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The efficacy of saliva osmolality as an index of hydration state: is it worth the spit?

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Abstract
Water represents ~60% of the body mass, ranging from 40-80% across individuals. In sedentary people, about 5-10% of this water is turned over daily, with urine flows averaging ~1.5 L.day-1 for normally hydrated individuals. However, when working in stressful environments for extended durations, particularly when wearing personal protective equipment, fluid losses via sweat secretion are dramatically elevated, and can approach 8-16 L.day-1. Indeed, during a moderate exercise-heat stress, whole-body sweat rates typically range between 1-1.5 L.h-1, and sustained and undefended fluid loss at this rate significantly impacts upon body water content, resulting in a 1% body-water loss for every 30-40 min of steady-state sweating without fluid replacement.

Keywords
saliva, osmolality, index, hydration, state, worth, spit, efficacy

Disciplines
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THE EFFICACY OF SALIVA OSMOLALITY AS AN INDEX OF HYDRATION STATE: IS IT WORTH THE SPIT?

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INTRODUCTION

Water represents ~60% of the body mass, ranging from 40-80% across individuals. In sedentary people, about 5-10% of this water is turned over daily, with urine flows averaging ~1.5 $L.day^{-1}$ for normally hydrated individuals. However, when working in stressful environments for extended durations, particularly when wearing personal protective equipment, fluid losses via sweat secretion are dramatically elevated, and can approach 8-16 $L.day^{-1}$. Indeed, during a moderate exercise-heat stress, whole-body sweat rates typically range between 1-1.5 $L.h^{-1}$, and sustained and undefended fluid loss at this rate significantly impacts upon body water content, resulting in a 1% body-water loss for every 30-40 min of steady-state sweating without fluid replacement.

These dehydration rates are well tolerated within healthy, low-risk individuals who commence such exposures when appropriately hydrated, particularly when dehydration is transient (1-6 h). In fact, the thirst mechanism is not activated until one incurs a water deficit of ~2%, and deficits of up to 4% are often observed across many sports, with losses in excess of 5% frequently observed in highly motivated individuals. Even within the general community, one routinely sees people with water deficits up to 3-4%.

Whilst there is also little doubt that transient, and less extensive dehydration (<10%) is well tolerated, though unpleasant, in healthy, low-risk individuals, protracted and extensive dehydration can be detrimental, since it impairs cardiovascular and renal functions, and elicits a wide range of symptoms, including weakness and lassitude, nausea and general malaise. Indeed, it can be lethal, and the implementation of early warning strategies to identify its onset is deemed to be essential for some physically demanding jobs.

Of the methods developed to assess hydration state (Taylor *et al*., 2009b), one of the most practical indices for use with large groups of people wearing protective clothing, centres around the use of saliva osmolality (concentration). Unfortunately, the efficacy of this technique has only been evaluated at hydration levels representing water deficits up to 3% (Walsh *et al*., 2004a, 2004b). Thus, in this project, the validity and sensitivity of this method was evaluated across a wide range of dehydration levels (1-7% water deficit) across 36 trials.

METHODS

Twelve physically active men participated in three trials, presented in the following order: 7% dehydration, 3% dehydration with partial rehydration, and 7% repeated dehydration. In each trial, subjects performed intermittent cycling in hot-humid conditions maintained at 35.6°C (±0.4) and 56.0% humidity (±1.0), in which the black globe temperature averaged 35.6°C (±0.3) and wind

velocity was less than 0.05 $m.s^{-1}$. Subjects wore only shorts and running shoes. Tests were conducted at approximately the same time of day for each person, using fully-hydrated subjects: pre-experimental mean urine specific gravity across all trials was 1.006 (SD 0.005).

The objective of this project was to gradually dehydrate subjects to both a 3% and a 7% reduction in body mass (water deficit). This was achieved using the controlled-hyperthermia (isothermal clamping) technique in hot-humid conditions to elevate and clamp the core temperature of each subject at approximately 38.5^{o}C.

Hydration state was determined from the change in body mass, with physiological responses and body-fluid samples collected at the attainment of each 1% dehydration target. An isotonic mouth rinse, drink (50 mL (trials 1 and 3) or 60% of the previous mass loss (partial rehydration trial)), and food (banana and biscuit: total mass: 90 g) were provided after reaching each of these targets. Sublingual, parotid and expectorated saliva samples were collected prior to each trial, on reaching each of the dehydration targets, and during recovery (with partial rehydration). Saliva osmolality was measured from 20-µL samples using a freezing-point osmometer (Fiske One-Ten Osmometer, Fiske Associates, Norwood, MA, U.S.A.), as low saliva volumes were obtained towards the end of the 7% dehydration trials.

RESULTS AND DISCUSSION

The pre-experimental standardisation procedures ensured that every subject presented in a euhydrated state (urine specific gravity: 1.013-1.021), and for >80% of the trials, subjects presented in a well-hydrated condition (<1.013). Prior to commencing each trial, data were collected while subjects rested (seated) in a thermoneutral laboratory, and these data confirmed that the cardiovascular, thermal and body mass status of all subjects were successfully standardised at a physiologically normal basal state.

The total trial durations (excluding data collection phases at each target (~10 min) and the 30-min controlled recovery) were 6.15 h (trial 1: 7%), 2.37 h (trial 2: 3%) and 5.27 h (trial 3: 7%). The dehydration targets were secured with precision. When averaged across all trials, these hydration states were achieved to within <0.10% of the actual target (trial 1: 0.098%; trial 2: 0.078%; trial 3: 0.056%).

At first glance, the mean relationship between expectorated saliva osmolality and water deficit appeared to be both strong and reproducible (Figure 1), apparently verifying the observations of Walsh *et al*. (2004a, 2004b). However, more thorough interrogation of these data revealed considerable variability about this relationship. For instance, within individuals, these relationships were robust, but due to the variability of basal saliva osmolality, and more particularly with its change as dehydration progressed (*i.e*. its gain), the application of mean prediction models to the current data sets resulted in less convincing predictive precision.

Twelve prediction models were used to describe these data sets. The model with the lowest mean coefficient of variation, when separately applied to data from each trial, was that developed using data points collected across all three dehydration trials. The overall sensitivity of this model was about 85%. However, this success was only possible if the dehydration thresholds (confidence intervals) were set to a confidence width of one standard deviation.

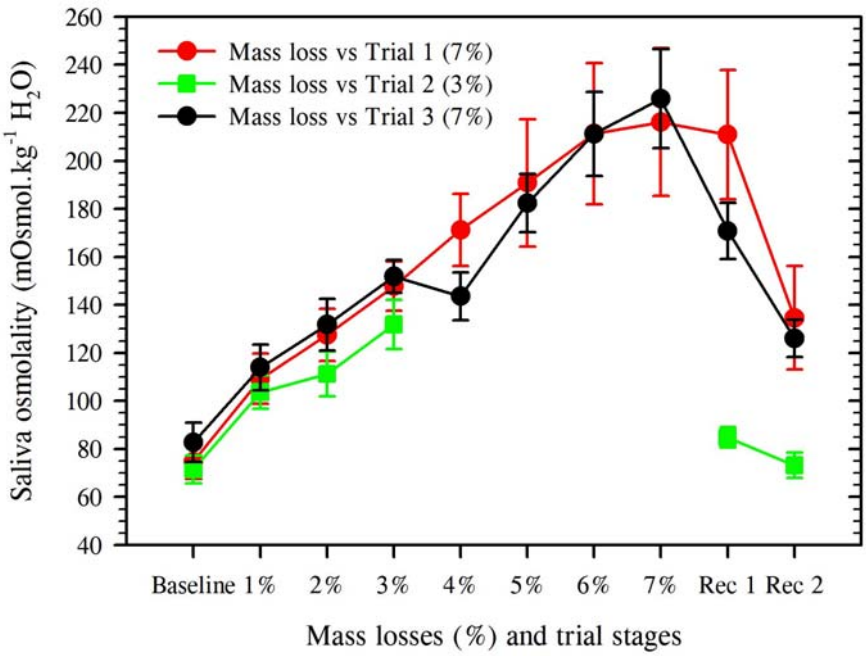

Figure 1: Expectorated saliva osmolality during three dehydration trials. Rec 1 and Rec 2 are recovery points 15 and 30 min after completing each trial. Data are means with standard errors of the means at each dehydration target.

When the efficacy of this predictive index was evaluated for field application by classifying data into one of three coloured hydration bands, using the same prediction model: green band: <3%; amber band: 3-6%, red band: >6% dehydrated. Approximately ~77% of individuals who were truly <3% dehydrated were correctly identified, while <50% of those within either of the two more important hydration bands were correctly identified (Table 1).

False negative classifications may have serious health implications, since such individuals incorrectly appear as though they are better hydrated. The current data showed that ~25% of the current subjects would have received a false negative classification when they were actually within the 3-6% hydration band (Table 1). More than 55% of subjects who were actually >6% dehydrated received a false negative outcome (Table 1). Such a high number of false negative classifications is unacceptable. Furthermore, the prediction model had an unacceptably low sensitivity, or probability of correctly identifying dehydrated individuals.

CONCLUSIONS

The current project provided a comprehensive evaluation of saliva osmolality as an index of hydration state (Taylor *et al*., 2009a). From this assessment, it is concluded that, while expectorated saliva osmolalities tracked changes in water deficit within individuals, the inter-subject osmolality variability was such that, at present, the technique lacked the sensitivity necessary for its further development and wider application for field use.

Table 1: Classification (hydration) bands (<3% (green); 3-6% (amber); >6% dehydration (red)). Data are numbers within each band with percentages in parenthesis, expressed relative to those within each classification (upper row).

Parameter	Green light	Amber light	Red light
Number classified	**125**	**78**	**19**
True positives	**96 (76.8%)**	**37 (47.4%)**	**8 (42.1%)**
True negatives	non-existent	96	37
False positives	29 (30.2%)	20 (25.6%)	non-existent
False negatives	non-existent	21 (26.9%)	11 (57.9%)
Sensitivity	not computed	63.8%	42.1%
Specificity	not computed	82.8%	not computed

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