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Original Article

Does anticipatory sweating occur prior to fluid consumption?

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Abstract: The purpose of this study was to examine if anticipatory sweating occurs prior to fluid consumption in dehydrated subjects. It was hypothesized that there would first be an anticipatory response to the sight of water, and then with drinking, a second response caused by mechanical stimulation of oropharyngeal nerves. Dehydrated subjects (n=19) sat in a heat chamber for 30 minutes. At minute 15, a resistance hygrometer capsule was attached and sweat rate was measured every 3 seconds. At minute 35:00, a researcher entered the room with previously measured water (2 ml/kg euhydrated body weight). At minute 35:30, the subject was allowed to drink. Data collection continued for 5 minutes post consumption. As expected, 16 of the 19 subjects responded to oropharyngeal stimuli with increased sweat rate. However, the new finding was that a majority (12 of 19) also showed an anticipatory sweating response prior to fluid consumption. Subjects were divided into 4 groups based on the magnitude of the sweating response. Strong responders' (n=4) anticipatory response accounted for 50% or more of the total change in sweat rate. Moderate responders' (n=4) anticipatory response accounted for 20%-49%. Weak responders' (n=4) anticipatory response accounted for 6-20%. Finally, non-responders (n=7) showed no anticipatory response. Although previously noted anecdotally in the literature, the current study is the first to demonstrate that measurable anticipatory sweating occurs prior to fluid intake in dehydrated subjects in a significant percentage of the population. Such data suggests that cerebral input, like oropharyngeal stimulation, can temporarily remove the dehydration-induced inhibition of sweating.

Keywords: Dehydration, sweating, oropharyngeal stimulation, fluid intake, anticipatory response

Introduction

Numerous studies [1-6] have demonstrated that increases in either skin or core body temperature can initiate a rapid and substantial sweat response in humans which, in turn, leads to evaporative cooling. However, the normal sweating response is attenuated with dehydration both in terms of the threshold for the onset of sweating [7] and the sweat rate relative to internal temperature [2, 8]. This is believed to be related to a decrease in blood volume [9] and/or an increase in plasma osmolality [10, 11], both of which have been shown to inhibit sweat production.

Interestingly, studies in both dogs [12] and humans [13, 14] have shown that fluid consumption causes a rapid reduction in osmoregulatory responses to dehydration (e.g., thirst and plasma vasopressin concentration) before there were any changes in plasma osmolality or blood volume. Further studies in both goats [15] and humans [11, 16, 17] have demonstrated that drinking removes the dehydration-induced, osmotic inhibition of sweating. Taken together, these studies suggest that the rapid response is caused by the mechanical stimulation of oropharyngeal afferent nerves. However a close examination of the previously published data makes it unclear exactly when the actual increase in sweat rate occurs relative to the initiation of drinking. For example, as an aside to their larger conclusions, Senay et al. (1964) observed that there may be an anticipatory sweat response, prior to the actual initiation of drinking, in some dehydrated subjects. Interestingly, recent research [18] found changes in skin blood flow based on anticipation of reward and/or punishment. In combination, these findings suggest that there may be an anticipatory sweat rate response to visual and/or auditory stimulation (i.e. the sight and/or description of water) in dehydrated subjects. However, a review of the literature suggests that no study has previously been published that examines the potential of an anticipatory sweat response in humans.

Therefore, the purpose of this study was to examine if anticipatory sweating occurs prior to fluid consumption in dehydrated subjects. It was hypothesized that there first would be an anticipatory response to the sight and description of water, and then with drinking, a second response caused by mechanical stimulation of the oropharyngeal afferent nerves.

Materials and methods

The subjects for this study were 14 male and 5 female volunteers with a mean (± SD) age of 23.7 ± 3.6 years and a mean weight of 80.1 ± 15.0 kg. The study was approved by the San Diego State University IRB and prior to testing and data collection and signed informed consent was obtained. Subjects reported to the lab two times, approximately 3-7 days apart at the same time of day. The sweat rate test was conducted in a heat chamber set at 35°C and 40% rH. For all subjects, a euhydrated weight was obtained on the first visit. Each day the subject was initially weighed on a balance beam scale to the nearest 0.1 kg, and a urine sample was collected and measured for specific gravity to ensure that dehydration levels had been achieved. Additionally, urine was analyzed to ensure that none of the female subjects were pregnant. Finally, following seated rest, a blood sample was taken via finger stick and frozen for later analysis of blood osmolality using a vapor pressure osmometer (Wescor, Logan, UT).

Prior to their first visit each subject was instructed via email to drink one or more liter(s) of water twelve hours before testing and an additional one liter of water three hours prior to testing to ensure they reported to the laboratory fully euhydrated. Euhydration was confirmed by a urinary specific gravity of ≤ 1.008. The subject's euhydrated weight was used for the dehydration trial to ensure dehydration of two percent (2%) or greater. Prior to the second day the subject was instructed to avoid any liquids for twelve hours before testing to promote a dehydration level of 2% or greater. Dehydration was confirmed by an initial body weight which was 2% less than the euhydrated weight combined with a urinary specific gravity of > 1.016. If these conditions were not met, the subject exercised in the heat chamber for fifteen minutes on a cycle ergometer set to a workload of 1W/kg body weight. This was repeated until the subject achieved a weight which was 2% less than the euhydrated value. Once the subject reached 2% dehydration they rested for at least 15 min before the trial began.

For the dehydrated trial, subjects sat in a heat chamber for 30 minutes to allow sweat rate to stabilize. At minute 15, a resistance hygrometer capsule (Thermo-hygrometer, VWR Scientific, Irvine, CA) was secured two inches distally from the elbow on the left side. At minute 30, data collection began with one data point collected every three seconds. At exactly minute 35:00 a researcher entered the room with a cup of previously measured cold water (2 ml/kg euhydrated body weight). For 30 seconds they described the water saying "We have some cold water for you to drink. We kept it in the refrigerator so that it would be very refreshing for you. If you look closely you can see condensation on the cup." The researcher then showed the subject the water, before asking what color straw the subject would like (red, yellow, green and blue were available). After the subject had chosen a straw, the researcher slowly got the straw, bent it into the drinking position and said "This water is going to taste so good. I'm going to hold it for you and I need you to drink the whole cup without stopping". Both the choices of straw color, and the statements, were used to ensure that a full thirty seconds passed to allow the subject to register an anticipatory response. At exactly min 35:30 the subject was allowed to drink. The act of drinking took 6-9 seconds in all subjects. Data collection continued for five minutes post-water consumption.

Statistical comparisons between the euhydrated and dehydrated conditions were made using paired t-tests with a Bonferroni correction. Statistical comparisons between the strong, moderate and weak response groups were made using a one-way analysis of variance and Tukey's post-hoc comparisons. Significance was set at the $P < 0.05$ level.

Table 1. Individual percent dehydration and anticipatory/oropharyngeal sweat responses expressed as a percentage of total sweating response

Subject Number	% Dehydration	Response Type	% Response Anticipation	% Response Oropharyngeal
1	2.77	Strong Responder	54	46
2	3.36	Non-Responder	0	100
3	3.26	Non-Responder	0	100
4	2.10	Moderate Responder	38	62
5	2.32	Weak Responder	7	93
6	3.40	Non-Responder	0	0
7	2.10	Weak Responder	12	88
8	3.30	Moderate responder	23	77
9	2.25	Strong Responder	63	37
10	2.00	Non-Responder	2	98
11	3.95	Moderate Responder	44	56
12	2.09	Non-Responder	0	100
13	2.00	Strong Responder	85	15
14	2.01	Moderate Responder	46	54
15	3.05	Non-Responder	0	100
16	3.10	Weak Responder	8	92
17	2.70	Strong Responder	100	0
18	3.50	Weak Responder	6	94
19	3.50	Non-Responder	0	0

Results

Table 1 shows the percentage dehydration, and the anticipatory and oropharyngeal sweat rate response expressed as a percentage of total sweat response for all 19 subjects. When fully euhydrated, subjects had a mean weight of 80.10 ± 15.01 kg and a mean urine specific gravity of 1.004 ± 0.003. At the start of the dehydrated trial, subjects were an average of 2.31% (± 0.83%) dehydrated with a mean weight of 78.2 ± 14.7 kg and a mean urine specific gravity of 1.021 ± 0.007. Both of these values were significantly ($P < 0.05$) different than euhydrated values. Due to insufficient initial dehydration, 6 of the 19 subjects were required to exercise in the heat chamber for 15 minutes and 2 for 30 minutes. Following further dehydration mean weight was 77.8 ± 14.7 kg, with all subjects being greater than 2% dehydrated. Dehydration status was further confirmed using blood osmolality which significantly ($P < 0.05$) increased from a mean of 285 ± 8 mmol/kg when euhydrated to 292 ± 13 mmol/kg prior to the start of the dehydrated trial.

As can be seen in **Table 1**, 16 of the 19 subjects responded to drinking induced oropharyngeal stimuli with an increased sweat rate. However, the new finding was that a majority (12 of 19) of the subjects also showed an anticipatory sweat response. Furthermore, the magnitude of the anticipatory response was quite variable between the 12 subjects. Thus, subjects were divided into 4 groups based on the magnitude of their anticipatory sweating response. Strong responders' (n=4) whose anticipatory sweating accounted for 50% or more of the total change in sweat rate. Moderate responders' (n=4) whose anticipatory response accounted for 20% -49% of the total change in sweat rate. Weak responders' (n=4) whose anticipatory response accounted for 6-20% of total change in sweating. The mean ± SD anticipatory sweating response for the strong, moderate and weak responders (n=4 per group) was 76 ± 21%, 38 ± 10%, and 8 ± 3%, respectively. They were all significantly different ($P < 0.05$) from each other. Finally, non-responders (n=7) who showed no anticipatory response. Mean for the both the strong and moderate responders were significantly different that the non-responders. Representative graphs for the 3 responding groups are presented in **Figures 1-3**.

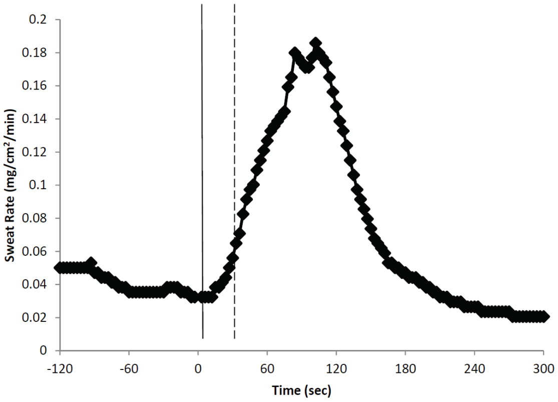

Figure 1. Representative subject (#7) from the weak responder group. The first solid line denotes when water was introduced and the second dashed line denotes when the subject actually started drinking. Data was collected and plotted every 3 seconds.

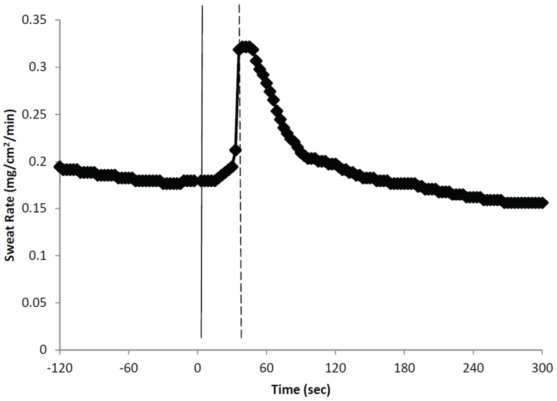

Figure 2. Representative subject (#8) from the moderate responder group. The first solid line denotes when water was introduced and the second dashed line denotes when the subject actually started drinking. Data was collected and plotted every 3 seconds.

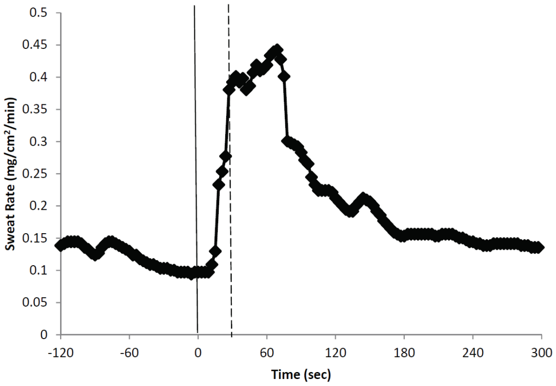

Figure 3. Representative subject (#13) from the strong responder group. The first solid line denotes when water was introduced and the second dashed line denotes when the subject actually started drinking. Data was collected and plotted every 3 seconds.

Discussion

Although previously noted anecdotally in the literature [17] the current study is the first to clearly demonstrate that measurable anticipatory sweating occurs in dehydrated subjects in a significant percentage of the population prior to actual fluid intake. Furthermore, the magnitude of the anticipatory sweat response is quite variable, ranging from 0% in non-responders to 100% of the total sweating response induced with fluid intake. The current study would suggest that the magnitude of the anticipatory sweating response is evenly distributed as 21% had a large response (> 50%), 21% had a moderate response (20-49%), 21% had a weak response (6-20%) and 37% had no response.

This study supports previous findings that the cerebral cortex and/or limbic system may play a key role in the control of sweat rate. Indeed, increases in sweat rate on both glabrous and non-glabrous skin have been observed in response to emotional stressors as diverse as mental arithmetic [19] and electrical shocks [20] in the absence of increases in either core or skin temperature. Likewise, the literature suggests that cerebral inputs can strongly moderate many of the instinctive visceral responses to “fight or flight” stimuli, including sweating [21].

In the current study the subjects were dehydrated and hyper- osmotic prior to water intake, and thus, sweat rate was most likely inhibited in the hypothalamus. Past studies in humans [11, 16, 17] have clearly demonstrated that drinking removes this dehydration-induced, osmotic inhibition of sweating prior to changes in plasma osmolarity or blood volume. The current data strongly suggests that in a majority of cases (63%) cerebral stimuli (i.e. visual and auditory) elicited an anticipatory increase in sweat rate, prior to actual fluid consumption. This suggests cerebral input, like oropharygeal stimulation, can temporarily remove the dehydration-induced osmotic inhibition of sweating. It appears that cortical input works via the hypo-

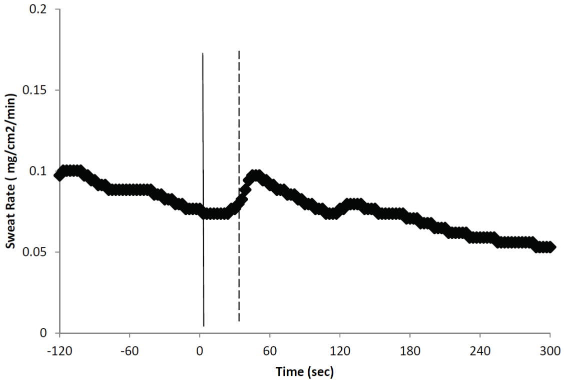

Figure 4. Representative pilot data from euhydrated subject showing that with euhydration there is neither an anticipatory nor an oropharyngeal response to fluid consumption. The first solid line denotes when water was introduced and the second dashed line denotes when the subject actually started drinking. Data was collected and plotted every 3 seconds.

thalamus and is not a direct reflex, as pilot work for the current study showed that anticipatory sweating does not occur in euhydrated individuals (see **Figure 4**).

There was no apparent relationship between the degree of dehydration and the anticipatory sweating response. For example, as can be seen in **Table 1**, subject 13 was only 2% dehydrated yet had a strong anticipatory sweating response. Conversely, subject 19 was 3.5% dehydrated from the overnight water depravation period yet had no anticipatory sweating.

Lastly, it is important to note that in agreement with past studies, the increase in sweat rate observed with drinking was short lived. Indeed, in 16 of the 19 subjects sweat rate had returned to baseline or below within five minutes of finishing drinking. This suggest s that the body can react in a rapid, feed forward manner in response to both mental (anticipatory) and mechanical (oropharyngeal receptors) cues that hydration is forthcoming.

In conclusion, the current study is the first to clearly demonstrate that measurable anticipatory sweating occurs prior to fluid intake in dehydrated subjects in a significant percentage of the population. This suggests cerebral input, like that of oropharygeal stimulation, can temporarily remove the dehydration-induced osmotic inhibition of sweating.

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