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Thirst responses following high intensity intermittent exercise when access to *ad libitum* water intake was permitted, not permitted or delayed

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HIGHLIGHTS

- HIIE caused an increase in blood lactate concentrations, raising serum osmolality.
- Despite decreased serum osmolality during recovery, thirst remained until satiated.
- 30 min delay in drinking resulted in a similar volume consumed immediately post-HIIE.

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ABSTRACT

An increase in subjective feelings of thirst and *ad libitum* drinking caused by an increase in serum osmolality have been observed following high intensity intermittent exercise (HIIE) compared to continuous exercise. The increase in serum osmolality is closely linked to the rise in blood lactate and serum sodium concentrations. However, during an ensuing recovery period after HIIE when serum osmolality will decrease, the resultant effect on sensations of thirst and subsequent water intake is unclear. Therefore the aim of the study was to assess the sensations of thirst and subsequent effect on *ad libitum* water consumption when water intake was immediately allowed, delayed or prevented following a period of HIIE.

Methods: Twelve males (26 ± 4 years, 80.1 ± 9.3 kg, 1.81 ± 0.05 m, $\dot{V}O_{2peak}$ 60.1 ± 8.9 ml·kg^{-1}·min^{-1}) participated in three randomised trials undertaken 7–14 days apart. Participants rested for 30 min then completed a 60 min HIIE exercise period (20 × 1 min at 100% $\dot{V}O_{2peak}$ with 2 min rest) followed by 60 min of recovery, during which *ad libitum* water intake was provided immediately (W), delayed until the final 30 min (W30) or not permitted (NW). Body mass was measured at the start and end of the trial. Blood lactate and serum sodium concentrations serum osmolality and sensation of thirst were measured at baseline, immediately post-exercise and during the recovery.

Results: Body mass loss was different between all trials (W: 0.25 ± 0.45, W30: 0.49 ± 0.37, NW: 1.29 ± 0.37%; $p < 0.05$). Sensations of thirst peaked post-exercise and decreased in W and W30 following water ingestion ($p < 0.05$). Total voluntary water intake was greater in W trial (0.846 ± 0.417 *vs.* 0.630 ± 0.277 l; $p < 0.05$) but was similar during the first 30 min period of allowed drinking (0.618 ± 0.297 *vs.* 0.630 ± 0.277 l; $p > 0.05$). Serum osmolality (299 ± 6 *vs.* 298 ± 5 *vs.* 298 ± 3 mOsmol·kg^{-1}), blood lactate (7.1 ± 1.1 *vs.* 7.2 ± 1.1 *vs.* 7.1 ± 1.2 mmol·l^{-1}) and serum sodium concentrations (142 ± 2 *vs.* 145 ± 2 *vs.* 145 ± 2 mmol·l^{-1}) peaked post-exercise (W *vs.* W30 *vs.* NW; $p < 0.05$) but were not different between trials ($p > 0.05$).

Conclusions: Sensations of thirst were increased following HIIE and remained until satiated by water intake. This was despite the likely primary stimulus, serum osmolality, decreasing during the recovery period following a post-exercise peak. A combined effect of reduction in blood lactate and serum sodium concentrations, restoration of plasma volume and water intake contributed to the similar decrease in serum osmolality observed throughout the trials.

1. Introduction

Thirst is an innate behaviour that drives an episodic desire to drink and is normally an adequate stimulus to maintain a state of

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euhydration under resting conditions [1]. However, when the body is placed under physiological stress, the thirst response often results in sufficient water consumed to satiate sensations of thirst but not to completely replace fluid losses (involuntary dehydration). Stricker and Verbalis [2] proposed two mechanisms relating to the generation of thirst sensations and desire to drink: hyperosmolality and hypovolaemia, whilst sensations of dry mouth have also been proposed as a mechanism of thirst [3–5].

In relation to hyperosmolality, serum osmolality thresholds at rest have been identified that drive arginine vasopressin (AVP) release (approximately 285 $mOsmol \cdot kg^{-1}$; [6]) and sensations of thirst (approximately 290 $mOsmol \cdot kg^{-1}$; [7]), whilst it has also been suggested that changes in serum osmolality of approximately 5 $mOsmol \cdot kg^{-1}$ will stimulate sensations of thirst [8]. Elevations in serum osmolality are detected by osmoreceptors in the organum vasculosum of the lamina terminalis and the subfornical region within the brain. Both of these circumventricular organs lack a blood–brain barrier, therefore allowing hormonal and osmotic stimuli to act [9]. Serum osmolality levels above the threshold for thirst will usually occur due to changes in cell tonicity, but can also arise due to the influence of blood lactate concentrations caused by a period of high intensity intermittent exercise (HIIE) [10]. Hypovolaemia is a common consequence of most exercise intensities, and will primarily occur due to ongoing sweat losses resulting from an effort to maintain body temperature. However, the relatively short duration of HIIE bouts may prevent water losses from reaching a sufficient level to stimulate sensations of thirst (approximately 0.8% body mass loss; [11]), therefore any change in blood volume following HIIE is likely to arise from changes in blood pressure and subsequent movement of water to the interstitial space [12].

Following HIIE, water moves from the vascular to the interstitial and intracellular spaces [12–14]. Serum osmolality and subsequent arginine vasopressin release will increase in relation to the increase in blood lactate concentration [12,14,15,16]. It has been hypothesised that the negatively charged lactate ions reduce sodium release from the vascular space thus increasing serum sodium concentrations and subsequent osmolality levels [14]. Therefore HIIE may in fact elevate serum osmolality above the threshold for thirst, and consequently influence drinking behaviour independent of associated water losses.

An increase in *ad libitum* drinking (total volume consumed) has been observed following a period of HIIE compared to continuous exercise [10]. The observed increase in water intake was associated with an increase in blood lactate, serum sodium and vasopressin concentrations, an increase in serum osmolality and a tendency for greater subjective feelings of thirst. During the recovery period access to water intake was allowed immediately after exercise. It was therefore difficult to determine if thirst and subsequent drinking behaviour was influenced by the reduction of factors that stimulated sensations of thirst (*i.e.* serum osmolality and associated variables), the satiation of thirst sensations or a combination. Although not measured, it was also possible that the increased respiration rate during the HIIE may have contributed to the increases in mouth dryness and thirst observed by Mears & Shirreffs [10]. By delaying and also preventing access to *ad libitum* water intake it is possible the mechanisms relating to thirst and serum osmolality can be better understood and a clearer insight into role played by HIIE on drinking behaviour can be established.

The aim of the study was to assess the sensations of thirst and the subsequent effect on *ad libitum* water intake during a recovery period following HIIE, when access to water was allowed immediately, delayed or prevented. It was hypothesised that sensations of thirst would increase, due to an increase in serum osmolality and that this would drive drinking behaviours. Delaying or preventing drinking would not satiate sensations of thirst.

2. Methods

2.1. Participants

Twelve healthy male participants (age 26 ± 4 years, mass 80.1 ± 9.3 kg, height 1.81 ± 0.05 m, $\dot{V}O_{2peak}$ 60.1 ± 8.9 $ml \cdot kg^{-1} \cdot min^{-1}$) took part in three experimental trials, in a randomised order. The experimental protocol was explained to all participants verbally and in writing and written informed consent was provided. The experiment was approved by the Loughborough University Ethical Advisory Committee.

2.2. Experimental protocol

Participants visited the laboratory on five separate occasions for a peak oxygen uptake ($\dot{V}O_{2peak}$) test, a familiarisation trial and three experimental trials differing in the time period during which *ad libitum* water intake was allowed following exercise; water permitted throughout the entire recovery period (W), water delayed until 30 min after exercise until the end of the recovery period (W30) and no water permitted at all during the recovery period (NW).

The first visit involved a discontinuous incremental test to volitional fatigue undertaken on an electrically braked cycle ergometer (Lode Corival; Lode BV, Groningen, Netherlands) was used to determine peak power and $\dot{V}O_{2peak}$. Expired gas was collected for 1 min at the end of each 4-min stage. The familiarisation trial was identical to the W trial, and intended to inform the participants of the experimental procedures employed throughout the study. Participants were asked to record their dietary intake in the 24 hours prior to the first experimental trial (food and drink consumed, amount and method of preparation) and refrain from strenuous physical activity and consumption of alcohol. For each subsequent trial they were asked to repeat this. Participants were asked to arrive at the laboratory after an overnight fast with the exception of consumption of 500 ml of water ingested two hours before arrival at the laboratory to ensure they were in a euhydrated state.

Experimental trials began in the morning at the same time for each participant and were separated by a period of 7–14 days. A schematic outline of the trial is shown in Fig. 1. Experimental trial order was randomised and participants were not aware of which trial they were participating in when arriving at the laboratory for the first and second experimental trials.

On arrival at the laboratory, participants voided and asked to empty their bladder; total urine volume was measured and a 5 ml aliquot retained for analysis. Nude body mass was measured. Participants were asked to insert a rectal thermistor 10 cm past the anal sphincter, and a heart rate monitor (Polar Vantage; Kempele, Finland) was positioned. Throughout the trials, core (T_c) and skin (T_{sk}) temperature were measured continuously, and data were averaged every 10 min (BIOPAC MP100 System; BIOPAC, Santa Barbara, CA, USA). Mean weighted skin temperature was calculated using the formula outlined by Ramanathan [17]. Participants rested in a seated position for 30 min in a comfortable environment (22.3 ± 0.4 °C and 47 ± 9% relative humidity; RH). Every 10 min during rest, exercise and recovery heart rate was recorded. Following the 30 min seated rest, participants completed two 100 mm visual analogue subjective feeling questionnaires relating to symptoms of thirst and dry mouth (0 mm = not at all thirsty/mouth not at all dry, 100 mm = very thirsty/mouth very dry). During the baseline period a 21 g cannula (Surflo, Terumo, Leuven, Belgium) was inserted into a superficial vein on the forearm to allow venous blood sampling. At the end of the rest period a baseline blood sample (7.5 ml) was collected.

Participants then completed 60 min of HIIE, comprising of repeated cycles of 1 min of cycle exercise at a power output equal to the maximum power achieved during the $\dot{V}O_{2peak}$ test, followed by 2 min rest. This was undertaken in 23.0 ± 0.4 °C and 48 ± 10% RH. During the 60-min period this pattern of activity was repeated 20 times. A blood