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The Effect of Fluid Balance on Exercise Performance in the Heat

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The Effect of Fluid Balance on Exercise Performance in the Heat

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Kinesiology

by

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Kobe University
Bachelor of Science in Exercise Science, 2014

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This thesis is approved for recommendation to the Graduate Council

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ABSTRACT

Introduction: In dehydrated individuals thirst seems to disappear after ingestion of small amount of water before full rehydration. This phenomenon has been linked to oropharyngeal receptors. However, some researchers suggest that drinking to satisfy thirst is enough for optimal performance. It is well established that water deficit greater than 2% of body weight decreases exercise performance in the heat. No study has ever examined the effect hydration on exercise performance in the absence of thirst via oropharyngeal stimulation. **Purpose:** The purpose of this study is to examine the effect of dehydration on exercise performance and thermoregulation during exercise in the heat independently of thirst. **Method:** Five competitive male cyclists (age, 31.6 ± 4.9 y, weight, 74.7 ± 3.7 kg, height, 180.9 ± 4.3 cm, VO_{2peak} , 57.5 ± 28 mL \cdot min $^{-1}$ \cdot kg $^{-1}$) were performed 2 hours cycling in 35°C and 30% relative humidity after that they completed 5K time trial. Two experimental trials were performed: on Dehydration without Thirst (DEH): drinking 25 ml water every 5 min with no infusion in the nasogastric tube, and the other was euhydration not thirst (EUH): drinking 25 ml water every 5 min while infusing in the nasogastric tube enough fluid to match sweat losses. **Results:** Sweat rate during 5K time trial in the EUH trial (2.2 ± 0.7 L/h) was higher than that in the DEH trial (1.9 ± 0.1 L/h). In the EUH trial, % body weight loss (-0.1 ± 0.3 %) was lower than that in the DEH trial (-2.2 ± 0.2 %) during 2 hours cycling. The finishing time of the 5K in the EUH trial was faster than that in the DEH trial (12.9 ± 0.5 and 13.4 ± 0.5 min). Core temperature at the end of the 5K time trial in the

EUH trial was lower than that in the DEH trial (39.0 ± 0.1 and 39.5 ± 0.8 °C). Mean skin temperature during the 5K time trial in the EUH trial was higher than that in the DEH trial. In both trials, there was no difference in the degree of thirst. **Conclusion:** In the EUH group, subjects completed faster the 5K time trial than in the DEH, probably due to lower thermoregulatory strain and better cardiovascular function.

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Dedication

This thesis is dedicated to all master's and doctoral students at the University of Arkansas,
College of Education and Health Professions.

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Introduction

Exercise performance is influenced by multiple factors, including but not limited to training status, energy balance and metabolism. Hydration status and fluid homeostasis are also determinants for exercise outcome (4). Aiming for optimized performance, athletes are therefore interested in ideal water intake.

It is well known that even dehydration of 2% of body mass loss increases cardiovascular strain and hampers innate thermoregulatory mechanism. This impairment of heat dissipation and cardiac output increases linearly with severity of hypohydration (4, 6, 7, 43). The decrease of total body water leads to a lowered blood and plasma volume which translates to a reduction in stroke volume and cardiac output and increase of heart rate (2, 6, 19, 46). It also causes reduced amount of sweat and increases the risk of hyperthermia (6, 7). All these factors are considered to decrease exercise performance, especially during aerobic activity (4, 6, 7, 46). Athletes did not rehydrate enough fluid during exercise when drinking ad libitum (5). Hence it is proposed that satisfying thirst is not enough to replenish water loss. This phenomenon is termed voluntary dehydration and occurs when there is a delay in complete rehydration following water loss.

Thirst is mechanically linked to oropharyngeal sensors and vasopressin (AVP) secretion; which is a water-retaining hormone (26, 34). When plasma osmolality increases, AVP is secreted and a person feels thirsty. In addition, the body tries to maintain fluid balance via increased renal water reabsorption (12, 26). Immediately following drinking, but before the

water is absorbed, AVP secretion is inhibited which leads to a downregulation of thirst through the oropharyngeal receptors (4, 12, 34). As a result, a decrease in plasma of AVP concentration provides the stimulus to terminate water ingestion an innate signaling mechanism that protects a healthy body from waterintoxication and overhydration (12, 26). Furthermore, recent studies showed that ingestion of water through drinking caused the inhibition of AVP secretion and thirst, but water delivered through a nasogastric tube had no effect on AVP secretion. These findings elicit the role of oropharyngeal reflex on modified AVP secretion (4, 34). It has also been suggested that the oropharyngeal region may be related to restoration of fluid balance by observing the volume or rate of fluid intake through oropharyngeal metering (12).

However, some researchers argue that when athletes drink ad libitum, performance does not decline and drinking to thirst should therefore be rendered enough to reduce the many kinds of risks of dehydration (31, 33). Moreover, full replacement of water loss lead to some negative effects, such as gastrointestinal symptoms, reduced serum sodium concentration, gaining weight, and impairing exercise performance, complications attributed to a water overload and incomplete absorption (31).

Some top marathon runners and cyclists record little water intake during their race and still yielding good results (31). For example, in 2004 Athens Women's Olympic Marathon Japanese runner Mizuki Noguchi lost much more than 2% of body weight in one of the hottest marathons in recent history. Some literature therefore suggests that drinking to satisfy thirst is

the best approach for optimal performance (31, 33). This message conflicts with the current guidelines of the American College of Sports Medicine on hydration that suggest an individualized hydration protocol based on sweat rate. As hypohydration evidence based on body water loss seems to be conflicting, with critics listing thirst as the sufficient fluid-balance regulator driver. However, no study has ever examined the effect hydration on exercise performance in the absence of thirst via oropharyngeal stimulation. Thus, the purpose of this study is to examine the effect of dehydration on exercise performance and thermoregulation during exercise in the heat independently of thirst.

Methodology

Participants

Five competitive male cyclists (age: 31.6 ± 4.9 y, weight: 74.7 ± 3.7 kg, height: 180.8 ± 4.3 cm, VO_{2peak} : 57.5 ± 28 mL \cdot min $^{-1}$ \cdot kg $^{-1}$, body fat: 15.2 ± 3 %) were recruited to participate in this study. Prior to participation, each subject provided a full medical history report and was briefed on experiment protocol and potential risks. Nasogastric tube insertion procedure was explained and demonstrated. Finally an informed consent was signed by each participants.

Experimental Protocol

Screening

On the first visit, the subjects practiced the insertion of the tube as well as provided feedback of the perception of the tube, fill out Medical History. After measuring height and

body mass, body composition (Dual energy X-Ray absorptiometry, GE Healthcare, Waukesha, WI) was measured. Participants then performed an exercise test to determine maximal oxygen consumption (VO_{2peak}) on an electronically braked ergometer (Racermate Veletron, Seattle, WA) with nose clips attached while breathing in room air and exhaling into mouthpiece connected to a metabolic cart (Parvo Medics' TrueOne® 2400, Sandy, UT). Exercise started at 100 watts (W) and increased 40 W every 2 minutes until volitional exhaustion. Every 2 minutes and at exhaustion, heart rate (HR) was measured.

Familiarization

At least 24 hours after the information visit, the participant performed a familiarization visit to familiarize the participant with the experimental protocol. During the visit, the participant exercised on an electronically braked cycle ergometer for 2 hours in a warm environment (35°C) at a moderate intensity (55% VO_{2peak}). Following the 2 hours ride subjects completed a 5 km time trial performance test. The purpose of this visit was to familiarize the participant with the exercise protocol and estimate sweat rate in order to calculate accurately fluid needs during future exercise protocols.

Experimental Trials

Within 7 days following the familiarization visit, the subjects performed their experimental trial. All experimental trials were separated by 7 days to ensure recovery. Upon arrival, participants were asked to rank their thirst in a visual analog scale. After that they

voided their bladder, recorded a nude body weight and inserted a rectal thermocouple 10 cm past the anal sphincter for the measurement of core body temperature. Participants then guided a nasogastric tube through one nostril into their stomach according to the standard operating procedure. The placement of the tube was pre-measured using the length of the distance from the tip of the nose, behind one ear, to the tip of the sternum as a guide, and placement was confirmed by extracting a small amount (3 ml) of gastric fluid from the stomach and verifying the placement by testing the pH of the gastric fluid. The pH of the fluid should be 1-5.5. The mode of fluid ingestion was studied by blinding the participants to the fluid that was infused via this nasogastric tube. The nasogastric tube was equipped with an extension set so the administration of fluid took place directly behind participants. This ensured that subjects were not aware whether fluids are infused, nor the amount which was important to prevent the placebo effect (46). After the correct gastric position was confirmed, the external portion of the gastric tube was taped to the nose and then run over the left ear and toward their left shoulder. Participants were instructed with skin temperature thermocouples (iButtons; Maxim Integrated) taped on the right side of the body at four sites (calf, thigh, forearm, and chest). Participants rested in a seated position for minutes, and a 15 ml blood sample was drawn from a venipuncture in the antecubital vein.

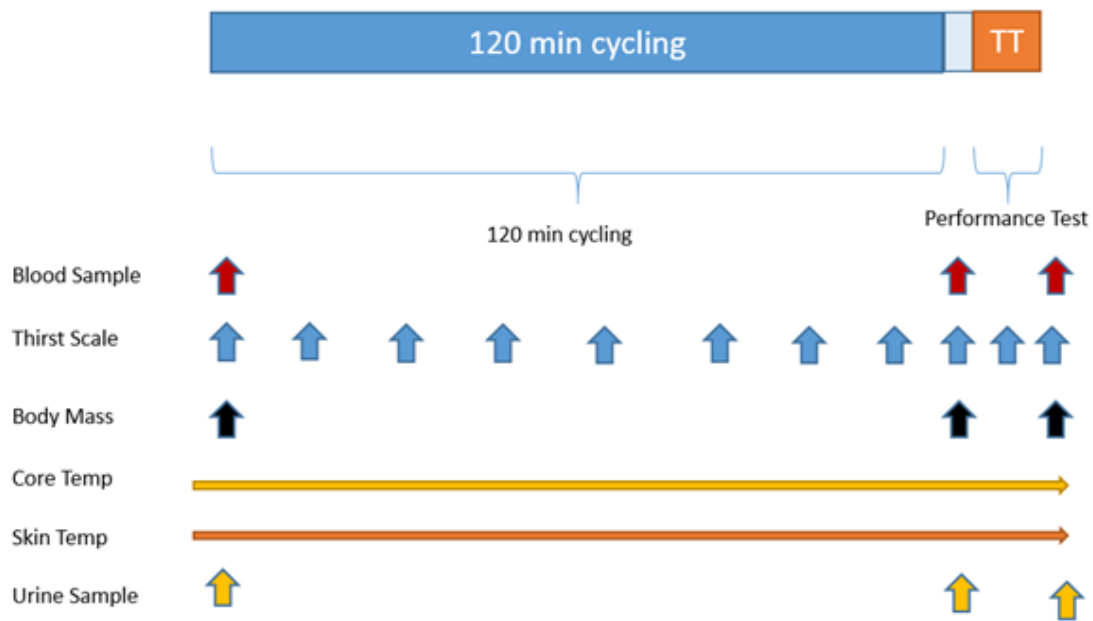
Each subject performed 2 identical experiments, differing by the mode and amount of fluid ingestion. Immediately following the instrumentation, participants saddled the cycle

ergometer, which was fitted to the participants matching the measurement of their own bike.

Participants cycled for 120 min at 55% VO_{2peak} in warm ambient conditions (35°C; 30% relative humidity) while being observed under the following interventions:

1. Dehydration without Thirst (DEH). Drinking 25 ml water every 5 min with no infusion in the nasogastric tube.
2. Euhydration not thirst (EUH). Drinking 25 ml water every 5 min while infusing in the nasogastric tube enough fluid to match sweat losses

These two trials were conducted in a randomized order.



Following the 2 hours ride subjects completed a 5 km time trial performance test.

Analytical Measurements

Blood samples were drawn immediately before and after the 2 hours cycling bout, as well as directly following the 5 km performance test. Urine samples was collected prior and

immediately after the exercise protocol. Core temperature and heart rate was recorded continuously throughout the protocol via LabChart on PowerLab. Skin temperature was calculated by Ramanathan equation (36).

$$T_{sk} = 0.3(T_{chest} + T_{forearm}) + 0.2(T_{thigh} + T_{calf})$$

Oxygen consumption (VO₂) via the metabolic cart was measured during exercise. Every 10 minutes, using a visual analog scale with a 12.5 cm line, the participant responded to perceptual questions such as “How thirsty do you feel now?”, “How dry does your mouth feel now?”, and “How full does your stomach feel now?”. After exercise, participants returned to the private bathroom, remove rectal thermometer, provided a voided urine sample undress and measure their body weight. Urine volume, urine osmolality, urine specific gravity, and urine color were measured on a voided urine sample.

Independent Variables: Modes of Fluid Ingestion,

Dependent Variables: Time to complete the 5 km performance, Body mass, Sweat rate, urine volume, urine osmolality, urine specific gravity, core temperature, skin temperature, heat rate, plasma osmolality, hematocrit , hemoglobin, serum Na, serum K, serum Cl, and thirst

Data Analysis

Only the mean values and standard error were used to describe the data since the number of subjects were small and statistical analysis was not be able to use.

Results

Body Mass and Sweat Rate

In the DEH trial, body mass before 2 hours cycling, after 2 hours cycling, and after 5K time trial, showed a gradual reduction with progressing of trials (75.1±3.2, 73.4±3.2, and 72.9±3.2 kg). However, in the EUH trial, before 2 hours cycling, after 2 hours cycling, and after 5K time trial, body mass did not show gradual reduction (74.8±3.5, 74.8±3.3, and 74.3±3.3 kg). Furthermore, sweat rate during 5K time trial in the EUH trial (2.2±0.7 L/h) was higher than that in the DEH trial (1.9±0.1 L/h). In the EUH trial, % body weight loss (-0.1±0.3 %) was lower than that in the DEH trial (-2.2±0.2 %) during 2 hours cycling (Table 1).

Table 1. Body mass, blood, and urine parameters (*N*=5).

	DEH			EUH		
	Pre	After 2hour Cycling	Post 5K T.T.	Pre	After 2hour Cycling	Post 5K T.T.
Bm (kg)	75.1±3.2	73.4±3.2	72.9±3.2	74.8±3.5	74.8±3.3	74.3±3.3
Change body mass (kg)	/	-1.7±0.1	-0.5±0.1	/	-0.1±0.2	-0.4±0.1
% Change body mass	/	-2.2±0.2	-0.7±0.1	/	-0.1±0.3	-0.6±0.1
Sweat Loss (L)	/	2.3±0.1	0.4±0.0	/	2.0±0.3	0.5±0.2
Sweat Rate (L/h)	/	1.1±0.1	1.9±0.2	/	1.0±0.1	2.2±0.7
UOsm (mOsm/kg)	516±89	465±82	/	369±64	300±60	/
USG (g/ml)	1.013±0.002	1.013±0.002	/	1.009±0.002	1.008±0.002	/
Posm (mOsm/kg)	291±2	295±3	300±3	291±1	286±2	291±1
% Change PV	/	-4.9±1.5	-7.4±2.4	/	-5.0±0.8	-4.2±1.6
Na+ (mmol/L)	138.3±1.2	141.5±1.4	142.2±1.4	139.1±0.8	137.0±0.8	137.6±0.6
Hct (%)	44±1	45±1	46±1	44±1	45±0	46±1
Hb (g/dL)	12.4±0.4	12.7±0.3	13.2±0.3	12.5±0.4	12.9±0.4	13.2±0.3
TPP (g/L)	7.0±0.1	7.9±0.1	8.3±0.1	7.2±0.1	7.7±0.2	8.0±0.0
Gastric pH	3±1	/	/	3±1	/	/

UOsm, urine osmolality; USG, urine specific gravity; POsm, plasma osmolality; % Change PV, % Change Plasma Volume; Na+, plasma sodium; Hct, hematocrit; Hb, hemoglobin;

Urine and Blood

Before the 2 hours cycling, plasma osmolality of the EUH trial and the DEH trial were the same (291.4±1.1 and 291.4±1.6 mOsm/kg), and both groups started 2 hours cycling a near euhydrated state. However, after 2 hours cycling and post 5K time trial plasma osmolality in

the EUH trial (286.3 ± 1.7 and 290.7 ± 1.4 mOsm/kg) was lower than that in the DEH trial (295.1 ± 2.7 and 299.6 ± 2.5 mOsm/kg). According to the American College of Sports Medicine (ACSM) (41) position stand, the cut-off point for a euhydrated state is lower than 290mOsmol. Thus, in the EUH trial subjects kept a near euhydrated state during the trial in contrast with the DEH trial subjects which became dehydrated. And, % change plasma volume during 5K time trial was lower in EUH trial than in DEH (-4.2 ± 1.6 and -7.4 ± 2.5). Also, before the 2 hour cycling, the sodium concentration of the EUH trial and the DEH trial were the same (139.1 ± 0.8 and 138.3 ± 1.2 mmol/L). However, after 2 hours cycling and post 5K time trial, sodium concentration in the EUH trial (137.0 ± 0.8 and 137.6 ± 0.6 mmol/L) were lower than that in the DEH trial (141.5 ± 1.4 and 142.2 ± 1.4 mmol/L).

5K Time Trial

The finishing time of the 5K in the EUH trial was faster than that in the DEH trial (12.9 ± 0.5 and 13.4 ± 0.5 min) (Fig. 1). Furthermore, the average power during the 5K time trial in the EUH trial was higher than that in the DEH trial (299 ± 15 and 281 ± 16 W) (Fig. 2).

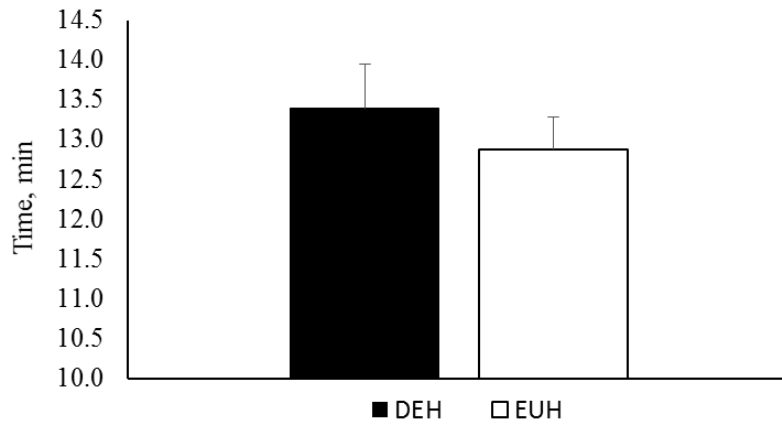


FIGURE 1-Mean 5K time trial result.

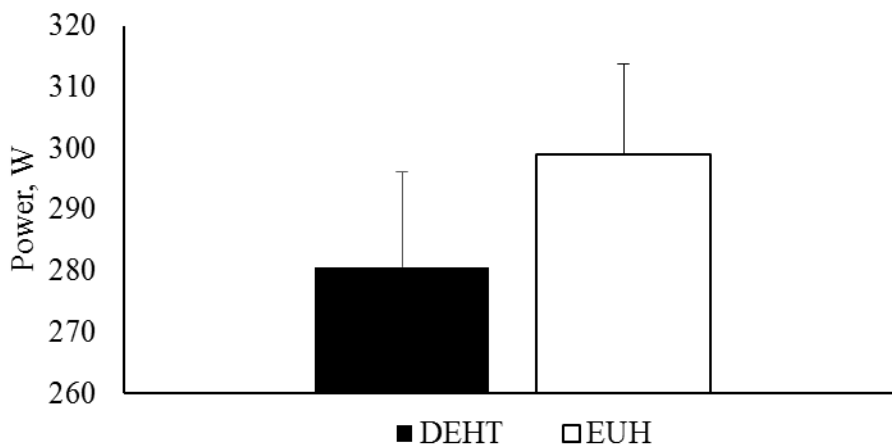


FIGURE 2-Mean power output during 5K time trial.

Thermoregulatory Markers and Heat Rate

Core temperature at the end of the 5K time trial in the EUH trial was lower than that in the DEH trial (39.0 and 39.5°C) (Fig. 4). Mean skin temperature during the 5K time trial in the EUH trial was higher than that in the DEH trial, especially at the distances of 1K 2K, and the finish (Fig. 6). The mean heart rate for both trials were the same throughout the trials. (Fig. 7 and Fig. 8).

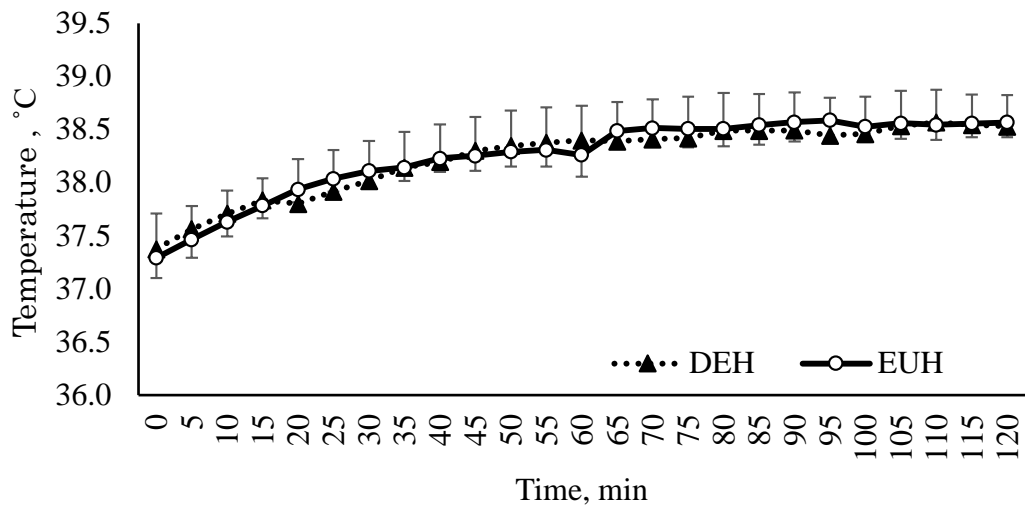


FIGURE 3-Mean core temperature during 2 hour cycling.

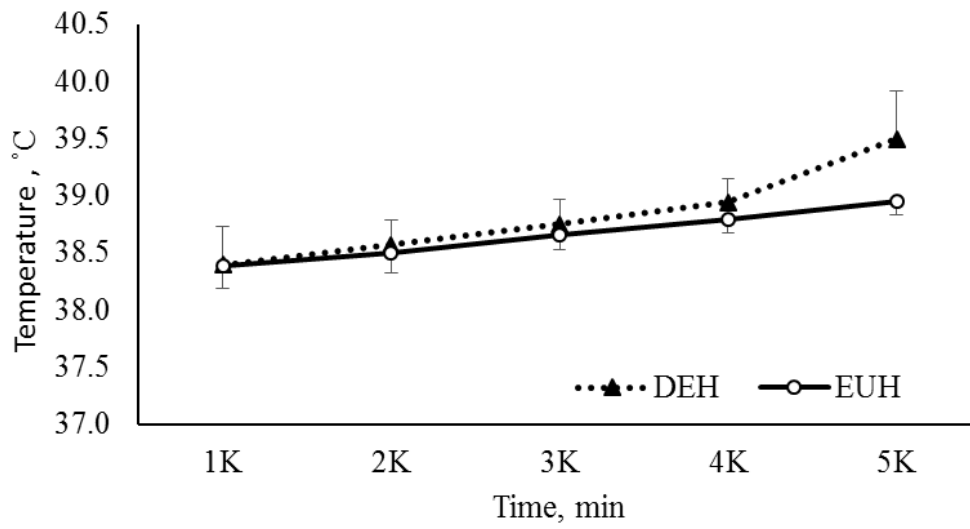


FIGURE 4- Mean core temperature during 5K time trial.

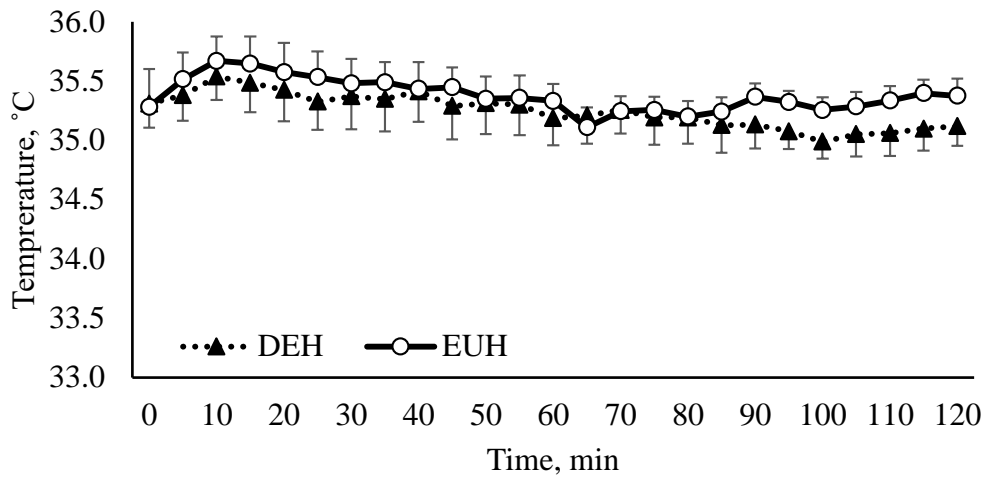


FIGURE 5-Mean skin temperature during 2 hour cycling.

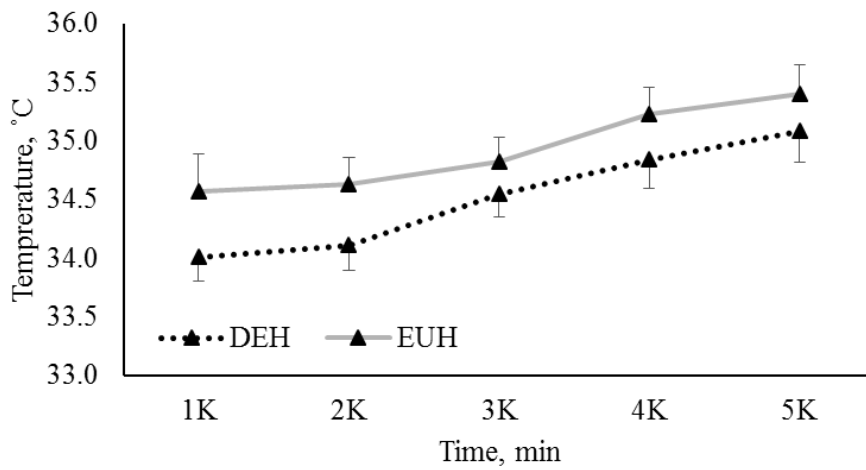


FIGURE 6-Mean skin temperature during 5K time trial.

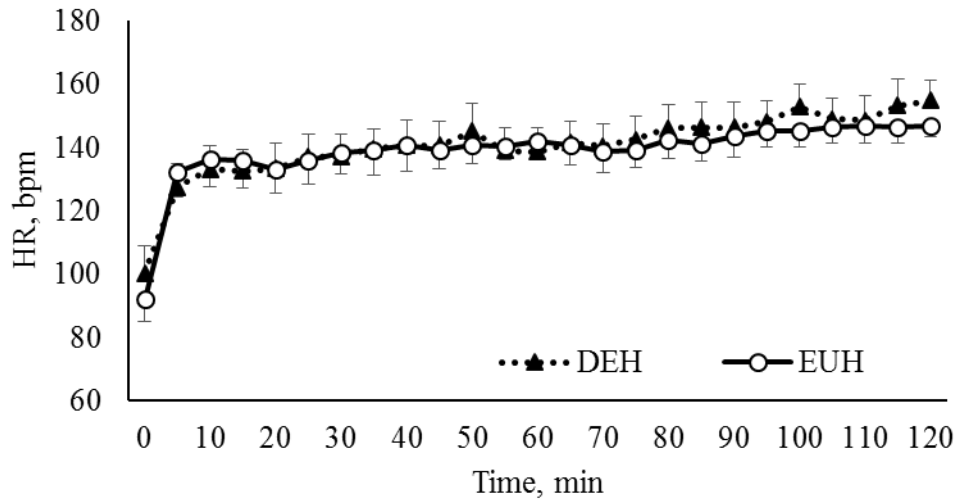


FIGURE 7-Mean heart rate during 5K time trial.

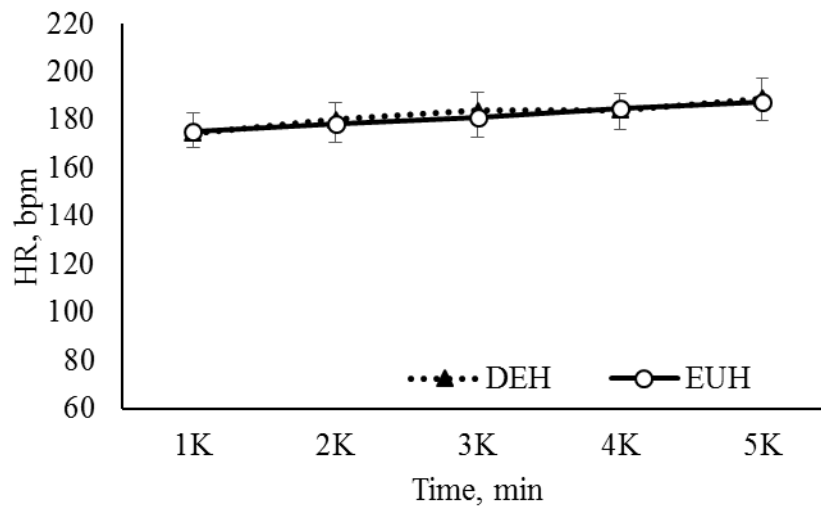


FIGURE 8-Mean heart rate during 5K time trial.

Thirst, Mouth Dryness, and Stomach Fullness

In both trials, subjects did not feel thirst during the trials (Fig. 9). There was no difference in the degree mouth dryness (Fig. 10) and stomach fullness (Fig. 11).

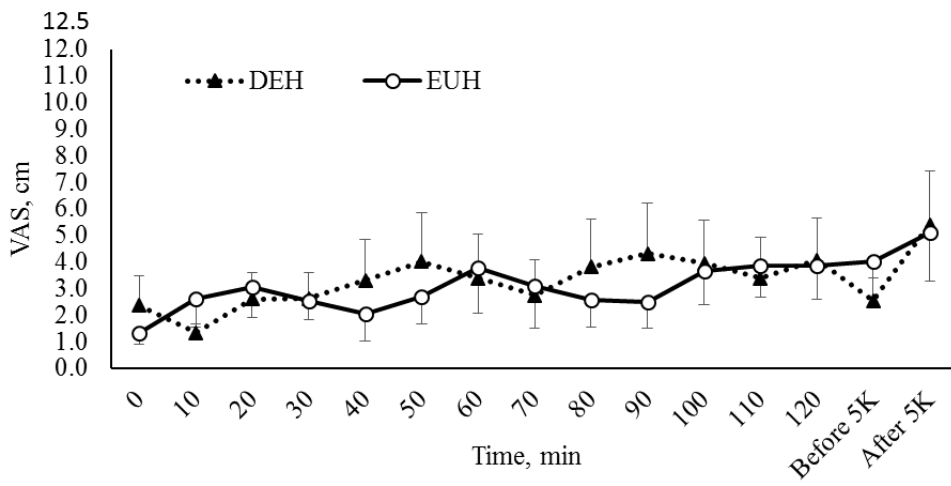


FIGURE 9-Mean value of the degree of thirst.

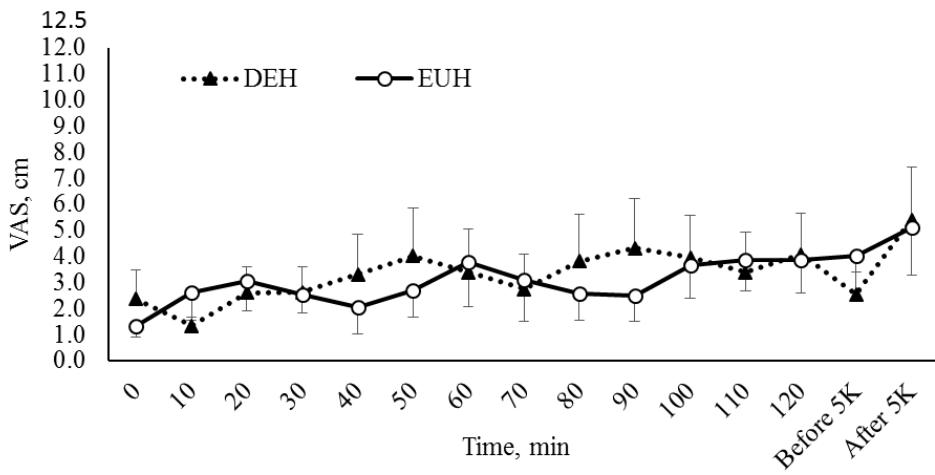


FIGURE 10-Mean value of the degree of mouth dryness.

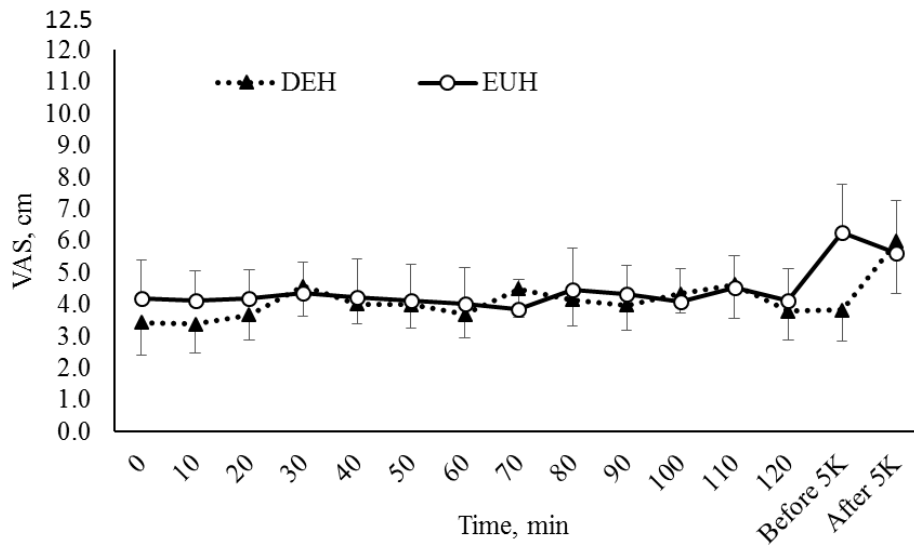


FIGURE 11-Mean value of the degree of stomach fullness.

Discussion

In the present study, we examined the effect of dehydration on performance and thermoregulation during exercise, in the heat, independently of thirst. Our data indicated that the 5K time trial performance in the EUH trial was better than that in the DEH trial, as indicated by both finishing time and power output, even though subjects did not feel thirsty on both trials. This is the first study which compared the exercise performance of subjects with different levels of actual fluid balance in the body, by using a nasogastric tube, when the subjects were not thirsty.

The sweat rate in the EUH group was higher than that in the DEH group during the 5K time trial. This shows that more heat was dissipated from sweat evaporation, and this led to a lower core temperature at the end of the EUH trial. In the DEH trial, plasma volume was lower

and plasma osmolality was higher. This higher plasma osmolality causes late responses of thermoregulatory cutaneous vasodilation and sweating by elevating their thresholds (15, 45). Thus, dehydration impaired heat dissipation from sweat evaporation (19, 43), led to increasing further heat storage by the body (14, 30). Also, higher core temperatures leads to a higher percentage of blood which is going to the skin and it caused a lower central blood volume (38). Thus, stroke volume was also going down, and it caused lower cardiac output. This effects is bigger when you are dehydrated (21). Furthermore, decreasing plasma volume leads to decreasing stroke volume by decreasing venous return and increasing heart rate. This causes a reduction of cardiac output (20, 39, 44). Dehydration of 2% to 4% body mass reduces VO₂max (40). For all these reasons exercise performance was decreased in the DEH group.

We found that the fluid status on the body directly influences the cycling performance in the heat. In other words, if you are dehydrated, even though you do not feel thirsty, exercise performance should be decreased. When you are dehydrated and plasma osmolality and AVP goes up, then you feel thirsty (26). Then, after drinking water, oropharyngeal sensors works and inhibit AVP secretion and thirst before absorption of water (34) even if you drink a small amount of water (4). Thus, in some case even though you do not feel thirsty, your body might be still dehydrated. As stated previously, dehydration of greater than 2% body weight decreases aerobic performance in a hot environment (41). Moreover, as it is mentioned above, thirst is inhibited before absorption of water giving the possibility that even though your body is still

dehydrated, you do not feel thirst. This research combined these concepts and we isolated a decrease in performance is due to dehydration, not thirst.

Arnaoutis et al. (4) showed through activation of the oropharyngeal receptors, dehydrated subjects increased exercise performance. However, my research has shown that even if the oropharyngeal receptors are activated, dehydrated subjects still show decreased exercise performance. Thus, the activation of the oropharyngeal receptors and the effects of dehydration have individual impacts on exercise performance. Further research is needed to state with certainty which effect is larger and how the oropharyngeal receptor influences on the exercise performance.

Conclusion

In the EUH group, the 5K time trial performance was higher than in the DEH group even though both groups did not feel thirsty. Thus, the fluid balance on the body by itself influences the cycling performance, independently of thirst. At the end of the time trial, the core temperature of the EUH trial was higher than that of the DEH trial. Furthermore, during 5K time trial the sweat rate of the EUH trial was bigger than that of the DEH trial. By dissipating heat resulted from sweat evaporation, the core temperature was kept lower. It is thought that for these reasons the EUH group demonstrated better exercise performance.

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October 14, 2015

MEMORANDUM

TO: J.D. Adams Lisa Jansen
Alison Schroeder Jillian Fry
Tracie Kirkland Jordan Smith
Yasuki Sekiguchi Cameron Nichols
Stavros Kavouras

FROM: Ro Windwalker
IRB Coordinator

RE: New Protocol Approval

IRB Protocol #: 15-02-507

Protocol Title: *Effect of Mode of Fluid Ingestion on Cycling Performance*

Review Type: EXEMPT EXPEDITED FULL IRB

Approved Project Period: Start Date: 10/14/2015 Expiration Date: 09/13/2016

Your protocol has been approved by the IRB. Protocols are approved for a maximum period of one year. If you wish to continue the project past the approved project period (see above), you must submit a request, using the form *Continuing Review for IRB Approved Projects*, prior to the expiration date. This form is available from the IRB Coordinator or on the Research Compliance website (<https://vpred.uark.edu/units/rscp/index.php>). As a courtesy, you will be sent a reminder two months in advance of that date. However, failure to receive a reminder does not negate your obligation to make the request in sufficient time for review and approval. Federal regulations prohibit retroactive approval of continuation. Failure to receive approval to continue the project prior to the expiration date will result in Termination of the protocol approval. The IRB Coordinator can give you guidance on submission times.

This protocol has been approved for 30 participants. If you wish to make *any* modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.