Effect of an exercise-heat acclimation program on body fluid regulatory responses to dehydration in older men

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Takamata, Akira, Tomoyuki Ito, Kazuhiro Yae gashi, Hisat ake Takamiya, Yasuyo Maegawa, Toshiyuki Itoh, John E. Greenleaf, and Taketoshi Morimoto. Effect of an exercise-heat acclimation program on body fluid regulatory responses to dehydration in older men. Am. J. Physiol. 277 (Regulatory Integrative Comp. Physiol. 46): R1041–R1050, 1999.—We examined if an exercise-heat acclimation program improves body fluid regulatory function in older subjects, as has been reported in younger subjects. Nine older (Old; 70 ± 3 yr) and six younger (Young; 25 ± 3 yr) male subjects participated in the study. Body fluid regulatory responses to an acute thermal dehydration challenge were examined before and after the 6-day acclimation session. Acute dehydration was produced by intermittent light exercise [4 bouts of 20-min exercise at 40% peak rate of oxygen consumption (V˙O2peak) separated by 10 min rest] in the heat (36°C; 40% relative humidity) followed by 30 min of recovery without fluid intake at 25°C. During the 2-h rehydration period the subjects drank a carbohydrate-electrolyte solution ad libitum. In the preacclimation test, the Old lost ~0.8 kg during dehydration and recovered 31 ± 4% of that loss during rehydration, whereas the Young lost ~1.2 kg and recovered 56 ± 8% (P < 0.05, Young vs. Old). During the 6-day heat acclimation period all subjects performed the same exercise-heat exposure as in the dehydra tion period. Exercise-heat acclimation increased plasma volume by ~5% (P < 0.05) in Young subjects but not in Old. The body fluid loss during dehydration in the postacclimation test was similar to that in the preacclimation in Young and Old. The fractional recovery of lost fluid volume during rehydration increased in Young (by 80 ± 9% P < 0.05) but not in Old (by only 34 ± 5% NS). The improved recovery from dehydration in Young was mainly due to increased fluid intake with a small increase in the fluid retention fraction. The greater involuntary dehydration (greater fluid deficit) in Old was accompanied by reduced plasma vasopressin and aldosterone concentrations, renin activity, and subjective thirst rating (P < 0.05, Young vs. Old). Thus older people have reduced ability to facilitate body fluid regulatory function by exercise-heat acclimation, which might be involved in attenuation of the acclimation-induced increase in body fluid volume.

older people tend to have reduced total body water (10) and blunted ability to recover from acute dehydration challenges (11). Decreased thirst (11, 12, 17, 18) and attenuated renal fluid and sodium reabsorption ability, which is possibly caused by reduced endocrine responses to a dehydration challenge and reduced renal responsiveness to fluid regulatory hormones, may account for the poor ability to recover from dehydration (6, 26). It has been reported that reduced number of glomeruli with aging results in decreased glomerular filtration rate, and reduced renal mass is a factor contributing to attenuated renal reabsorption capacity in older people (10).

Body fluid regulatory function is influenced by acclimation status (8, 14, 30). Short-term heat acclimation induced by exercise and heat exposure increases body fluid and plasma volume (PV) and improves body fluid regulatory responses to dehydration, mainly by increasing voluntary fluid intake (8, 30). Zappe et al. (30) reported that repeated exercise-heat exposure for 4 days did not increase blood volume (BV) in older subjects, whereas the same exposure did increase BV in younger subjects. They also reported that the attenuated increase in body fluid volume in older subjects was due to attenuated increase in daily fluid intake during this exercise-heat exposure (30). However, a 4-day exposure might be too short for older people to increase their body fluid volumes. In addition, the effect of repeated exercise-heat exposures on fluid ingestion responses, including subjective thirst responses, to acute dehydration in older people has not been adequately studied.

Thus the purpose of this study is to test the hypothesis that older people have the ability to increase BV and to improve body fluid regulatory responses to thermal dehydration after a 6-day repeated exercise-heat acclimation exposure program.

METHODS

This study was approved by the Review Board on Human Experiments, Kyoto Prefectural University of Medicine. After the experimental protocol and procedures were fully explained, nine older (Old) and six young (Young) subjects (Table 1) gave their written informed consent before participating in this study. A physical examination was conducted by physicians on each subject before their participation. The physical examination included resting 12-lead electrocardiogram and blood pressure measurements, standard blood biochemical examination, and a maximal exercise test with cycle-ergometer. Both Young and Old were relatively active, but none engaged in any regular exercise training program. All subjects were normotensive and free from medication, except for two older subjects who took drugs for hyperlipidemia that controlled their plasma lipid concentration. We examined body fluid regulatory responses to an acute dehydration challenge before (preacclimation test; day 1) and after (postacclimation test; day 8) a 6-day exercise-heat acclima-
tain a predetermined target heart rate (HR) at 40% of peak humidity. The cycle ergometer load was controlled by a recovery at room temperature of 36°C and 40% relative humidity. The subjects performed four bouts of intermittent cycle-ergometer exercise per period, blood and urine samples were taken, and their subjective thirst rating was assessed. Then the subjects performed four bouts of intermittent cycle-ergometer exercise in a semirecumbent position for 20 min followed by a 10-min recovery at room temperature of 36°C and 40% relative humidity. The cycle ergometer load was controlled by a feedback system (CatEye Ergociser EC 3700, Osaka) to maintain a predetermined target heart rate (HR) at 40% of peak rate of oxygen consumption (VO2peak), which was determined from the linear regression equation of HR on VO2 for each subject before the preconditioning test. The target HR was 94 ± 4 beats/min for Old and 110 ± 4 beats/min for Young. After this dehydration regimen the subjects sat on a chair for 30 min at room temperature (25°C) to equilibrate body fluid distribution and to exclude the effect of increased body temperature on drinking behavior or endocrine responses.

Exercise heat acclimation program. Experiments were conducted in May and June, so the subjects were assumed not to be heat-acclimated.

Test protocol. On test days 1 and 8, the subjects reported to the laboratory at 0830 after a light breakfast, voided, entered the environmental chamber, and sat for 60 min at an ambient temperature of 25°C (control period). A catheter for blood sampling was inserted into an antecubital vein during the control period, blood and urine samples were taken, and their subjective thirst rating was assessed. Then the subjects performed four bouts of intermittent cycle-ergometer exercise in a semirecumbent position for 20 min followed by a 10-min recovery at room temperature of 36°C and 40% relative humidity. The cycle ergometer load was controlled by a feedback system (CatEye Ergociser EC 3700, Osaka) to maintain a predetermined target heart rate (HR) at 40% of peak rate of oxygen consumption (VO2peak), which was determined from the linear regression equation of HR on VO2 for each subject before the preconditioning test. The target HR was 94 ± 4 beats/min for Old and 110 ± 4 beats/min for Young. After this dehydration regimen the subjects sat on a chair for 30 min at room temperature (25°C) to equilibrate body fluid distribution and to exclude the effect of increased body temperature on drinking behavior or endocrine responses.

| Table 1. Anthropometric variables and peak oxygen uptake of older and younger subjects |
|------------------------------------------|-----------------|-----------------|
| Age, yr                                  | Old (n = 9)     | Young (n = 6)   |
| Height, cm                               | 161.4 ± 5.7     | 163.3 ± 3.3     |
| Weight, kg                               | 61.8 ± 7.2      | 64.3 ± 6.1      |
| BMI                                      | 23.7 ± 1.1      | 22.7 ± 0.8      |
| SBPrest, mmHg                            | 134.0 ± 3.8     | 121.2 ± 3.8     |
| DBPrest, mmHg                            | 75.3 ± 3.6      | 77.0 ± 3.4      |
| HRrest, beats/min                        | 65.8 ± 4.3      | 63.2 ± 4.3      |
| VO2peak, ml·min⁻¹·kg⁻¹                  | 31.0 ± 1.88     | 57.23 ± 3.27*   |
| HRpeak, beats/min                        | 155.3 ± 5.6     | 195.7 ± 15.0    |

Values are means ± SE; n = no. of subjects. BMI, body mass index (weight/height²); SBPrest, resting systolic blood pressure; DBPrest, resting diastolic blood pressure; HRrest, resting heart rate; VO2peak, peak oxygen consumption; HRpeak, heart rate at VO2peak. *Significant difference between Old and Young.

incremental cycle-ergometer protocol. Oxygen uptake was calculated from recording of O2 and CO2 fractions in expired gas and the expired ventilatory volume (Aeromonitor AE 260, Minato, Japan). Subjects exercised until exhaustion. The criteria for determining were respiratory exchange ratio >1.1 and leveling off of VO2 with increasing work load. PV was determined with the Evans blue dye (New World, Debarly, FL) dilution technique. After sitting for at least 30 min, a control blood sample was taken, and then Evans blue dye (12–15 mg) was injected, and blood samples were drawn at 10 and 20 min after injection. The time-dependent change in plasma absorbance caused by the turbidity change was eliminated by measuring the absorbance of sample plasma at 620 and 740 nm (Shimadzu Spectrophotometer UV-2200, Kyoto); absorbance of plasma at 620 nm of each sample was estimated from the regression equation of the relationship between absorbance of 620 and 740 nm in control plasma (5). From absorbance of the 10-min plasma sample and the injected amount of Evans blue (precisely weighed), PV was calculated. BV, calculated from PV and hematocrit (Hct), was corrected by 3% trapped plasma and for an F-cell ratio of 91%

Body fluid loss during the exercise-heat exposures was determined by body weight change. Body fluid balance during the rehydration period was calculated from fluid intake minus urinary output, assuming that the respiratory water loss must be negligible during the recovery period (13).

Subjective thirst rating was measured with a visual linear analog scale 18 cm in length, with an intersecting line at 0 cm indicating "not thirsty at all" and an intersecting line at 12 cm indicating "extremely thirsty". The subjects were instructed to place a mark on the scale at the point best representing his rating at the time, and to mark on the scale beyond 12 cm if they so desired. We normalized the rating so that 0 cm became 0% and 12 cm became 100% (27).

Blood samples for determination of Hct, hemoglobin concentration ([Hb]), and plasma protein concentration were processed immediately. The sample for determination of plasma osmolality ([Ponmol]) and plasma sodium concentration ([Na⁺]) was transferred into the heparin-treated tube or, for hormone assays, into the chilled EDTA-treated tube, and centrifuged immediately. The separated plasma for hormone assay was stored at −80°C or, for measurement of Ponmol and [Na⁺], −20°C until the assays were performed.

Hct was determined by capillary tube centrifugation. [Hb] was determined by the cyanmethemoglobin method, and plasma protein concentration was determined by refractometry (Atago refractometer, Tokyo). [Ponmol] and urine osmolality were determined by freezing-point depression (Fiske 1–10 osmometer, Needham Heights, MA), and [Na⁺] and urine sodium concentrations were determined by flame photometry (Corning 480 Flamephotometer, Medfield, MA). Plasma and urine creatinine concentrations were determined with a modified Jaffé reaction (Wako Chemicals, Tokyo). Plasma aldosterone concentration ([ALDO]) was determined by RIA (Mitsubishi Kagaku, Tokyo); Intra- and interassay coefficients of variance for 0.97 pg/ml AVP were 11.4% and 3.1%, respectively; for 2.24 pg/ml they were 7.1 and 4.1%, respectively. Plasma aldosterone concentration ([ALDO]), was determined by RIA (Spac-S; Daiichi Radiosotope, Tokyo). Intra- and interassay coefficients of variance for 75 pg/ml AVP were 5.6 and 1.6%, respectively; or 380 pg/ml they were 3.6 and 2.1%, respectively. Plasma renin activity (PRA) was also determined by RIA (SRL, Tokyo). Intra- and interassay coefficients of variance for 1.90 ng ANG l⁻¹·min⁻¹·ml⁻¹ were 5.6 and 4.2%, respectively, and for 5.21 ng ANG l⁻¹·min⁻¹·ml⁻¹ were 6.4 and 5.4%, respectively.
RESULTS

Blood volumes and plasma constituents. PV and BV were not different between Old and Young in the pre- and postacclimation tests (Fig. 1). Both PV and BV increased after the 7-day exercise-heat exposure in Young by ~5%, but PV and BV did not increase in Old.

The baseline $P_{\text{osmol}}$ in Old tended to be higher, but only baseline $P_{\text{osmol}}$ in the postacclimation test in Old was significantly higher than in Young (Fig. 2, top). Changes in $P_{\text{osmol}}$ were similar between the two age groups in each test period and between pre- and postacclimation in each age group, except that $P_{\text{osmol}}$ at 120 min in the postacclimation test in Young was significantly lower than in Old and also lower than in the preacclimation test (Fig. 2, top). $[\text{Na}^+]_p$ during the rehydration period was lower in Young than in Old in the preacclimation test but not in the postacclimation test (Fig. 2, middle). The effect of heat acclimation on $[\text{Na}^+]_p$ was significant only in Young after dehydration (Fig. 2, middle). The $\Delta PV$s were not different between the pre- and postacclimation tests in Young and between Young and Old in the preacclimation test, but the decrease in PV during the dehydration period in the postacclimation test in Old was much smaller when compared with the preacclimation test and also compared with the postacclimation test in Young (Fig. 2, bottom). Heat acclimation tended to enhance recovery of PV loss in both Old and Young.

Thirst ratings and hormonal responses. Baseline thirst rating at the preacclimation test in Young (56.0 ± 3.2%) was higher than in Old (26.1 ± 9.4%), but the baseline thirst rating in Old (36.5 ± 7.3%) in the postacclimation test was not different from the rating in Young (46.2 ± 7.1; Fig. 3, top). The thirst ratings at the end of the dehydration were higher in Young than in Old, and heat acclimation did not influence thirst responses in either group (Fig. 3, top). The subjective thirst rating was not significantly correlated with fluid intake during the first 10 min of rehydration in Old, but these were significantly correlated ($r = 0.69$) in Young (Fig. 3, bottom).

The responses of the fluid-regulating hormones to the acute dehydration were generally attenuated in Old compared with Young (Fig. 4). Baseline $[\text{AVP}]_p$ in Old and Young was not different in both pre- and postacclimation tests. The increase in $[\text{AVP}]_p$ during the dehydration period was smaller in Old than in Young in both pre- and postacclimation periods; there was no difference between Old and Young during the dehydration period, except for $[\text{AVP}]_p$ at 60 min of rehydration in the preacclimation test, which was higher in Young (Fig. 4, top). Heat acclimation augmented the increase in $[\text{AVP}]_p$ during dehydration in both Old and Young, and also increased $[\text{AVP}]_p$ during rehydration in Old (Fig. 4, top).

PRA at the end of the dehydration period was also lower in Old than in Young in both pre- and postacclimation tests. PRA during the rehydration period was also lower in Old than in Young in the preacclimation test, but was not different in the postacclimation test. Heat acclimation increased PRA at the end of dehydration in Old but reduced in Young (Fig. 4, middle).

$[\text{ALDO}]_p$ in Old was lower than in Young throughout both pre- and postacclimation tests, except for baseline $[\text{ALDO}]_p$ in the postacclimation test (Fig. 4, bottom). Heat acclimation did not influence $[\text{ALDO}]_p$, except for
the baseline [ALDO]₀ in Young, which was different between the pre- and postacclimation tests.

Figure 5 shows [AVP]₀ (Fig. 5, left) and subjective thirst rating (Fig. 5, right) as a function of P₀smol. These two relationships shifted downward to the right in Old from those in Young in both pre- and postacclimation tests.

Body fluid volume balance. Figure 6 demonstrates cumulative fluid intake (Fig. 6, top) and urinary output (Fig. 6, middle) during the rehydration period and body fluid volume balance from 0 min of rehydration during the experiments (bottom). Fluid loss via sweat and urine during the exercise-heat exposure was smaller in Old than Young in both pre- and postacclimation tests, but there was no significant difference between pre- and postacclimation tests within the groups. In the preacclimation test the fractional recovery from the lost volume during the rehydration period in Old (31 ± 4%) was lower than that in Young (56 ± 8%), which was mainly due to reduced fluid intake (Fig. 6). The fractional recovery of the lost volume during the 2-h rehydration period increased to 80 ± 9% in Young, but was unchanged in Old (34 ± 5%) (Fig. 6). Fluid retention fraction, calculated as (fluid intake – urine output)/(fluid intake) × 100, was lower in Old (77.7 ± 2.9%) than in Young (89.6 ± 1.9%) in the preacclimation test. The fluid retention fraction did not increase in Old with acclimation (79.5 ± 5.8%), but it increased in Young to 93.6 ± 1.1%.

Renal responses. Urine flow (UV) during baseline and dehydration was higher in Old than in Young in the preacclimation test, but was not different between groups in the postacclimation test. Baseline UV decreased with acclimation in both groups and during the dehydration period in Old. There was no difference in urinary sodium excretion rate (UNaV) between Old and Young throughout the experiment except for the first 1 h of rehydration, but did not in Young. Creatinine clearance in Old was lower than in Young in the preacclimation test except during the dehydration period; however, there was no difference between the groups in the postacclimation test. Fractional excretion of water (FEH₂O) in Old during the controls and dehydration period was higher than in Young in both pre- and postacclimation tests, and the effect of heat acclimation was significant only during the control period in Old. Fractional excretion of Na (FENa) in Old during the control and dehydration periods was also higher than in Young throughout both pre- and postacclimation tests, and heat acclimation decreased FENa in Old throughout the experiment.

Fig. 2. Plasma osmolality (P₀smol; top), plasma sodium concentration ([Na⁺]₀; middle) and change in PV (ΔPV; bottom) during pre- and postacclimation tests in Old (left) and Young (right). Values are means ± SE of 9 Old and 6 Young. * Significant difference between pre- and postacclimation tests; # significant difference between Old and Young.
DISCUSSION

Attenuation of body fluid regulatory responses to an acute dehydration challenge has been reported in older adults, including reduced thirst perception and blunted renal fluid handling (9, 11, 12, 17, 18). Heat acclimation improves body fluid regulatory function in younger people mainly by increasing voluntary fluid intake (8, 14). Thus we tested the hypothesis that exercise-heat acclimation program should improve body fluid regulatory function in older subjects. The most significant finding of the present study was that, in addition to their decreased ability to recover from dehydration, the old subjects could not improve their recovery of fluid balance during the 2-h rehydration period after the 7-day exercise-heat exposure, whereas the young subjects improved their recovery of fluid balance. Body fluid balance at the end of rehydration after acute thermal dehydration was improved in Young by the acclimation program but not in Old; Young recovered 56% of their loss on day 1 and 80% on day 8, whereas Old recovered only 31% on day 1 and 34% on day 8 (Fig. 6). The level of involuntary dehydration (water deficit) during the rehydration period was higher in Old before acclimation, and acclimation did not improve their fluid balance after acute dehydration. The increased fluid balance at the end of the rehydration period in Young was due mainly to increased fluid intake, whereas the contribution of renal function to the improved fluid balance after acute dehydration was relatively insignificant (Table 2).

Acclimation program. Exercise-heat acclimation for 7 days increased PV by ~5% in Young, but PV was unchanged in Old (Fig. 1). Zappe et al. (30) also reported that a 4-day exercise-heat exposure did not increase PV in older subjects, whereas the same protocol increased PV in younger subjects. Endurance exercise training in a cool environment also increases PV (3, 4). Pickering et al. (19) reported that PV in older subjects increased after 16 wk of endurance training. Thus a longer exercise training period might be required to increase PV in older people compared with young people (3, 4). Reduced ability to increase fluid ingestion after the exercise-heat acclimation program could explain why the PV in Old did not increase after the 7-day exercise-heat exposure.

Heat acclimation in younger subjects induces PV expansion with improved thermoregulatory function (8, 16). In the present study, the PV increased in Young but not in Old. Unchanged PV after the acclimation program in Old suggests that they might not acquire heat acclimation status with the acclimation program used in the present study. Because the absolute work load was automatically controlled to maintain a predetermined HR by the feedback system, measured HR and tympanic temperature at the end of the dehydration protocol was not different between pre- and postacclimation tests, and we could not monitor absolute...
work load because of technical problems. Armstrong and Kenney (2) reported that a 9-day acclimation program (40% VO_{peak} exercise at 45°C for 1.5–2 h) improved thermoregulatory responses to passive body heating in older subjects (61 ± 1 yr) as much as VO_{peak}-matched young subjects (26 ± 2 yr), suggesting that older people have the capacity for heat-acclimation. However, it is difficult to conclude whether our older subjects acquired heat acclimation status as the subjects in the study by Armstrong and Kenney (2) because the older subjects in our study had a much lower than the younger subjects.

Effect of aging on fluid intake. Older people have an attenuated thirst in response to water deprivation (18), thermal dehydration (11, 12), and hypertonic saline infusion (17). In the present study, the Old had a lower thirst rating than Young in relation to the dehydration-induced increase in P_{osmol} (Fig. 6). The influence of aging on the relationship between [AVP]_p and P_{osmol} was similar to the influence on the relationship between thirst and P_{osmol}, suggesting that the aging effect on osmoregulation is not specific for thirst but rather a general response. The [AVP]_p-P_{osmol} relationship and thirst-P_{osmol} relationship in Old is likely to be shifted in parallel from the relationships in Young, which was similar to the findings of Mack et al. (11). Although we did not have enough data points to determine the slope or threshold for these osmoregulatory responses, the results suggest that the attenuated osmoregulatory responses must be a main factor for attenuated fluid ingestion during rehydration in Old. Our hypothesis agrees with the results of Phillips et al. (17), that older men have attenuated thirst response to hypertonic saline infusion, and differs from the findings of Stachenfeld et al. (25), that older and younger people have similar osmoregulatory responses to osmotic challenge. It is difficult to know the reason why this discrepancy occurred. However, we speculate that different PV levels and characteristics of subjects, including fitness level and gender, could contribute to the difference.

Reduced BV (reduced central BV) is another factor that influences thirst and AVP secretion. Increased central BV produced by head-out water immersion attenuates thirst and fluid ingestion in young people (22, 29). Stachenfeld et al. (24) found less attenuation of thirst and fluid intake during water immersion in older subjects than in younger subjects and concluded that attenuated cardiopulmonary baroreceptor response to
central BV change could be involved in the age-induced hypodipsia. In the present study, the PRA response to dehydration was smaller in Old than in Young in both pre- and postacclimation tests, suggesting a reduced response to hypovolemia. Because reduction of PV itself during the dehydration period was too small to induce thirst and vasopressin secretion in the present and other studies (28); ~10% reduction in BV is required to elicit thirst; the effect of hypovolemia itself should be minor. Robertson et al. (20, 21) reported that vasopressin secretion and thirst, as a function of Posmol, were modified by the level of BV or blood pressure. Hypovolemia augments and hypervolemia attenuates osmosensitivity for these responses (21). A reduced volume-effect on osmoregulatory thirst and vasopressin secretion might be attenuated by aging; the interaction between hyperosmotic and hypovolemic effects on these physiological responses needs further study.

Old subjects who had higher thirst ratings did not necessarily drink more (Fig. 4). The discrepancy between thirst rating and fluid intake in Old suggests that factors other than thirst, e.g., satiety factors or palatability of the solution, might be involved in the mechanisms of reduced fluid intake during recovery from dehydration. In any event, the reduced osmoregulatory function is most likely a factor for reducing fluid ingestion in Old in the present study.

Effect of the acclimation program on fluid intake. The heat acclimation program increased fluid intake in Young but not in Old in the present study (Fig. 6). Greenleaf et al. (8) reported similar results in young subjects. The reduced ability of Old to recover from acute dehydration was mainly a result of attenuated fluid intake, which is due partly to reduced thirst (Figs. 3 and 6). Because the osmoregulatory responses to dehydration were not influenced by the exercise-heat acclimation program (Fig. 5), it would seem that osmoregulatory adaptation itself plays a minor role in acclimation-induced improvement of fluid balance.

Voluntary fluid intake is controlled by both stimulation and satiety factors (1). Thus the loading of cardiopulmonary baroreceptors by drinking could act as a satiety factor for fluid intake. The acclimation program increased PV in Young but not in Old (Fig. 2). Although the mechanism of PV expansion by heat acclimation still is not clear enough, one hypervolemic factor is reduced cardiopulmonary baroreceptor sensitivity (7). Thus the increased fluid intake in Young after the acclimation program could be a result of reduced cardiopulmonary baroreceptor sensitivity to volume loading resulting in termination of drinking. The hypothesis that increased fluid intake in Young after the exercise-heat acclimation program is due to reduced cardiopulmonary baroreceptor sensitivity could explain why Young increased fluid intake without increase in thirst rating just before rehydration and without change in fluid intake-thirst relationship (Fig. 3). Exercise training alone in older women did not reduce cardiopulmonary baroreceptor sensitivity and did not increase PV (23), but PV was increased in younger men (3, 4, 7), which may be the reason why increased fluid intake did not occur in our men. In the present study, the exercise-heat acclimation program reduced the PRA response to dehydration in Young (Fig. 3, middle right), although the change in PV by dehydration was similar (Fig. 1), whereas acclimation did not reduce but did increase the PRA response to dehydration in Old. These results in the present study are consistent with the hypothesis that attenuated cardiopulmonary baroreceptor sensitivity produced by acclimation is involved in the increased dehydration-induced fluid intake and PV expansion after exercise-heat acclimation in young people. We speculate that older people might have attenuated cardiopulmonary baroreflex sensitivity, and the acclimation program did not induce further attenuation of cardiopulmonary baroreceptor sensitivity, thus fluid intake was not influenced by the acclimation program.
A smaller reduction of PV during dehydration in the postacclimation test in Old (Fig. 3) could also explain why their fluid intake did not increase after acclimation. Because increased P_{osmol} by dehydration in the postacclimation test was similar to that in the preacclimation test, fluid movement from the intracellular to the extracellular spaces should be similar (15). Also, the changes in PV calculated from changes in the plasma protein concentration were similar; thus the mechanism for the attenuated reduction in PV in Old remains elusive.

Our subjects were rehydrated with a carbohydrate-electrolyte solution, which has a taste that could influence drinking behavior. Fluid ingestion was increased in Young after the exercise-heat acclimation program but not in Old, even though both groups drank the same solution before and after the acclimation program. Thus the change in palatability of solution in Young might be involved in the increased fluid intake.

Renal responses. In addition to attenuated thirst, reduced renal function has been implicated in the decreased PV and total body water in older people (10). Factors which reduce renal function in older people are decreased glomerular filtration rate caused by reduced number of glomeruli and reduced renal concentrating capacity (10). In the present study, both renal FE_{H2O} and FE_{Na} tended to be lower in Old, suggesting decreased water and sodium reabsorption ability. Reduced levels of PRA and fluid-regulating hormones could contribute to the reduced reabsorption ability of H_2O and Na^+ (Fig. 5). Heat acclimation had minimal effect on the renal responses, although a small improvement occurred in Old (Table 2). The increased fluid retention fraction during rehydration in Young was due mainly to increased fluid intake with unchanged urine output. Thus in this study renal fluid and electrolyte handling played a minor role for regulation of the body fluid balance. The main difference in the levels of involuntary dehydration between the two age groups after heat acclimation was attenuated fluid intake in Old and enhanced fluid intake in Young; the latter contributed to improvement of fluid balance after dehydration. However, Old had a lower fluid retention fraction than Young (they drank less than Young, but urine output was similar), and their retention fraction was not.
increased by the acclimation program, whereas it was increased in Young (increased fluid intake and unchanged urine output). Therefore, it appears that forced drinking after dehydration should not improve body fluid balance in Old. Additional forced drinking in preacclimated condition in Young will not restore body fluid balance as much as postacclimation drinking. We suggest that the regulated fluid balance should be shifted by aging or acclimation in Young.

In summary, we confirmed that older men have a lower ability to recover from acute dehydration, which might be associated with reduced osmosensitivity. We also found that an exercise-heat acclimation program, which increased PV and reduced the level of involuntary dehydration (water deficit) with ad libitum drinking in younger subjects, did not increase PV or reduce the level of involuntary dehydration in Old due mainly to unchanged fluid intake. The question still remains whether or not a longer acclimation period improves body fluid regulation in older subjects. However, the standard exercise-heat acclimation program did not improve body fluid balance after thermal dehydration by ad libitum drinking in Old due mainly to unchanged fluid intake. The question still remains whether or not a longer acclimation period improves body fluid regulation in older people and if the acquisition of heat acclimation status results in improved body fluid regulation in older people. Further studies are required to elucidate the mechanism of attenuated adaptability in older people.

Perspectives

Body fluid volume and its constituents are strictly controlled within a very narrow range. Body fluid regulatory function is attenuated in older people; they cannot recover from dehydration as quickly as younger people do; thus they tend to remain dehydrated. Because dehydration has adverse effects on thermoregulatory and cardiovascular function, maintaining euhydration is especially important in older people to prevent heat illness or circulatory failure and to maintain a higher activity level. We examined whether the standard exercise-heat acclimation program, which improves both thermoregulation and body fluid regulation in response to dehydration in younger people, should improve body fluid regulation in older subjects. However, the standard exercise-heat acclimation program did not improve body fluid balance after thermal dehydration by ad libitum drinking in Old due mainly to unchanged fluid intake. The question still remains whether or not a longer acclimation period improves body fluid regulation in older people and if the acquisition of heat acclimation status results in improved body fluid regulation in older people. Further studies are required to elucidate the mechanism of attenuated adaptability in older people.

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Table 2. Renal function during control, dehydration, and rehydration in pre- and postacclimation experiments in older and younger subjects

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<th>Control</th>
<th>Dehydration</th>
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<td>1 h</td>
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<td>Preacclimation test</td>
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<td>Old</td>
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<td><strong>UV, µl·min⁻¹·kg⁻¹</strong></td>
<td>15.4 ± 2.9</td>
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<td><strong>UNaV, µeq·min⁻¹·kg⁻¹</strong></td>
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<td><strong>Ccr, ml·min⁻¹·kg⁻¹</strong></td>
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<td><strong>FEH₂O, %</strong></td>
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<td><strong>FEH₂O, %</strong></td>
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<td>1.09 ± 0.22</td>
<td>0.77 ± 0.22</td>
</tr>
<tr>
<td>Postacclimation test</td>
<td>Old</td>
<td>Young</td>
<td>Old</td>
</tr>
<tr>
<td><strong>UV, µl·min⁻¹·kg⁻¹</strong></td>
<td>9.6 ± 2.3*</td>
<td>11.2 ± 2.3*</td>
<td>7.2 ± 1.3</td>
</tr>
<tr>
<td><strong>UNaV, µeq·min⁻¹·kg⁻¹</strong></td>
<td>1.28 ± 0.28*</td>
<td>1.13 ± 0.20*</td>
<td>0.95 ± 0.15</td>
</tr>
<tr>
<td><strong>Ccr, ml·min⁻¹·kg⁻¹</strong></td>
<td>1.09 ± 0.17</td>
<td>1.14 ± 0.13</td>
<td>1.17 ± 0.20</td>
</tr>
<tr>
<td><strong>FEH₂O, %</strong></td>
<td>0.78 ± 0.16*</td>
<td>1.07 ± 0.24</td>
<td>0.65 ± 0.07</td>
</tr>
<tr>
<td><strong>FEH₂O, %</strong></td>
<td>0.65 ± 0.12*</td>
<td>0.63 ± 0.09*</td>
<td>0.53 ± 0.06*</td>
</tr>
</tbody>
</table>

Values are means ± SE; n = 9 Old and 6 Young subjects. UV, urine flow; UNaV, urinary sodium excretion rate; Ccr, creatinine clearance; FEH₂O, fractional excretion of water; FEH₂O, fractional excretion of sodium. *Difference between pre- and postacclimation experiments within groups; † difference between age groups.
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