level was set at $p<0.05$.

RESULTS

Physiological changes

To before and after swimming session was 37.1±0.2, and 37.8±0.1 ℃ in WR, and 37.0±0.1, 37.8±0.1 ℃ in WD, respectively. There was a slower body temperature rise in WR (0.7±0.13 ℃) compared to WD (0.8±0.12 ℃), but this was not significantly different.

The total amount of sweat lost during the swimming session was 0.38±0.06 and 0.37±0.04 kg for WR and WD respectively. The sweat loss was only 10 g (2.7%) higher in the WR compared to the WD. In the WR condition, the total amount of fluid taken during the swimming session was 0.100±0.017 l, producing a fluid intake ratio of 26.7±4.08%. Heart rate during the swimming session was 187.5±3.6 bpm in the WR and 183.8±3.1 bpm in WD. There was no significant difference between the two treatments.

There was, however, a significant difference ($p<0.05$) in the mean swimming time, with the WR maintaining a highest velocity compared to the WD. The mean swimming time for each session was 35.22±0.36 sec in the WR, but 35.62±0.39 sec in the WD (Fig. 2). RPE for the WR was 16.2±0.5 and 17.0±0.6 for the WD (Fig. 3). These were statistically different ($p<0.05$).

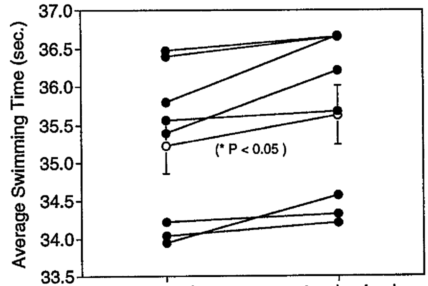

Fig. 2. Effect of water intake or deprivation on the average swimming time in subjects that performed 20 sessions of intermittent 50 m swims with a 1 min interval between each session. Open circles are mean ± SEM.

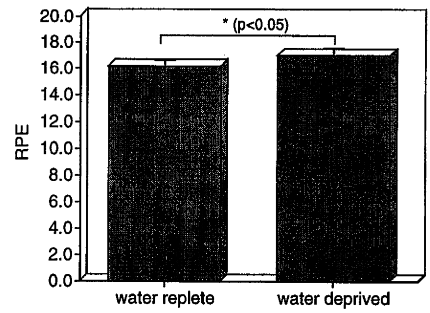

Fig. 3. Effect of water intake or deprivation on the RPE in subjects that performed 20 sessions of intermittent 50 m swims with a 1 min interval between each session. Values are mean ± SEM.

In the second experiment (CS II), The mean swimming time was 1339.67 ± 8.87 sec (1.13 ± 0.01 m/sec). Body temperature (To) changes was 0.7 ± 0.1 ℃ and sweat water loss was 5.9 ± 0.7 g/kg during swimming. Heart rate before and after exercise was 90.0 ± 4.4 bpm and 146.0 ± 3.3 bpm, respectively. Heart rate and body temperature during swimming was significantly increased. The close correlation was observed between the SV and SWL ($r=0.881$, $p<0.05$) (Fig. 4), but there was no significant correlation between the SV and body temperature changes during swimming ($r=0.700$).

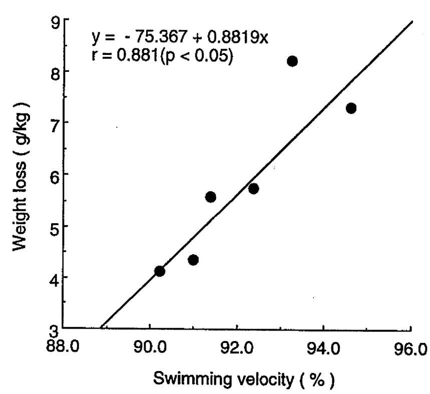

Fig. 4. The correlation between swimming velocity and sweat loss in subjects that performed at submaximal velocity for a 1500 m free style swimming.

Biochemical changes

Blood lactate concentrations before and after swimming exercise were 1.2±0.1, and 7.8±0.7 mmol/l in WR and 1.2±0.1 and 6.4±1.2 mmol/l in WD. This showed a significant exercise induced increase in blood lactate concentrations in either group, but there was no significant difference between the two groups. There was no significant difference between

WR and WD in the changes in plasma volume. There was a decrease in plasma volume of 8.1±0.8 and 7.5±1.3 % in the WR and WD respectively.

Posm at the end of exercise were 282.3±1.7 mosmol/kg H_2O in WR and 289±1.3 mosmol/kg H_2O in WD respectively. This revealed an increase of 5.1±1.3 in the WR and 5.9±1.9 mosmol/kg H_2O in WD, revealing no statistically significant difference. However, there was a significant difference in plasma osmolality between pre–and post exercise values.

Discussion

The major findings in these experiments are that, in high intensity swimming exercise lasting ~ 12 mins, ingestion of plain water did not significantly influence thermoregulatory and cardiovascular responses. However, ingestion of water resulted in enhanced athletic performance, lowered RPE, reduced mean swimming time and blunted To and Posm rises. In the second set of experiments, a close correlation ($r = 0.881$, $p < 0.05$) was observed between SWL and SV. This close correlation reveals the higher metabolic requirements of faster swimming and the resulting requirement for greater heat loss causing the higher SWL. However, in the comparison of WR subjects during the 20 x 50 m swimming bouts, SWL in the two groups did not differ significantly. Therefore, differences in thermoregulatory requirements were not relevant in these conditions. This was not surprising. It was previously reported in studies on land that the rate of sweating is not influenced by fluid ingestion (Doubt and Deuster, 1994 ; Noakes, 1993), or the concentration of the ingested fluid (Galloway and Maughan, 1998). In addition, in subjects with a higher aerobic capacity, body temperature is maintained with a lower amount of sweat than that in subjects with a lower aerobic capacity (Yoshida *et al.,* 1995). Because subjects used in these experiments were well trained athletes, and the total exercise times lasted ~ 12 mins, there appeared to be minimal requirement for exogenous fluid in order to maintain thermoregulatory homeostasis. This may explain the relatively low fluid intake (sweat output exceeded water intake by a ratio of ~ 3.5:1), even though during exercise in the heat, sweat output often exceeds water intake with consequent hypohydration and electrolyte losses.

It appears unlikely that the minor difference in fluid balance due to the water intake of 100 ml in the WR group influenced cardiovascular filling and, consequently, circulatory performance to a measurable degree that could explain the slightly but significantly better performance of the WR subjects and their less severe rating of the exercise load in comparison to the WD subjects. Prolonged strenuous exercise however may produce a different pattern of thermoregulatory changes. In one study, 2 h of prolonged strenuous exercise conducted at 21℃ resulted in a 3.2±0.1% weight loss in subjects on no fluid, while 50% (of the maximum) and 100% fluid intakes resulted in losses of 1.8±0.1 and 0.1±0.1%, respectively. Subjects deprived of fluid also showed elevated HR and To at the termination of exercise compared to 50% and 100% fluid intakes (McConell *et al.,* 1997). These beneficial effects were obtained because fluid ingestion maintained serum osmolality at pre–exercise levels (Noakes, 1993).

However, with the short duration of exercise imposed in the present study thermoregulatory benefits of fluid ingestion remained subliminal.

The results of this study also revealed that fluid intake improved endurance capacity. Several previous studies have shown that the intake of carbohydrate and electrolyte solutions enhanced endurance capacity and delayed the onset of fatigue (Brouns *et al.*, 1992 ; Nassis *et al.*, 1998 ; Wong *et al.*, 1998). The maintenance of serum osmolality at pre-exercise levels was said to be responsible for these beneficial effects (Noakes, 1993). Most researchers recommended the addition of carbohydrate (CHO) and electrolytes (Es) to sports drink, because the use of CHO-E drinks are most effective for rehydration (Maughan and Leiper, 1994). Particularly, Es which are lost through sweating are highly recommended. It is, however, unlikely that the lack of significant beneficial thermoregulatory effects might have been due to the ingestion of plain water, because another study revealed that during 13 h of sustained activity in a hot environment, E solution and water provided similar thermoregulatory and hydrational benefits (Levine *et al.*, 1991). In addition, it was previously reported that maintenance of optimum thermoregulation can only be achieved if a volume of fluid in excess of the sweat loss is ingested together with sufficient electrolytes (Maughan and Leiper, 1994). However, in this study the volume of water ingested was only $\sim$ 30% of the total sweat lost. On one hand, we thought low fluid intake by our subjects in relation to the sweat loss may be because plain water lacked flavor. On the other hand, it may be a physiological homeostatic mechanism since some risks are associated with drinking large amounts of plain water to compensate sweat loss due to the induction of hyponatremia (Brouns *et al.*, 1992).

In conclusion, it was shown that plain water ingestion during short duration high intensity swimming exercise enhanced athletic performance and lowered perception of exertion, but did not significantly offer rises in heart rate, body temperature, and plasma osmolality. Thus, in view of the unlikelyhood of any effect of the observed water ingestion on thermoregulatory and cardiovascular performance, an affective component associated with drinking during exercise seems to account for the improvement of athletic performance in this condition. This does, however, not question the conclusion that the beneficial effects of fluid ingestion on performance should persuade all athletes to remain in a fully fluid replete state during short-duration high intensity intermittent exercise.

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