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Fluid and cation changes during head-out immersions in 25° and 35°C water

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Deuster PA, Doubt TJ, Ryan CJ, Montgomery LC, Haberman KJ. Fluid and cation changes during head-out immersions in 25° and 35°C water. Undersea Biomed Res 1989; 16(6):427–437.—To compare fluid and ion changes during cold (25°C) and thermoneutral head-out immersion (HOI) 9 men were studied under 4 resting conditions lasting 3 h: 2 in 35°C and 2 in 25°C water. At each temperature, subjects consumed 250 ml of either water or a 7% glucose polymer solution every hour to evaluate possible differences in fluid composition. Plasma volume increased by 3.9% for 35°C and decreased by 9.7% for 25°C HOI after 3 h. Urine flow increased significantly during HOI, but there were no differences between water temperatures (35°C: 8.37 ± 0.44; 25°C: 9.55 ± 0.57 ml · min^{-1}). Free water clearance and urinary sodium excretion were also elevated during HOI, but water temperature did not alter the magnitude of the response. No HOI-induced kaliuresis was noted. Finally, there was a significant cold-induced increase in serum potassium and sodium, but this reflected largely the decrease in plasma volume. In sum, differences in water temperature seemed to have minimal influence on fluid and cation changes, an indication that immersion is the primary stimulus. Whether greater differences would be noted with colder water remains to be determined.

cold water
fractional excretion
free water clearance
osmotic clearance
plasma volume
potassium
sodium
thermoneutral water
urine flow

The effects of head-out immersion (HOI) on human fluid responses and renal excretory patterns have been well studied in thermoneutral water (1–8), but the effects of cold water have received less attention. In general, HOI induces a rapid diuresis and natriuresis in both thermoneutral (2) and cold (9, 10) water, but there are no studies wherein comparisons between water temperatures have been conducted. Thus, whether fluid and cation excretory patterns in cold water are more marked than those in thermoneutral water has not been determined.

The following study was conducted to test the hypothesis that fluid and cation changes during HOI are similar in thermoneutral and cold water. Specifically, we

were interested in evaluating the patterns of change in: a) urinary excretion of Na and K; b) serum Na and K relative to changes in plasma volume; c) urine flow; d) free water clearance; and e) osmotic clearance during resting HOI for 3 h in cold (25°C) or thermoneutral (35°C) water. In addition, the above patterns were evaluated for differences that might occur as a result of ingesting a glucose polymer-electrolyte solution instead of water.

MATERIALS AND METHODS

Subjects

Approval for the study was obtained from the Committee for Protection of Human Subjects at the Naval Medical Research Institute and from the Human Use Review Committee at the Uniformed Services University of the Health Sciences. The purpose of the study and the nature of the procedures were explained in detail before written informed consent was obtained from 10 healthy male subjects. However, 1 subject was withdrawn from the immersion studies due to a sensitivity to the tape used, and another was unavailable for selected conditions. In addition to subject withdrawal before the experiments, 3 subjects were removed from the water after only 2 h because their core temperatures dropped to 35°C. Moreover, blood samples and urine samples were either contaminated or could not be obtained for selected time periods; for example, on several occasions during the 25°C immersions peripheral vasoconstriction prevented obtaining blood samples. Thus, in some cases the number of data points has been decreased as indicated.

Experimental design

There were four main experimental conditions; two HOI in 35°C water and two HOI in 25°C water. For one HOI at each water temperature, the subject consumed 250 ml of water (W) during each hour of immersion, whereas for the other, the subject consumed an equal volume of a glucose polymer (GP) solution. Nine of the original 10 subjects participated in these tests. A subset of 5 subjects was used to document the fluid and electrolyte changes associated with consuming both fluids during a 3-h dry, nonimmersed state (D). A second subset of 5 other subjects was used to assess immersion diuresis at both water temperatures without ingesting any fluid (NF). Because there were missing blood and urine samples at selected time points in this subset, the population size was considered too small ($n = 3$ for some collection periods) for meaningful statistical comparison to the main experimental conditions; however, the data are presented for qualitative purposes. A brief description of each condition is presented in Table 1. The order of all treatments was balanced among conditions, and each test was separated by 1 wk. Two subjects were tested at the same time. To minimize differences due to dietary intake of Na and K, subjects were provided a dinner and breakfast menu to standardize dietary intakes before each test session.

Preparation for the experiments began at 0800 h. After voiding, subjects drank a volume of water equivalent to 0.5% of their body weight to ensure uniform hydration. In the D conditions, the subject was seated in a chair near the empty tank for 3 h;

TABLE 1
EXPERIMENTAL CONDITIONS FOR SUBJECTS

Condition Code	n^a	Description of Condition
Main conditions		
35W	9	HOI in 35°C water with water as the fluid replacement
35GP	9	HOI in 35°C water with glucose polymer as the fluid replacement
25W	8	HOI in 25°C water with water as the fluid replacement
25GP	8	HOI in 25°C water with glucose polymer as the fluid replacement
Subset conditions		
DW	5	Sitting in the dry with water as the fluid replacement
DGP	5	Sitting in the dry with glucose polymer as the fluid replacement
35NF	5	HOI in 35°C water with no fluid replacement
25NF	5	HOI in 35°C water with no fluid replacement

[a] n = number of subjects starting each condition.

the chair was made of a metal mesh material to allow free circulation of air or water around the body. For the HOI, water temperature was either 35° or 25°C; the subject remained seated throughout the 3-h immersions. Water in the tank was constantly agitated to prevent formation of a boundary layer next to the subject's skin. If rectal temperature dropped below 35°C the subject was removed from the water. Ambient air temperature was maintained between 25° and 26°C. Urine was collected every 30 min by an external urinary catheter (Hollister Inc, Libertyville, IL) attached to a collection bag that allowed the subjects to urinate when needed without standing up or exiting the tank.

The subject drank 250 ml of W or a GP solution at the beginning of each test when fluid was ingested; the fluid temperature was 10°C to optimize gastric emptying (11). At the end of Hours 1 and 2 an additional 250 ml of fluid was ingested, for a total fluid intake of 750 ml. The water was deionized, and the GP solution was a commercially available product (Exceed Fluid Replacement, Ross Products; Columbus, OH). The GP was prepared in deionized water such that the final composition of the ingested solution per 100 ml contained: 4.6 g glucose polymer, 2.5 g fructose, 0.93 mmol sodium, 0.5 mmol potassium, 0.11 mmol calcium, 0.11 mmol magnesium, and 0.97 mmol chloride. The osmolality of the solution was 250 mOsM/kg water and each 100 ml provided approximately 29.2 kcal (122 kJ).

Sample processing and biochemical analyses

Blood and urine samples were obtained before and every 30 min during the experiments. Blood samples (25 ml) were transferred from a syringe into chilled tubes: a) a plain tube without anticoagulant for serum creatinine (Cr), sodium (Na), potassium (K), and osmolality (Osm); b) an EDTA tube for plasma aldosterone (ALDO) and plasma renin activity (PRA); and c) an EDTA tube for hematocrit (Hct) and hemoglobin (Hb) measures. Immediately after the blood draw, blood Hb concentration was determined by the cyanomethemoglobin method (HemoCue Photometer, Leo Diagnostics AB, Helsingborg, Sweden) and Hct ratio by centrifugation. Tubes for

ALDO and PRA were centrifuged immediately; plasma was transferred to storage tubes and frozen immediately. Tubes for serum determinations were allowed to clot at room temperature for 30 min and then centrifuged for serum separations. Serum was removed and frozen in tubes on dry ice. Total urine volume for each collection period was recorded, and samples were frozen for analysis of Na, K, Cr, and Osm.

Serum and urinary Cr and serum Na and K concentrations were determined with a Centrifichem 500; and plasma ALDO and PRA by radioimmunoassay. Urinary Na and K were determined with Na and K ion-selective electrodes (Radiometer KNal Sodium-Potassium Analyzer). Serum and urine osmolalities (SOsm and UOsm) were determined by the freezing point method (Advanced Instruments Osmometer).

Calculations

Percent change in plasma volume (PV) at each time point ($\%CPV_i$) relative to pre-experiment PV was calculated as described by Dill and Costill (12). Total content of blood constituents was calculated from PV and the concentration of the specific constituent. The average rate of urine flow (V_U) in milliliters per minute was calculated by dividing the total urine volume collected by time of the collection period. Endogenous Cr clearance (C_{Cr}) was used to estimate the glomerular filtration rate (GFR). Osmotic clearance (Co_{SM}), free water clearance (C_{H_2O}), and fractional excretion of Na and K were calculated by conventional methods.

Statistical analyses

The computer package SAS was used for all statistical analyses (13). Data were analyzed as a factorial design with repeated measures; a multivariate analysis of variance technique was used. When significant effects were detected, Duncan's Multiple Range Test procedure was used to detect differences across conditions. Standard correlation and regression techniques were used to identify relations among variables. The level of significance was set at 0.05. Data are expressed as mean ± standard error (SEM).

RESULTS

Mean age of the final 9 subjects was 29.3 ± 1.2 yr (± SE), mean weight 80.4 ± 2.3 kg, and mean height 179.5 ± 2.4 cm. Percent body fat, as determined from hydrostatic weighing, was 17.2 ± 1.5%. Over the course of the 3-h immersions a significant decrease in rectal temperature was noted only in the 25°C conditions, with average reductions of 1.24 ± 0.12, and 1.22 ± 0.14°C for W and GP, respectively. No significant differences between the W and GP fluid regimens were noted for any of the variables measured; thus these data were combined and considered fluid treatments.

Patterns of change in PV differed among the HOI fluid conditions, with decreases noted in 25°C and increases noted for the 35°C conditions; mean percent changes at the end of HOI fluid treatments relative to pre-experiment values were +2.6 ± 1.6% and −11.6 ± 3.5% for 35° and 25°C HOI conditions, respectively. Mean PV change for the D fluid conditions was +5.6 ± 2.9%. For the NF subset conditions, the

directions of change in PV were similar for the respective water temperatures (35°C: $+5.3 \pm 2.5\%$ and 25°C: $-5.9 \pm 4.8\%$). As evidenced by the large SEM, the variability was great.

Pre-experiment V_U averaged across all fluid conditions was 1.6 ± 0.1 ml · min^{-1}. V_U increased significantly ($P < 0.01$) during all fluid HOI conditions, but there were no differences between the two water temperatures (Table 2). In addition, V_U increased during D conditions because of the fluid ingested, but was significantly less than during immersion ($P < 0.01$). Mean V_U during NF conditions tended to be similar to D conditions but lower than HOI with fluid conditions. V_U averaged across all 3-h test periods with W and GP was 8.37 ± 0.438, 9.55 ± 0.57, and 4.52 ± 0.49 ml · min^{-1} for the 35°, 25°C, and D conditions, respectively, and 5.05 ± 0.84 and 5.85 ± 0.34 ml · min^{-1} during 35° and 25°C NF conditions.

Also presented in Table 2 are the mean values for C_{OSM} and C_{H_2O} at each time period. For all three fluid conditions, C_{OSM} values did not differ from pretreatment values, whereas values during HOI-NF conditions tended to increase. C_{OSM} values averaged during treatment periods were 4.39 ± 0.5, 4.34 ± 0.15, and 3.23 ± 0.4 ml · min^{-1} for 35°, 25°C, and D fluid conditions, and 4.36 ± 0.80 and 8.65 ± 3.36 ml · min^{-1} for 35° and 25°C NF conditions, respectively; baseline C_{OSM} values averaged 3.80 ± 0.39 for the W and GP conditions and 1.21 ± 0.62 ml · min^{-1} for the NF conditions. A different pattern emerged for C_{H_2O}; C_{H_2O} increased from baseline values of -0.76 ± 0.41 ml · min^{-1} for all fluid conditions by 30 min; average values for treatment periods were 4.71 ± 0.90, 5.17 ± 0.39, and 1.55 ± 0.92 ml · min^{-1} for the 35°, 25°C, and D, respectively, with the magnitude of increase significantly greater during HOI than D conditions. For NF conditions, C_{H_2O} went from a baseline value of 0.08 ± 0.28 to 2.44 ± 0.89 and -1.98 ± 2.68 ml · min^{-1} for 35° and 25°C NF conditions, respectively. No significant changes in the fractional excretion of either Na or K for any of the treatments were noted. ALDO and PRA followed expected patterns during immersion, with significant decreases with both water temperatures (Table 3). Although there was an increase in SO_{SM} during the 25°C exposures, the changes were not significant (Table 3).

Figure 1 presents the patterns of change in serum Na and K for the fluid conditions. Serum concentrations of both cations rose steadily over the course of 25°C W and GP immersions but did not change significantly during 35°C immersions. Mean values averaged across all treatment periods were 144.7 ± 0.6, 147.1 ± 1.1, and 143.9 ± 0.5 mmol/liter for Na, and 4.24 ± 0.13, 5.21 ± 0.11, and 4.20 ± 0.14 mmol/liter for K under the 35°, 25°C, and D fluid conditions, respectively. Despite the marked increase with cold water immersion, these changes could be explained in large part by the significant decrease in plasma volume. Patterns for the 35° and 25°C NF conditions were similar to their respective fluid conditions: average values for serum Na were 145.6 ± 0.4 and 146:4 ± 0.3 mmol/liter, and for serum K were 4.26 ± 0.05 and 5.11 ± 0.12 mmol/liter for the 35° and 25°C NF conditions, respectively.

Changes in urinary Na and K excretions for the W and GP conditions combined are shown in Fig. 2. Urinary excretion of Na was significantly higher during immersion as compared to D conditions. Despite a tendency toward higher values during 25°C conditions, the difference between water temperatures was not significant. Excretion of Na increased from baseline values of 133.7 ± 11.7 and 32.1 ± 11.3 μmol · min^{-1} for fluid and NF conditions, respectively, to mean values averaged across treatment periods of 231.3 ± 20.1, 322.4 ± 29.8, and 149.3 ± 23.9 μmol · min^{-1} for 35°, 25°C,

TABLE 2

MEAN (± SEM) URINE FLOW RATES (V_U), OSMOTIC CLEARANCE (C_{OSM}), AND FREE WATER CLEARANCE (C_{H_2O}) OVER THE COURSE OF 35° AND 25°C IMMERSIONS AND UNDER DRY CONTROL (D) CONDITIONS LASTING 3 H

V_U[b]	35[a]	1.93 ± 0.56	4.80 ± 1.20	8.38 ± 1.73	8.28 ± 1.44	13.38 ± 1.48	7.62 ± 1.34	7.78 ± 1.34
	25	1.79 ± 0.56	8.33 ± 2.03	10.93 ± 1.14	12.96 ± 1.38	8.53 ± 0.85	5.68 ± 0.97	10.68 ± 1.32
	D	2.03 ± 0.45	3.43 ± 1.33	4.26 ± 1.11[c]	3.58 ± 0.87[c]	5.37 ± 1.15[c]	6.85 ± 1.11	3.66 ± 0.91[c]
C_{OSM}	35	3.82 ± 0.68	6.49 ± 1.20	6.81 ± 1.16	3.47 ± 0.55	5.86 ± 1.50	3.27 ± 0.51	3.96 ± 0.71
	25	4.46 ± 0.80	8.13 ± 1.76	6.29 ± 2.02	8.41 ± 1.36	3.82 ± 0.41	6.59 ± 1.03	3.82 ± 0.68
	D	3.11 ± 0.66	6.10 ± 2.38	4.75 ± 1.06	3.90 ± 1.09	2.92 ± 0.65	4.81 ± 0.68	4.54 ± 2.15
C_{H_2O}	35	0.04 ± 0.76	1.46 ± 1.38	4.36 ± 1.17	6.34 ± 1.26	7.69 ± 0.77	5.36 ± 1.28	4.60 ± 0.97
	25	−0.99 ± 0.82	0.36 ± 1.73	6.21 ± 2.32	8.41 ± 1.36	6.41 ± 0.47	2.24 ± 0.73	4.65 ± 1.01
	D	−1.33 ± 0.70	0.31 ± 1.25	0.58 ± 1.41[b]	0.03 ± 1.41[b]	2.93 ± 0.82[b]	2.84 ± 0.44	0.31 ± 2.01[b]

[a] Number of subjects for 35°, 25°C, and D conditions: V_U: n = 18, 16, and 10; C_{OSM}: n = 14, 10, and 8; C_{H_2O}: n = 14, 10, and 8.

[b] All values are expressed as ml/min.

[c] Significantly different from 25° and 35°C conditions ($P < 0.01$).

TABLE 3

MEAN (± SEM) PLASMA ALDO CONCENTRATION, PRA, AND (SOSM) OVER THE COURSE OF 35° AND 25°C IMMERSIONS, AND UNDER D CONTROL CONDITIONS LASTING 3 H

		Before	60	180
ALDO, ng/dl	35°[a]	11.0 ± 1.7	4.9 ± 0.7[b]	6.8 ± 1.7[b]
	25°	14.6 ± 3.7	8.6 ± 1.5[b]	8.9 ± 2.8[b]
	D	15.5 ± 4.1	25.5 ± 11.6	11.3 ± 2.1
PRA, ng/ml/h	35°	0.75 ± 0.10	0.38 ± 0.05[b]	0.31 ± 0.08[b]
	25°	1.58 ± 0.59	0.53 ± 0.15[b]	0.57 ± 0.15[b]
	D	0.73 ± 0.03	1.17 ± 0.33	0.97 ± 0.17
SOSM, mOSM/liter	35°	283.2 ± 0.9	284.7 ± 1.2	285.9 ± 1.7
	25°	284.5 ± 1.2	289.2 ± 1.3	290.0 ± 1.7
	D	286.5 ± 2.1	284.0 ± 0.5	283.6 ± 1.9

[a]Number of subjects for 35°, 25°C, and D conditions: ALDO: n = 14, 10, and 10; PRA: n = 8, 6, and 6.
[b]Significantly different from Before value ($P < 0.05$)

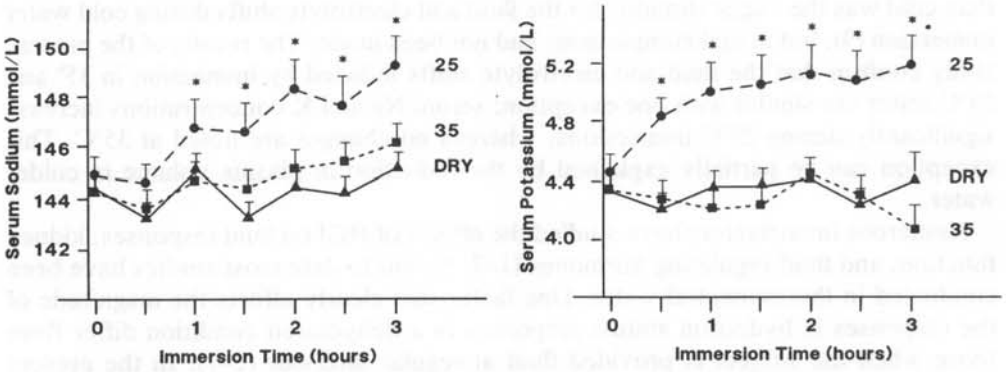

Fig. 1. Changes in serum Na and K concentrations over the course of 35° *(dashed line)* and 25°C *(broken line)* immersions lasting 3 h, and under dry control *(solid line)* conditions. *Significantly different from 35°C and dry conditions; $P < 0.01$. Number of subjects for 35°, 25°C, and D conditions: Na: n = 14, 10, and 8; K: n = 14, 10, and 8

and D fluid conditions, and 227.9 ± 29.0 and 289.5 ± 45.0 μmol · min^{-1} for 35° and 25°C NF conditions, respectively. In contrast, there were no significant differences across the fluid treatments conditions for urinary K excretion. However, baseline K excretion values (fluid: 72.6 ± 12.7 and NF: 15.5 ± 6.4 μmol · min^{-1}) were significantly lower than average treatment excretions values (fluid: 151.9 ± 14.9, 162.1 ± 9.6, and 114.4 ± 13.4 μmol · min^{-1} for 35°, 25°C, and D conditions, and NF: 169.7 ± 29.2 and 228.9 ± 15.0 μmol · min^{-1} for 35° and 25°C conditions).

DISCUSSION

The present study was conducted to identify differences in fluid and electrolyte shifts when subjects consuming fluids are immersed in thermoneutral as compared

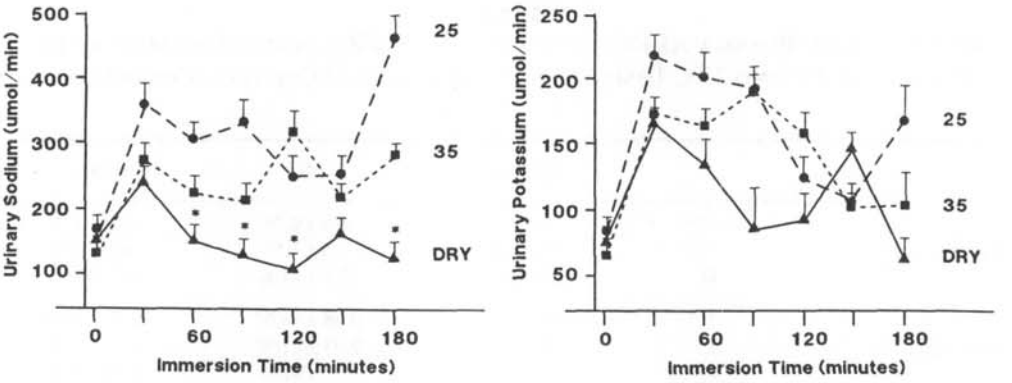

Fig. 2. Changes in urinary excretion of Na and K over the course of 35° *(dashed line)* and 25°C *(broken line)* immersions lasting 3 h, and under dry control *(solid line)* conditions. Number of subjects for 35°, 25°C, and D conditions: Na: n = 18, 16, and 10; K: n = 18, 16, and 10.

to cold water. Previous work in our laboratory had suggested that immersion rather than cold was the major stimulus for the fluid and electrolyte shifts during cold water immersion (9), but actual comparisons had not been made. The results of the present study confirm that the fluid and electrolyte shifts induced by immersion in 35° and 25°C water are similar with one exception: serum Na and K concentrations increase significantly during 25°C immersions, whereas no changes are noted at 35°C. This exception can be partially explained by the reduction in plasma volume in colder water.

Numerous investigators have studied the effects of HOI on fluid responses, kidney function, and fluid-regulating hormones (1–7, 9), but to date most studies have been conducted in thermoneutral water. One factor that clearly affects the magnitude of the responses is hydration status; responses in a dehydrated condition differ from those when the subject is provided fluid at regular intervals (2–7). In the present study all subjects were uniformly hydrated before beginning the treatments, and fluid was provided hourly to maintain hydration. Given these conditions, urine flow was significantly lower during D and HOI-NF as compared to fluid HOI conditions, but there were no differences between the two W temperatures. A cold-induced diuresis has been reported (9, 10, 14, 15), and Young et al. (10) demonstrated that the diuresis was greater in cold water than cold air. Results of the present study provide evidence that, at least for the W temperatures investigated, urine flow did not vary as a function of temperature. There was, however, a slight tendency for urine flow to be higher during the first 90 min of immersion in 25°C W even though flow averaged over the 3 h did not differ. This tendency may reflect a more pronounced peripheral vasoconstriction in colder water that causes slightly more blood to accumulate in the central thoracic region; this would stimulate a greater diuresis. No doubt the effect is slight and attenuated by time because there were no significant differences in urine flow over the full duration of the immersions. Further investigation would be needed to determine whether this observation would hold for lower W temperatures, but it is reasonable to speculate that the rate of cooling might also affect the magnitude of the diuresis.

Although the magnitude of the immersion-induced diuresis was not influenced by W temperature, directional changes occurred in plasma volume. The absence of a significant change in PV after 3 h in 35°C W, coupled with a notable decline in 25°C water, suggests a temperature-dependent shift in fluid among body tissues and the vascular compartment. Additional studies would be required to more fully document the mechanism of this shift.

The effects of HOI on free water (C_{H_2O}) and osmotic (C_{OSM}) clearance have been examined in thermoneutral water (3–7) and cold air (14, 15) but not in cold water. In the present study under conditions of uniform hydration and hourly provision of fluids there were significant increases in C_{H_2O} and no change in C_{OSM} for either W temperature; further, no differences as a function of W temperature were noted. However, the responses during immersion were significantly greater than those observed with D conditions. When subjects are immersed in thermoneutral W there are reports of a decrease (5, 7), an increase (4, 5, 8) and no change (3, 6) in C_{H_2O}, and an increase (3, 7, 8) and no change (6) in C_{OSM}. The differences in C_{H_2O} seem to depend on the hydration status of the subject. When subjects are provided fluid hourly during immersion, as in the present study, C_{H_2O} increases (4), whereas when fluid is restricted and/or the subject has been deprived of fluid for 8 to 14 h before immersion, C_{H_2O} decreases (5, 7) or is unchanged (3, 6). A pattern of little or no change in C_{H_2O} was also noted for our NF conditions. Changes in C_{OSM} are more difficult to explain because responses in the literature seem, in part, to be independent of fluid intake (3, 7, 10). To date, no response has been examined under conditions such as those in the present study, but it is reasonable to predict that over the course of immersions C_{OSM} would change minimally if subjects remain well hydrated, whereas C_{OSM} might increase if subjects were fluid deprived. Such patterns were noted in the present study, and it seems that changes in C_{OSM} and C_{H_2O} may be independent of water temperature. This suggests that immersion per se, rather than cold, is the stimulus for the responses.

To date, little attention has focused on how cold water immersion affects serum and urinary electrolytes. With HOI in thermoneutral water minimal changes are reported for either serum Na or K (1, 3, 6), and this is consistent with our findings. In contrast, immersion in 25°C water induced increases in both serum Na (+5.5%) and K (+14.5%) regardless of whether fluid was provided. Although a large portion of the increase noted in the present study could be attributed to the decrease in plasma volume (−11.6%), it is possible that other mechanisms are operating to effect the change. Young et al. (10) reported that when men were immersed in 18°C water for 90 min there was a significant increase in serum K (+12%) but no change in serum Na (+0.6%); their reported 17% decrease in plasma volume may also account for a portion of the rise in serum K. The differences between the two studies relative to changes in serum Na are more difficult to reconcile, but the rapid rate of cooling in their study may have affected the response.

Head-out immersion in thermoneutral W induces a natriuresis that is independent of hydration status (2), but the presence of a kaliuresis is open to question (2, 3, 6, 8, 13). Some investigators report an increased K excretion (2, 8), whereas others do not (3, 6, 13). In the present study we observed a significant immersion-induced natriuresis of comparable magnitude in both 35° and 25°C water as compared to D conditions; a similar pattern was noted when no fluid was provided. This suggests that immersion may be a more powerful stimulus than cold water in the range of 25°C. We noted an immersion-induced kaliuresis, but there was also a kaliuresis when

subjects were provided fluid under D conditions. As such, there were no significant differences in K excretion across fluid treatments. In general the rise in K excretion occurred within the first 60 min, after which it began to decline. Young et al. (10) noted a three- to fourfold increase in urinary K excretion during 90 min of cold water immersion as compared to baseline excretion, a finding consistent with the magnitude of increase noted in the early portion of our study. Further, no fluids were provided to the subjects in their study, and this is consistent with our NF conditions; the magnitude of the kaliuresis tended to be greater in 35° and 25°C NF as compared to fluid conditions because of baseline values. Finally, in the present study, as has been previously reported for thermoneutral (2–4, 7) and cold water (15) immersions, clearance rates for both Na and K increased significantly as a function of immersion, but water temperature had no effect.

The comparable fluid and electrolyte responses to ingesting W as compared to GP probably reflect the small amount of glucose and electrolyte consumed with the pattern of fluid ingestion we used. Consumption of 250 ml of GP provided only 2.3 mmol of Na and 1.3 mmol of K per hour. Given that intestinal absorption is not instantaneous and that these electrolytes would be distributed throughout the body, it is likely that such small amounts would have negligible influences on serum and urine measurements. Furthermore, we have no reason to believe that the carbohydrate contained in the GP solution would alter any of the variables measured. Thus, it can be concluded that similar amounts of W or GP have the same net results, and the predominant effects observed are due to immersion per se.

In summary, the results of the present study provide evidence that renal excretory patterns during immersion are largely independent of water temperatures between 25° and 35°C. Cold water does not accentuate the immersion-induced diuresis, natriuresis, and kaliuresis over a 3-h period. In contrast, intravascular Na and K shifts are affected by water temperature, with significant increases in serum concentration of both cations during cold water immersion. However, the increases could be accounted for in large part by relative changes in plasma volume. Finally, water temperature did not influence the magnitudes of the C_{H_2O} and C_{OSM} responses. Whether colder water would modify these responses will require further investigation.

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