

Research article

## Water temperature, voluntary drinking and fluid balance in dehydrated Taekwondo athletes

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### Abstract

Voluntary drinking is one of the major determiners of rehydration, especially as regards exercise or workout in the heat. The present study undertakes to search for the effect of voluntary intake of water with different temperatures on fluid balance in Taekwondo athletes. Six young healthy male Taekwondo athletes were dehydrated by moderate exercise in a chamber with ambient temperature at 38-40°C and relative humidity between 20-30%. On four separate days they were allowed to drink ad libitum plain water with the four temperatures of 5, 16, 26, and 58°C, after dehydration. The volume of voluntary drinking and weight change was measured; then the primary percentage of dehydration, sweat loss, fluid deficit and involuntary dehydration were calculated. Voluntary drinking of water proved to be statistically different in the presented temperatures. Water at 16°C involved the greatest intake, while fluid deficit and involuntary dehydration were the lowest. Intake of water in the 5°C trial significantly correlated with the subject's plasma osmolality change after dehydration, yet it showed no significant correlation with weight loss. In conclusion, by way of achieving more voluntary intake of water and better fluid state, recommending cool water (~16°C) for athletes is in order. Unlike the publicly held view, drinking cold water (~5°C) does not improve voluntary drinking and hydration status.

**Key words:** Fluid intake; exercise in the heat; involuntary dehydration; fluid deficit.

### Introduction

During exercise in the heat, sweat output often exceeds water intake, which results in a fluid deficit or hypohydration. Aerobic exercise tasks are likely to be adversely affected by this state (Naghii, 2000; Sawka, 1992). Unfortunately, scheduling of mass events as the Olympics, World Cup, or even a sponsored single-event can not be postponed until the weather conditions are perfect. When an athlete trains or competes in a more temperate environment, problems are likely to arise (Maughan et al., 2004). After exercise, people fail to drink sufficient volumes of fluid to restore fluid balance. This was described as 'voluntary dehydration' in previous studies. This term, however, has been changed to 'involuntary dehydration' to recognize that the hypohydrated individual has no volition to rehydrate even when fluids and opportunity are available (Burke, 2001). But the water lost must be replaced in order to maintain body water balance and allow the best possible athletic performance to be achieved. The way in which the athletes deal with the condition of exer-

cising in the heat may be the most important factor influencing the impact of the climatic stress on their performance. The successful competitor will have prepared a coping strategy that includes acclimatisation, rehydration, and behavioural and psychological components (Maughan et al., 1997). With the exception of unusual circumstances, the hydration status can be considered as a function that is largely based upon voluntary drinking (Zetou et al., 2008). So in order to aid better rehydration, it is important to find out when a dehydrated athlete desires to drink more fluid. There is some information in the literature about drinks inducing better intake. Drinks containing electrolytes stimulate the drive to drink by maintaining the plasma osmolality, so higher volumes would be consumed (Maughan et al., 1997). Drinks containing carbohydrate (CHO) are useful for their appetite appeal (Burke, 2001). The pleasing flavor of the drink is also effective, as in orange juice which is proved to be drunk more than other kinds of drinks (Maughan et al., 1993; Szlyk et al., 1989). Studies show that cooler temperatures of drinking water are preferred over warmer water and relatively greater amounts of cooler water are consumed (Adolph et al., 1947; Szlyk et al., 1989). Do cold drinks induce the highest voluntary drinking? It is claimed that offering progressively colder drink actually decreases the volume consumed (Boulze et al., 1983; Butudom et al., 2004). Cold water was introduced to be both more pleasurable and less drunk by Boulze et al. (1983). They investigated voluntary drinking in different water temperatures from 0 to 50 and detected 15 as the optimum point of drinking. On the other hand, Sandick et al. (1984) conducted a similar experiment for temperatures ranging from 5 to 38 and found 5 as the water temperature inducing the greatest intake. Therefore, the results achieved by these researchers are rather controversial.

The other aspects of such studies worth noting is that fluid losses and fluid intake practices of athletes, irrespective of drink temperature, have been reported for athletes of a number of sport fields such as water polo and volleyball players (Cox, 2002; Zetou et al., 2008), and appear to be different across sports. No investigation on fluid balance in Taekwondo athletes has been reported. The human subjects of the studies mentioned above were mountain climbers, patients going to a watering place, or soldiers. We have assessed fluid balance in Taekwondo athletes after a controlled exercise-heat stress while they drank water in voluntary volumes and with various temperatures. Except the few studies mentioned, our extensive

search in the literature and international databases yielded no record as to various drink temperatures and voluntary intake.

## Methods

### Subjects

Six young healthy male Taekwondo athletes mean (SD) age 23.7 (0.6) years; weight 80.7 (5.7) kg; and height 1.81 (0.02) m participated in this study. All subjects were familiarized with all the testing procedures. To reduce bias, explanations were given with no emphasis on drinking behavior and they were free to drink water of the offered temperature in voluntary volumes. The study was reviewed and approved by the Investigation Committee of Tabriz University of Medical Sciences and the Ethics Committee of the university and all subjects gave their voluntary, written and informed consent for their participation.

### Dehydrating procedure

Each subject participated in four experiment sessions on separate days. Pretest instructions included eating a light lunch, refraining from drinking any beverage from 12.00 noon and no exercise on the day of the experiment. Before each experiment, subjects rested in sitting position for 30 min at a thermoneutral temperature (28°C). Then a blood sample was drawn by venipuncture as the first control sample, and their body weights were measured (nude weight) using a Seca beam balance, accurate to  $\pm 100$ g (EK-500D, Japan). Experiments started at 16.00 and were conducted in an environmental chamber with controlled temperature at 38-40°C and relative humidity between 20-30%. Environmental conditions were monitored during experiment sessions. Total heat exposure time was 120 min and subjects were under constant observation for indications of any inability to tolerate the experimental conditions (e.g., elevated heart rate, nausea or confusion). Subjects performed a mild physical activity by alternating 10-min rest and 20 min exercise periods for 60 min, and physical activity continued for the last 30-min period to induce a reduction in total body water through sweating. The exercise consisted of ergometer cycling. On the cessation of exercise, subjects dried their body with a towel and were weighed. An indwelling cannula was inserted into a large superficial vein in the forearm to collect free-flowing blood samples. Second control blood sample was drawn through the cannula at 3 min before drinking (-3 min). The first control blood sample compares the plasma concentrations of sodium pre and post heat exposure while second control blood sample is considered as control to compare before and after drinking.

### Voluntary intake

After the procedures, subjects were allowed to drink ad libitum plane water with the four temperatures of 5, 16, 26, and 58°C, on four separate experiments. Their drinking volume was measured. Blood samples were drawn through the indwelling cannula at 3, 9, and 15 min after drinking. Blood samples were immediately centrifuged at 3,000 g and 4°C for 5 min to determine the plasma so-

dium concentration by Eppendorf flame photometry (model EFOX 5054, Instrumentation Laboratory, Germany).

### Calculated measures

Body weight at the start of the procedure, just before entering the chamber, was considered nude weight. Weight loss induced by the procedure, *primary weight loss*, was calculated by the difference between body weight before and after the procedure,:

$$\text{Primary weight loss} = \text{pre-procedure weight} - \text{post-procedure weight}$$

In sport medicine, the level of dehydration is quantified by the amount of weight loss, usually by exercise. An athlete who loses 3% of his/her body weight is considered to be "3% dehydrated" (Oppliger and Bartok, 2002). So *primary percentage of dehydration* was calculated as (Cox, 2002):

$$\text{Primary percentage of dehydration} = (\text{primary weight loss} / \text{nude weight}) * 100$$

*Sweat loss* (ml) is calculated as (Zetou et al., 2008):

$$\text{Sweat loss (ml)} = \text{weight loss (gr)} + \text{fluid intake (ml/gr)}$$

Because our subjects had no intake during the procedure, primary weight loss equals sweat loss.

Weight loss after voluntary drinking, which equals *fluid deficit* (ml/gr), was calculated as:

$$\text{Fluid deficit (ml or gr)} = \text{primary weight loss (gr)} - \text{water intake (ml)}$$

So *involuntary dehydration* would be:

$$\text{Involuntary dehydration} = (\text{fluid deficit} / \text{nude weight (gr)}) * 100.$$

Because sodium and its associated anions account for about 94 percent of the solute in the extracellular compartment, plasma osmolality can be roughly approximated as:

$$\text{Posm} = 2.1 * \text{Plasma sodium concentration (Guyton and Hall, 2006)}.$$

### Statistical analysis

Data were analyzed by SPSS15 software. Descriptive statistics were calculated for all variables of all trials. Difference in variables was assessed using paired *t* test (one measurement) and repeated measures analysis of variance (multiple measurements). Pearson Correlation was used for assessing the correlation of variables. Kolmogorov-Smirnov Test was used for assessing the normality of variables' distribution. Values of  $p < 0.05$  were considered statistically significant, and all data are presented as means (SD).

## Results

### Dehydrating procedure

Dehydration induced weight loss (sweat loss), percentage of dehydration, and raise in Posm as shown in Table 1.

**Table 1.** Physiologic changes of subjects induced by dehydration.

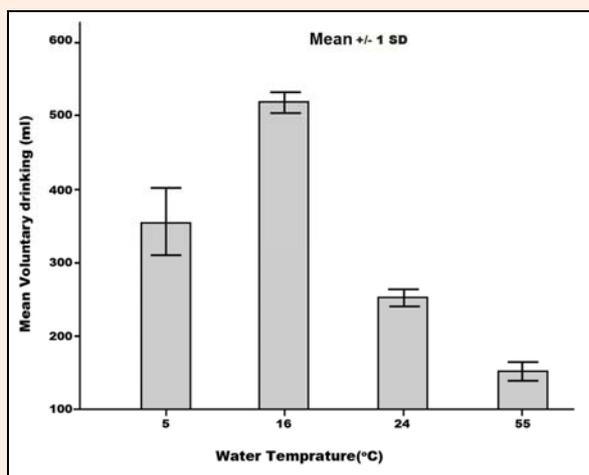
| Subject   | Nude weight(kg) | Dehydrated weight (kg) | Weight loss (gr) or sweat loss (ml) | Percentage of primary dehydration | Posm change following dehydration |
|-----------|-----------------|------------------------|-------------------------------------|-----------------------------------|-----------------------------------|
| 1         | 86.0            | 84.0                   | 2000 *                              | 2.33                              | 9.975 *                           |
| 2         | 89.0            | 86.9                   | 2100 *                              | 2.36                              | 7.875 *                           |
| 3         | 86.0            | 84.1                   | 1900 *                              | 2.21                              | 5.775 *                           |
| 4         | 96.5            | 94.4                   | 2100 *                              | 2.18                              | 5.775 *                           |
| 5         | 64.0            | 62.4                   | 1600 *                              | 2.50                              | 6.825 *                           |
| 6         | 63.0            | 61.3                   | 1700 *                              | 2.70                              | 6.825 *                           |
| Mean (SD) | 80.75 (13.90)   | 78.85 (13.71)          | 1900 (209.76) *                     | 2.38 (.19)                        | 7.175 (1.58) *                    |

The difference between nude weight and dehydrated weight (weight loss) was highly significant (\*  $p < 0.01$ ). The difference between Posm before and after dehydration (Posm change following dehydration) was statistically significant (\*  $p < 0.01$ ) for all experiments.

The Posm changes did not differ statistically on different days.

The difference between nude weight and dehydrated weight was highly significant ( $p < 0.01$ ). Also the difference between Posm before and after dehydration was statistically significant for all experiments. Just three min before drinking, mean (SD) Posm reached 311.6 (5.5) from a baseline value of 304.4 (3.4) mosmol/kgH<sub>2</sub>O (Table 2).

There was no significant correlation between dehydrated Posm and weight loss. There was a significant correlation between percentage of dehydration and dehydrated Posm in 58°C ( $r = 0.8$ ,  $p < 0.05$ ) and it was insignificant in trials at other temperatures.



**Figure 1.** Amount of voluntary drinking in trials with different water temperatures presented as mean (SD). Significantly different amounts have been drunk in different trials.

### Voluntary intake

For each water temperature, the amount of water taken in is shown in Figure 1. As can be seen, more water was consumed when it was 16°C, compared with colder and

warmer water; and the least voluntary intake occurred for 58°C water.

The amount of water consumed by subjects did not vary intra-experimentally while it was highly different inter-experimentally (between temperatures) ( $p < 0.01$ ). Intake was not significantly correlated with the subject's weight loss, but in 5°C trial it was significantly correlated with Posm change induced by dehydration ( $r = 0.8$ ,  $p < 0.05$ ). This correlation was insignificant in other trials.

### Plasma osmolality

Following the significant increase in Posm induced by dehydration procedure, no significant change occurred after water intake in samples taken up to 15min after drinking. Plasma osmolality of subjects during the experiments is shown in table 2.

### Fluid balance

Voluntary intake was statically less than sweat loss (in ml) and the difference was highly significant ( $p < 0.01$ ).

Fluid deficits in different temperatures are shown in Table 3. They were statistically different inter-experimentally ( $p < 0.01$ ) and being the least in water at 16°C, increasing in both colder and warmer water offered. Average involuntary dehydration in all trials was 1580 ml.

Involuntary dehydration in different temperatures is shown in Figure 2. It was statistically different inter-experimentally ( $p < 0.01$ ) and, as can be seen, was the least in water at 16°C, increasing in colder and warmer water offered. Average involuntary dehydration in all trials was 1.973%.

The correlation between involuntary dehydration and primary percentage of dehydration was highly significant in all trials ( $r = 0.9$ ,  $p < 0.01$ ). Involuntary dehydration had no significant correlation with weight loss. It was statistically less than that of primary dehydration.

## Discussion

### Voluntary intake

**Table 2.** Plasma osmolality (mosmol/kgH<sub>2</sub>O) of subjects while they drink water with different temperatures -shown as mean (SD).

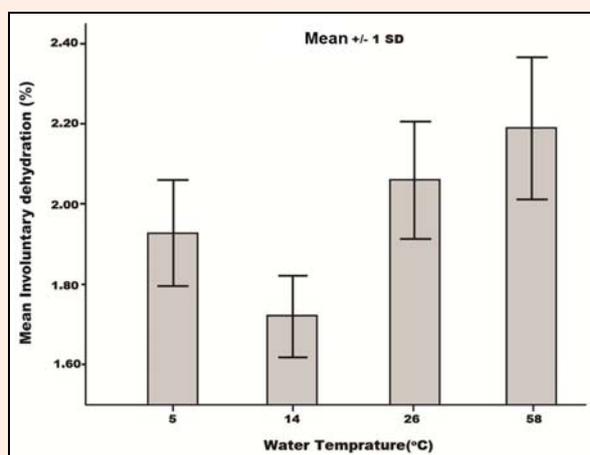
| Water temperature | Posm before procedure | Posm 3min before drinking | Posm 3min after drinking | Posm 9min after drinking | Posm 15min after drinking |
|-------------------|-----------------------|---------------------------|--------------------------|--------------------------|---------------------------|
| 5°C               | 297.50 (3.16)         | 304.50 (3.25) *           | 305.20 (3.43)            | 304.85 (1.58)            | 314.15 (1.58)             |
| 16°C              | 308.00 (2.54)         | 313.25 (3.62) *           | 313.60 (1.71)            | 313.60 (4.73)            | 312.55 (3.09)             |
| 26°C              | 306.25 (1.58)         | 313.60 (4.54) *           | 313.11 (3.23)            | 312.90 (4.60)            | 311.50 (3.91)             |
| 58°C              | 305.90 (3.43)         | 315.00 (5.48) *           | 314.65 (4.08)            | 314.30 (4.34)            | 313.25 (4.08)             |

The difference between Posm before and after dehydration (before procedure and before drinking) was statistically significant for all experiments. No significant (\*  $p < 0.01$ ) change of Posm occurred after water intake up to 15min after drinking.

**Table 3. Fluid deficit while subjects drank water with different temperatures.**

| Fluid deficit (ml) | 5°C trial | 16°C trial | 26°C trial | 58°C trial |
|--------------------|-----------|------------|------------|------------|
| Minimum            | 1270      | 1090       | 1360       | 1450       |
| Maximum            | 1750      | 1570       | 1840       | 1940       |
| Mean               | 1543 *    | 1382 *     | 1648 *     | 1748 *     |
| SD                 | 188       | 199        | 202        | 200        |

Voluntary intake was statistically less than sweat loss (equaling the fluid deficit) and the difference was highly significant ( $p < 0.01$ ). Fluid deficit was statistically different in trials of different temperatures ( $p < 0.01$ )



**Figure 2. Involuntary dehydration while subjects drink water with different temperatures, presented as mean (SD). Significantly different involuntary dehydration have occurred in different trials.**

The main pursuit of this study was to assess the effect of post-dehydration drinking of waters with various temperatures on fluid balance in Taekwondo athletes. The temperatures were described by the subjects as cold (5°C), cool (16°C), tepid (26°C) and warm (58°C). Therefore, this investigation set out to test the effect of these feelings on voluntary drinking of water. These temperatures are commonly used in daily life as refrigerated water (5°C), cool tap water (16°C), water approximately at room temperature (26°C), and water at the temperature of a hot drink e.g. coffee (58°C). As shown statistically, intake of subjects was normally distributed, which means they consumed similar amounts of water intra-experimentally. The highly significant difference in the amount of water intake inter-experimentally brings emphasis on the fact that water temperature is an important factor in the determination of voluntary drinking. Boulze et al. (1983) report that water temperature is the main factor in short term water intake. Most previous studies, however, have investigated the effects of 'forced' hydration by instructing subjects to drink specific amounts and, unfortunately, there has been little investigation on voluntary drinking which naturally occurs during or after exercise (Butudom et al., 2004).

The water temperature at which the highest voluntary intake occurred was 16°C. This is almost the same figure reported by Boulze et al. (1983) (15°C). Similarly, the Office of Surgeon General has recommended 16°C for field drinking water (Sandick et al., 1984), and American College of Sports Medicine recommends that ingested fluids be cooler than ambient temperature, between 15 degrees and 22 degrees C (Convertino et al., 1996).

Boulze et al. (1983) also reports that when subjects were asked to mix their preferred temperatures, they chose 14.9±1 °C. These are inconsistent with the findings of Sandick et al. (1984) that reported more voluntary drinking of 5°C water than 16°C water. Adolph et al. (1947) have shown that soldiers in the desert with two bottles of 13°C and 28°C water or 15°C and 43°C prefer 13°C and 15°C. This, again, shows the fact that human subjects in hot environments prefer cool water but they have not tested any preference for water below 13°C (cold water). In a study on dehydrated normothermic horses it was shown that they preferred water at 20°C (near ambient temperature) more than 10°C and 30°C (Butudom et al., 2004). The study has assessed no temperature between 10°C and 20°C, so, 20°C in this study could be considered close to both 16°C and 26°C in the present investigation. Also, the fluid used in the study of horses was 0.9% saline and authors discussed the effect of temperature on the taste of saline. To induce consuming a greater volume of beverages, their composition together with their palatability should be taken into account when free choice is given to individual, as indeed occurs in most situations (Maughan et al., 1997). Human subjects have reported less salty taste when the temperature of the solution rose to 22°C, so horses may prefer saline at 20°C because it has less salty taste (Butudom et al., 2004; McBurney et al., 1973). Palatability is commonly referred to pleasing flavor of the drink, but a classic study defines palatability as flavoring and cooling the drink, and demonstrates that both increase voluntary drinking (Szlyk et al., 1989).

Temperature preference in human adults seems to have its own special aspects. Human newborns stop sucking more often and for longer periods with cold milk than with warm milk (Makoi et al., 1978). Interestingly, horses showed a tendency to take fewer longer drinks in 20°C saline than 10°C and 30°C (Butudom et al., 2004) which shows a similarity to newborns. Preference for cooler water by adult humans differs from human newborns and rats so it may be a learned behavior because humans have daily access to cold water (Butudom et al., 2004; Boulze et al., 1983).

A dehydrated subject who is hyperthermic due to heat exposure is up against the challenge of thermal state and fluid state, thus he desires cold drink to provide both fluid and heat sink. Cool or cold drinks ingested during and after exercise can act as a heat sink and lower core temperature (Wimer et al., 1997), thus having a soothing effect on hyperthermia. It seems the bodily systems involved tend to render a balanced response in dealing with these two alterations, i.e. helping the extirpation of surplus temperature and improving altered fluid state by intake of water. This is probably why according to Boulze et al. (1983) resting humans prefer water at 20°C.

Our subjects drank less cold (5°C) water. Cold water has been described as both more pleasurable and less drunk by Boulze et al. (1983). They have shown that although colder water is preferred following exercise, offering a progressively colder drink (<10°C) can actually decrease volume consumed. As a result, hyperthermia, rather than dehydration, seems to be a more important mechanism for the preference for colder water. It has been established that coldness of the drink has a satisfying effect on thirst (Guyton and Hall, 2006). In the study on athletic horses it is concluded that greater satiation of thirst by oropharyngeal cooling may have contributed to lesser intake of colder fluid (Butudom et al., 2004). Gastric emptying is slower for cold solutions than for warm solutions (Deaux, 1973). As gastrointestinal distention may partially alleviate thirst (Guyton and Hall, 2006), intake of cold water could prolong satiation by slowing gastric emptying rate (Butudom et al., 2004) thus decreasing voluntary drinking. And finally it seems intolerable to intake a great quantity of cold water which has a temperature much different from body temperature. It follows that drinking cold water seems to provide thermal needs at the expense of fluid needs. Contrary to the commonly held view, cold water (~5°C) does not induce more voluntary drinking and better hydration status.

Our subjects showed the least voluntary drinking in warm water (58°C). Drinking warm water seems both intolerable because of the temperature difference, and unpleasant for its excess thermal load.

Intake in 5°C trial was significantly correlated with Posm change induced by dehydration. The correlation between intake and Posm change was insignificant in other trials. In a study on horses water intake was reported to be significantly correlated with the increase in plasma sodium concentration induced by administration of oral electrolyte pastes (Dusterdieck et al., 1999). Posm seems to affect voluntary drinking, but why the correlation is insignificant in trials other than 5°C is not yet clear.

The borderline correlation of intake and the subject's weight loss in 16°C trial and 58°C trial shows some possible relationships across these parameters. It has been reported that voluntary fluid intake and subjective rating of thirst were related to body weight loss during exercise (Mack et al., 1986). Sandick et al. (1984) reported a significant positive correlation between amount of 5°C water drunk and weight loss ( $r = 0.66$ ,  $p < 0.005$ ). Intake of water at the other temperatures (16, 22, 38°C) was not significantly correlated with the subject's weight change in their study.

### Dehydration

As shown by statistical values, our dehydration procedures induced highly significant weight loss ( $p < 0.01$ ) and significant rise in Posm, which was similar on different days. Dehydration was 2.37%. Wyndham and Strydom, 1969 has been reported that any loss of mass in excess of 3% of the body weight can seriously disrupt temperature regulation and physical performance. On the other hand, according to Convertino et al. (1996) a 1% loss of body weight can result in mild symptoms of dehydration which becomes evident at a 3% weight loss.

Therefore, the dehydration induced in the present investigation could be considered to lie at an intermediate level. The significant correlation between primary percentage of dehydration and dehydrated Posm in 58°C shows that some relationships may be existent in the physiological alteration of these parameters.

### Plasma osmolality

All our subjects had a significantly raised Posm after heat exposure and exercise and before drinking. The changes in Posm during dehydration were similar in different trials, indicating the similar effect of dehydrating procedure and similar induced thirst on different days. Posm did not decrease until 15 minutes after drinking, when the last sample was collected, indicating that voluntary drinking had no systemic effect on hydration of subjects until 15 minutes. Despite thirst stimulus induced by increased Posm, subjects stop drinking, probably because oropharyngeal and gastric mechanisms satisfy thirst as mentioned above. It has been shown that intermittent water intake of lower quantities before and after exercise results in delayed restoration until after 60 minutes of exercise (Miller et al., 2009). Also, when euhydrated subjects drank different liquids (water, pickle juice, carbohydrate-electrolyte drink) at rest, plasma sodium concentration and plasma osmolality did not change during 60 minutes after ingestion (Melin et al., 1994).

### Fluid balance

Ideally, intake should be more than sweat loss, because obligatory urine losses persist even in the dehydrated state (Maughan et al., 1997). Our subjects drank much less than their sweat loss ( $p < 0.01$ ), so evident fluid deficit occurred (averagely 1580ml). Subjects in the study conducted by Boulze et al. (1983) had deficit far from being recovered and they discussed that short term water intake is not adjusted immediately to the needs in humans and the influence of water temperature may increase this phenomenon of *voluntary dehydration*. In normal healthy people, the daily replacement of fluid losses and maintenance of fluid balance are well regulated by thirst and urine losses. However, under conditions of stress such as environmental heat, thirst may not be a sufficient stimulus for maintaining euhydration and there may be a considerable lag of 4–24 h before body fluid levels are restored. Post-exercise rehydration is difficult in situations where moderate to high levels of hypohydration have been incurred (i.e. deficits of 2–5% body mass or greater) (Burke, 2001). Fluid deficit of subjects was highly different among trials. As drinking water at 16°C resulted in the least fluid deficit, it seems that rehydration problem could be less with cool water.

Hydration level of the subjects, however, was much improved by voluntary drinking in all trials, as percentage of involuntary dehydration was less than primary dehydration. Drinking water at 16°C resulted in the least involuntary dehydration and the best hydration state ( $p < 0.01$ ). As it could be expected, primary percentage of dehydration and involuntary dehydration were highly correlated in all trials ( $p < 0.01$ ), meaning that more dehydration before drinking would result in more involun-

tary dehydration after drinking.

Fluid strategies and guidelines have been introduced to help athletes rehydrate appropriately, especially for exercise in the heat. They include trivial considerations on beverage temperature (Convertino et al., 1996; Manning, 2010; OptumHealth Inc., 2010). Cooler drinks are claimed to reduce involuntary dehydration (Adolph et al., 1947). As other studies indicate, and this investigation demonstrates via incorporating a different, and perhaps more reliable procedure, the effect of fluid temperature on voluntary drinking and fluid balance of athletes is quite outstanding. So we suggest consideration of fluid temperature (16°C for water) in athletic strategies and trainings. Also, further investigations about voluntary drinking of different beverages (e.g. sports drinks) with different temperatures are recommended.

### Methodology

Dehydration was induced through a controlled exercise-heat stress. The methodology included the calculation of fluid deficit in the subjects and gathering blood samples in order to measure plasma osmolality indicating the systemic fluid state. The effects of rehydration could then be measured. The two aforementioned studies about water temperature and voluntary drinking (Boulze et al., 1983; Sandick et al., 1984) employed simpler methods to dehydrate their subjects. They took no blood sample and did not include calculations for fluid deficits. Furthermore, they allocated different subject groups for comparison of voluntary intake of water with various temperatures, but we repeated the experiments offering water with various temperatures to the same subjects on different days which would give more reliable data.

### Conclusion

In order to have more voluntary intake of water and less fluid deficit, cool water (near 16°C) is recommended for athletes. Such water would also aid thermoregulation to some extent and increase palatability as well.

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### Key points

- For athletes dehydrated in hot environments, maximum voluntary drinking and best hydration state occurs with 16°C water.
- Provision of fluid needs and thermal needs could be balanced using 16°C water.
- Drinking 16°C water (nearly the temperature of cool tap water) could be recommended for exercise in the heat.

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