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Original Article

Voluntary drinking versus imposed drinking in the methodology of investigations about the *drinking-induced thermoregulatory sweating*

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Abstract: Studies have shown that dehydrated humans or animals in a warm environment begin to sweat within seconds to minutes after drinking. This phenomenon is one of the *drinking-induced thermoregulatory responses*; being investigated from different aspects. Our objective is to show the difference of voluntary drinking and imposed drinking in the methodology of these experiments. Six healthy subjects 23.7 ± 0.6 yr old and 80.7 ± 5.7 kg wt were dehydrated by performing mild exercise (ergometer cycling) in a hot and humid chamber (38-40°C, 20-28% relative humidity). We incorporated two protocols: after dehydration, subjects were allowed to drink water with 1) imposed volumes of 1, 3, 5 ml/kg and 2) voluntary volumes; on four separate days. The sweating rate was measured on the forehead area before and after drinking. Sweating increased markedly just a few minutes after the onset of drinking. The mean sweat rates of the imposed volumes of 1, 3, 5 ml/Kg were 0.33 ± 0.15, 0.31 ± 0.17, 0.47 ± 0.21 respectively and for the voluntary volume it was 0.54 ± 0.19. The mean intake in the voluntary trial was 6.58 ± 1.14 ml/Kg, more than the imposed volume of 5 ml/Kg. The trend of the rate of the sweating response in the imposed trials was distinct from the response in the voluntary trial. Conclusion: There exists a difference between voluntary drinking and imposed drinking in the sweating response that follows rehydration. So it is suggested to use the methods of voluntary drinking in the investigations of this phenomenon, to reveal the natural events that happen in the actual circumstances.

Keywords: Drinking-induced sweating, thermoregulatory evaporation, post rehydration, voluntary intake, imposed water consumption

Introduction

Heat stress happening in ordinary life, in athletic competition, in military endeavors, and even in animals, is the focus for many investigations worldwide, numerous ones with the aim of introducing the physiologic and pathologic phenomena and numerous others with the aim of finding novelties for promoting performances [1-8]. Of such phenomena under research are the drinking-induced thermoregulatory responses. During heat stress together with dehydration, happening naturally together, thermoregulation is partly suppressed to save body fluid and circulation, because most of the mechanisms of thermoregulation including sweating, panting in animals, skin vasodilatation and etc., result in fluid loss and/or circulation deterioration. *Drinking* which means fluid compensation for the body, induces the recovery of thermoregulatory responses, and this is called *drinking induced thermoregulatory responses* [1, 9-23]. One of these responses, the *drinking induced sweating* is discussed methodologically in this paper.

Drinking induced sweating has been studied since 1965 in a study of animal model [24] until now in studies of human athletes [25, 26]. The methodology for its research have components of fluid loss and raised temperature induced by physical activity, hot and humid environment, and occasionally prescription of diuretics; thereafter fluid intake mostly by consumption, and sometimes by IV injection or NG tube. Most of the authors have utilized imposed intake, although in reality voluntary intake occurs and there are significant differences between impo-

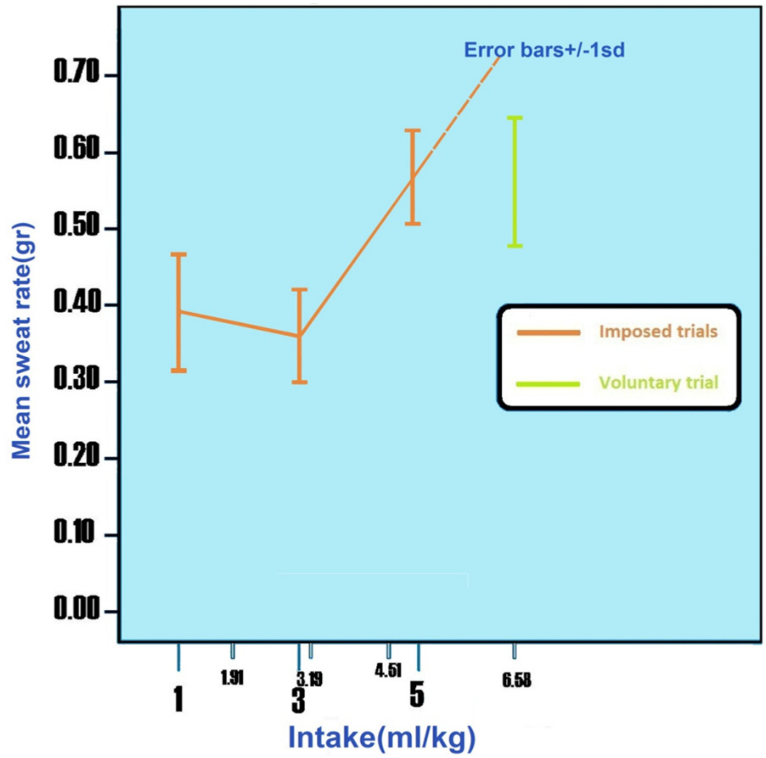

Figure 1. Sweat rates versus volume of intake in the 4 imposed/voluntary trials.

sed and voluntary drinking. It has been proved that subjects prefer various volumes in various conditions [5, 26-32]. Nevertheless, "imposing" may indicate stress and sympathetic stimulation while autonomic nervous system especially the sympathetic branch is involved in mechanisms of sweating, and this may be a confounding factor. Therefore, there may be advantages in methodologies with voluntary intake. This paper is an attempt to demonstrate plainly the difference of voluntary and imposed drinking in studying the *drinking induced sweating*. We have performed two series of experiments, one with imposed drinking and the other with voluntary drinking [5, 25, 26], and comparison of the resulted sweating responses were evaluated to estimate the confounding effect of imposed drinking.

Materials and methods

Subjects

Six healthy male Taekwondo Athletes mean age 23.7 ± 0.6 years old (range: 22-26), mean weight 80.7 ± 5.7 kg, and mean height 181 ± 2 cm, participated in this study. All subjects were familiarized with the testing procedures. They were normotensive, nonsmokers, and took no medications. The study was approved by the Research Vice-Chancellor of Tabriz University of Medical Sciences and the Ethics Committee of the University, and written informed consent was obtained from all subjects.

Procedure

Pretest instructions included eating a light lunch, refraining from drinking any beverage several hours before the experiment, and no exercise on the day of the experiments. Before each experiment, subjects entered a chamber and rested in the sitting position for 30 min at a thermoneutral temperature (28°C, 20-28% relative humidity). Body weight was measured with light clothing. After drawing a blood sample by venopuncture as the first control sample, subjects entered another chamber (38-40°C, 20-28% relative humidity). They performed a mild exercise (ergometer cycling) by alternating 10 min rest and 20 min exercise periods for 90 min, then exercise continued for the last 30 min period to induce a reduction in total body weight through sweating. Total heat exposure time was 120 min. During heat exposure, subjects were under constant observation for indications of any inability to tolerate the experimental conditions (e.g., elevated heart rate, nausea or confusion).

After the cessation of exercise, subjects dried their body and their forehead, and were then 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 indwelling cannula. The first control blood sample compares the plasma concentrations of sodium before and after heat exposure while second control blood sample is considered as a control to compare them before and after drinking.

Table 1. Dehydration profile, and intake volume of each trial: mean (SD)

Trial type	Weight loss (gr) or sweat loss (ml)	Dehydration Percentage%	Posm before procedure*	Posm after procedure*	Intake (ml)
Imposed volume of 1 ml/kg	2205.2 (471.7)	2.73 (0.28)	302.05 (1.58)	309.05 (2.45)	80.75 (13.90)
Imposed volume of 3 ml/kg	2246.8 (552.1)	2.77 (0.37)	305.55 (2.57)	317.10 (4.41)	242.25 (41.72)
Imposed volume of 5 ml/kg	2125.0 (541.5)	2.62 (0.40)	308.35 (1.58)	312.90 (1.88)	403.75 (69.53)
Voluntary intake	1900.0 (209.8)	2.38 (0.19)	308.00 (2.54)	313.25 (3.62)	531.01 (91.99)

*(mosmol/kg H_2O).

Before drinking, sweat rate was measured as control, then subjects were allowed to drink tap water at temperatures of 16°C, at volumes of 1, 3, and 5 ml/Kg of body weight and in voluntary volumes in four separate experiment days. Blood samples were drawn through the indwelling cannula at the start of drinking (0 min) and at 3, 9, 12, and 15 minutes after drinking.

Measurements

Forehead sweat rate was chosen to represent a localized area of sweating and was measured by the weight gain of a covered filter paper disk (96 cm^2) placed on the skin over the forehead. The front sides of the disks were covered with waterproof tape to prevent evaporation. The disk was left on the skin each 3 minutes. It was enough to reliably detect weight gain and for saturation of the filter paper. The weight of a filter paper disk was gauged using EK-500 G beam balance, accurate to ± 0.01 g. Body weight was measured using a Seca beam balance, accurate to ± 100 g. As a result of experimental conditions, a decrease in weight primarily reflects water loss by thermoregulatory responses, mainly sweating.

Plasma sodium concentration was determined by eppendorf flame photometry (model EFOX 5054, Instrumentation Laboratory). Sodium concentrations were measured as milliequivalents per kilogram of water by correcting for total solids. Because sodium and its associated anions account for about 94 percent of the solute in the extracellular compartment (including plasma), plasma osmolality can be roughly approximated as: Posm = 2.1 *Plasma sodium concentration [33].

We applied this formula for the estimation of plasma osmolality from plasma sodium concentration.

Statistics

Data were analyzed by SPSS16. The difference in variables was assessed using paired t test (one measurement) and repeated measures analysis of variance, ANOVA (multiple measurements). Values of $P < 0.05$ were considered statistically significant, and all data are presented as means ± SD.

Results

After dehydration procedure, subjects showed a highly significant decrease in their weight ($P < 0.01$), with mean dehydration of 2.63%. Also, their plasma osmolality (Posm) significantly raised from mean of 305.99 before procedure to mean of 313.08 after procedure ($P < 0.05$) and it was statistically similar in the rest of the experiments until 15 minutes after drinking ($P > 0.05$). The weight loss and Posm change did not vary among the trials ($P > 0.05$). The mean intake in the voluntary trial was 6.58 (1.14) ml/Kg. The parameters affected by dehydration, together with the intake of each trial is shown in **Table 1**.

Abrupt increase in sweating occurred 3 minutes after drinking ($P < 0.05$). The sum of all measured sweatings of the subjects was used to calculate the mean sweat rate in each trial, demonstrated versus the volume of intake in **Figure 1**.

Discussion

Our results show the prominent difference of the sweating response after voluntary intake and imposed intake. After significant dehydration demonstrated by raise in Posm (**Table 1**), subjects voluntarily drank 6.58 ± 1.14 ml/Kg of tap water, more than the imposed volumes of 5 ml/Kg. It has been reported previously that the volume of fluid intake varies due to beverage temperature [5, 16, 26-28, 30, 34-41], taste [28, 31, 32, 40-42], and composition [4, 8, 14, 29, 43-45]. Beverage temperature of nearly 16°C, which equals the temperature of cool tap water, has been introduced as optimum for rehydration and fluid balance [5, 30, 31]. Drinks containing electrolytes, glucose, and fruit taste, now produced as *sport drink*s, have been shown to induce more intake and more drinking pleasure [4, 8, 17, 28, 29, 31, 32, 38, 39, 41, 44-46]. However, we used plain water which is the most available beverage in daily life. The sweating response, and even the hormonal reactions involved, vary according to the volume of intake [25], so the sweating response of voluntary intake compared to the imposed intake should vary due to the difference in volumes of consumption. The volume of intake in voluntary trial was more than 5 ml/Kg, and the induced sweating response was more than the sweating response of imposed intake of 5 ml/Kg, but the SD bar of voluntary trial in **Figure 1** has fallen quite apart from the trend of imposed trial, apparently lower. This could be better assessed if the imposed volumes were chosen equal to the voluntary volume, with the imposed trial performed after the voluntary trial, however, if the imposed volume is too close to what the subject would prefer, the effect of *imposing* may be masked to some extent. Surely, more studies with different volumes could make this fact more clear. Anyhow, the reason for apparently lower sweating response may be changes in hormonal reactions. During heat stress and rehydration, plasma levels of vasopressin, epinephrine and norepinephrine change, and are dependant to thirst, intake volume and other factors [2, 3, 25, 35, 47-54]. Epinephrine and norepinephrine are sympathetic hormones changing with stress and affecting sweating as an autonomic output [33, 55]. Imposing consumption of a determined volume may burden stress and influence the sympathetic epinephrine and norepinephrine release, confoundingly raising the sweating response. As can be seen (**Figure 1**), the increase in sweating response is sharper in higher volumes, which may indicate more sympathetic confound with imposing higher volume intake.

Ultimately, it can be concluded that imposed drinking may have confounding effects in the methodology of investigations about the drinking-induced sweating, and even for any study about rehydration, and future studies had better consider voluntary intake.

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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