NASA Technical Memorandum 103942

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Summary

The purpose of this study was to formulate and to evaluate rehydration drinks, which would restore total body water and plasma volume (PV), for astronauts to consume before and during extravehicular activity, a few hours before reentry, and immediately after landing. In the first experiment (rest, sitting), five healthy men (23-41 yr), previously dehydrated for 24 hr, drank six (Ia, II, IV, V, VI, VII) fluid formulations (one each at weekly intervals) and then sat for 70 min. Pre-test PV were measured with Evans blue dye, and changes in PV were calculated with the hematocrit-hemoglobin transformation equation. This rest experiment simulated hypohydrated astronauts preparing for reentry. The second experiment (exercise, supine) followed the same protocol except four healthy men (30-46 yr) worked for 70 min. in the supine position on a cycle ergometer at a mean load of 71 ± 1% of their peak aerobic work capacity. This exercise experiment simulated conditions for astronauts with reduced total body water engaging in extravehicular activity.

In the rest experiment the change of PV after drinking the beverage formulations ranged from –3.8% ($P < 0.05$) at 3 min. to +7.6% ($P < 0.05$) at 70 min. Plasma volume decreased ($P < 0.05$) during the initial 9 min. with drinks II (19.6 mEq Na^+ + aspartame), V (19.6 mEq Na^+ + glucose), and VI (Performance); and was unchanged with Ia (water + aspartame), IV(157 mEq Na^+ + aspartame), and VII (Power Surge). At 70 min. PV changed by +1.1% to +1.5% (NS, similar to water) with drinks Ia, II, and VI; and increased ($P < 0.05$) by 3.1% (VII) by +4.6% (VI) and by +7.6% (IV).

In the exercise experiment a similar pattern of PV responses occurred, but at a lower level. In the rest study all six drinks resulted in changes of PV at 70 min. from +1.1 to +7.6%; but with exercise consumption of all six drinks resulted in depression of PV from 5.2% to 14.0% at 70 min. Results from prior studies indicate that when subjects had consumed no fluids, the reduction in PV at 70 min. with this moderately heavy exercise load would have been about 12%-14%. With the exception of Ia (water), which produced the same response as consuming no fluids and appeared to be the least desirable drink, changes in PV with the remaining five drinks were similar to resting PV responses. It appears that performance of intensive exercise immediately after drinking inhibited fluid transfer from the gastrointestinal tract into the vascular system.

Thus, fluid formulations containing sodium compounds near isotonic concentrations (i.e., the same concentration as blood plasma) were more effective than more dilute solutions for restoring and increasing PV in resting, hypohydrated men. Fluid formulations containing sodium compounds near isotonic concentrations and the more dilute sodium formulations were effective for maintaining PV in exercising, hypohydrated men.

Introduction

Astronauts in microgravity exhibit a reduction in total body water (hypohydration) of 3-4% of body weight for the duration of their missions, and this chronic hypohydration probably reduces both extracellular (interstitial and vascular) and cellular fluid compartments (Greenleaf, 1990). As an adaptive response, this chronic hypohydration does not appear to influence astronauts' physical or mental performance in microgravity unless it is exacerbated by significant additional fluid and electrolyte losses from vomiting, diarrhea, or sweating. The latter can also occur during heavy physical exercise such as extravehicular activity (EVA). This "latent" hypohydation will manifest itself as actual hypohydration when acceleration and gravitational forces increase during reentry. Hypohydration can then impair performance during reentry, and orthostatic responses immediately after landing when the astronauts attempt to arise from their seats (Nicogossian, 1982). The result may be syncope.

The present recommendation for rehydrating astronauts a few hours prior to reentry is the voluntary consumption of NaCl tablets and water in isotonic concentration (1 g NaCl/100 ml H_2O) (Bungo, 1985; Frey, 1991).

*Shaklee U.S., Inc., San Francisco, California.

Consuming the tablets and water in this precise ratio (concentration) is inconvenient for the astronauts because rehydration commences about two hours before reentry, when they are strapped into their seats wearing reentry suits. The abdominal bladder of the reentry suit exerts pressure even when it is not inflated and causes discomfort before, during, and especially after drinking.

The major problem with using salt tablets and water separately for optimal concentration is achieving a proper ratio of salt to water. Excess salt taken without sufficient water can accentuate plasma osmolality (increase the hypohydration), whereas excess water taken with insufficient salt will probably be excreted in the urine, cause discomfort, and provide little restoration of the hypohydration. Pre-mixed beverage formulations would ameliorate the optimal concentration difficulty, and perhaps the volume discomfort problems if the drink volume could be reduced and still provide for adequate restoration of total body water. Rehydration fluid is provided in the EVA suit. Apparently no definitive studies have been conducted to determine the optimal content or concentration of electrolytes and carbohydrates of rehydration fluid formulations for astronauts. A brief review of the effect of oral rehydration and hyper-hydration on orthostatic, lower body negative pressure, and acceleration tolerances before and after deconditioning is presented in table 1.

The purpose of this study was to evaluate six oral rehydration fluid formulations which could be used by astronauts and cosmonauts before and during EVA, prior to reentry, and after landing.

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Methods

Subjects

Seven men (23-46 yr, table 2) gave informed consent and passed a comprehensive medical examination which included their history, blood and urine analyses, and a treadmill stress test. All were non-smokers and none took non-prescribed drugs. They were divided selectively into two groups; a rest (sitting) group (N = 5) and an exercise (supine) group (N = 4). Two men participated in both groups.

Procedure

Peak oxygen uptake was measured before the drinking phases began. The protocol for both experiments (fig. 1) required the men to dehydrate for 24 hr immediately before testing by restricting fluid intake and eating dry food. Their level of dehydration, termed hypohydration when the reduced fluid level of the body has reached a steady-state, can be determined prior to each experiment from the control level (–5 min.) of plasma osmolality. Normal, hydrated ambulatory control plasma osmolality is about 285 ± 2 mOsm/kg. The initial range in this study was 298 to 305 mOsm/kg in the rest experiment, and 291 to 304 mOsm/kg in the exercise experiment, so the test subjects could be considered moderately dehydrated or hypohydrated.

The subjects arrived at the Laboratory for Human Gravitational Physiology at Ames Research Center at 0700 hr. They urinated, were weighed to ±5g (model 5780 digital scale, National Controls, Inc., San Carlos, CA 94070), and inserted a rectal temperature thermistor probe 16 cm. Dressed in shorts and shoes the men rested sitting (rest experiment) or supine (exercise experiment) for 50 min. (control period) while EKG electrodes, a cheek laser-doppler probe, forearm impedance electrodes (exercise experiment), skin temperature probes (exercise experiment), a forearm venous cathether, and the transcranial-doppler head harness (rest experiment) were attached. The subjects, in the sitting position, then drank slowly one of six fluid formulations designated Ia, II, IV, V, VI, VII (table 3). Drinks I and IV were not tested. Drink volume was 12 ml/kg (898 to 927 ml) and mean drinking time varied from 2.3 to 6.2 min. (table 4). They either sat or exercised at 71 ± 1% of their peak oxygen uptake for 70 min. A urine sample was taken and, after they were dried with towels, a final weight was taken.

Plasma volume was measured with Evans blue dye (T1824) just before drinking. An 8-ml pre-injection blood sample was taken at –15 min. of the resting control period (fig. 1). Samples were drawn through a heparinized antecubital teflon catheter (Quik-Cath, Travenol Laboratories, Inc., Deerfield, IL 60015). Additional 20 ml blood samples were taken at –5, +3, +9, +15, +30, and +70 min. of the test periods (fig. 1). The 70-min. sample was taken just before exercise stopped. The –5 min. post-dye injection blood sample was the control sample.

Physiological Measurements

Peak oxygen uptake ($\dot{V}_{O_2}$ peak) was measured, after two familiarization sessions, at least three times before the study began with the subjects in the supine position on an Imaging/Ergometer Table (model 846T, Quinton

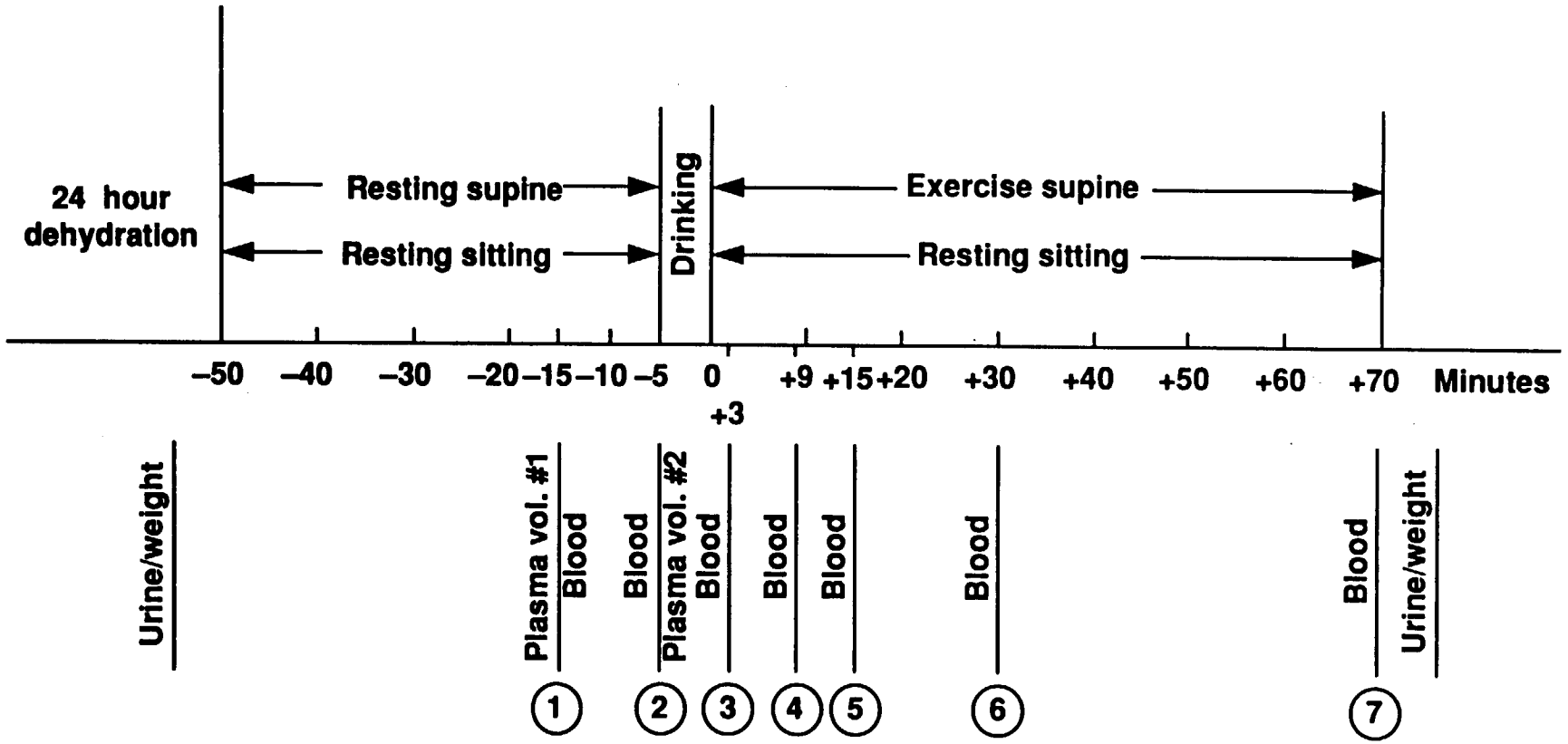

Figure 1. Experimental protocol.

Instruments Co., Seattle, WA 98121). Shoulder braces, handgrips, and heel supports were used. The respiratory measurements system utilized a low-resistance, low-dead-space Rudolph value (model 2700, Hans Rudolph, Inc., Kansas City, MO 64108), a Tissot-tank calibrated electronic spirometer (model S-301 Pneumoscan, K.L. Engineering Co., Slymar, CA 91342), and a 3-liter mixing chamber from which the expired gas was sampled at 0.5 liters/min. and then drawn through anhydrous calcium sulfate (N.A. Hammond Drierite Co., Xenia, OH 45385) to oxygen and carbon dioxide analyzers (Applied Electrochemistry models S-3AI and CD-3A, respectively; Ametek, Thermox Instruments Division, Pittsburg, PA 15238). The analyzers were calibrated with gases standardized with the Lloyd-Haldane apparatus. Analog data were processed with an analog-to-digital converter (VISTA system IBM model 17002, Vacumed, Ventura, CA 93003) and transmitted to an IBM (model AT) computer; output metabolic data were printed each 15 sec and peak $\dot{V}_{O_2}$ was the mean of the final four 15-sec values. Peak oxygen uptake was extrapolated from the heart rate at 180 beats/min. Heart rate and oxygen uptake curves were plotted for each subject from resting data and two submaximal exercise loads of 75W and 150W. The heart rate curve was extended to 180 beats/min. and a vertical line was drawn to intersect the extended oxygen uptake curve. The intersection was the estimated peak oxygen uptake. The exercise load corresponding to an oxygen uptake of 70% of the estimated peak $\dot{V}_{O_2}$ was selected as the load to be used during the drinking experiments. The final mean relative exercise load was 71 ± 1% (range = 68 to 77%) (table 5).

Skin blood flow (volume and velocity) were measured on the cheek just below the zygomatic bone with a laser Doppler probe (LaserFlo Blood Perfusion Monitor, model BPM 403A, TSI-Vasamedics, Inc., St. Paul, MN 55117). Forearm total blood flow was measured (Greenleaf, Montgomery, et al., 1979) with a modified bilateral impedance rheograph (model BR-100, Beckman Instruments, Inc., Brea, CA 92621). Blood pressure (arm) was measured with conventional mercury sphygmomanometry, and heart rate was determined with a cardiotachometer (model 78203C, Hewlett-Packard, Waltham, MA 02154) connected to Quinton Quik-Prep electrodes attached to the skin in the area of the sternal notch, xiphoid process, and the fifth intercostal space. Middle cerebral arterial flow velocities (expressed as frequency Doppler shift), peak systolic, diastolic, mean area, and pulsatility index were measured in the rest group with a transcranial ultrasonic doppler (MedaSonics, Fremont, CA 94539). Rectal and six skin temperatures (exercise experiment) were measured with series 700 thermistors (Yellow Springs Instrument Co., Yellow Springs, OH 45387) and recorded on a Digitek Datalogger thermometry system (model 2000, United Systems Corp., Dayton, OH 45401). The skin thermistors, attached with holders that permitted free movement of air (Greenleaf, 1976), were placed on the arm, forearm, thigh, calf, right chest, and left chest. Mean skin temperature ($\overline{T}_{sk}$) was calculated (Hardy, 1938):

$$\overline{T}_{sk} = 0.06(T_{arm}) + 0.13(T_{forearm}) + 0.21(T_{thigh})$$

$$+ 0.21(T_{calf}) + 0.20(T_{r.chest}) + 0.19(T_{l.chest})$$

During the exercise experiment the subject's back was in contact with the plastic covering on the ergometer, so heat loss from that skin area was impeded. Room temperature was 22.0 ± SD 0.07°C and relative humidity was 46.9 ± SD 5.9%.

Blood Measurements

Plasma sodium and potassium concentrations were determined with specific ion electrodes (System E2A, Beckman Instruments, Brea, CA 92621), plasma osmolality by freezing point depression (model 3DII, Advanced Instruments Digimatic Osmometer, Needham Heights, MA 02194), and plasma total protein with a colorimetric method utilizing the BCA assay reagent (Pierce, Rockford, IL 61105).

Blood and plasma densities were measured with the mechanical oscillator technique which utilizes continuous determinations of the oscillation time of a U-shaped, hollow glass tube filled with whole blood brought to bending-type vibration by electromagnetic energy (Hinghofer, 1987; Kratky, 1966).

Plasma volume was measured with the subjects at rest with Evans blue dye (T-1824) (New World Trading Corp., Longwood, FL 32650) just before drinking from one 10-min. post-dye injection 20 ml blood sample (Campbell, 1958; Greenleaf, Convertino, et al., 1979). The micro-hematocrit tubes were centrifuged for 10 min. at 11,500 rpm (model MB, International Equipment Co., Needham Heights, MA 02194) and the hematocrit (Hct) was read from a modified microcapillary tube reader (model CR, International Equipment Co.). Blood hemoglobin was determined (cyanomethemoglobin method) with a hemoglobinometer (Coulter Electronics, Hialeah, FL 33014). Percent change in plasma volume was calculated using the Hb-Hct transformation equations (Greenleaf, Convertino, et al., 1979).

Plasma vasopressin was measured with a modified radioimmunoassay (Keil, 1977), plasma renin activity with a radioimmunoassay for angiotensin I (New England Nuclear, Boston, MA 02118), plasma aldosterone by radioimmunoassay (Coat-A-Count kit, Diagnostics Products, Los Angeles, CA 90045) and immunoreactive atrial natriuretic factor (atriopeptin) by radioimmunoassay (Gauquelin, 1990). Plasma epinephrine and norepinephrine were measured with reverse phase liquid chromatography (Davis, 1981).

Urinary Measurements

The volume of urine samples [pre-resting control versus post-test (+70 min.)] was timed and measured in graduated cylinders. Urinary flow ($\dot{V}$) was expressed in ml/min. Urinary sodium (U_{Na}), potassium (U_K), and osmotic (U_{osm}) concentrations were determined with the same methods as the plasma variables. Other urinary functions were calculated: Osmotic clearance (C_{osm}) was urine osmotic excretion ($U_{osm}\dot{V}$) divided by plasma osmolality (P_{osm}). Free water clearance (C_{H_2O}) was $\dot{V}$-C_{osm}, fractional excretion of sodium was $U_{N_a}\dot{V}$ and fractional excretion of potassium was $U_K\dot{V}$.

Drink Composition

Four experimental drinks (Ia, II, IV, and V) and two commercial rehydration beverages (VI and VII) were tested: "Performance" (Shaklee U.S., Inc., San Francisco, CA 94111) and "Power Surge" (Perc Products, Moscow, PA 18444) (table 3). The basic ingredients of the beverages were approximately 20 mEq sodium (0.045%), isotonic "saline" (157 mEq Na^+, 0.36%) in the form of sodium chloride and sodium citrate to ameliorate the unpleasant salty taste of sodium chloride, and 9.7% total carbohydrate. Note that both commercial beverages contained about 20 mEq sodium and 9.7% carbohydrates. The non-caloric sweetener Aspartame^R and annetto (natural orange coloring) were added to the non-commercial drinks so that all drinks would appear and taste similarly. Power Surge contained FD&C yellow #6 coloring. The high salt content of drink IV (157 Na^+) was obvious to the subjects. All drink formulations except Power Surge were prepared by Shaklee chemists in their laboratory.

Statistical Procedures

Data were analyzed with Students t-test for dependent variables where appropriate. The null hypothesis was rejected when $P < 0.05$. Nonsignificant differences were denoted by NS, or the terms "trend" or "tendency."

Results and Discussion

Plasma Volume

Mean (±SE) percent changes in plasma volume (PV) for the rest (upper panel) and exercise (lower panel) experiments are presented in figure 2. In the rest experiment two general responses occurred during the first 15 min. after consumption: either no change in PV (drinks IV and VII), or a significant decrease in PV by 3-4% (drinks Ia, II, V, VI) indicating a reduction (shift) of plasma from the vascular space. All PV shifts had returned to zero at 15 min. Thereafter, the PV changes of the water-like drinks (those containing glucose and/or low electrolytes) tended to increase to +1% (NS), while the PV changes of those who had consumed the two drinks (IV and VI) with the greater ionic content increased progessively to reach +7.6% ($P < 0.05$) and +4.6% ($P < 0.05$), respectively, at 70 min.

A different pattern of PV response emerged from the exercise experiment (fig. 2, lower panel). Plasma volume decreased significantly ($P < 0.05$) between 3 to 15 min. with all drinks. The 70-min. values ranged from –5.2% (NS) with drink V, to –13.5% ($P < 0.05$) with drink VII and to –14.1% ($P < 0.05$) with drink Ia. Again, water and a water-like drink (VII) resulted in the greater sustained decreases in PV (hypovolemia); while the two other water-like drinks II (19.6 Na^+) and V (19.6 Na^+ + glucose), and the isotonic drink IV (157 Na^+), resulted in lesser levels of hypovolemia. The exercise hypovolemic response after drinking water (Ia) was similar to the exercise hypovolemic response curve without prior fluid intake; that is a reduction of about 12-14% with a relative exercise load of 71% (Greenleaf, 1986). Thus, compared with the exercise hypovolemia which occurred at 70 min. after drinking Ia (water) and VII (Power Surge); drinks II (19.6 Na^+), IV (157 Na^+), V (19.6 Na^+ + glucose), and VI (Performance) provided significant restoration of PV or attenuation of about five to nine percentage units of the exercise-induced hypovolemia in the previously hypohydrated men. The magnitude of this restoration at 70 min. was similar to the +7.7% hypervolemia induced by drink IV (157 Na^+) in the rest experiment.

Blood Density and Plasma Density

Mean (±SE) blood density (fig. 3, upper panel) and plasma density (fig. 3, lower panel) values for the rest experiment generally reflected a reverse image of the corresponding percentage changes in resting PV (fig. 2, upper panel). An increase in plasma density indicated a reduction in PV. The exercise experiment plasma densities are presented in figure 4 and followed a similar reverse image pattern as the resting data.

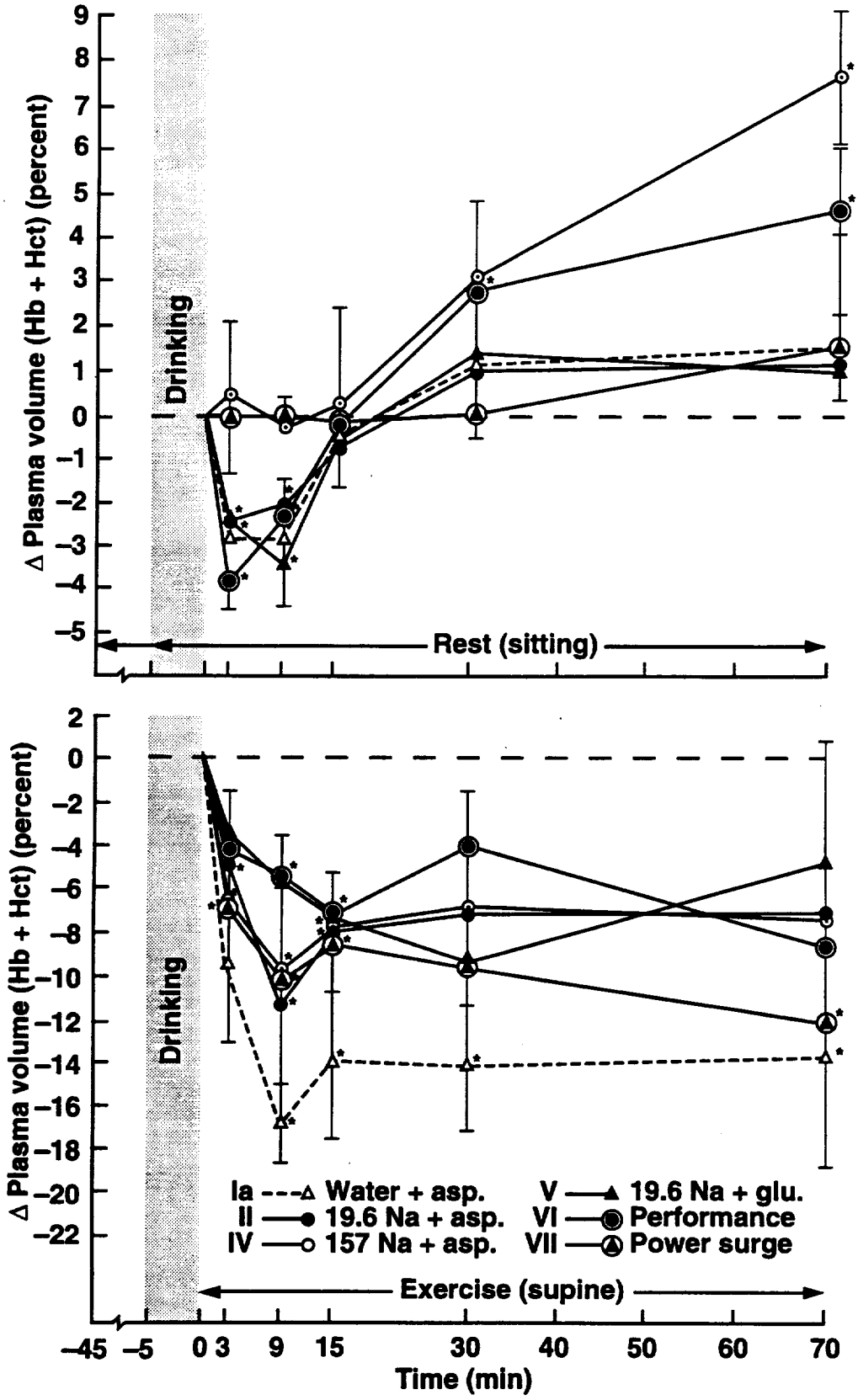

*Figure 2. Mean (±SE) calculated changes in plasma volume during the rest (sitting) and exercise (supine) experiments. *P < 0.05 from time 0 min.*

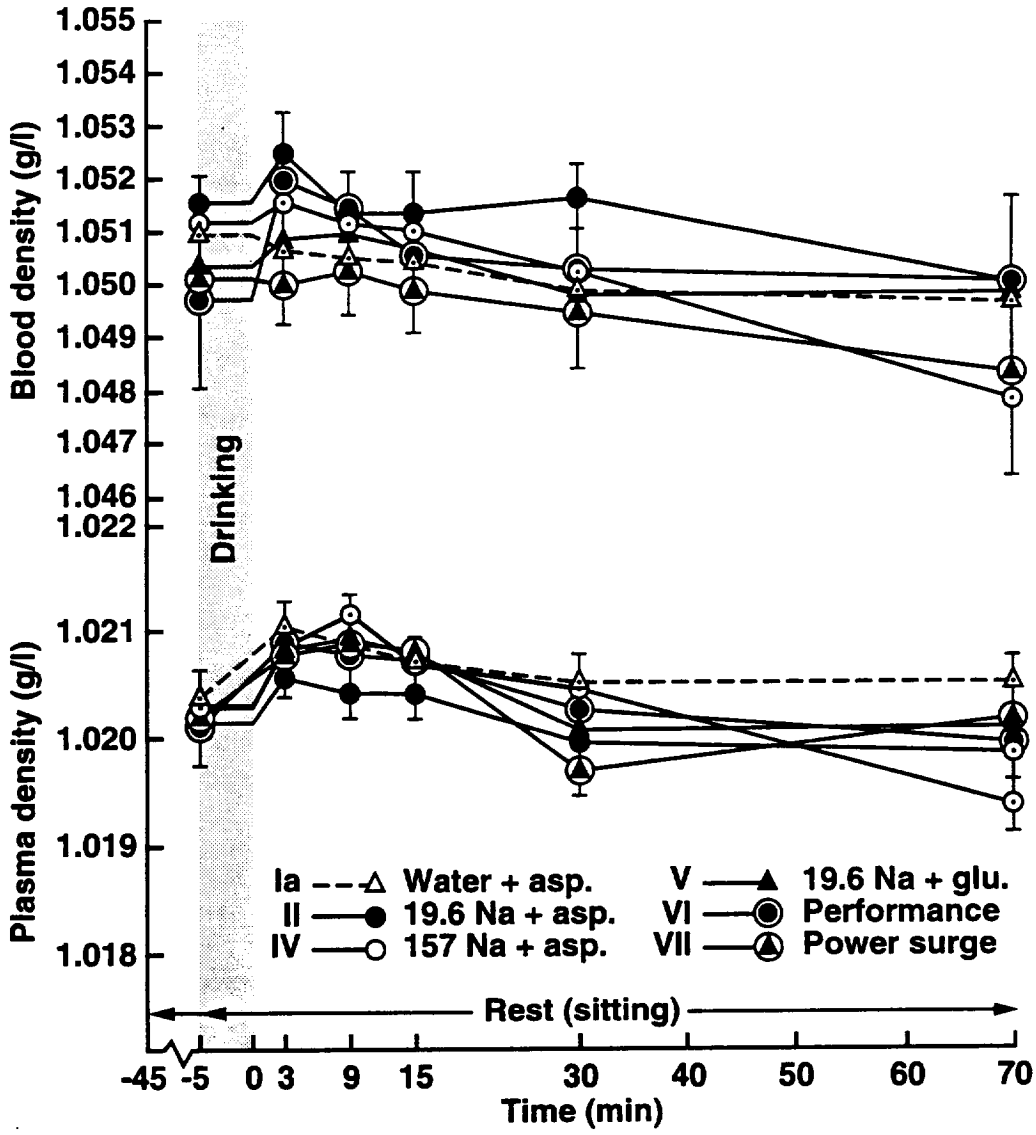

Figure 3. Mean (±SE) blood density and plasma density during the rest experiment.

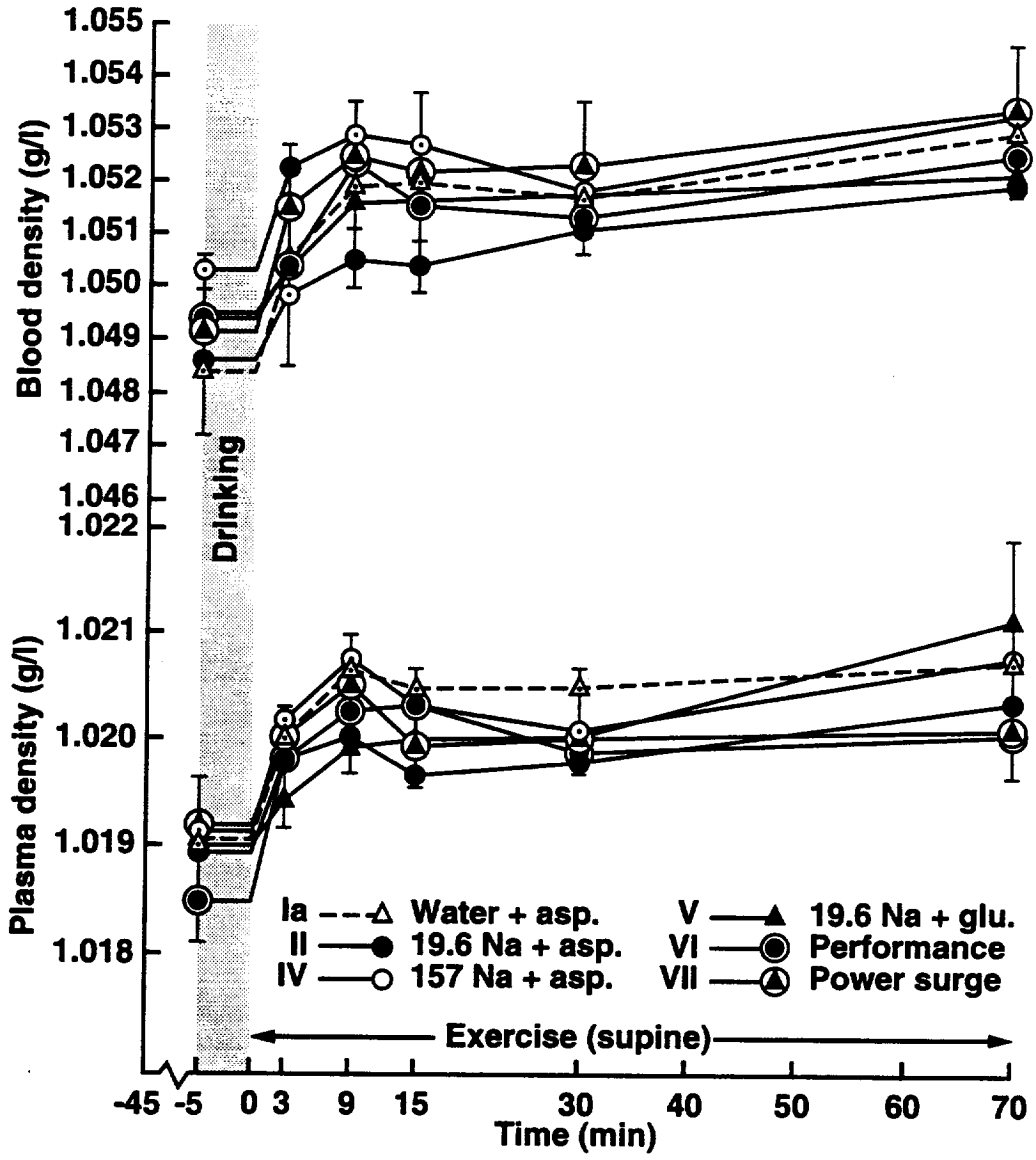

Figure 4. Mean (±SE) blood density and plasma density during the exercise experiment.

Plasma Osmotic Concentration and Content

These variables are presented in figure 5 (rest experiment) and figure 6 (exercise experiment). Osmotic content is osmotic concentration × PV. As would be expected, all resting plasma osmotic measures were lowest with the water drink, whose osmolality (30 mOsm/kg) was derived mainly from the Aspartame^{R} content (table 3): Pure water had an osmolality of 1 mOsmol/kg. The largest change in plasma osmolality was an increase following consumption of drink VI (Performance) which contained the greatest number of ions, but not the highest total ionic concentration: Only drink VII (Power Surge) was lower (table 3). By the end of the rest experiment, drink IV (157 Na^+), which had the highest total ion concentration, also showed the greatest elevation in plasma osmotic content. This elevated content accompanied the 7.4% increase in PV. No consistent relationship was evident between drink total osmolality and change in plasma osmotic content in the rest experiment. This was probably because most of the carbohydrate contents in the drinks were metabolized during the 70-min. period and their osmotic effect was progressively diminished. Thus, the osmotic concentrations and contents of all drinks except IV (157 Na^+) and VI (Performance) produced essentially the same response as water by the end of the experiment (fig. 5).

Unlike the responses of plasma osmolality during the rest experiment, those during exercise exhibited less variation (fig. 6, all panels). At the end of exercise the changes in plasma osmolality were essentially the inverse of those in the rest experiment; Ia (water) and IV (157 Na^+) tended to be higher while VI (Performance) and VII (Power Surge) tended to be lower (fig. 6, middle panel). Changes in plasma osmotic content followed more closely the changes in PV with drinks Ia (water) and VII (Power Surge) attaining the lowest plasma osmotic contents (fig. 6, lower panel). Conversely, drinks IV (157 Na^+) and VI (Performance) resulted in the highest (least attenuated) plasma osmotic content levels which were associated with the lesser decreases in PV. These findings indicate that better PV stabilization during submaximal exercise occurred after consuming drinks with the higher ion contents.

The mixtures of carbohydrate and citrate levels per se did not appear to be essential for maintenance of exercise PV if sufficient ion content was present in the drink. The function of carbohydrates in maintaining plasma osmolality and volume is not clear from the present data because subjects who consumed drinks II (19.6 Na^+) and V (19.6 Na^+ + glucose) responded similarly during exercise (with both plasma osmolality and volume), and responses to both drinks were more similar to drink IV (157 Na^+) than to water (fig. 6).

Plasma Sodium Concentration and Content

Most body sodium is located in the extracellular fluid compartment. Since plasma sodium and its anions constitute over 80% of the content of plasma osmolality, it is not surprising that these two variables showed some similar responses, particularly in the rest experiment (fig. 7 vs. fig. 5). The pattern of sodium and osmotic concentrations, and changes in their concentrations and contents over time were generally similar; for example, the sodium and osmotic content at 70 min. for drink IV (157 Na^+) was elevated to a greater degree than for the other drinks.

However, this general comparability was not evident in the exercise experiment (fig. 8 vs. fig. 6). During the 70 min. of work the plasma sodium concentrations were less variable than the plasma osmotic concentrations. The variabliity (±SE) of the changes in concentrations was similar, but after 15 min. the plasma sodium contents of all drinks had increased (had returned) to or beyond the baseline (zero) while plasma osmotic contents remained depressed below the baseline. After 30 min. of exercise a similar hierarchy of plasma osmotic and sodium content levels became evident, but at 70 min. this relationship disappeared and the distribution became essentially random: the IV (157 Na^+) drink sodium content was at the same level as that of the water-like drinks; V (19.6 Na^+ + glucose), VII (Power Surge), and Ia (water). Sodium contents of the other two drinks (II and VI) were just slightly lower. At the end of exercise the plasma sodium content had clearly stabilized at pre-exercise control levels despite its wide range (0 to 157 mEq/liter) and the presence of many other constituents in the various drinks. Thus, the attenuated decrease of PV at 70 min. of exercise after consuming drinks II, IV, V and VI (fig. 2, lower panel) was not related to plasma sodium content per se, but more to plasma total osmotic content. It appears that osmotic components other than sodium play an important role in maintaining and enhancing PV during exercise.

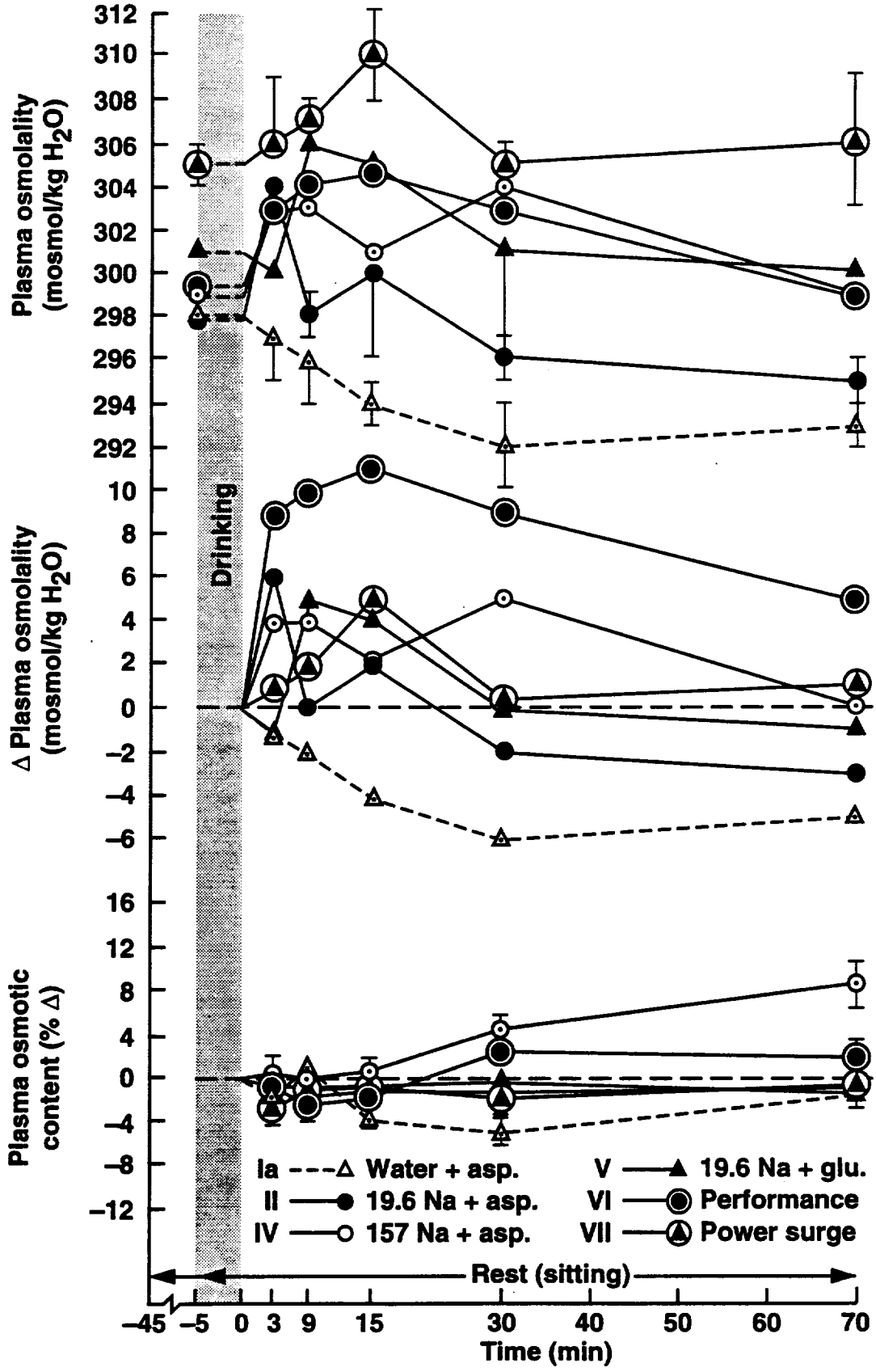

Figure 5. Mean (±SE) plasma osmolality, change in plasma osmolality, and percent change in plasma osmotic content during the rest experiment.

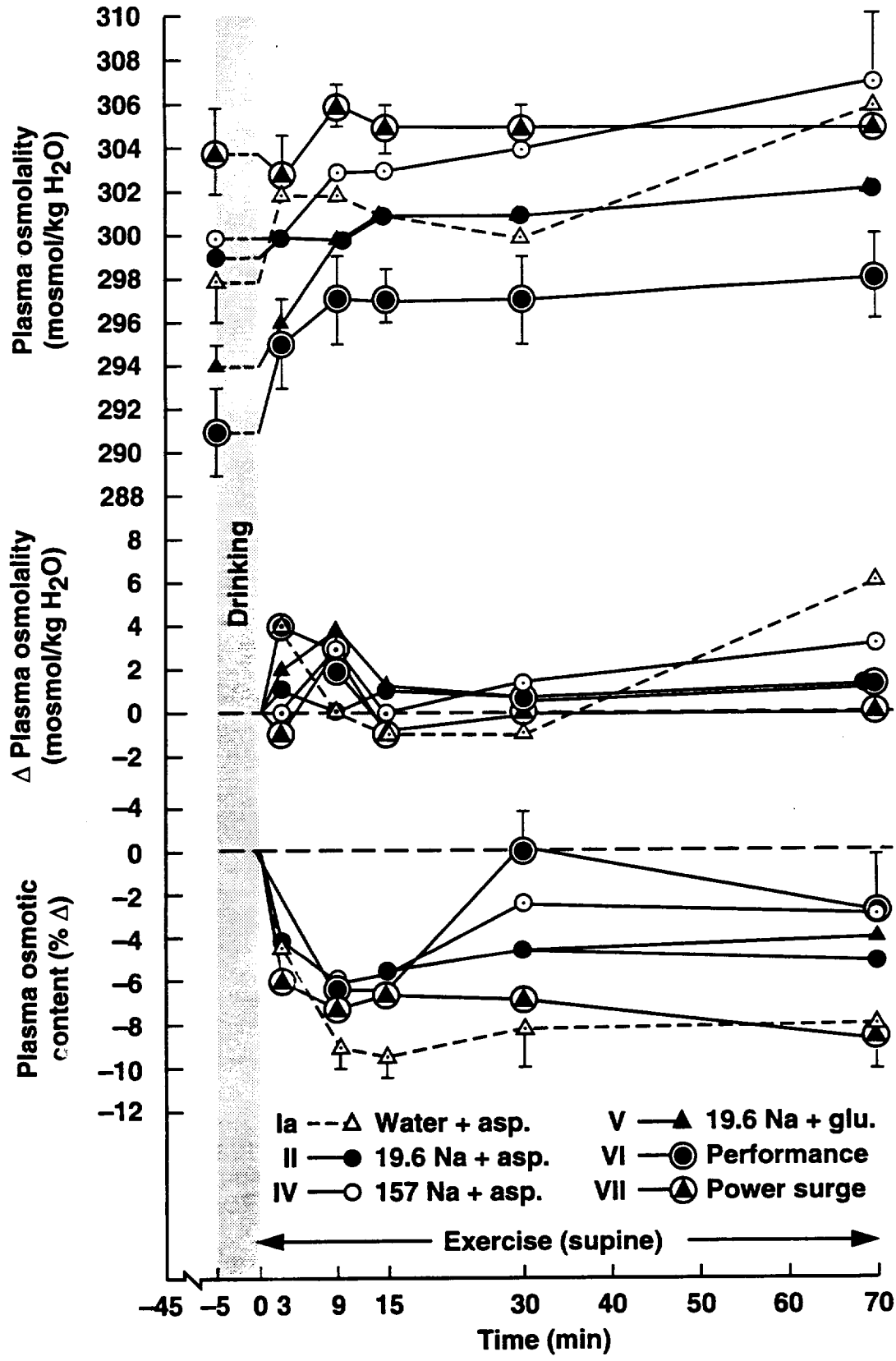

Figure 6. Mean (±SE) plasma osmolality, change in plasma osmolality, and percent change in plasma osmotic content during the exercise experiment.

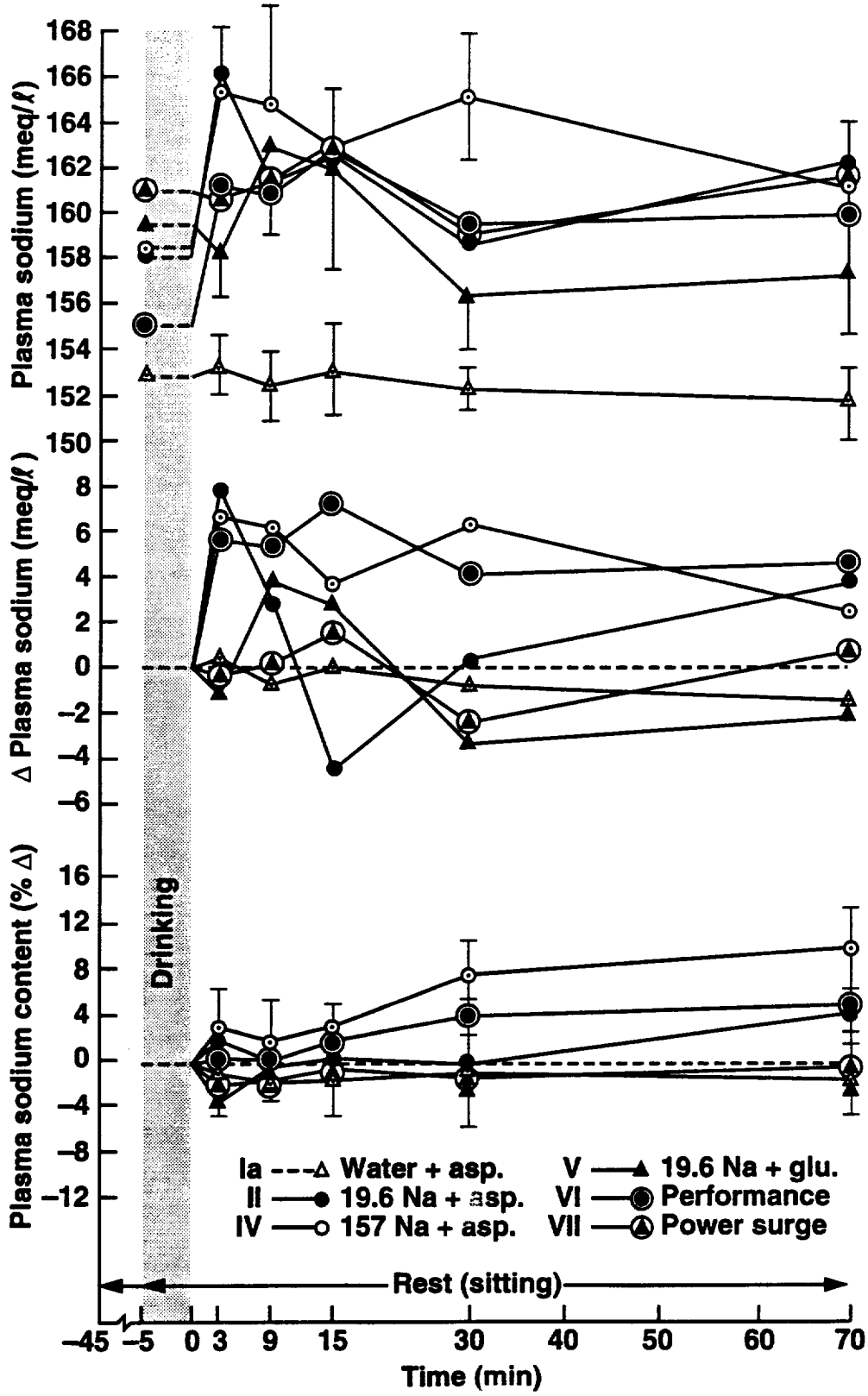

Figure 7. Mean (±SE) plasma sodium concentration, change in plasma sodium concentration, and percent change in plasma sodium content during the rest experiment.

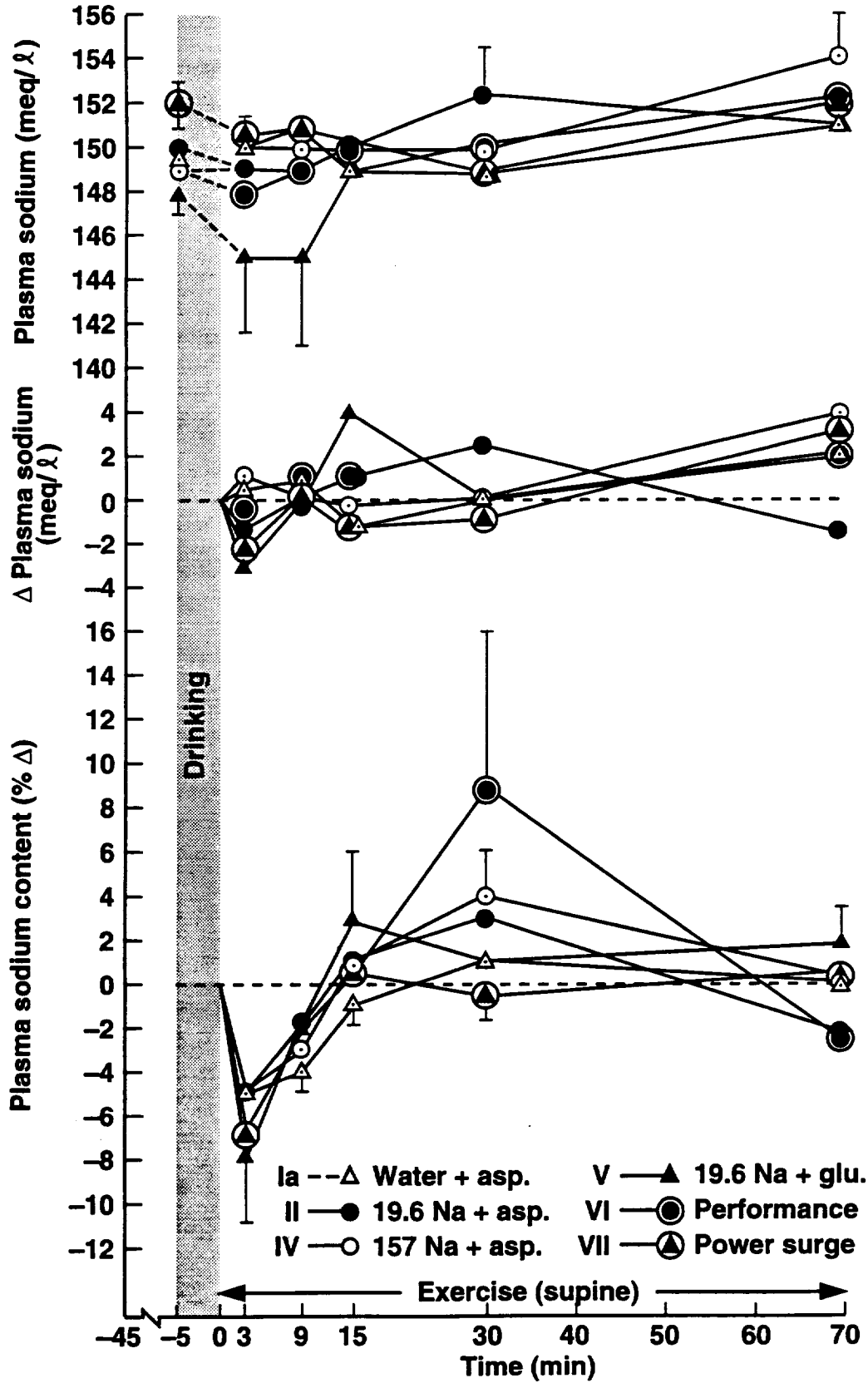

Figure 8. Mean (±SE) plasma sodium concentration, change in plasma sodium concentration, and percent change in plasma sodium content during the exercise experiment.

Plasma Potassium Concentration and Content

Unlike sodium, most body potassium is contained within cells in the cellular fluid compartment. Changes in plasma potassium content can reflect ion exchange between the cellular and extracellular fluid compartments, as well as the accompanying water movement. For example, an increase in plasma potassium content could indicate movement of potassium from cells to the extracellular (vascular) space, and vice versa. Also, potassium is present in plasma in much smaller concentrations than sodium and therefore contributes significantly less to plasma osmolality. An increase in potassium in the extracellular fluid compartment indicates a shift of potassium from the cellular fluid compartment. Note that potassium was present only in VI (Performance, 5.01 mEq/2 liters) and VII (Power Surge, 2.51 mEq/2 liters).

Changes in plasma potassium concentration and content during the rest experiment (fig. 9), similar to the plasma sodium and osmotic responses, exhibited greater variability than comparable responses during exercise (fig. 10). Unlike plasma sodium and osmotic responses, potassium content during the rest experiment remained clustered around baseline (zero) at 70 min. The slightly depressed content from zero to 15 min. suggests that during the rest experiment the potassium content accompanied the fluid shift from the vascular space (fig. 2, upper panel). Similar to changes in sodium and osmotic contents, the IV (157 Na^+) drink (containing no K^+) also had the greatest increase in potassium content after 70 min. of rest (fig. 9, lower panel). Adjacent to the drink IV (157 Na^+) value was the II (19.6 Na^+) drink value which also contained no potassium. Only drinks VI (Performance) and VII (Power Surge) contained potassium. The general trend toward increasing plasma potassium concentrations reflected the early hypovolemic response during exercise (fig. 10, middle panel), although potassium content remained essentially constant around baseline (zero) (fig. 10, lower panel). The reason for the large fluctuations in potassium content at 15 and 30 min. with drinks V (19.6 Na^+ + glucose) and VI (Performance) is not clear; drink VI contained potassium (5.01 meq/2 liters) although drink V did not. In contrast, drink VII (Power Surge) also contained potassium (2.51 meq/2 liters) and its content pattern was essentially unchanged over the 70 min. (fig. 10, lower panel).

With the exception of drinks II (19.6 Na^+) and IV (157 Na^+) during the rest experiment, it does not appear that an appreciable amount of potassium entered the vascular space from the cellular space during either the rest or the exercise experiment. This suggests that cellular dehydration was minimal.

Plasma Protein Content and Hematology Variables

Raw (uncorrected) hematocrit (Hct), hemoglobin (Hb), mean corpuscular hemoglobin concentration (MCHbCn), and percent change in plasma protein content (plasma protein concentration × PV) are presented in figure 11 (rest) and figure 12 (exercise). The perturbations of the rest Hct and Hb values (fig. 11) are reflected in the PV data (fig. 2); with an Hct of 50%, a one percentage unit change in Hct results in a 4% change in PV. All MCHbCn, which indicate changes in blood cellular volume (hydration), were essentially constant suggesting that vascular fluid shifts occurred between the vascular space and the interstitial space, and not into red blood cells or other vascular constituents. There was a tendency (NS) for plasma protein content elevation in the IV (157 Na^+) drink at 70 min., but it was not appreciably greater when compared to the other drinks. A higher protein content , combined with the effect of the greater sodium content with the IV (157 Na^+) drink, would generally lead to retention of more plasma fluid.

Compared with responses during the rest experiment, a somewhat different pattern of responses was evident during exercise (fig. 12). The Hct and Hb data showed less variablity than the MCHbCn and protein content data. The trend toward increased Hct and Hb concentration during the first 15 min. of exercise reflects the reduction in plasma volume. Plasma protein content tended to be higher with the VI (Power Surge) and IV (157 Na^+) drinks which could be the result of an actual increase in protein content or, more likely, from a greater shift of fluid to the interstitial space as indicated in figure 2 (lower panel).

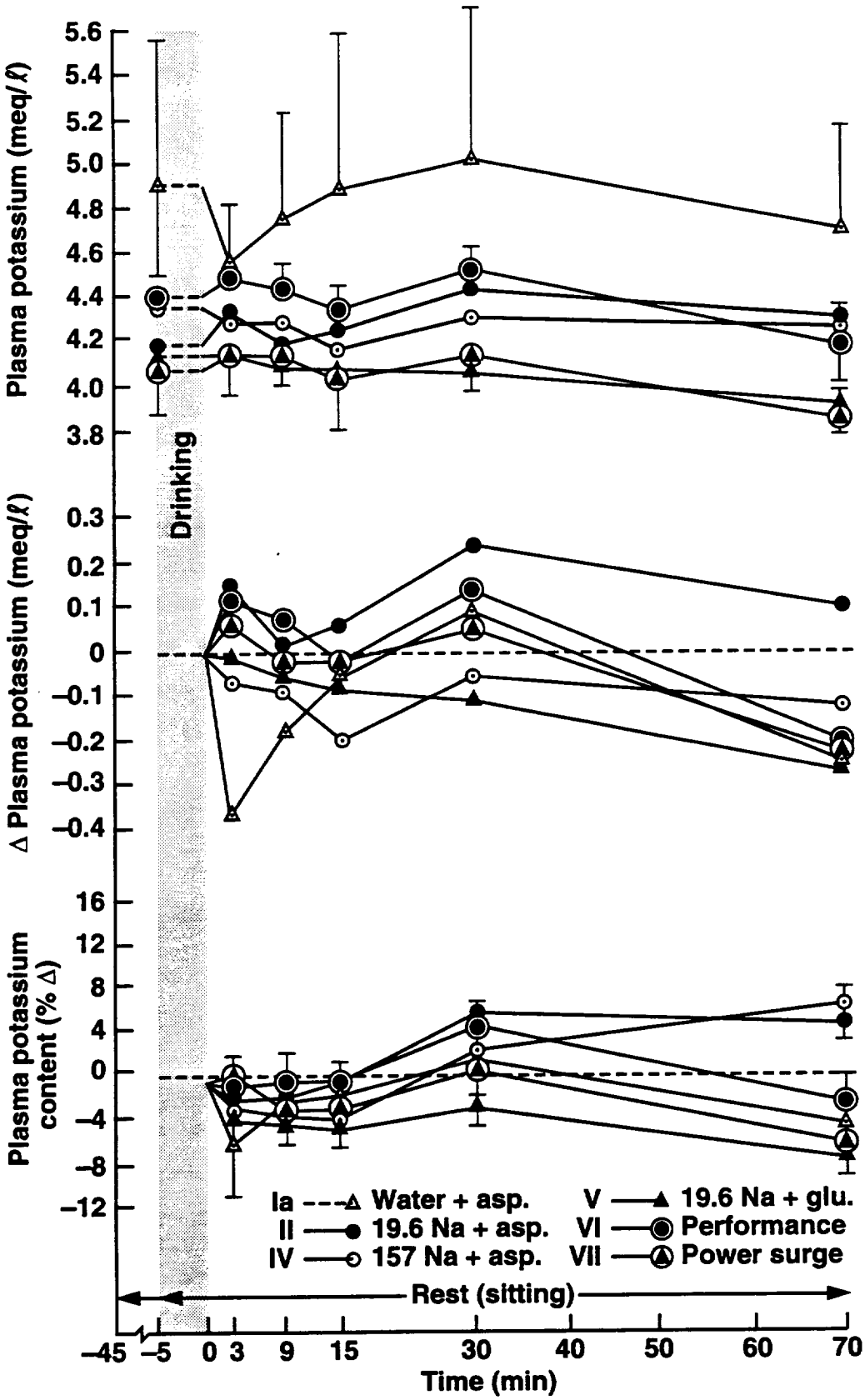

Figure 9. Mean (±SE) plasma potassium concentration, change in plasma potassium concentration, and percent change in plasma potassium during the rest experiment.

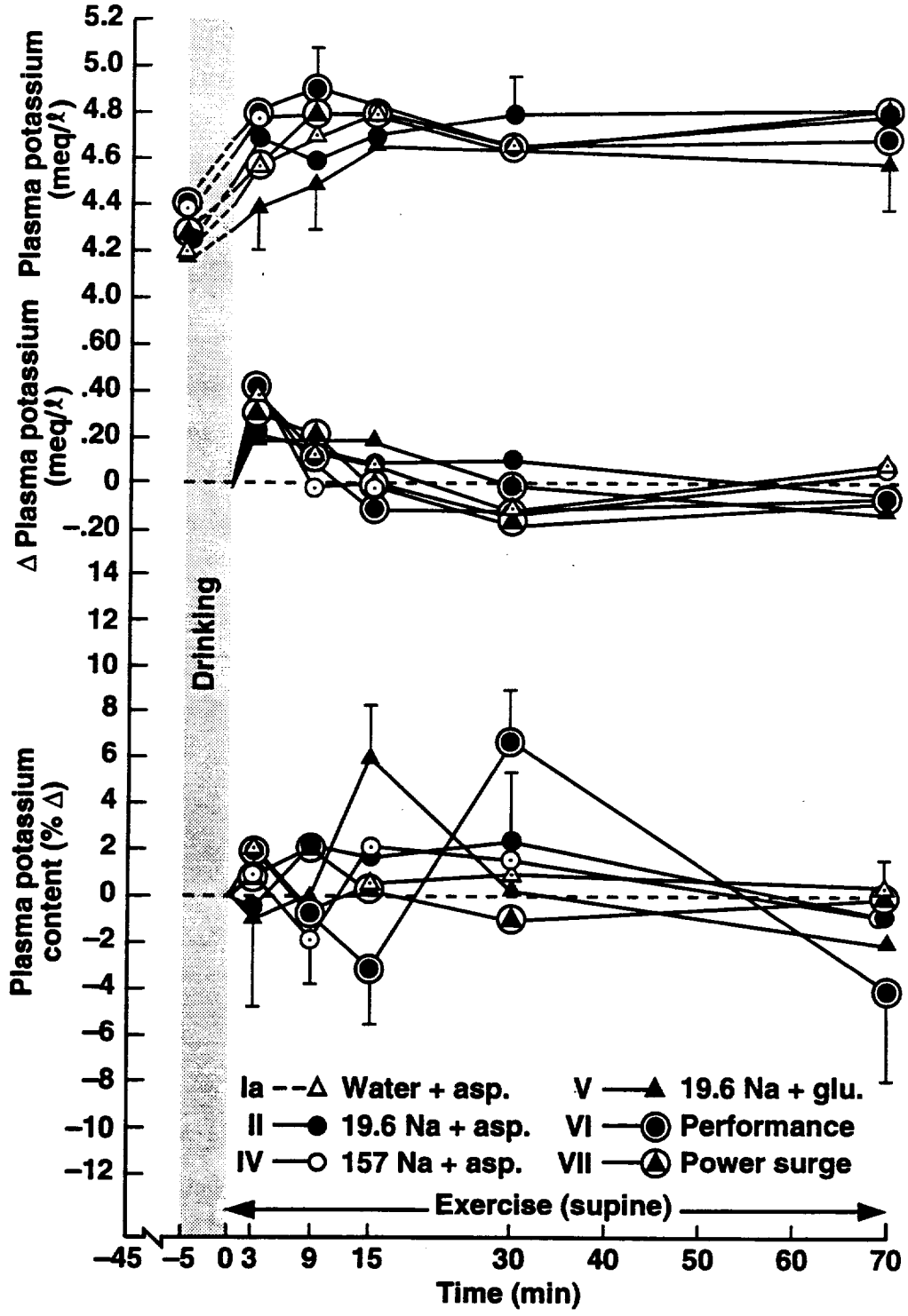

Figure 10. Mean (±SE) plasma potassium concentration, change in plasma potassium concentration, and percent change in plasma potassium content during the exercise experiment.

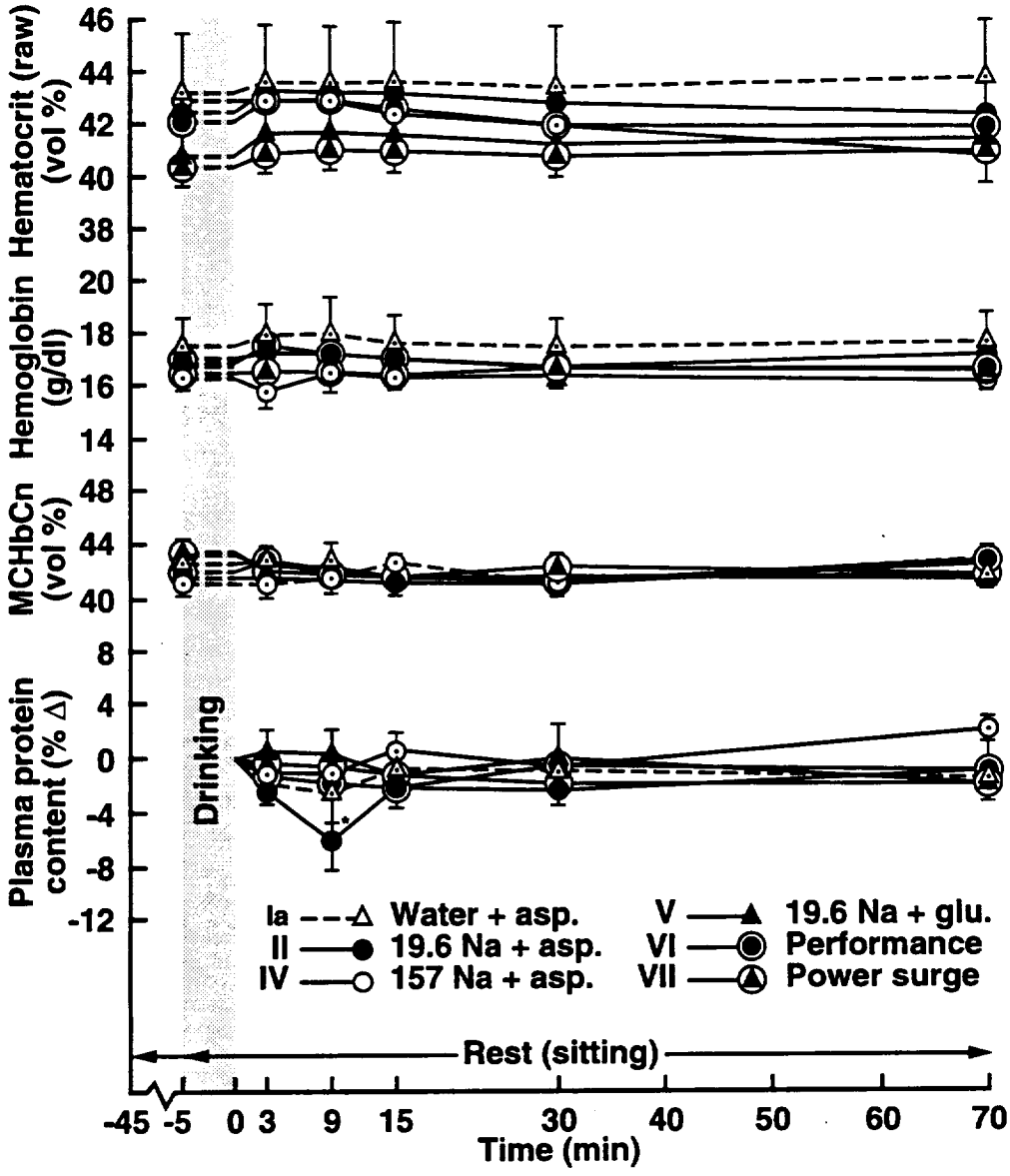

Figure 11. Mean (±SE) hematocrit, hemoglobin, mean corpuscular hemoglobin concentration, and percent change in plasma protein content during the rest experiment.

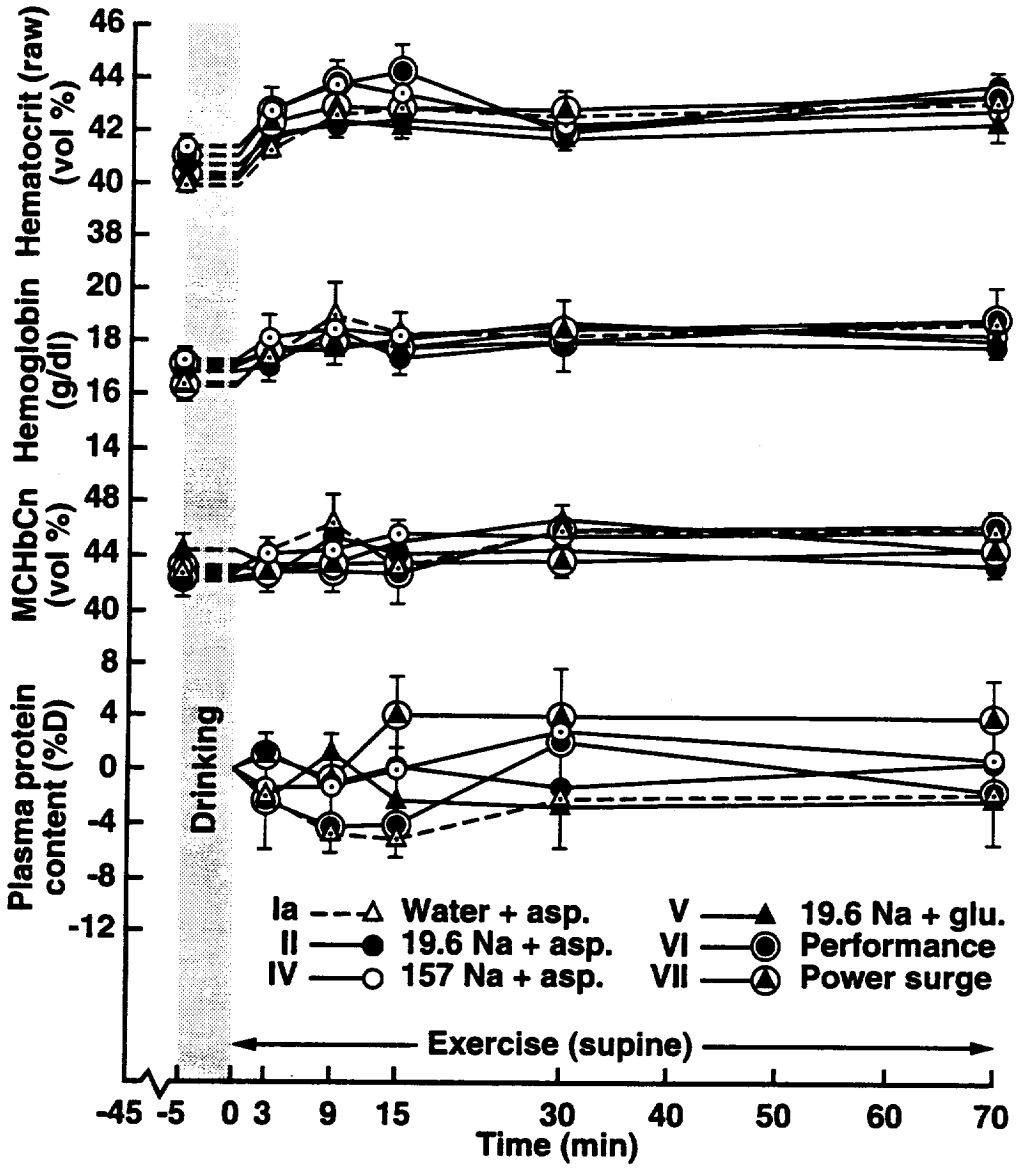

Figure 12. Mean (±SE) hematocrit, hemoglobin, mean corpuscular hemoglobin concentration, and percent change in plasma protein content during the exercise experiment.

Plasma Enzyme and Endocrine Response

In resting subjects, plasma vasopressin (PVP) exhibited the characteristic statistically significant decrease almost immediately after drinking (fig. 13). In spite of control (–5 min.) levels of PVP between 1.7 and 3.7 pg/ml, this range was reduced to 0.7-1.4 pg/ml at 3 min., and further reduced to 0.7-0.8 pg/ml at 9 min. The range increased somewhat from 15 min. onward. These immediate decreases in PVP occurred with no changes in plasma renin activity (PRA) or in plasma aldosterone (PA) (fig. 13).

During exercise (fig. 14) PVP tended to increase, more so with drinks Ia (water), IV (157 Na^+), and II (19.6 Na^+) than with the other three drinks where PVP was essentially unchanged. Plasma renin activity increased ($P < 0.05$) at 70 min. with drinks Ia (water) and VII (Power Surge) while plasma aldosterone increased ($P < 0.05$) with nearly all drinks (fig. 14). Plasma atriopeptin (PAP) tended to decrease during the rest experiment, particularly with Ia (water, $P < 0.05$) and IV (157 Na^+, $P < 0.05$) during the first 15 min. (fig. 15), while IV recovered and Ia did not. Plasma epinephrine levels were unchanged while norepinephrine increased

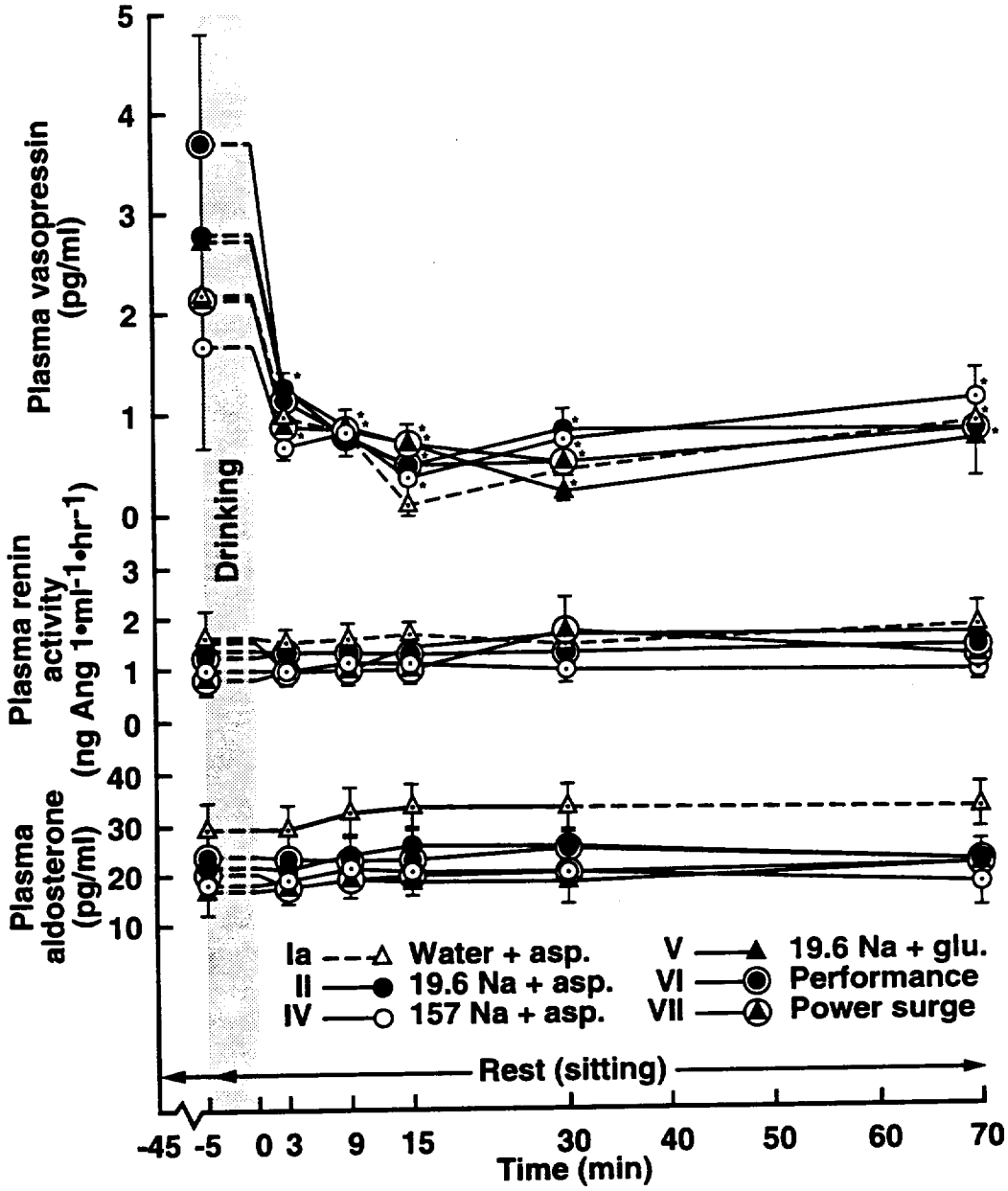

*Figure 13. Mean (±SE) plasma vasopressin, plasma renin activity, and plasma aldosterone during the rest experiment. *P < 0.05 from time –5 min.*

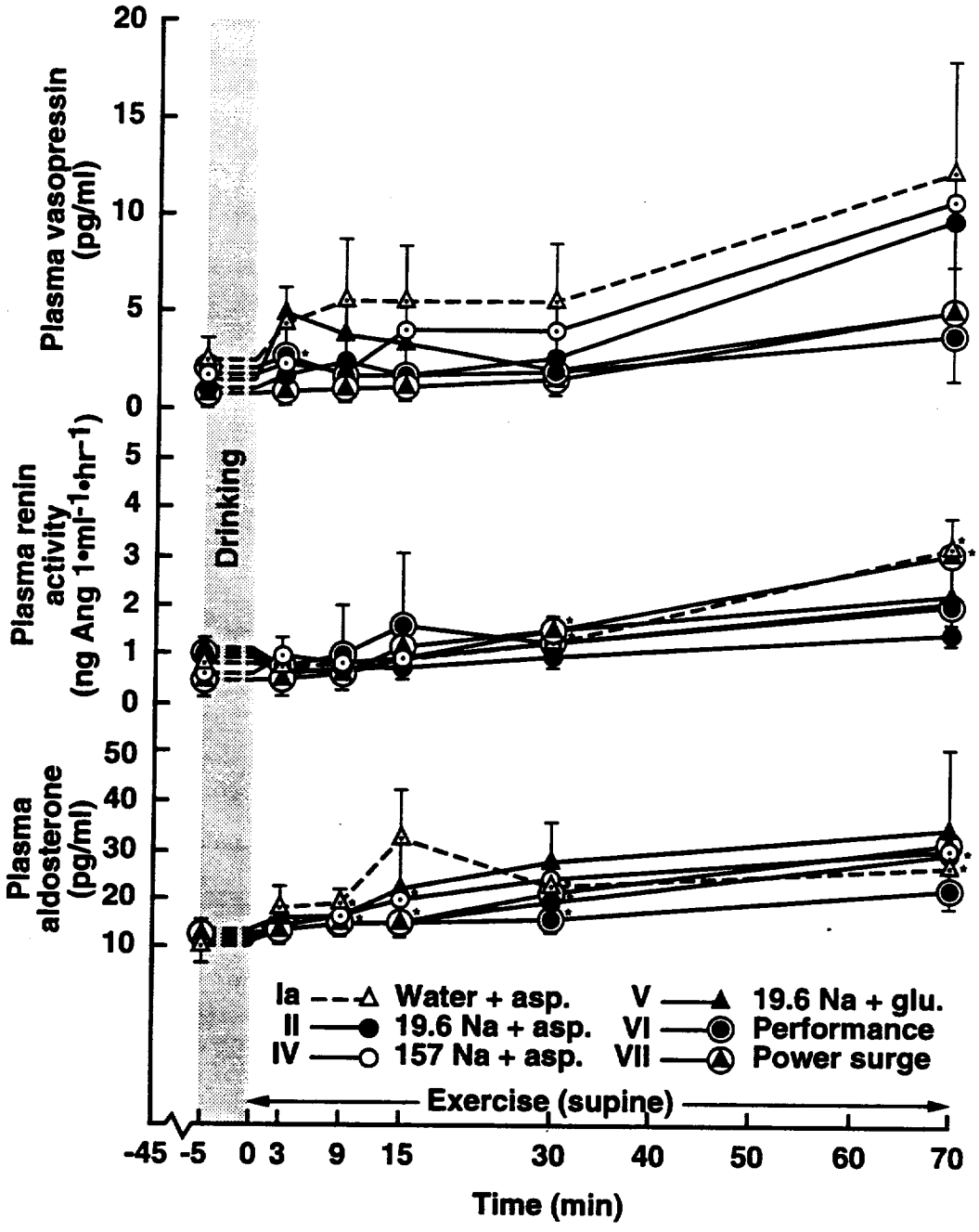

*Figure 14. Mean (±SE) plasma vasopressin, plasma renin activity, and plasma aldosterone during the exercise experiment. *P < 0.05 from time –5 min.*

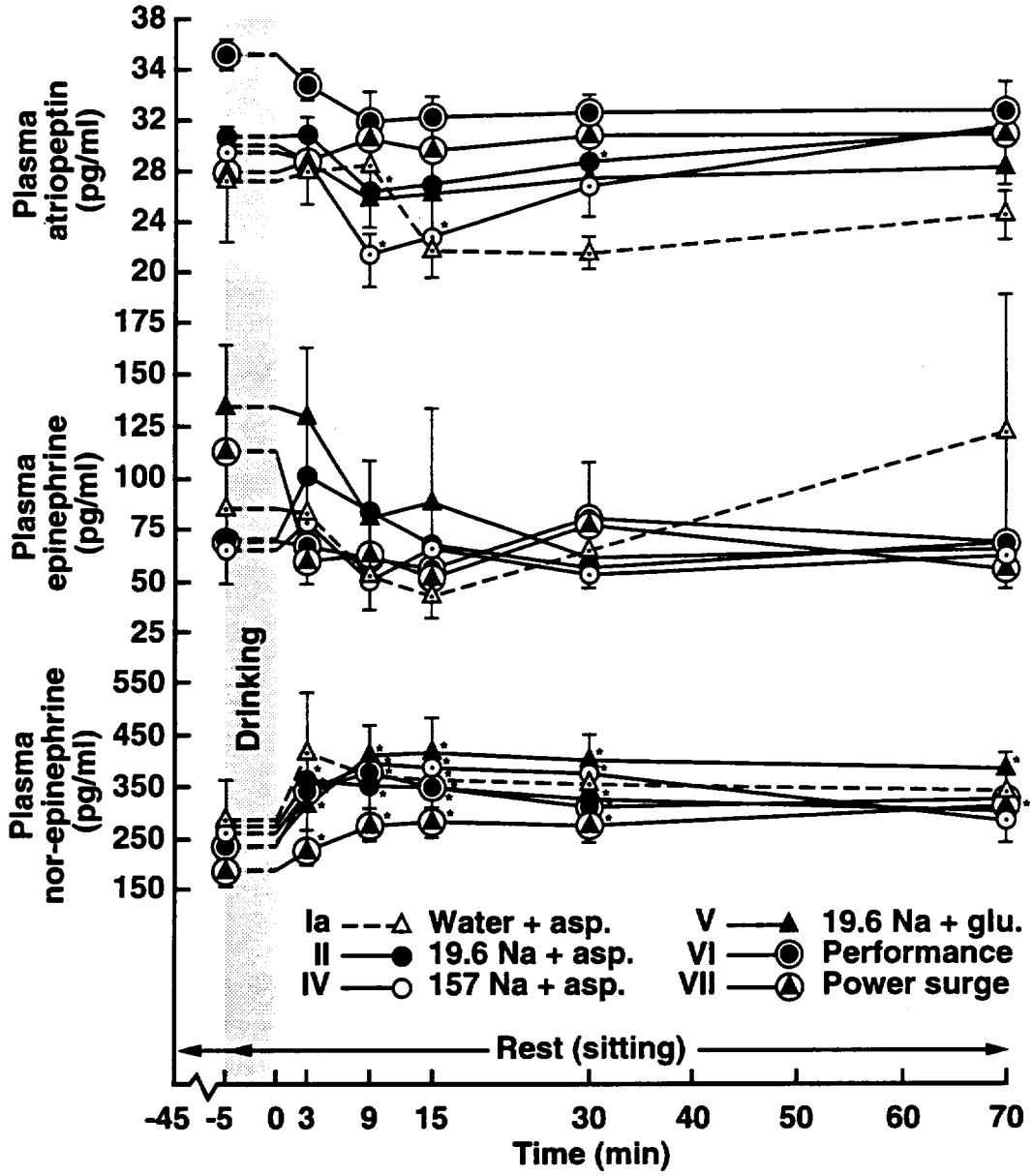

*Figure 15. Mean (±SE) plasma atriopeptin concentration, plasma epinephrine concentration, and plasma norepinephrine concentration during the rest experiment. *P < 0.05 from time –5 min.*

significantly ($P < 0.05$) with all drinks. At 70 min. the increase ($P < 0.05$) remained for drinks V and VII.

With exercise (fig. 16) PAP tended to increase during the first 30 min., particularly with II (19.6 Na^+, $P < 0.05$), IV (157 Na^+ $P < 0.05$), and VII (Power Surge $P < 0.05$). Plasma epinephrine was generally higher with IV (157 Na^+, $P < 0.05$), Ia (water, $P < 0.05$), and II (19.6 Na^+, NS) at 70 min. Plasma norepinephrine showed an upward trend (NS) throughout the exercise period with no apparent effect of drink composition.

Blood Pressure, Heart Rate, and Blood Flow

At rest, blood pressures and heart rate were essentially constant and unaffected by drink composition (fig. 17). Pressures (systolic/diastolic) averaged about 120/75 mmHg and heart rates were about 70 beats/min. With exercise, systolic pressures exhibited the characteristic increase to about 170 mmHg and diastolic pressures decreased slightly to about 75 mmHg (fig. 18). Heart rates increased to about 140 beats/min. commensurate with a relative exercise load of 71% in middle-aged men.

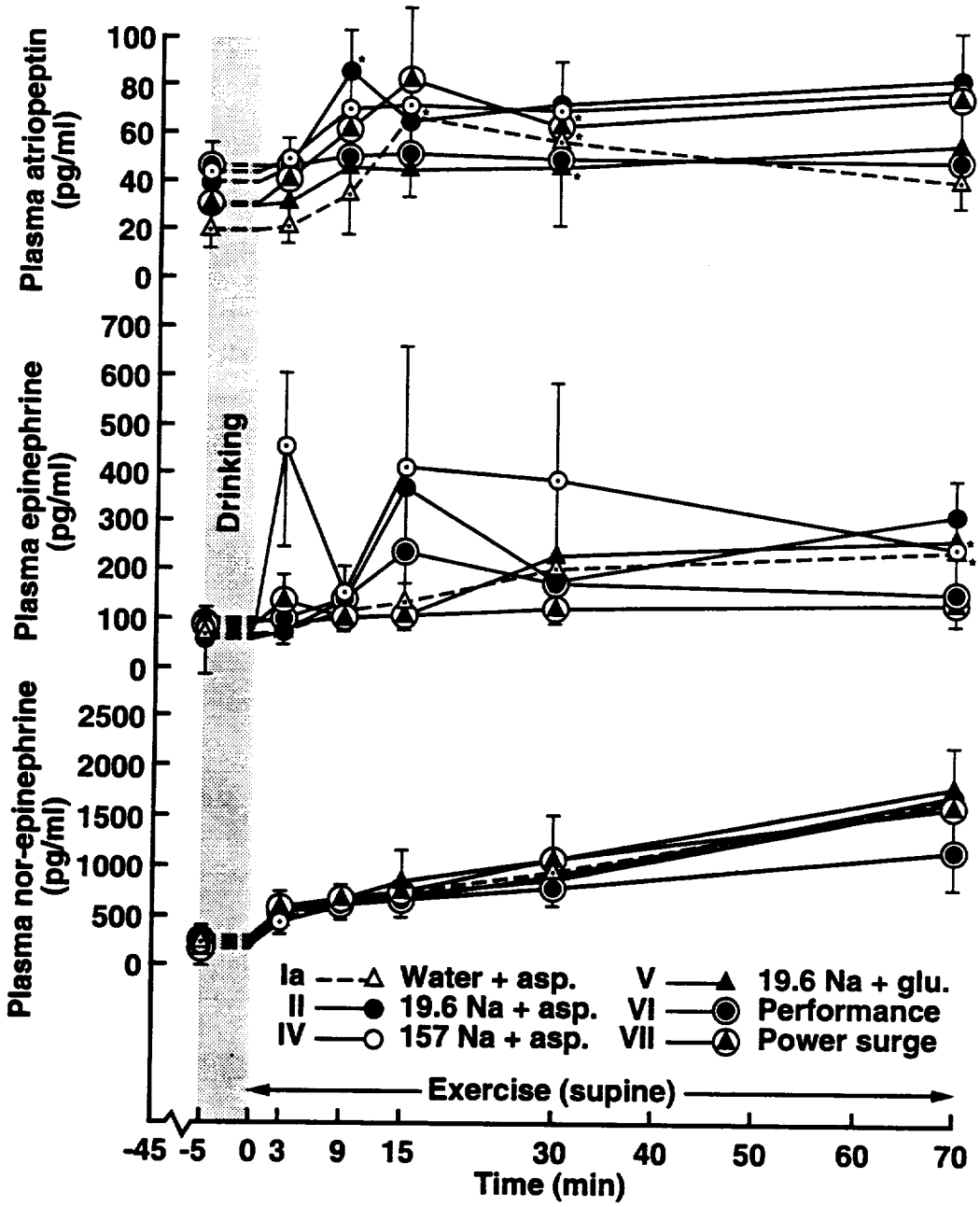

*Figure 16. Mean (±SE) plasma atriopeptin concentration, plasma epinephrine concentration, and plasma norepinephrine concentration during the exercise experiment. *P < 0.05 from time –5 min.*

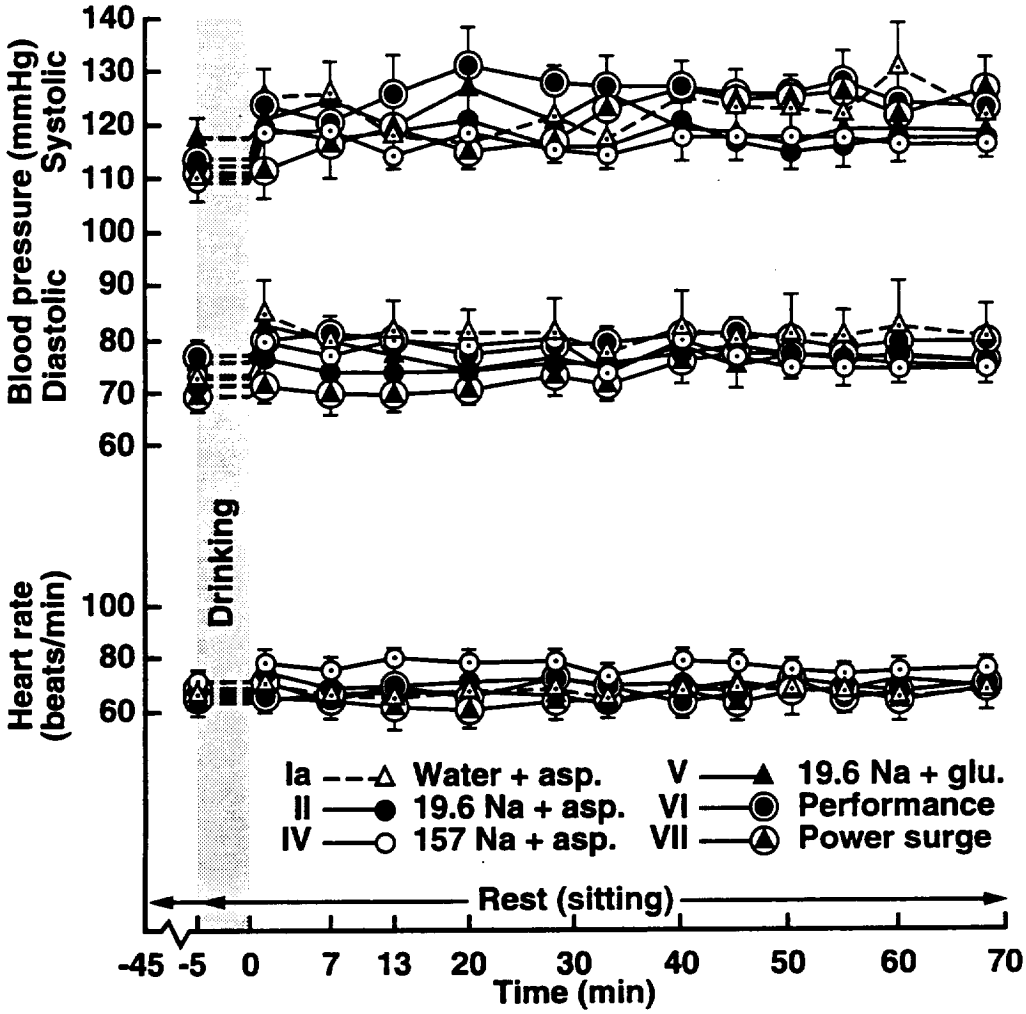

Figure 17. Mean (±SE) systolic and diastolic blood pressures and heart rate during the rest experiment.

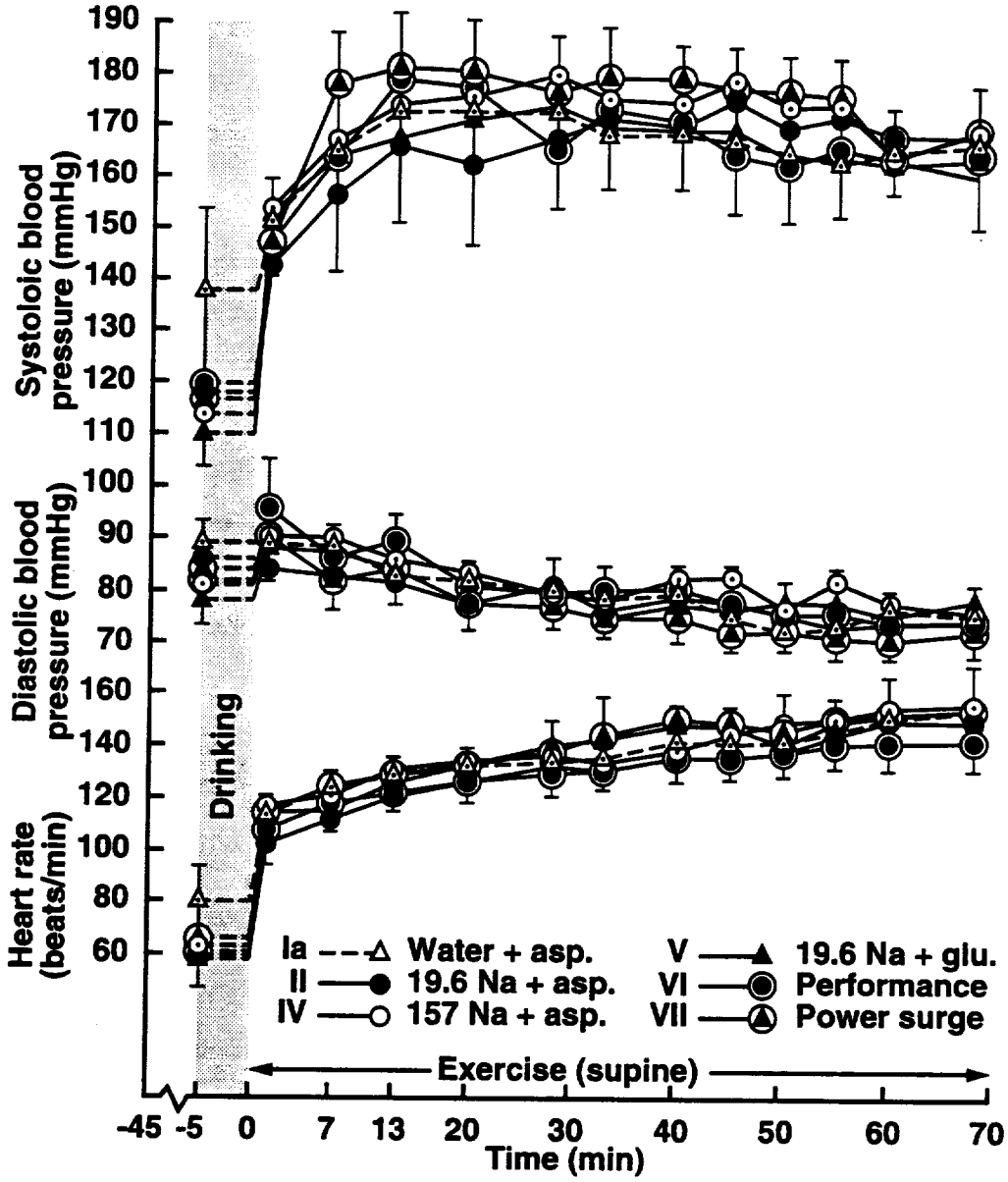

Figure 18. Mean (±SE) systolic and diastolic blood pressures and heart rate during the exercise experiment.

The units of measurement of skin blood flow, volume, and velocity (fig. 19) are: ml/min./100g tissue, average number of Doppler shifts per photon, and mean Doppler shift frequency (expressed in mm/sec when multiplied by 2.2), respectively. Both skin blood volumes and velocities on the cheek (fig. 19) and total forearm blood flows (fig. 20) tended to increase during exercise. Skin blood velocities by the end of exercise were lowest (unchanged) with V (19.6 Na^+ + glucose), and Ia (water), and IV (157 Na^+), and tended to increase with VII (Power Surge) and VI (Performance), and II (19.6 Na^+). At 70 min. forearm total blood flow during exercise responded similarly: attenuated increasing trends with V (19.6 Na^+ + glucose), VII (Power Surge), and IV (157 Na^+), and greater increasing trends with Ia (water), VI (Performance), and II (19.6 Na^+) at 70 min. (fig. 20).

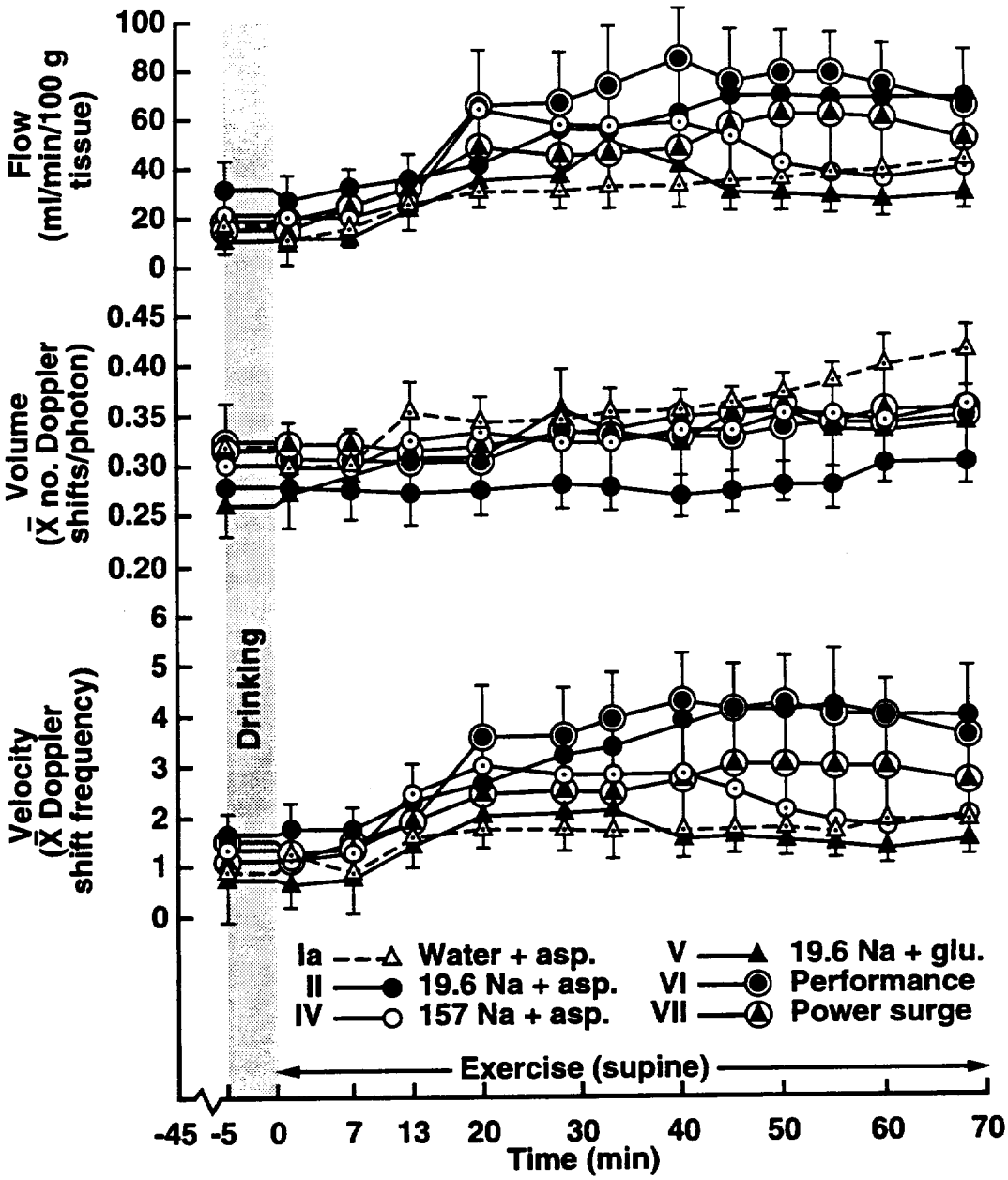

Figure 19. Mean (±SE) cheek peripheral blood flow, volume, and velocity during the exercise experiment.

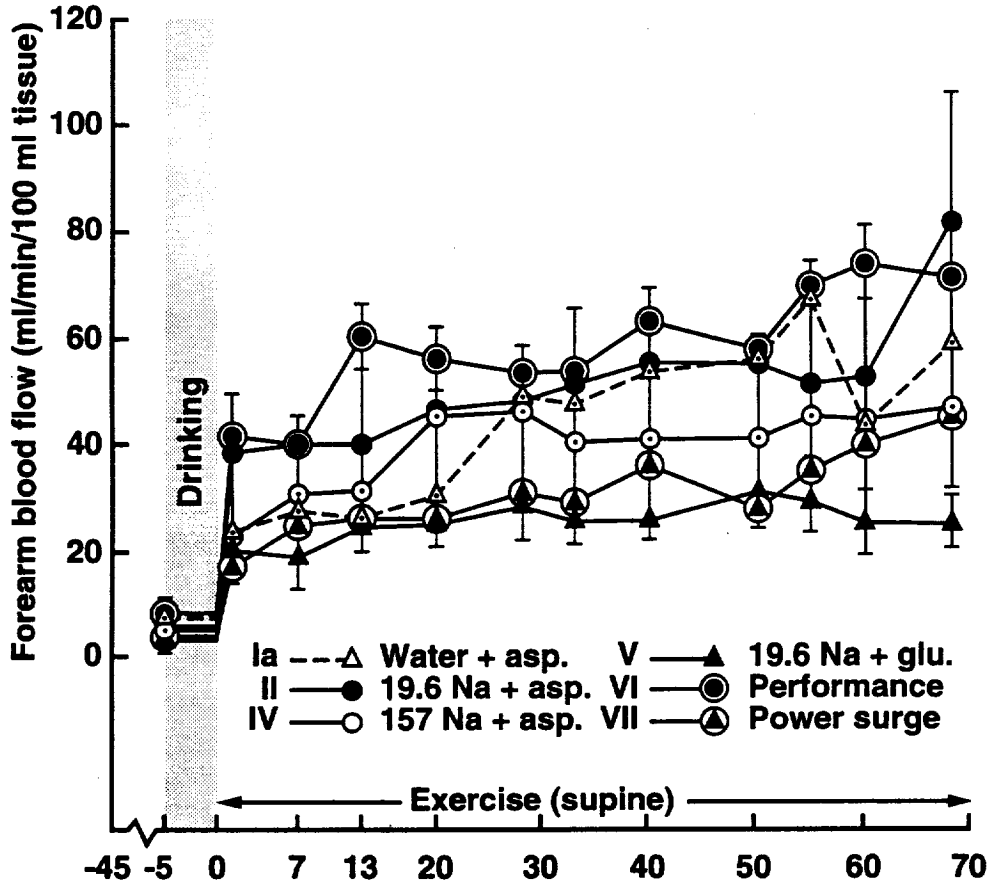

Figure 20. Mean (±SE) forearm total blood flow during the exercise experiment.

Middle Cerebral Arterial (MCA) Velocity Parameters (Resting Experiment)

Systolic frequency values were similar for the six drinks; drink Ia was lower and drink V had the higher values. Frequency diastolic values were essentially similar and unchanged over the 70-min. resting period (fig. 21). Mean area was generally lowest with drink Ia and highest with drink V (fig. 22). Pulsatility index was greatest with drink VII. MCA velocity was essentially constant varying from 20 to 35.

Body Temperatures

Rectal (T_{re}) and mean skin ($\overline{T}_{sk}$) temperatures were measured only during exercise (fig. 23). Rectal temperatures exhibited the characteristic slight decline of about 0.1°C at the onset of exercise. Not all T_{re} (drinks Ia, IV, VI, VII) had reached steady-state after 70 min., due perhaps to the supine position and inhibition of sweating from the subject's back. There were no statistically significant differences in T_{re} between Ia (water) and the remaining drinks. With drinks II (19.6 Na^+, T_{re} = +0.84 ± 0.09°C) and VI (Performance, ΔT_{re} = +0.85 ± 0.12°C), T_{re} appeared to reach steady-state and these two drinks tended to attenuate (NS) the rise in rectal temperature (table 6). Rectal temperature changes with the remaining drinks were: Ia (water, ΔT_{re} = 1.27 ± 0.22°C), IV (157 Na^+, ΔT_{re} = 1.17 ± 0.32°C), V (19.6 Na^+ + glucose, ΔT_{re} = 1.11 ± 0.20°C), and VII (Power Surge, T_{re} = 1.11 ± 0.16°C). Mean skin temperatures increased by 1.40°C to 2.81°C (table 6) because air motion was low.

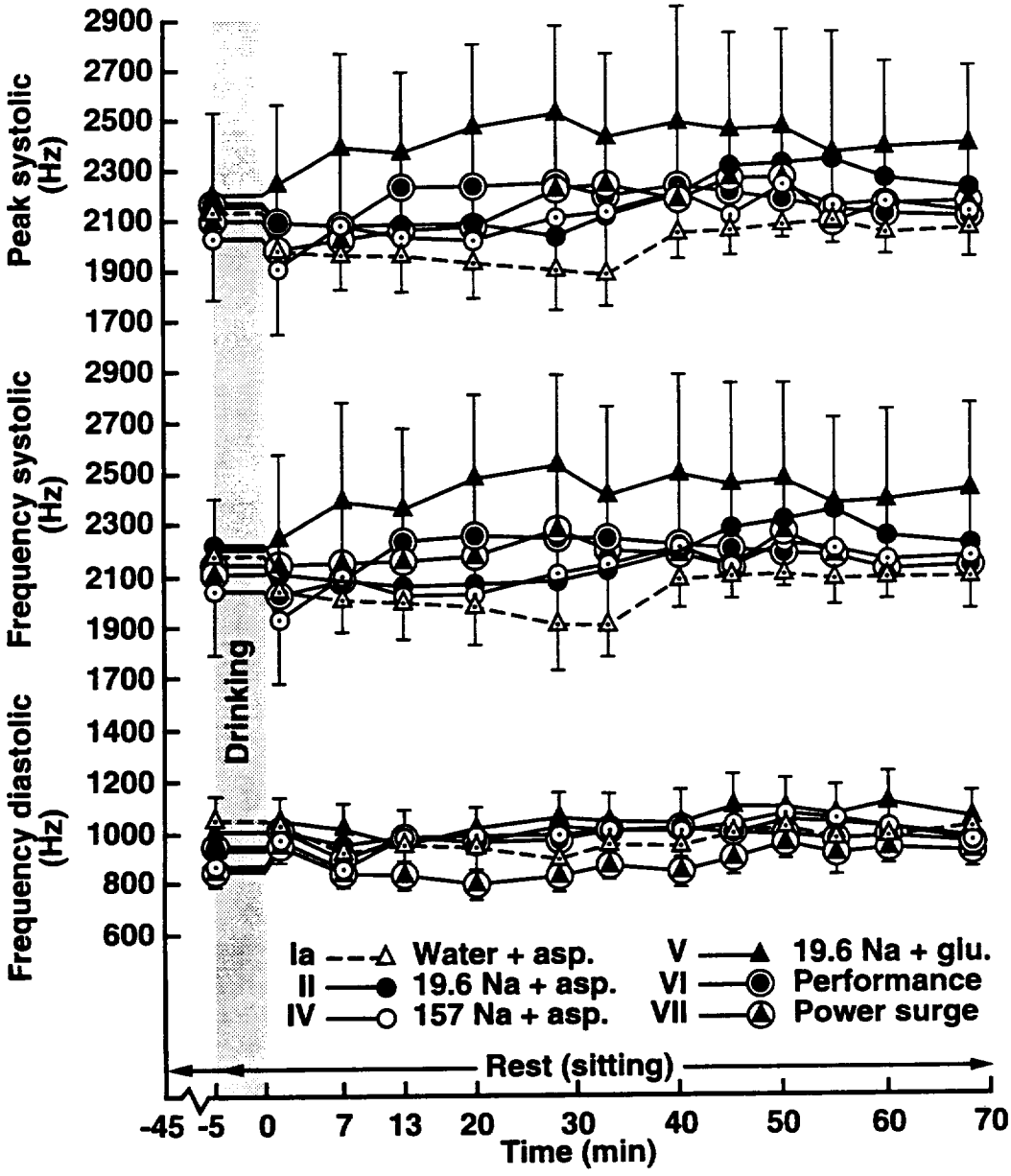

Figure 21. Mean (±SE) cranial peak systolic, frequency systolic, and frequency diastolic measures during the rest experiment.

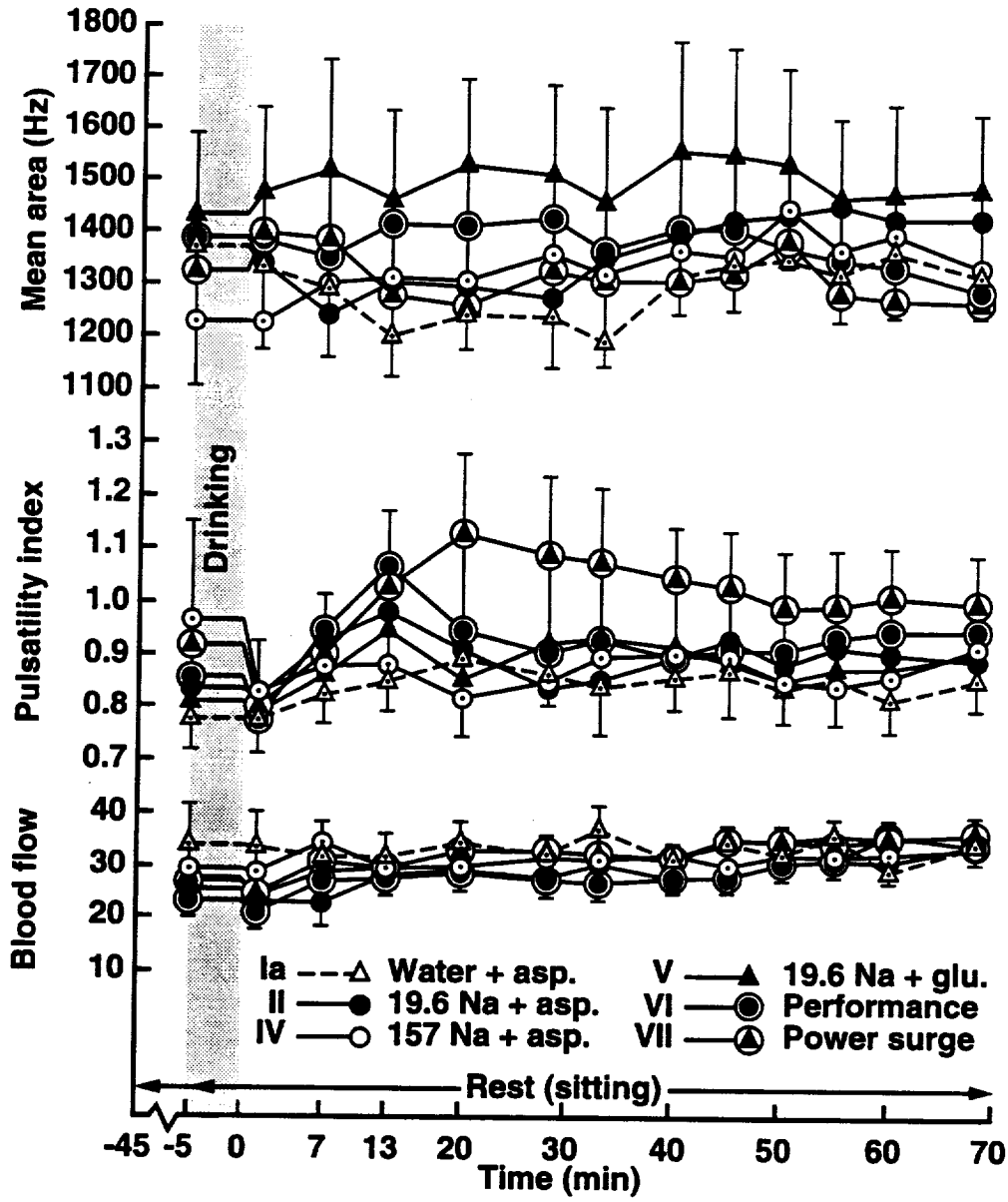

Figure 22. Mean (±SE) cranial mean area, pulsatility index, and blood flow during the rest experiment.

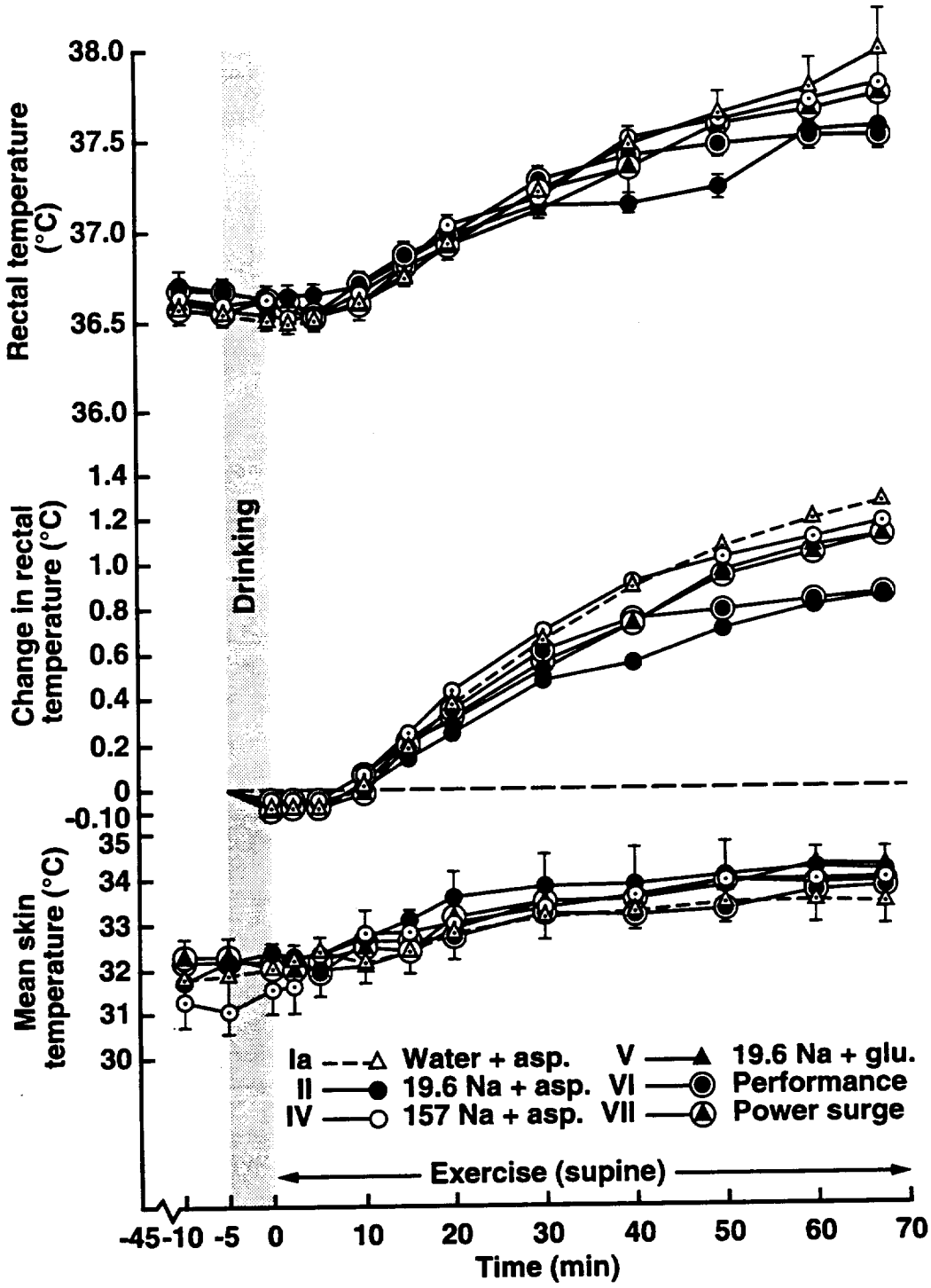

Figure 23. Mean (±SE) rectal temperature, change in rectal temperature, and mean skin temperature during the exercise experiment.

Urinary Parameters

Mean (±SE) urinary excretion rates ($\dot{V}$) during the six rest and six exercise experiments are presented in figure 24. The solid horizontal line is the mean of the six resting $\dot{V}$ (1.1 ±SE 0.1 ml/min.), and the dash line is the mean value of the six exercise $\dot{V}$ (1.2 ± SE 0.2 ml/min.). Average normal 24-hr urine flow is about 1.0 ml/min. There were no statistically significant changes in $\dot{V}$ in the rest experiments; urine flow varied between 0.7 (Drink V) and 1.5 (Drink II) ml/min. On the other hand, $\dot{V}$ changed significantly during the exercise experiments: urinary

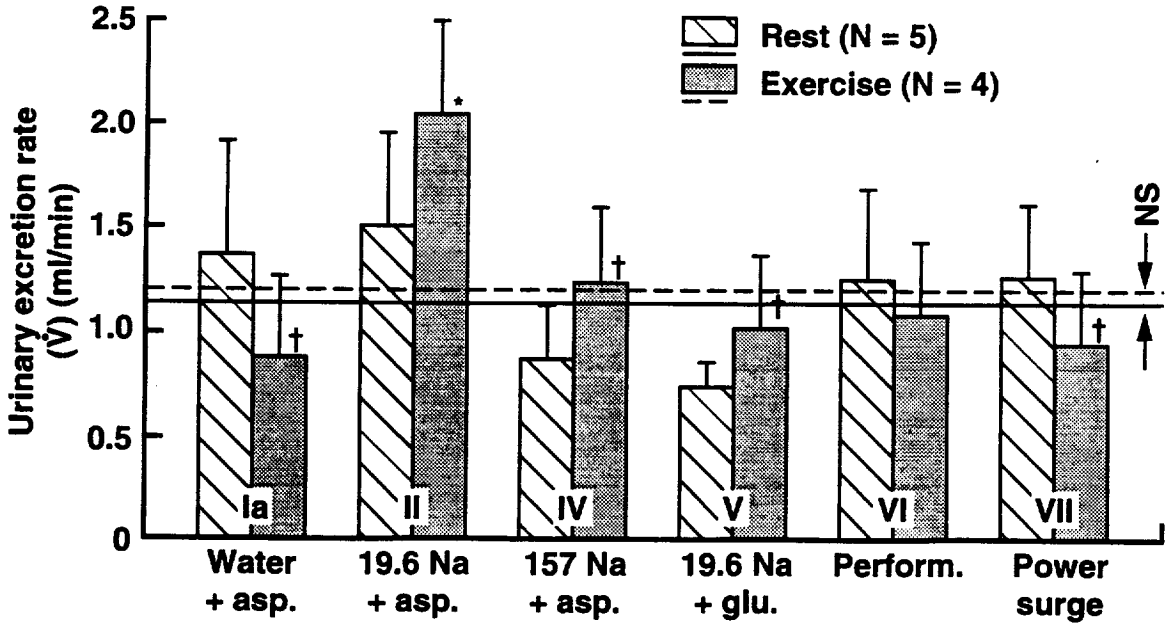

*Figure 24. Mean (±SE) urine excretion rate during the rest and exercise experiments. The solid and dashed horizontal lines are mean levels for the rest and exercise experiments, respectively. *P < 0.05 from corresponding Ia value. P < 0.05 from corresponding II value.*

excretion with drink II was greater ($P < 0.05$) than that with drinks Ia, IV, V, and VII, and urine flow was not significantly different among drinks Ia, IV, V, VI, and VII. Thus, drink II (19.6 Na^+) resulted in a significant increase in urinary flow during exercise when compared with all other exercise experiments, which were not different from drink Ia (water).

Urine osmotic clearance (C_{osm}) (fig. 25) was unchanged at rest for all drinks. In the exercise experiments C_{osm} was elevated ($P < 0.05$) with drink II (19.6 Na^+) over drink Ia (water), as well as over drinks IV (157 Na^+), VI (Performance), and VII (Power Surge). Thus drink II, containing only 19.6 mEq/l of sodium (osmolality of 70 mOsmol/kg), caused a significant osmotic diuresis; while drink Ia (water) with a lower osmolality (30 mOsmol/kg), and drink IV (157 Na^+) with a higher osmolality (270 mOsmol/kg) had osmotic clearances no different than the other drinks, some with much higher osmotic concentrations.

Urine free water clearances (C_{H_2O}) (fig. 26) were not different in the rest and exercise experiments. Similar to C_{osm} responses, C_{H_2O} for drink II (19.6 Na^+) tended to be greater (more negative, NS) than for the other drinks.

Urinary sodium excretion (fig. 27) followed the pattern of osmotic clearances, except the total combined exercise excretion response ($\overline{X}$ Ia, II, IV, V, VI, VII) was significantly lower ($P < 0.05$) than the total combined resting response. Compared with the sodium excretion total responses, urine potassium total responses exhibited the reverse pattern (fig. 28). That is, the resting potassium total excretion was significantly lower than the exercise total excretion in experiment V. Only sodium in experiment II (19.6 Na^+) and potassium in experiment V (19.6 Na^+ + glucose) did not follow the general ratio responses. Thus, exercise induced retention of sodium and promoted excretion of potassium.

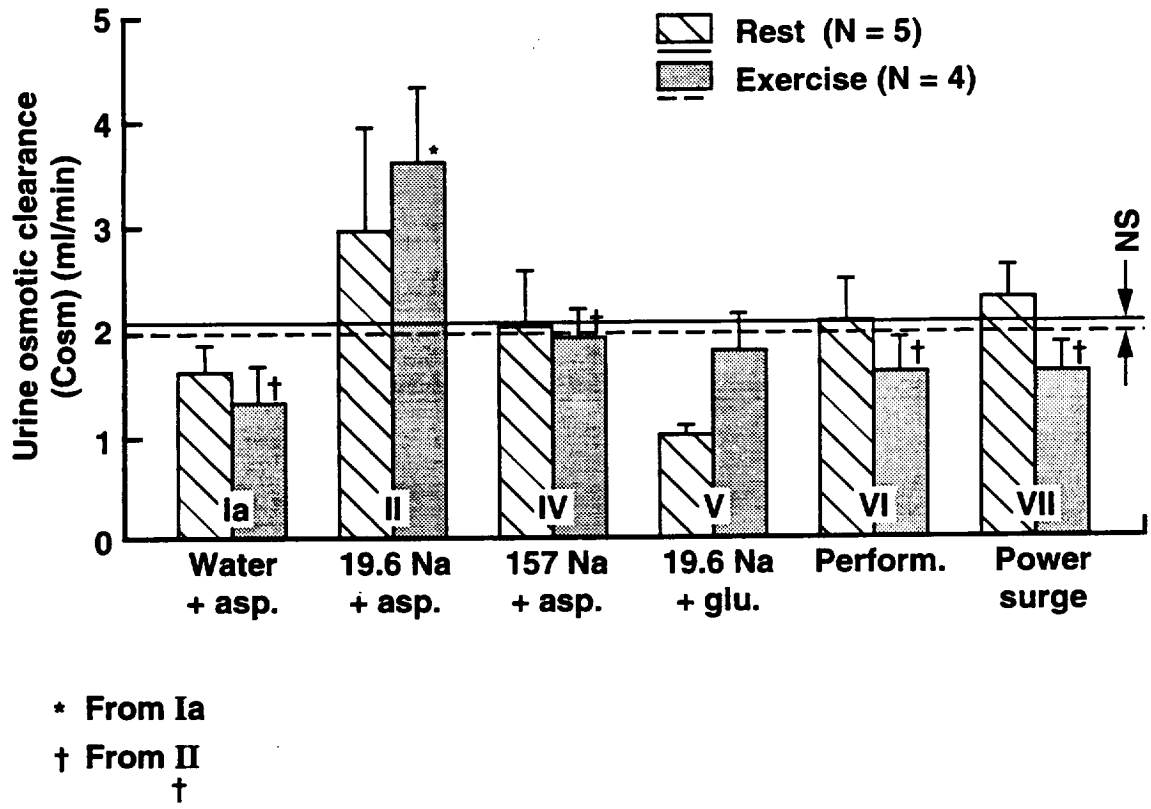

*Figure 25. Mean (±SE) urine osmotic clearance during the rest and exercise experiments. The solid and dashed horizontal lines are mean levels for the rest and exercise experiments, respectively. *P < 0.05 from the corresponding Ia value. P < 0.05 from the corresponding II value.*

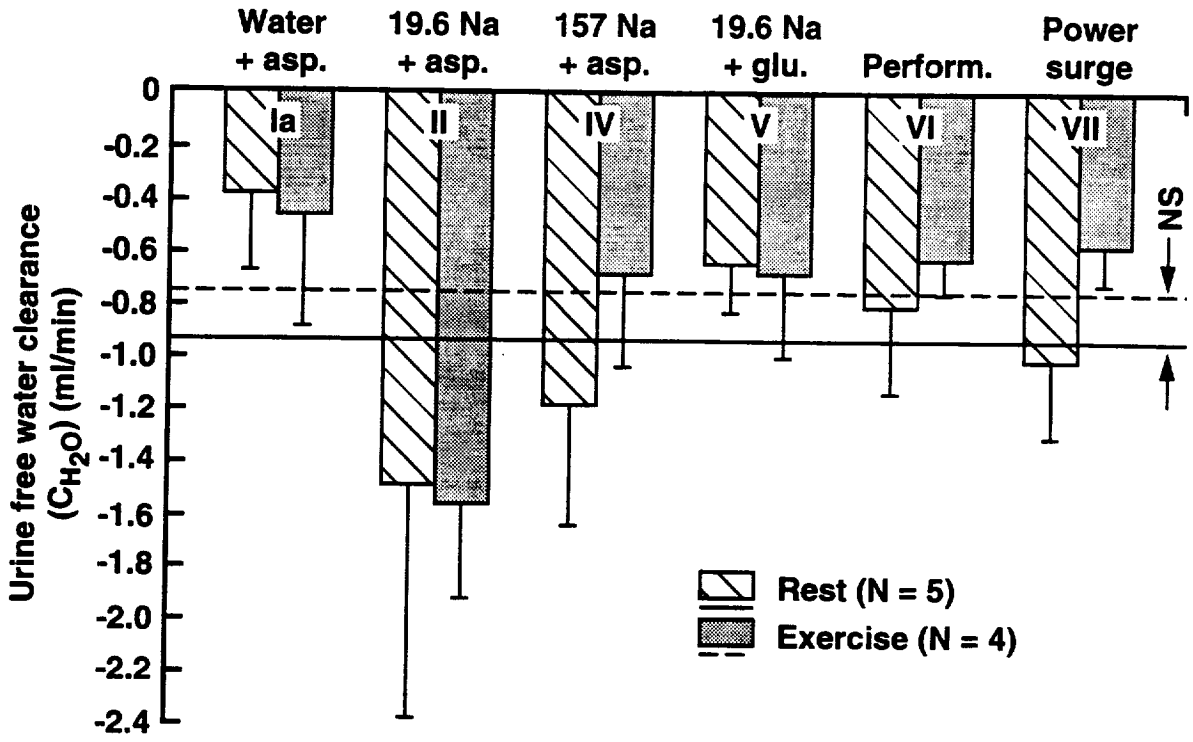

Figure 26. Mean (±SE) urine free water clearance during the rest and exercise experiments. The solid and dashed horizontal lines are mean levels for the rest and exercise experiments, respectively. There were no significant changes.

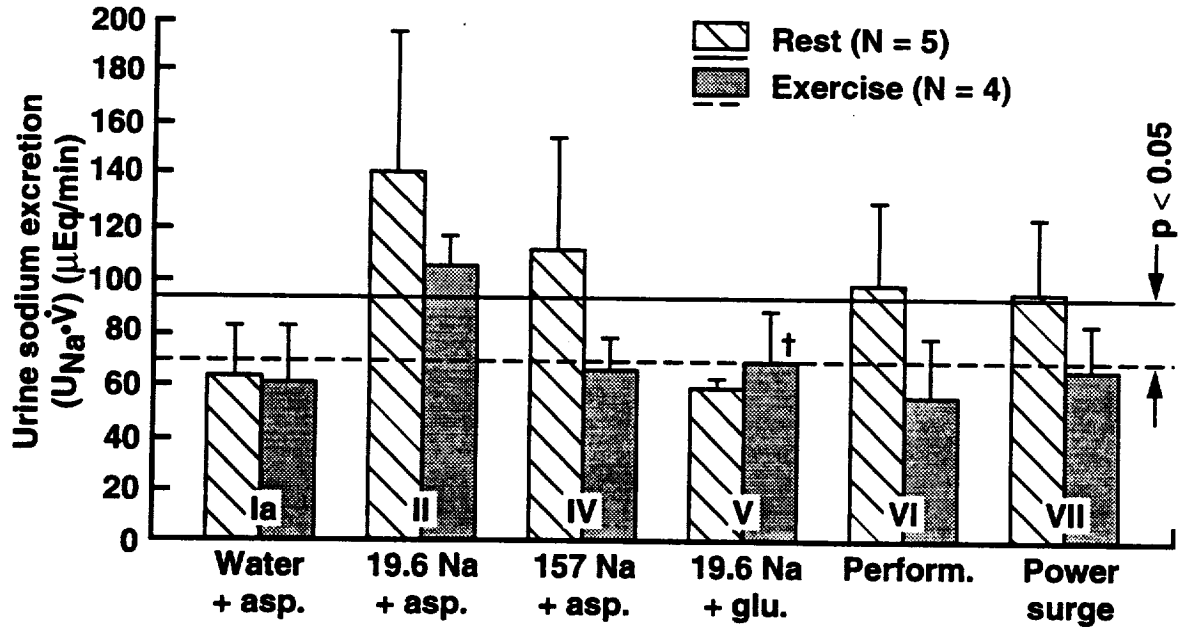

Figure 27. Mean (±SE) urine sodium excretion during the rest and exercise experiments. The solid and dashed horizontal lines are mean levels for the rest and exercise experiments, respectively. P < 0.05 from the corresponding II value.

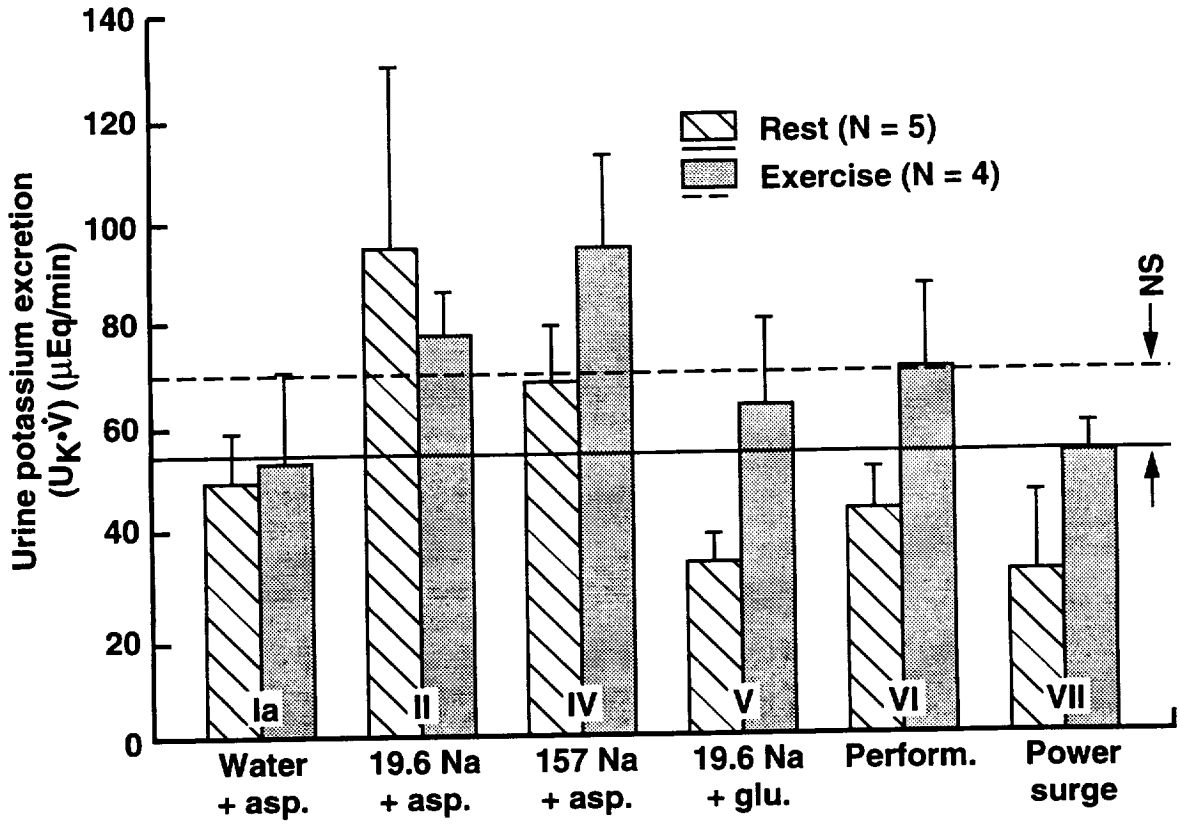

Figure 28. Mean (±SE) urine potassium excretion during the rest and exercise experiments. The solid and dashed horizontal lines are mean levels for the rest and exercise experiments, respectively. There were no significant changes.

Conclusions

1. The fluid formulations containing sodium compounds near isotonic concentrations are more effective than more dilute solutions for restoring and increasing plasma volume in resting, hypohydrated men.

2. There was no regular relationship between drink total osmolality and change in plasma osmotic content in the rest experiment. This is perhaps due to metabolism of the carbohydrate contents during the 70-min. period, which diminished its osmotic effect. Thus, all drinks except IV (157 Na^+) and VI (Performance) responded like water by the end of the 70-min. experiment.

3. Performance of exercise immediately after drinking probably attenuated fluid transfer from the gastrointestinal tract into the vascular system for the first 15 min. of exercise.

4. The fluid formulations containing sodium compounds near isotonic concentrations, as well as the more dilute sodium formulations, were effective for maintaining plasma volume in exercising, hypohydrated men.

5. Better plasma volume stabilization during submaximal exercise occurred after consuming drinks with the higher ionic (but not necessarily osmotic) contents.

6. The partial restoration of plasma volume at the end of exercise was not related as much to plasma sodium content as it was to plasma total osmotic content. Thus, osmotic constituents other than sodium play an important role in maintaining and enhancing plasma volume during exercise.

7. The constancy of all mean corpuscular hemoglobin concentrations indicates that the vascular fluid shifts occurred between the vascular and extravascular spaces and not between the vascular space and red blood or other vascular cells.

8. At the end of the rest experiment, the slight elevation of plasma protein content with drink IV (157 Na^+) acted to retain more plasma fluid.

9. Plasma vasopressin concentrations in the rest experiment exhibited the characteristic abrupt decrease following drinking. Their final levels were not influenced by drink composition; but more likely they were affected by the limit of sensitivity of the vasopressin assay.

10. In the exercise experiment drinks II (19.6 Na^+) and VI (Performance) tended to attenuate the rise of rectal temperature by the end of exercise.

11. Exercise induced retention of sodium and promoted excretion of potassium.

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Table 1. Effect of oral rehydration and hyperhydration on orthostatic, lower body negative pressure, and acceleration tolerances before and after deconditioning.

Reference	Protocol	Drinks	Results	Conclusions
Clark et al. (1946); 8 subjects, ambulatory.	200 $+G_z$ runs, ramp 3+G_z/sec maintained for 15 sec; visual end-point.	1.5-2.0 liters of H_2O or milk.	Full stomach increased +Gz tolerance by 0.3-0.4G (range 0.0 to 1.1G) Increase of intrarectal pressure by 40 mmHg results in 1.0G increase in tolerance. Fluid increased tolerance by 0.2G.	Increased $+G_z$ tolerance after drinking due to increased intraabdominal pressures.
Greenleaf et al. (1973); 8 men, 14d bed rest.	Three $+G_z$ runs subjects relaxed 2.1G, 3.2G, and 3.8G at ramp of 1.8+G_z/min.	1.0-1.9 liters of 143 mEq/l Na^+, 31 mEq/l K^+, and 620mOsm/kg.	Bed rest decreased ($P<0.05$) $+G_z$ tolerance by 36% at 2.1G, by 30% at 3.2G, and by 44% at 3.8G. Rehydration did not affect post-bed rest tolerances at 3.2G, but it restored 64%($P<0.001$) of tolerance at 2.1G.	Oral rehydration with hypertonic solutions can increase $+G_z$ tolerance in hypohydrated bed-rested men.
Asyamolov et al. (1974); 4 men.	Four hr bed rest with no water; two % body wt water load when ambulatory; twelve hr bed rest with 2 % water load at hr 8; four hr bed rest with 1% water load at hr 3; and four hr bed rest with 0.5% water load at hr 3. Orthostatic test (not specified).	Water at 0.5% to 2% of body wt.	There was a linear relationship ($r=0.92$) between decrease in heart rate and net (intake-outgo) water content during orthostasis 30 min after drinking.	Drinking water reduced orthostatic stress via decreases in heart rate.
Greenleaf et al. (1977); 6 men, ambulatory.	Acceleration tolerance to 0.5 +G_z/min during hydrated control, after withdrawl of 400 ml blood, after blood reinfusion, and after 800 ml 0.9% NaCl.	800 ml 0.9% NaCl.	Blood withdrawl reduced tolerance by 15.1% ($P<0.05$). Both reinfusion and drinking restored ambulatory tolerance.	Oral rehydration is as effective as blood reinfusion for restoring $+G_z$ acceleration tolerance decrements due to hypovolemia.

Reference	Protocol	Drinks	Results	Conclusions
Hyatt el al. (1977); 6 men, 7d bed rest.	-30 mmHg lower body negative pressure while consuming 1.0 liter 154 mEq/l Na+; saline consumption without LBNP.	1000 ml beef bouillon containing 154 mEq/l Na+.	Plasma volume, heart rate, and systolic blood pressure responses to LBNP returned to pre-BR control levels; saline consumption alone had a lesser effect.	LBNP combined with saline drinking is better than saline alone for restoring CV responses to LBNP after bed rest.
Grigor'yev et al. (1978); 22 men, bedrested.	Studied various water and saline drinks on LBNP and head-up tilting responses.	Water-20ml/kg body wt; Isotonic NaCl 20 ml/kg wt; Divided doses of 0.9 NaCl, 3% NaCl, and 4% NaCl; Divided doses of dry NaCl = to 1.5%, 1.8%, and 0.75%.	All subjects on these four regimens increased body hydration: water only for 1.5-2.0h; isotonic NaCl for 10h; divided liquid for 10h; divided dry NaCl for 24h.	Adiministration of dry salt over 24h had the best fluid retention and heart rate and blood pressure responses to LBNP and tilting.
Kakurin et al. (1978); 6 subjects, 49 day -4° head down tilt. Plus an additional 10 subjects.	Studied controlled fluid intake to ameliorate hypohydration. Also, gave dry salt.	Water-40 ml/ kg/day Dry salt-0.20g/kg/ day with water or juice up to 20 ml/kg per day.	Subjects had increased diuresis and no change in LBNP cardiovascular responses with plain water. Both fluid balance, salt balance, and pulse rates were better after intake of dry salt plus fluid to tilting and LBNP tests.	Administration of dry salt plus fluids significantly ameliorated adverse effects of bed-rest deconditioning on tilting and LBNP.

Reference	Protocol	Drinks	Results	Conclusions
Gazenko et al. (1979); 2 cosmonauts on 53d of the second group aboard Salyut 3 in July 1975.	In-flight LBNP test preceeded by NaCl and water intake. LBNP was 2 min control, 2 min-25mmHg, 3 min at 35mmHg, and 3 min recovery.	Four grams of NaCl with 900-1200 ml H_2O in two equal doses 5-6 h prior to LBNP on day 53; and 9.0g NaCl plus 1000-1200 ml fluid taken in 3 parts on last day of micro-g.	Both cosmonauts had better CV responses to LBNP on day 53, with increased endurance. Both cosmonauts reported rush of blood to the head after pre-reentry intake of salt and fluid. After landing the cosmonauts did not experience marked thirst, as they had after previous shorter missions.	Pre-reentry hyperhydration is beneficial in restoring fluid homeostasis and CV stability.
Johnson (1979); 6 men, 14d BR; 6 men,28d BR.	Bedrest used flight food and LBNP test. Used heart rate response to 4h LBNP at -50mmHg plus one liter of isotonic NaCl. Measured plasma volume, red cell mass, extracellular vol., and total body water.	One liter of isotonic NaCl during 4h LBNP, saline alone, or nothing on days 13,14, and 15 of bed rest.	Increase in PV was greatest when saline alone was given. Heart rate was lowest with LBNP plus saline versus saline alone. LBNP response to -50 mmHg same after 10 days spaceflight and 13 days of bedrest.	The augmented PV following saline ingestion lasts longer than the cardiovascular protection from LBNP stress alone.
Gazenko et al. (1980).	Review paper on cosmonaut fluid-electrolyte responses to microgravity.		Early responses to microgravity are decreases in thirst, fluid intake, and salt appetite.	

Reference	Protocol	Drinks	Results	Conclusions
Grigoriev, A.I. (1983); >100 test subjects during 14d, 49d, 182d, -4° head-down bed rest; and 12 cosmonauts during 63d and 185d space flights.	12 men at 49d -4° bed rest; 6 men at 182d -4° bed rest; both groups exercised. 24 men dry water immersed 3d to 13d plus $+G_z$ acceleration, 0.6-2.0G for 60-90 min/day at 0.2 $+G_z$/sec. 21 men at 14d and 49d-4° bed rest with LBNP (-10 to -60 mmHg) for 60 to 160 min during last 5, 3, or last day of BR. 22 men tested ambulatory.	1.0 to 1.8 liters of H_2O or 0.9% NaCl used in conjuction with $+G_z$ acceleration and LBNP.	Exercise performed during BR attenuated fluid-electrolyte losses, but did not influence extracellular fluid vol. $+G_z$ applied daily during immersion decreased urine fluid and electrolytes. Better retention with $+G_z$ plus saline. LBNP plus saline (20 ml/kg wt) had best results. The water-salt supplement plus LBNP plus exercise was best during 49d and 182d BR periods. This combined countermeasure was used effectively 2-5 days before reentry during 63d and 185d flights.	Combined stimuli are better countermeasures for post-flight orthostasis and recovery.
Kokova, N.I. (1984); 18 men undergoing 7d dry immersion.	6 men had 7d dry immersion with no fluid; 6 men had 7d dry immersion plus fluid; and 6 men were ambulatory control plus fluid. $+G_z$=0.003 G/sec.	0.15g NaCl plus 18ml H_2O/kg wt given 16h, 12h, and 2h before $+G_z$, plus 200-300 ml tea 40 min before $+G_z$.	$+G_z$ tolerance was decreased from ambulatory control in both immersion groups. Water-salt drink attenuated $+G_z$ decline. Correlation r=-0.96 between degree of fluid retention and decrease in $+G_z$.	Necessary to retain or increased body water by 1,700 ml to eliminate $+G_z$ tolerance decrements, during prolonged immersion.
Bungo et al. (1985); 26 astronauts: 17 took fluid and 9 did not during flights of 54h to 192h.	Crewmembers consumed 2.7 liters of usual fluids on last flight day. Salt plus H_2O 2h before reentry.	1.0g NaCl with 114ml H_2O (0.9%) for a total of 8 tablets plus 912 ml H_2O. Some took H_2O and others took frui t juices.	Inflight fluid intake varied from 0.5 to 1.0 liters. The three incidence of presyncope or syncope occurred in control subjects who took no fluid or salt.	Fluid loading had a positive effect on post-flight orthostatic tolerance.

Reference	Protocol	Drinks	Results	Conclusions
Dlusskaya et al. (1985); 37 men given tilt-test and water loading before $+G_z$ acceleration.	Used tilt plus water loading tests to predict $+G_z$ tolerance; 0.4 $+G_z$/sec to $+3.0G_z$ and $+5.0G_z$ each for 30 sec.	Subjects drank boiled water (2% body wt) within 4-5 min. Five min tilt measured pre- and post-drinking.	26 men tolerated $+G_z$ acceleration well while 11 did not. The tilt-test was well tolerated by all subjects.	Good or poor tolerance to tilt cannot predict tolerance to $+G_z$ acceleration.
Kotovskaya et al. (1987); 62 men given $+G_z$ acceleration and salt-water supplements in ambulatory control and in dry-immersion.	Group I: ambulatory control, no fluid; Group II: ambulatory control, 7ml/kg H_2O; Group III: ambulatory control, 14 ml/kg H_2O; Group IV: 7- day dry immersion, 18 ml/kg H_2O + 0.15g NaCl/kg 16h before $+G_z$. $+G_z$ ramp= 0.003 G/sec to 3.0 G to tolerance.	18 ml/kg H_2O + 0.15g NaCl/kg, or water.	Compared to Group I, $+G_z$ tolerance increased by 0.3G (NS) in Goup II, by 0.8G ($P<0.01$) in Group III; and by 0.5G ($P<0.05$) in Group IV.	$+G_z$ acceleration tolerance and CV parameters are better with water, and water plus salt supplements.

Reference	Protocol	Drinks	Results	Conclusions
Frey et al. (1991); 5 men consumed 6 drinks.	The 1.0 liter refrigerated drinks were consumed over a 30-min period. Then the subjects rested sitting for 4 hr. Blood and urine were analyzed. Change in PV measured by Hb-Hct.	a)Demineralized water b)0.9% NaCl c)1% glucose d)0.74% NaCll e)0.9% NaCl + 1% glucose f)1.07%NaCl	Immediately after drinking hypervolemia was greatest with glucose-containing drinks (c,d,e). After 1 to 2 hr the hierarchy of plasma volume was f (highest) followed by d,b,e,c, and a (lowest). Drinks a and c had greatest diuresis; drink f the least diuresis.	One to two hours after drinking glucose was effective for measuring PV only if combined with NaCl. Hypertonic saline (drink f) had greatest hypervolemia and the smallest diuresis.

Table 2. Anthropometric and Peak Oxygen Uptake Data for the Two Experimental Groups

Subject	Age (yr)	Height (cm)	Weight (kg)	S.A. (m^2)	$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)	Peak ($ml \cdot min^{-1} \cdot kg^{-1}$)	Peak load (Watts)
REST GROUP							
AHE	36	180.0	78.32	1.98			
BRO	23	174.5	65.75	1.80			
GOL	41	184.0	83.37	2.03			
MCB	29	172.0	75.60	1.89			
REA	31	179.5	86.98	2.06			
$\bar{X}$	32	178.0	78.00	1.95			
±SD	7	4.8	8.15	0.11			
±SE	3	2.1	3.64	0.05			
EXERCISE GROUP							
FOW	46	171.5	72.30	1.85	1.76	24.3	148
KAL	33	162.5	67.00	1.72	3.23	48.2	340
MCB	30	173.0	74.19	1.88	3.09	41.6	246
REA	32	177.2	86.16	2.04	2.17	25.2	242
$\bar{X}$	35	171.0	74.91	1.87	2.56	34.8	244
±SD	7	6.2	8.09	0.13	0.71	12.0	78
±SE	4	3.1	4.05	0.07	0.36	6.0	39

Table 3. Drink Composition (per 2000 ml)

	I	Ia	II	III	IV	V	VI	VII
		Artifically Sweetened Solutions						
	Water	Water	0.045% Na	0.9% NaCl	NaCl/NaCitrate (0.36% Na)	9.7% Glucose + 0.045% Na	Shaklee* Performance	Power** Surge
Sodium Chloride (gm)	–	–	2.24	18.00	9.00	–	–	–
Sodium Citrate (gm)	–	–	–	–	15.44	3.87	3.87	0.99
Dextrose (gm)	–	–	–	–	–	216.00	41.12	34.81
Aspartame (gm)	–	0.72	0.72	0.88	0.72	–	–	–
Shaklee Performance (gm)	–	–	–	–	–	–	222.28	–
Power Surge (gm)	–	–	–	–	–	–	–	208.70
Total	–	0.72	2.96	18.88	25.16	219.87	222.28	208.70
Total Volume (ml)	2000	2000	2000	2000	2000	2000	2000	2000
Ionic Concentration: (meq/% wt/vol)								
Na^+	–	–	19.61/0.045	157/0.360	157/0.360	19.61/0.045	19.61/0.045	23.47/0.055
K^+	–	–	–	–	–	–	5.01/0.020	2.51/0.010
Cl^-	–	–	18.95/0.067	152/0.540	76/0.270	18.95/0.067	4.98/0.018	–
Mg^{++}	–	–	–	–	–	–	0.40/0.002	–
Ca^{++}	–	–	–	–	–	–	1.96/0.016	–
P^{++++}	–	–	–	–	–	–	0.51/0.008	–
Total			38.56/0.112	309/0.900	233/0.630	38.56/0.112	32.47/0.109	26.48/0.065
Carbohydrate (% wt/vol)								
Glucose	–	–	–	–	–	9.716	1.850	1.74
Fructose	–	–	–	–	–	–	2.426	1.44
Maltodextrin	–	–	–	–	–	–	5.440	3.47
Sucrose	–	–	–	–	–	–	–	3.07
Total	–	–	–	–	–	9.716	9.716	9.72
Osmolality	1	30	70	320	270	650	380	390

* Shacklee U.S., Inc., San Francisco, CA 94111

** Perc Products, Moscow, PA 18444

Table 4. Mean (±SE) Body Weight, Drink Volume, and Drinking Time for the Six Drinks in the Rest and Exercise Experiments

Drinks	Ia	II	IV	V	VI	VII
Body weight (kg)						
A. Rest	77.45 (3.84)	76.67 (3.50)	76.66 (3.40)	76.56 (3.58)	77.25 (3.56)	77.02 (3.50)
B. Exercise	74.85 (3.86)	75.00 (4.05)	75.27 (4.09)	75.22 (4.37)	75.14 (4.00)	74.99 (3.77)
Drink volume (ml) (12 ml/kg)						
A. Rest	927 (51)	922 (43)	920 (41)	919 (43)	927 (43)	924 (42)
B. Exercise	898 (46)	900 (49)	904 (49)	903 (52)	902 (48)	900 (45)
Drinking time (min)						
A. Rest	4.6 (1.5)	5.7 (1.9)	6.2 (2.1)	4.1 (1.0)	4.1 (1.6)	4.0 (1.5)
B. Exercise	3.6 (0.5)	2.3 (0.2)	4.0 (0.8)	2.8 (0.8)	3.0 (1.2)	3.4 (0.7)

Table 5. Individual Submaximal Exercise Loads, Heart Rates, Oxygen Uptakes, and Relative ($\%\ \dot{V}_{O_2\ peak}$) Oxygen Uptakes for the Six Exercise Experiments

Subject (Load, W)			Ia	II	IV	V	VI	VII	$\bar{X} \pm SE$*
FOW (82)	HR (b/min)		134	127	135	136	147	139	136 ± 3
	$\dot{V}_{O_2}$ (L/min)		1.10	1.22	1.41	1.29	1.40	1.31	1.29 ± 0.05
	$\dot{V}_{O_2}$ (%)		62	69	80	73	80	74	73 ± 3
KAL (147)	HR (b/min)		145	138	150	182	138	154	157 ± 7
	$\dot{V}_{O_2}$ (L/min)		2.18	2.19	2.60	2.02	2.08	2.18	2.21 ± 0.08
	$\dot{V}_{O_2}$ (%)		67	68	80	63	64	67	68 ± 2
MCB (163)	HR (b/min)		148	135	144	122	114	147	135 ± 6
	$\dot{V}_{O_2}$ (l/min)		2.19	2.10	2.27	2.06	1.83	2.15	2.10 ± 0.06
	$\dot{V}_{O_2}$(%)		71	68	73	67	59	70	68 ± 2
REA (114)	HR (b/min)		137	134	137	142	130	144	137 ± 2
	$\dot{V}_{O_2}$ (L/min)		1.51	1.56	1.60	1.56	1.67	1.64	1.59 ± 0.02
	$\dot{V}_{O_2}$ (%)		70	72	74	72	77	76	74 ± 1
	HR	$\bar{X}$	141	134	142	146	132	146	140 ± 2
		±SE	3	2	3	13	7	3	
	$\dot{V}_{O_2}$	$\bar{X}$	1.75	1.77	1.97	1.73	1.75	1.82	1.80 ± 0.04
		± SE	0.27	0.23	0.28	0.19	0.14	0.21	
	$\dot{V}_{O_2}$ (%)	$\bar{X}$	68	69	77	69	70	72	71 ± 1
		± SE	2	1	2	2	5	2	

*Data calculated horizontally (N = 6).

Table 6. Mean (±SE) Rectal and Mean Skin Temperatures for the Six Exercise Drinking Experiments

Subject	Water (Ia)			19.6 Na^+ (II)			157 Na^+ (IV)			19.6 Na^+-Glu (V)			Performance (VI)			Power (VII)		
	Tre_R	Tre_{68}	ΔTre	Tre_R	Tre_{68}	ΔTre	Tre_R	Tre_{68}	ΔTre	Tre_R	Tre_{68}	ΔTre	Tre_R	Tre_{68}	ΔTre	Tre_R	Tre_{68}	ΔTre
FOW	36.49	37.53	1.04	36.82	37.63	0.81	36.64	37.63	0.99	36.42	37.71	1.29	36.54	37.59	1.05	36.56	37.40	0.84
KAL	36.54	38.18	1.64	36.46	37.53	1.07	36.67	37.77	1.10	36.65	38.14	1.49	36.58	37.36	0.78	36.65	38.12	1.47
MCB	36.46	38.10	1.64	36.70	37.53	0.83	36.15	38.20	2.05	36.31	37.42	1.11	36.46	37.47	1.01	36.41	37.70	1.29
REA	36.77	37.51	0.74	36.78	37.43	0.65	36.86	37.41	0.55	37.02	37.58	0.56	37.00	37.55	0.55	36.76	37.60	0.84
$\bar{X}$	36.57	37.83	1.27	36.69	37.53	0.84	36.58	37.75	1.17	36.60	37.71	1.11	36.65	37.49	0.85	36.60	37.71	1.11
±SE	0.07	0.18	0.22	0.08	0.04	0.09	0.15	0.17	0.32	0.16	0.15	0.20	0.12	0.05	0.12	0.07	0.15	0.16
	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$	$\bar{T}sk_R$	$\bar{T}sk_{68}$	$\Delta\bar{T}sk$
FOW	31.79	31.93	0.14	32.88	33.55	0.67	32.04	32.18	0.14	32.30	34.22	1.92	30.27	32.92	2.65	32.18	33.13	0.95
KAL	33.30	34.38	1.08	32.20	35.95	3.75	30.18	34.81	4.63	33.46	34.93	1.47	32.58	34.29	1.71	33.06	33.41	0.35
MCB	31.43	32.90	1.47	31.78	34.12	2.34	30.44	34.23	3.79	32.32	34.01	1.69	31.81	33.99	2.18	32.42	34.47	2.05
REA	30.87	33.78	2.91	31.26	33.86	2.60	31.62	34.30	2.68	31.14	33.72	2.58	33.12	33.65	0.53	31.13	33.86	2.73
$\bar{X}$	31.85	33.25	1.40	32.03	34.37	2.34	31.07	33.88	2.81	32.31	34.22	1.92	31.95	33.71	1.77	32.20	33.72	1.52
±SE	0.52	0.53	0.58	0.34	0.54	0.64	0.45	0.58	0.98	0.47	0.26	0.24	0.62	0.29	0.45	0.40	0.29	0.54

$Tre_R = \bar{X}$ -10 and -5 min pre-exercise control values

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13. ABSTRACT ***(Maximum 200 words)***

The purpose of this study was to formulate and to evaluate rehydration drinks, which would restore total body water and plasma volume (PV), for astronauts to consume before and during extravehicular activity, a few hours before reentry, and immediately after landing. In the first experiment (rest, sitting), five healthy men (23-41 yr), previously dehydrated for 24 hr, drank six (Ia, II, IV, V, VI, VII) fluid formulations (one each at weekly intervals) and then sat for 70 min. Pre-test PV were measured with Evans blue dye, and changes in PV were calculated with the hematocrit-hemoglobin transformation equation. This rest experiment simulated hypohydrated astronauts preparing for reentry. The second experiment (exercise, supine) followed the same protocol except four healthy men (30-46 yr) worked for 70 min. in the supine position on a cycle ergometer at a mean load of 71 ± 1% of their peak aerobic work capacity. This exercise experiment simulated conditions for astronauts with reduced total body water engaging in extravehicular activity.

14. SUBJECT TERMS

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