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Effects of Acute Plasma Volume Expansion on Altering Exercise-Heat Performance

M. N. Sawka, R. W. Hubbard, R. P. Francesconi, and D. H. Horstman

U.S. Army Research Institute of Environmental Medicine,
Kansas Street, Natick, MA 01760, USA

Summary. To determine the effect an acute plasma volume expansion has on body temperature responses and exercise performance in the heat, seven unacclimatized male volunteers attempted to complete two 90-min walks (45% of $\dot{V}O_2$ max) in a hot/dry (45° C/20% rh) environment. The experimental walk was preceded by an infusion of human albumin (50 g in a 200-ml solution) and the control walk was preceded by an infusion of isotonic saline (200 ml). Saline infusion did not alter the plasma volume. The albumin infusion was found to significantly ($p < 0.01$) increase plasma volume ~ 13% over control levels. No significant differences were found for performance time, final heart rate or final rectal temperature values between the two walks. In general, significant differences were not found for systolic blood pressure, rectal temperature, mean skin temperature, heat storage, sweat rate, plasma lactate, plasma osmolality, or plasma protein content values between the two walks. However, heart rate responses were found to be significantly lower ($p < 0.05$; ~ 13 bt · min^{-1}) during the 25-min and 40-min measurements of the experimental walk. These data suggest that plasma volume expansion may be a supportive adaptation to enable lowered heart rate responses but does not improve thermoregulatory function or performance time in the heat.

Key words: Albumin infusion – Heat acclimation – Heat stress – Plasma volume – Temperature regulation

Introduction

Heat acclimation enables an individual in a thermally stressful environment to complete a given exercise task with a relatively lower core temperature (Wyndham 1973). The physiological adaptations which are suggested as being

Offprint requests to: Dr. Michael N. Sawka (address see above)

responsible for the lowered core temperature include an improved sweat response (Nadel et al. 1974) and an expanded plasma volume (Senay et al. 1976). Senay et al. (1976) have reported that during a heat acclimation program, plasma volume expanded by approximately 9% and 24% by days 2 and 6, respectively. This hemodilution was probably mediated by an influx of proteins from the lymph into the vascular space (Senay 1972; Senay 1975). It was hypothesized that an expanded plasma volume mediated the cardiovascular and thermoregulatory improvements noted early in the heat acclimation program.

The purpose of the present investigation was to determine the effect acute plasma volume expansion has upon body temperature responses and exercise performance in the heat. Previous reports from our laboratory indicated that the combination of heat exposure and albumin administration (50 g) can expand (by $\sim$ 13%) and maintain ($>$ 6 h) an individual's plasma volume (Francesconi et al. 1983; Hubbard et al. 1981). In addition, the magnitude of this hemodilution was similar to that reported to occur within the initial 5 days of a heat acclimation program (Senay et al. 1976; Shapiro et al. 1981; Wyndham et al. 1968). Therefore, these procedures were employed in the present investigation to enable our subjects to expand their plasma volume without participating in a heat acclimation program.

Methods

Subjects. Seven male volunteers participated in this investigation. The subjects had a mean ($\pm$ SD) age of 25 $\pm$ 4 years, weight (wt) of 77.7 $\pm$ 11.3 kg, body surface area (A_D) of 1.95 $\pm$ 0.20 m^2, and aerobic power ($\dot{V}O_2$ max) of 53 $\pm$ 6 ml $\cdot$ kg^{-1} $\cdot$ min^{-1}. Before the initial test session, each subject was informed of the purpose of the study, the extent of their involvement, any known risks, and their right to terminate participation at will. Each expressed understanding by signing a statement of informed consent.

Protocol. All testing was conducted at Natick, Massachusetts in the late winter and early spring months (March–May) when the subjects were unacclimated to heat. Prior to experimental testing, each subject completed two submaximal and two maximal tests on a motor-driven treadmill. The submaximal protocol consisted of walking (1.56 m $\cdot$ s^{-1}) for 4 min at 0, 3, 6, and 9% grades to enable determination of steady state oxygen uptake responses. The maximal protocol was progressive in intensity but discontinuous in nature. The exercise bouts consisted of running (2.68 m $\cdot$ s^{-1}) for 3-min intervals with a subsequent 10-min rest period. The initial grade was zero, and the grade was increased by 3% increments for each additional exercise bout. These preliminary tests were conducted in a comfortable environment. In addition, on two occasions prior to experimental testing, plasma volume was determined by the indocyanine green (ICG) method.

The experimental portion of this study required each subject to complete two treadmill walks in a hot-dry (45° C/20% rh) environment. These walks (1.56 m $\cdot$ s^{-1}) were performed at a treadmill grade that elicited approximately 40% of each subject's $\dot{V}O_2$ max. The walks were 90 min in duration unless terminated by physical exhaustion or the pre-determined end-points of a heart rate greater than 180 bt $\cdot$ min^{-1} or a rectal temperature greater than 39.5° C. The subjects received an intravenous infusion of either human albumin (50 g in a 200-ml isotonic saline solution, American Red Cross Blood Services) for the experimental walk or isotonic saline (200 ml) for the control walk. The treatment order was randomized and minimum of 7 days spaced the two walks.

Each subject reported to the laboratory on the afternoon before the prolonged walk session and spent the night under our supervision. The following morning each subject was awoken (at 06:00 h),

provided with a light breakfast and asked to enter the heat chamber (at 07:00 h). Figure 1 presents an outline of the protocol employed after each subject entered the heat chamber. After entering the heat chamber, subjects were instructed to sit quietly and a catheter was placed into an arm vein. During the time prior to exercise, body weights were periodically obtained and subjects were encouraged to drink water to enable full rehydration. During the walks, all subjects were provided 200 ml of water to ingest during each 20-min period.

Physiological Variables. The electrocardiogram was obtained with chest electrodes (CM 5 placement), and heart rate (bt · min^{-1}) was calculated from a 20-s recording. Systolic blood pressure was determined by the auscultation method. Oxygen uptake ($\dot{V}O_2$, l · min^{-1} STPD) and pulmonary ventilation ($\dot{V}E$, l · min^{-1} BTPS) were determined by open circuit spirometry. Subjects breathed via a two-way breathing valve (Otis-McKerrow) and expired gases were collected in 150-l Douglas bags. Expired gases were then analyzed for O_2 and CO_2 concentrations with an electrochemical O_2 analyzer (Applied Electrochemistry S-3A) and an infrared CO_2 analyzer (Beckman LB-2), respectively. Minute volume of expired air was measured by a dry gasometer (Parkinson-Cowan CD-4) modified for digital readout. The dry gasometer was previoulsy calibrated against a 120-L Tissot gasometer.

During exercise in the heat, both rectal and skin temperatures were monitored with a 10-channel digital thermometer (Omega 2176 A). Rectal temperature (T_{re}, ° C) was obtained from a thermocouple inserted ~ 12 cm past the anal sphincter. Mean weighted skin temperature ($\bar{T}_{sk}$, ° C) was calculated from thermocouples placed at the chest, arm, thigh, and calf (Ramanathan 1964). Heat storage (ΔS, W · m^{-2}) was calculated as: $\Delta S = 0.965\ (0.2\,\Delta\bar{T}_{sk} + 0.8\,\Delta T_{re})$ (wt) · A_D^{-1}). Sweat rate was determined as the net body weight loss, corrected for fluid intake and respiratory water loss.

Venous blood samples were collected from an indwelling teflon catheter (Deseret Angiocath with Pharmaseal extension tube) placed within an arm vein. The catheter was filled with heparinized saline between each collection period. During each collection period the 2-ml catheter was flushed with at least 3 ml of blood before the 6-ml sample was obtained. Quadruplicate determinations were made of hematocrit and duplicate determinations were made of all other blood measurements. Commercial kits were used to determine hemoglobin (Hycel, cat. # 116C) and plasma lactate (Sigma, cat. # 826-UV) concentrations, while plasma protein content was determined with a refractometer (American Optical) and plasma osmolality was determined by freezing point depression (Precision Systems Inc., Osmette A).

Plasma volume determinations were made in duplicate on a seated subject using the ICG method on an afternoon a few days prior to the prolonged walks. For this, a small (0.5 mg · kg^{-1}) volume of ICG dye (Cardio-Green) was injected into an arm with blood samples withdrawn from a catheter in the contralateral arm at precisely 2-min intervals. The ICG concentration of these samples was determined on a spectrophotometer (Perkin-Elmer Lambda-3). The relative percent changes in plasma volume were calculated from appropriate hemoglobin and hematocrit values (Dill and Costill 1974). The exercise plasma volume values were calculated from the plasma volume measured at rest adjusted for the relative percent change in plasma volume during the experimental session.

Statistical Analysis. Means, standard deviations, standard errors of the mean and paired *t*-tests were performed with a programmable calculator (Hewlett-Packard 9815 A). Statistical significance was established at the $p < 0.05$ level.

Results

Table 1 provides a description of the subject population immediately before the prolonged walks which were preceded by albumin infusion (APW) and saline infusion (SPW). Prior to both prolonged walks, each subject had a similar body weight, rectal temperature, skin temperature, and plasma osmolality. Albumin

Table 1. Description of the subject population prior to each treadmill walk ($n = 7$)

	Weight (kg)		Rectal temperature (° C)		Skin temperature (° C)		Plasma volume (l)		Plasma osmolality (mosmol · kg^{-1})	
	Albumin	Saline	Albumin	Saline	Albumin	Saline	Albumin	Saline	Albumin	Saline
$\bar{X}$	77.6	77.8	37.3	37.3	35.2	35.4	3.26	2.88	281	284
SD	11.4	11.3	0.1	0.3	0.5	0.5	0.46	0.50	4	5
p	n.s.		n.s.		n.s.		< 0.01		n.s.	

n.s. is not significantly different

Table 2. Performance time and physiological responses to treadmill walking

	Performance time (min)		Heat storage (W · m^{-2})		Sweat rate (g · m^{-2} · h^{-1})		Final heart rate (bt · min^{-1})		Final rectal temperature (° C)	
	Albumin	Saline	Albumin	Saline	Albumin	Saline	Albumin	Saline	Albumin	Saline
$\bar{X}$	71.2	61.8	54	58	644	640	175	176	39.0	38.9
SD	20.1	18.8	21	34	79	97	16	12	0.6	0.3
p	n.s.		n.s.		n.s.		n.s.		n.s.	

n.s. is not significantly different

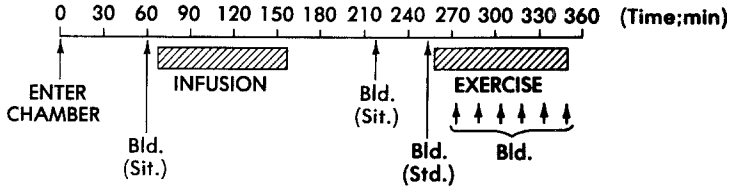

Fig. 1. The protocol for each prolonged walk session. Bld. is for blood collection, and sit. is from the sitting and std. is from the standing posture

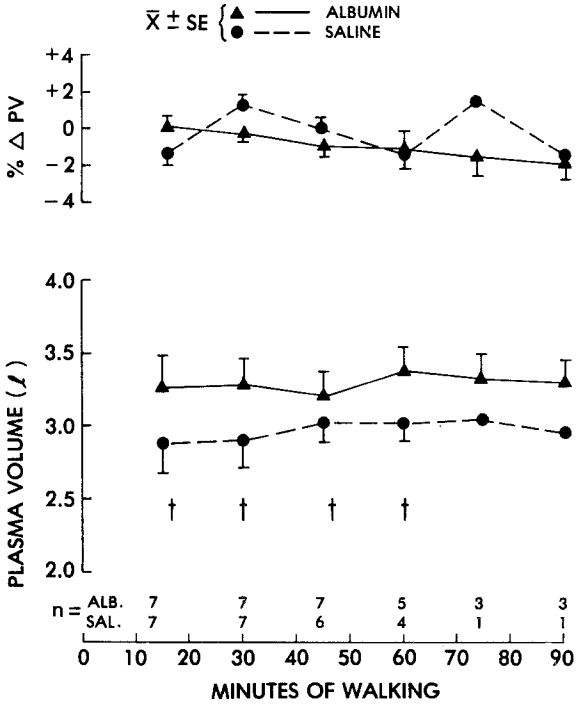

Fig. 2. Comparison of calculated plasma volume and percent change in plasma volume (%ΔPV) data between the albumin and saline walks. The data points represent mean values for all observations during a time period. Probability of dependent t-tests are expressed as † for $p < 0.01$

infusion was found to significantly ($p < 0.01$) increase plasma volume by approximately 13%. This hemodilution corresponded to ~ 7.6 ml of plasma per gram of albumin infused. Plasma volume was virtually unaffected as a result of infusion of 200 ml isotonic saline.

The subjects exercised at mean relative intensities of 47% and 44% of $\dot{V}O_2$ max for the APW and SPW, respectively. These exercise intensities corresponded to a mean $\dot{V}O_2$ of 1.93 and 1.79 l · min^{-1}. No significant differences in $\dot{V}O_2$ were demonstrated between the two walks. Exercise was terminated for the APW because of physical exhaustion for two subjects, achievement of pre-determined end-points for two subjects and completion of the test for three

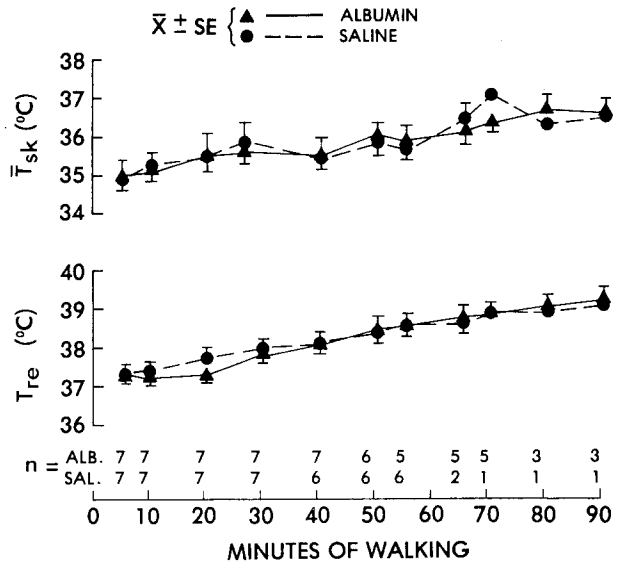

Fig. 3. Comparison of mean skin temperature ($\bar{T}_{sk}$) and rectal temperature (T_{re}) data between the albumin and saline walks. The data points represent mean values for all observations during a time period

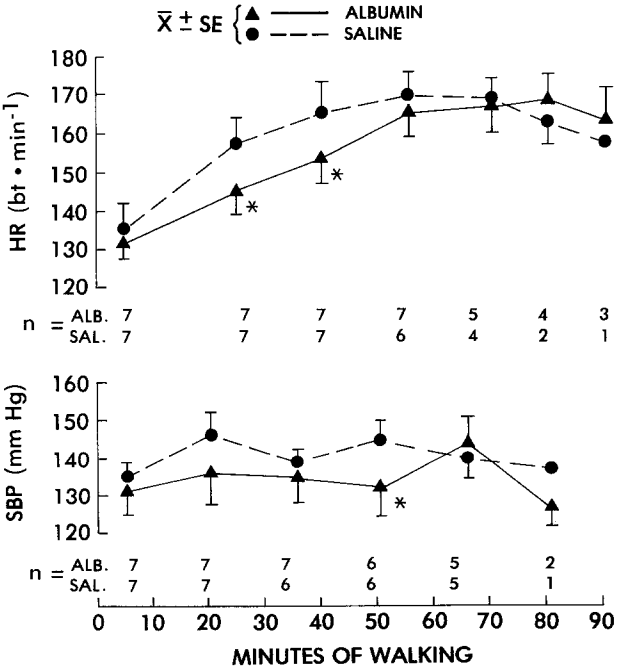

Fig. 4. Comparison of heart rate (HR) and systolic blood pressure (SBP) data between the albumin and saline walks. The data points represent mean values for all observations during a time period. Probability of dependent *t*-tests are expressed as * for $p < 0.05$

subjects. Exercise was terminated for the SPW because of physical exhaustion for five subjects, achievement of pre-determined end-points for one subject and completion of the test for one subject. No significant differences were found between the APW and SPW for the final heart rate or final rectal temperature values (see Table 2). Performance time was not significantly different for the two walks (see Table 2), but the subjects averaged 9.4 min longer for the ABW.

Figure 2 presents the calculated plasma volume and percent change in plasma volume (%ΔPV) data obtained during the two walks. Plasma volume was found to be significantly ($p < 0.01$) greater during the APW than SPW. In comparison to the pre-exercise levels, plasma volume did not change with the initiation of exercise. No significant differences in %ΔPV were found between the two walks at any time period. During exercise plasma lactate (~ 1.8 mmol $\cdot$ l^{-1}), protein content (~ 8.2 g $\cdot$ dl^{-1}) and osmolality (~ 283 mosmol $\cdot$ kg^{-1}) values remained relatively constant. For these variables no significant differences were found between the APW and SPW.

Figure 3 illustrates the rectal and mean skin temperature values for the two walks. Both of these variables were found to increase with time, and have similar slopes for the APW and SPW. No significant differences were found for rectal or mean skin temperature at any time period between the two walks. In addition, no significant differences were found for heat storage or sweat rate (see Table 2) between the APW and SPW. Figure 4 presents the subjects' heart rate and systolic blood pressure responses for the two walks. Heart rate was found to increase with time, and was significantly lower at the 25-min and 40-min measurements during the APW. Systolic blood pressure was found to remain fairly constant throughout the duration of the two walks and, with the exception of the 50-min values (when SPW was higher), no differences were found between corresponding time periods.

Discussion

Plasma volume has been shown to expand by 9–24% during the initial 2–6 days of a heat acclimation program (Senay et al. 1976; Shapiro et al. 1981; Wyndham et al. 1968). During the remainder of the heat acclimation program, however, plasma volume has been reported to remain relatively constant (Senay et al. 1976; Shapiro et al. 1981) or return towards control levels (Senay 1975; Shapiro et al. 1981; Wyndham et al. 1968). It is during the period of rapid expansion that a portion of the lowering of heart rate and core temperature responses to exercise seems to occur (Eichna et al. 1950; Wyndham et al. 1968). Using procedures similar to those described in a previous report we employed a high ambient temperature to expand the vascular space (via cutaneous vasodilation), and an albumin infusion to move fluids into the vasculature (Francesconi et al. 1983; Hubbard et al. 1981). Previous investigations have proposed that the rapid plasma volume expansion during heat acclimation is the result of protein influx

into the vasculature (Senay 1972; Senay 1975). Therefore, we expanded plasma volume in a manner similar to that believed to occur during heat acclimation.

An individual's core temperature response to exercise in the heat has been reported to decrease during the initial 3–4 days of a heat acclimation program (Eichna et al. 1950; Piwonka and Robinson 1967; Rowell et al. 1967; Senay et al. 1976; Wyndham et al. 1968). In general, these changes in core temperature have been associated with an increased sweat rate (Eichna et al. 1950; Piwonka and Robinson 1967; Rowell et al. 1967; Wyndham et al. 1968) and/or a decreased rate of metabolic heat release (Eichna et al. 1950) during a standardized exercise task. In contrast to these findings, Senay et al. (1976) have reported that "much" of the decrease in core temperature occurs prior to an increased sweat rate. Since these investigators employed an ambient temperature of 45° C, it is doubtful that radiation and convection heat loss would account for these lowered core temperature values. In the present study, rectal temperature responses were nearly identical during the two walks, despite an expanded plasma volume during the APW. This finding seems reasonable since sweat rate values were similar for the two walks. In agreement with our findings, Fortney et al. (1981) reported that blood volume expansion did not alter the core temperature response to exercise in a 35° C environment. Their observation occurred despite the fact that forearm blood flow was greater for a given esophageal temperature after blood volume expansion.

During prolonged exercise under thermally stressful conditions heart rate (HR) responses have been observed to gradually increase over time (Rowell 1974). This increased HR has been associated with a falling pulmonary artery pressure and stroke volume (Rowell 1974). The present study's HR responses also increased throughout the duration of both walks. However, during the 25-min and 40-min measurements HR values were approximately 13 bt · min^{-1} lower during the APW than SPW. Similar to our findings, Wyndham et al. (1968, 1976) have reported that for the initial 4 days of a heat acclimation program HR decreases, but that both stroke volume and cardiac output increase during exercise. During these initial 4 days plasma volume was reported to increase by approximately 16% (Wyndham et al. 1976). Fortney et al. (1981) have investigated the effect acute blood volume expansion has upon hemodynamics during 30 min of exercise in the heat. In comparison to control exercise levels, blood volume expansion was found to lower HR, but increase stroke volume and cardiac output. Based upon the data of these investigations, it seems reasonable to hypothesize that in the present study an expanded plasma volume initially increased ventricular filling pressure which enabled a greater stroke volume. These cardiovascular advantages, however, did not appear to continue after the 40-min measurement.

The present study indicates that plasma volume expansion is probably an important contributor to the lowered heart rate responses observed during the initial 4 days of a heat acclimation program. It is important to note that despite an expanded plasma volume, no lowering of core temperature or increased performance was observed during the APW. Therefore, we conclude that plasma volume expansion is a supportive adaptation which enables lowered

heart rate responses but does not improve thermoregulatory function or performance time in a high ambient temperature environment.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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