MEASURES OB HUMAN HYDRATION STATE

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INTRODUCTION

There are many effects of the process of dehydration, ranging from impaired **exercisethermoregulation**at about 1% body weight loss to likely collapse at **7%**body weight loss **(6).** Thirst does not provide a good index of body water requirements (7), and numerous investigators report that *ad libitum* water intake results in incomplete water replacement or "voluntary" dehydration during exercise in the heat (1,4). This paper aims to investigate several different physiological measures as indicators of hydration state, some of which have been investigated previously, and looks to developing them as useful methods for monitoring the hydration state **of** workers in industry, as techniques for professionals and the workers themselves. Methods for measuring hydration state were compared to two recognized indicators of hydration state (1,3,5): urine osmolality and urine specific gravity.

METHOD

Subjects. Eight male, unacclimated subjects participated in the study. The subjects had a mean (SD)age of 24 ± 4 years, height of $1.81 \pm .09$ m, weight of 80.1 ± 7.9 kg, percent body fat of $16.8 \pm 4.3\%$ and predicted maximal O_2 uptake of 4.58 ± 0.87 L·min^{-1} (predicted using ACSM guidelines [2]).

Experimental design. Subjects participated in the protocol on 2 occasions (balanced design), exercising on a cycle ergometer in a hot-dry environment $(40.3 \pm 0.1°C$ *dry* bulb, $34.3 \pm 0.3\%$ relative humidity, 0.41 ± 0.1 m·s^{-1} **air** velocity). Each exposure lasted 170 min in duration, consisting of 5 sets of 20 min cycling and 10 min rest. On one occasion, subjects were given cool water $(5.4 \pm 0.5°C)$ to drink, which was measured to match the rate at which sweat was lost (drinking condition). Subjects were weighed after each of the 5 cycle sessions, and they were given the equivalent of the body mass lost to drink during the next cycle session. On the other occasion, subjects received no fluid replacement (no drink condition). A battery of physiological tests was carried out pre- and post-exercise. To ensure that subjects were in similar hydration and nutritional states at the *start* of each experimental session, diet, fluid intake and exercise during the 15 h preceding each trial were controlled.

Measurements. The following measurements were taken during the experiments: aural temperature (T_{au}), 4-point mean skin temperature (T_{sk}), heart rate (HR), body weight loss (% BW loss) and samples of blood, urine and sweat. T_{au}, T_{sk}, and HR were recorded continuously throughout the experiment. %BW loss

125

was recorded at the beginning and end of the heat exposure, and also after each of the **5** cycle periods. Sweat samples, which were collected in sweat patches at **7** sites over the body, were taken after each cycle period and analyzed for sodium (Sw_{Na}) and potassium (Sw_K) concentration. Blood and urine samples were taken pre- and post-heat exposure (in addition, a urine sample was given **6** h post-exposure). Blood samples were used to determine hemoglobin (Hb), hematocrit (Hct) and change in plasma volume (ΔPV). The following measures were taken from the urine samples: osmolality (U_{osm}); specific gravity (U_{sg}); color (U_{col}); volume (U_{vol}); temperature (U_{temp}); pH (U_{pH}); sodium (U_{Na}) and potassium (U_K).

Statistical analyses. Analyses utilized the Student's t-test, Pearson product moment correlation coefficient matrices, Spearman's rank correlation and calculations of linear regression. Significance was determined at the $P < .05$ confidence level, and all terms were expressed as the mean $\pm$ SD.

RESULTS

Drinking. Of the *urinary* variables, U_{col}, U_{temp}, U_K and U_{osm} *(P< .05)* were affected by the exposure, and this effect continued until 6 h post-exercise for U_{col}, U_K and U_{osm} *(P< .05)*. None of the hematological measures showed a difference with heat exposure, but HR, T_{au} and T_{sk} were significantly affected ($P < .05$). Of the sweat measures, Sw_{Na} was affected by the exposure throughout the work period (Patch 1 vs. 2, 3, 4 & **5** and Patch 2 vs. 3, 4 & **5**, P < .05), but Sw_K showed no change during the exposure.

No drinking. Of the *Urinary* variables, only U_{col}, U_{temp} and U_K (P < .05) were affected by the exposure. Hb was the only hematological measure affected by the heat exposure (P < .05), and HR, Tau, T_{sk} and oral temperature (T_{or}) also changed significantly (P< .05). For the sweat measures, Sw_{Na} was affected by the exposure throughout the work period (Patch 1 vs. 2, 3, 4 & **5** and Patch 3 vs. 4, $P < .05$), but there was only a difference between Patches 1 & 4 for Sw_K (P < .05).

Comparison of drinking and no drinking conditions. There were si&-cant differences between the conditions post exposure for U_{vol}, U_{col}, T_{or} *(P< .05)* and T_{au} *(P < .05)*, and also for sweat rate and the 4th sweat patch for Sw_K *(P <.05)*.

Change in variables. Due to inevitable inter-subject variability of measures of hydration, t-tests were then carried out on changes in variables over the experiment between conditions. For the change in values between pre- and post-exposure, only Ucol was significantly different *(P<.05)* between the conditions. However, for the change in values for post to **6** h post-exposure, U_{osm}, U_{sg} and U_{col} were all significant *(P< .05)* between the conditions.

Relationships between variables. Three correlation matrices (Pearson product moment correlation coefficient) were constructed for pre-, post- and 6 h post-exposure measurements, which identified significant relationships between physiological, *urinary,* hematological and sweat variables. Table 1 presents selected relationships (correlation coefficients and significance levels), which demonstrated the highest correlations of all the variables; these variables will be

	Drinking			No Drinking		
	Pre	Post	6h post	Pre	Post	6h post
U_{osm} and U_{sg}	+.977*	+.985*	+.877*	+.873*	+.953*	+.971*
U_{sg} and U_{col}	+.986*	+.906*	+.823*	+.837*	+.866*	+.765*
U_{osm} and U_{col}	+.892*	+.919*	+.828*	+.781*	+.665	+.654
U_{osm} and U_{vol}	-.783*	-.774*		-.700	-.863*	
U_{sg} and U_{vol}	-.791*	-.774*		-.883*	-.944*	
U_{col} and U_{vol}	-.954*	-.872*		-.792*	-.868*	

discussed further. Overall, U_{col} correlates well with reliable measures of hydration tion (U_{osm} and U_{sg}), and urine volume also correlates with U_{osm}, U_{sg} and U_{col}. For post-exposure and 6 h post-exposure, no significant relationships were found between **urinary** and hematological correlations.

DISCUSSION

Changes in hydration state were not accurately reflected in hematological indices because the body actively attempts to preserve the plasma volume by moving fluid from the intracellular to the extracellular space. These findings support those of Armstrong et al. (3) and the hypotheses of Francesconi et al. (5). Strong linear relationships were found between the 2 recognized measures of hydration state, U_{osm} and U_{sg}, and of U_{col} with these 2 variables. U_{col} correlates significantly with U_{osm} and U_{sg} both between and during experimental conditions and this confers with the findings of Armstrong et al. (3). Changes in variables over the experiments (pre to post) showed a significant difference ($P < .05$) between drinking and no drinking for U_{col}, indicating that it is sensitive to hydration state. The ease of use of the 8-shade subjective color scale renders it very practical during field work monitoring hydration state of workers exposed to heat. Since U_{osm} and U_{sg} produce higher correlations than with U_{col}, they should be used as indicators of hydration state, where possible, for example by occupational nurses. However, the urine color scale, and also urine volume, could be used as a guide so that people that work in the heat may monitor their own hydration state. In the drinking condition, **urinary** and physiological variables were still affected by heat exposure and exercise, even though the amount of sweat produced was replaced with an equivalent amount of water to **drink.** This suggests that because sweat rates were so high (0.85 ± 0.08 L·h⁻¹), the volume of water subjects needed to ingest was too large and was therefore not absorbed in the gut. For this reason, the conditions were not named "euhydration" and "hypohydration." When considering the hydration state of workers in industry, drinking before and after heat exposure is necessary, as water lost in sweat cannot be replaced immediately. The additional urine samples collected 6 h post-exposure suggest that the effects of exercise were still apparent. Three of the variables, U_{osm}, U_K and U_{col}, were still significantly elevated, perhaps indicating

that water conserving mechanisms were still in place. Although neither diet nor drinking were controlled after the experiment, these findings suggest rehydration regimes lasting several hours post-exercise heat exposure are required. The range in U_{osm}, U_{sg}, U_{col} and U_{vol} was quite widespread for both conditions, pre- and post- heat exposure, despite the fact that diet and fluid intake was controlled, indicating that perhaps **15** h was not long enough to standardize hydration levels. This also indicates that individuals must learn how much they need to drink to remain adequately hydrated.

CONCLUSIONS

Since thirst is well known to be an inefficient indicator of hypohydration and the need to intake fluids (7), people that work in the heat require a reference to give them information about their current hydration state. The use of U_{col} as an indicator appears to be a practical solution, where more detailed clinical analysis is not available. In addition, some education and training may be required to increase awareness of the importance of regular fluid replacement, even after exposure, and to familiarize workers with the processes of monitoring their own hydration state, as U_{col} can be affected by factors such as medication, illness and certain foods.

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