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Summary

The purpose of this pilot study was to investigate sitting orthostatic tolerance and determine potentially adverse signs and symptoms that would incapacitate subjects in a hot environment (Gemini reentry cabin temperature profile) after 48 hr and 96 hr of horizontal bed rest (BR), which simulated microgravity deconditioning. Six college men (23–29 yr) were allocated into two groups: heat acclimated (three subjects: No. 1—control, No. 2—48 hr BR, No. 3—96 hr BR) and nonheat acclimated (three subjects: No. 4—control, No. 5—48 hr BR, No. 6—96 hr BR). After BR they sat in an ambient temperature of 57°C (135°F) for 30 min which then was decreased to 49°C (120°C) for up to 480 min. Tolerance time in the heat with seated orthostatic stress was 480 min (subject No. 1) and 180 min (subject No. 4) in the two ambulatory men, but was reduced to 22–150 min in the four bed-rested men irrespective of their heat acclimation status.

Although heat acclimation appeared to enhance tolerance and attenuate accompanying physiological responses, as well as ameliorate the frequency and intensity of adverse signs and symptoms at termination of exposure, tolerance was reduced in the bed-rest deconditioned subjects regardless of their acclimation level. Thus, these few collective findings do not indicate an unequivocal positive effect of acute heat acclimation on sitting orthostatic tolerance in acute bed-rest deconditioned subjects.

Introduction

In 1964, during planning for the manned spaceflights, evidence indicated there would be significant increase of cabin temperature in the reentry capsule (ref. 1). The increased temperature, coupled with the additional stress of the upright (seated) posture of the microgravity deconditioned and dehydrated astronauts after their Gemini capsule landed in the water (fig. 1), could induce or exacerbate orthostatic hypotension which could result in nausea, vomiting, or unconsciousness (fainting).

Prior to 1965, scientific evidence concerning the effect of heat acclimation on orthostatic (head-up tilt) tolerance was sparse and inconclusive (ref. 2). Findings from the four major studies indicated that acute heat exposure

and physical exercise decreased orthostatic tolerance (refs. 3–5), while extended acclimation to heat with concomitant exercise training had no impact on tolerance (ref. 6). The effect of exercise and exercise training—in trained or untrained subjects in cool or hot environments—on orthostatic tolerance remains unclear (ref. 7). On the other hand, essentially all results from 14 studies conducted before 1965 indicate that orthostatic cardiovascular responses and tolerance deteriorate significantly following prolonged (>24 hr) bed-rest deconditioning (ref. 8).

This study was undertaken at the request of the then assistant director for engineering and development (M. A. Faget) at the NASA Manned Spacecraft Center at Houston to investigate the effect of the increased Gemini reentry cabin temperature profile on subjects after 48 hr and 96 hr of bed rest which simulated microgravity deconditioning. This appears to be the first and only study which has investigated orthostatic tolerance responses to the combined effects of increased ambient temperature in heat-acclimated subjects after bed-rest deconditioning.

Methods

Subjects

Six college men (23–29 yr) in good physical condition were employed as test subjects for these experiments conducted at Ames Research Center during December 1964. They passed a comprehensive medical examination and provided written informed consent. Three men were not heat acclimated, and three others had just been acclimated by six 2 hr/day treadmill exercise (6.4 km·hr⁻¹) sessions in the heat [T_{db} = 47.2°C (116°F), rh = 33%] on an every-other-day sequence (ref. 9). Induction of heat acclimation was indicated by progressive increase in total body sweating from 993 to 1598 ml·hr⁻¹, while sweat osmotic and NaCl concentrations decreased progressively and exercise heart rate decreased from 168 ± SE 6 to 156 ± 4 beats·min⁻¹ by the sixth exposure (ref. 9). The experimental protocol was approved by the Ames human experiments review board.

Procedure

Three subjects were allocated into the heat acclimation group (No. 1—ambulatory control, No. 2—48 hr BR, No. 3—96 hr BR), and three into the nonacclimation group (No. 4—ambulatory, No. 5—48 hr BR, No. 6—96 hr BR). All were exposed to a Gemini reentry variable temperature profile (fig. 2) for up to 8 hr in the small environmental chamber then located in the East bay of building N219 (fig. 3). The 48 hr and 96 hr periods were anticipated Gemini flight durations.

The subjects were bed-rested in the horizontal position on standard hospital beds in a mobile home located on the adjacent parking lot. They were permitted to lean on one elbow to eat and to get up briefly to defecate. Urine was collected in a bedpan. Water was consumed ad libitum and food intake was unrestricted. Room temperature was $22 \pm 1^\circ\text{C}$.

After BR the subjects were carried on a stretcher to the chamber where they walked about 2 m to the chair inside. The chair was of standard space capsule configuration and was formerly used in University of Southern California acceleration studies. It was inclined forward by 8 deg from the vertical to conform to the Gemini astronaut position with the capsule floating in the water (fig. 1). Chamber testing began at 1000 hr after the subject had his normal breakfast at 0700 hr. They had no food, but water was available ad libitum in the chamber. Chamber temperature was 21°C (70°F) when the subject entered and was increased rapidly to 57°C (135°F) for the first 30 min; then it was decreased slowly to 49°C (120°F) over the ensuing 30 min and held there for an additional 7 hr (fig. 2) or until the subject was removed with pre-syncope signs and symptoms. Relative humidity was maintained between 20% and 30% during the first hour and at 20% thereafter.

Instrumentation

The subjects were instrumented with ECG leads for heart rate, an ear oximeter and pulse wave transducer, an automatic blood pressure cuff with microphone pickup, a rectal probe, and a skin temperature probe located on the medial aspect of the right thigh to estimate mean skin temperature (ref. 10).

Statistical Analysis

Mean data were analyzed with Student's t-test for independent samples where $t = 2.776$ for $P < 0.05$ (model 65 calculator, Hewlett-Packard, Cupertino, California). Nonsignificant differences or trends were denoted as NS.

Results and Discussion

Physiological Findings

Acclimation— Mean reclining pulse rates (both 60 b/min) and systolic/diastolic blood pressures ($113\text{--}123/69\text{--}77$ mmHg) were within the normal range for resting men (ref. 11) and were not influenced by acclimation state (table 1). The initial cardiovascular and temperature measurements were taken at 21°C (70°F) ambient temperature before the chamber was heated, so ensuing responses were caused by the change from the supine to the sitting position. Pulse rate increased by 28 and 42 b/min in the acclimated and nonacclimated groups (excluding subjects Nos. 1 and 4), respectively, whereas systolic and diastolic blood pressures increased only in the nonacclimated groups; responses were characteristic of heat acclimation (refs. 2 and 12). The initial sitting rectal (Tre) and skin (Tsk) temperatures in the chamber were essentially normal in both groups. Terminal pulse rate, blood pressures, and body temperatures were determined, to a degree, by the tolerance time—more so in the nonacclimated group where higher Tre was associated with lower tolerance. The somewhat greater mean tolerance of 210 min (NS) in the acclimated group was also accompanied by the lower terminal pulse rate, Tsk, and ΔTre ; again, responses were indicative of the heat acclimation state. There was no significant difference in $\Delta\text{Tre}/\text{tolerance}$ between the two groups. This suggests that the former may not influence the latter; e.g., control subject No. 1 completed the 8 hr exposure with a terminal Tre of only 37.8°C , whereas control subject No. 4 was removed from the chamber at 3 hr with a Tre of 39.0°C . Overall, heat acclimation appears to enhance tolerance and associated physiological responses in ambulatory subjects, and in bed-rested and water-immersed (ref. 13) deconditioned subjects.

Bed rest deconditioning— The initial sitting (orthostatic) pulse rates in the cool chamber were higher in the BR subjects when compared with those of their respective ambulatory control subjects (table 1), which is the typical response following deconditioning (ref. 8). Tolerance was greatly reduced to 60–90 min in the acclimated BR subjects when compared with the ambulatory subject's tolerance of 480 min. Tolerance of the nonacclimated BR subjects was more variable (22 and 150 min) when compared with those of the acclimated BR subjects. But it is clear that tolerance was reduced in the deconditioned subjects irrespective of their heat acclimation status.

Signs and Symptoms

In general, the nature and severity of the adverse signs and symptoms were similar in the two groups. It should be emphasized that nausea, cramps, and vomiting were not present in the two control subjects at their termination (table 1): subject No. 1 (acclimated) was terminated in good condition after 8 hr, and subject No. 4 (non-acclimated) was terminated because of elevated Tre. While both BR groups were terminated for adverse signs and symptoms, the somewhat more severe responses appeared in the nonacclimated subjects. However, more adverse orthostatic responses have been reported after heat acclimation in physically fit men (ref. 14).

Subject No. 1 (acclimated, ambulatory control) entered the chamber with a pulse rate of 62 b·min⁻¹, blood pressure of 108/80 mmHg, Tre of 36.7°C, and Tsk of 35.4°C. At the end of 8 hr the subject's pulse was 112 b·min⁻¹, blood pressure 140/90 mmHg, Tre 37.8°C, and Tsk 37.0°C (table 1). The subject was removed from the chamber at 480 min in good condition. His chief complaint during the latter part of the test was discomfort in his lower back due to the forward inclination of the chair.

Subject No. 4 (nonacclimated, ambulatory control) entered the chamber with a pulse rate of 82 b·min⁻¹, blood pressure of 140/92 mmHg, Tre of 37.0°C, and Tsk of 38.5°C. After 180 min his pulse rate was 146 b·min⁻¹, blood pressure 138/74 mmHg, Tre 39.8°C, and Tsk 39.0°C. The subject, flushed and weak, was removed from the chamber because of high Tre. Recovery was virtually complete after 1 hr.

Subject No. 2 (acclimated, 48 hr BR) had a resting pulse rate of 64 b·min⁻¹ and blood pressure of 136/74 mmHg. After rising to the sitting position in the chamber his pulse rate was 99 b·min⁻¹, blood pressure 116/90 mmHg, Tre 36.9°C, and Tsk 36.4°C. At 1 hr he began to experience abdominal cramps. At 92 min he was forced to leave the chamber due to severe cramps followed by diarrhea when his blood pressure was 130/80 mmHg, Tre 38.0°C, and Tsk 36.2°C. He had normal stools prior to BR and had not defecated during the 48 hr of BR. Recovery was rapid and no additional diarrhea occurred.

Subject No. 5 (nonacclimated, 48 hr BR) had a resting pulse rate of 54 b·min⁻¹ and blood pressure of 106/68 mmHg. After entry into the chamber his pulse rate was 108 b·min⁻¹, blood pressure 128/60 mmHg, Tre 36.5°C,

and Tsk 35.8°C. After 19 min he ingested 200 mL of water and at 22 min began vomiting. Since he appeared presyncopal, he was removed from the chamber when his pulse rate was 122 b·min⁻¹, blood pressure 116/90 mmHg, Tre 36.7°C, and Tsk 38.0°C. Recovery was virtually complete in less than 1 hr.

Subject No. 3 (acclimated, 96 hr BR) had a resting pulse rate of 56 b·min⁻¹ and blood pressure of 110/80 mmHg. After entry his pulse rate was 96 b·min⁻¹, blood pressure 120/70 mmHg, Tre 36.4°C, and Tsk 40.5°C. At 55 min, 8 min after ingesting his first 200 mL of water, he became slightly nauseated. This nausea gradually increased and at 63 min he became presyncopal and was removed from the chamber when his pulse rate was 126 b·min⁻¹, Tre 37.4°C, and Tsk 36.5°C. He did not vomit. Recovery was complete in 1 hr. This subject was noted for high motivation in this and previous experiments.

Subject No. 6 (nonacclimated, 96 hr BR) had a resting pulse rate of 65 b·min⁻¹ and blood pressure of 120/70 mmHg. After entry into the chamber his pulse rate was 96 b·min⁻¹, blood pressure 134/90 mmHg, Tre 36.3°C, and Tsk 36.5°C. At 49 min he reported intermittent episodes of dizziness; his pulse rate had risen to 144 b·min⁻¹, blood pressure to 120/104 mmHg, Tre to 37.2°C, and Tsk to 38.0°C. At 78 min, 3 min after ingesting 50 mL water, he began to vomit. Because this was attributed to the water and he felt comfortable, he was allowed to remain in the chamber. However, his pulse rate continued to rise. At 150 min he developed substernal discomfort which prompted immediate removal from the chamber when his pulse rate was 168 b·min⁻¹, blood pressure 120/96 mmHg, Tre 39.5°C, and Tsk 38.0°C. His chest discomfort was immediately relieved by belching. Had this chest discomfort not occurred, he would have been removed from the chamber due to his elevated rectal temperature.

Although heat acclimation appeared to increase tolerance and attenuate adverse physiological responses during heat exposure, tolerance was reduced in the deconditioned subjects irrespective of their heat acclimation status. Thus, the adverse physiological effects of acute bed-rest deconditioning appear to take precedence over the positive effects of acute heat acclimation for determining tolerance when young men are raised to the sitting (orthostatic) position in a hot environment.

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Table 1. Cardiovascular, body temperature, and tolerance data for the acclimated and nonacclimated groups.

Subj.	Condition	Outside chamber		Inside chamber										Comments	
		Reclining pulse rate, b/min	Reclining blood pressure, sys./dias. mmHg	Initial sitting pulse rate, b/min	Initial sitting blood press., sys./dias. mmHg	Initial sitting temperature		Terminal pulse rate, b/min	Terminal blood pressure, sys./dias. mmHg	Terminal temperature		ΔT_{re} , °C	Tolerance, † min		$\Delta T_{re}/tol.$, °C/min
						Rectal, °C	Skin, °C			Rectal, °C	Skin, °C				
Heat acclimated															
1	Ambulatory control	-	-	62	108/80	36.7	35.4	112	140/90	37.8	37.0	1.1	480	0.002	Removed from the chamber in good condition. Chief complaint was discomfort in lower back due to forward inclination of the chair.
2	48 hr bed rest	64	136/74	99	116/90	36.9	36.4	119	130/80	38.0	36.2	1.1	90	0.012	Terminated due to severe cramps followed by diarrhea. Recovery was rapid.
3	96 hr bed rest	56	110/80	96	120/70	36.4	40.5	126	135/85	37.4	36.5	1.0	60	0.017	Terminated due to syncope. Became nauseated after drinking 200 cc of water.
	\bar{X}	60	123/77	86	115*/80	36.7	37.4	119	135/85	37.7	36.6*	1.1	210	0.010	
	$\pm SE$	4	13/3	12	4/6	0.2	1.6	4	3/3	0.2	0.2	0.0	135	0.004	

Table 1. Concluded.

Subj.	Condition	Outside chamber		Inside chamber										Comments	
		Reclining pulse rate, b/min	Reclining blood pressure, sys./dias. mmHg	Initial sitting pulse rate, b/min	Initial sitting blood press., sys./dias. mmHg	Initial sitting temperature		Terminal pulse rate, b/min	Terminal blood pressure, sys./dias. mmHg	Terminal temperature		ΔT_{re} , °C	Tolerance, † min		$\Delta T_{re}/tol.$, °C/min
						Rectal, °C	Skin, °C			Rectal, °C	Skin, °C				
4	Nonheat acclimated Ambulatory control	-	-	82	140/92	37.0	38.5	146	138/74	39.8	39.0	2.8	180	0.016	Terminated due to high rectal temperature. Flushed and weak when removed from chamber.
5	48 hr bed rest	54	106/68	108	128/60	36.5	35.8	122	116/90	36.7	38.0	0.2	22	0.009	Terminated in 22 min due to vomiting after drinking 200 cc of water.
6	96 hr bed rest	65	120/70	96	134/90	36.3	36.5	168	120/96	39.5	38.0	3.2	150	0.021	Terminated due to substernal discomfort. Previously vomited after drinking 50 cc of water.
	\bar{X}	60	113/69	95	134/81	36.6	36.9	145	125/87	38.7	38.3	2.1	117	0.015	
	$\pm SE$	6	7/1	8	3/10	0.2	0.8	13	7/7	1.0	0.3	0.9	48	0.003	

*P < 0.05 from corresponding nonheat acclimated mean data.

† When experiments were terminated, efforts were directed toward removing the subject from the chamber; thus, blood pressure and pulse rate could not be taken manually. In most cases, they were taken some minutes earlier and therefore the above data may not reflect his condition at the time of termination. All cases of presyncope occurred with very little warning.

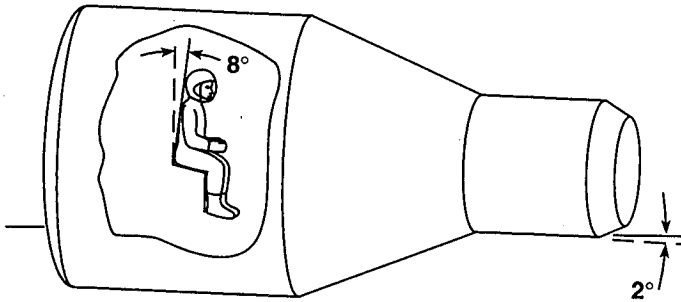


Figure 1. Gemini spacecraft postlanding flotation position.

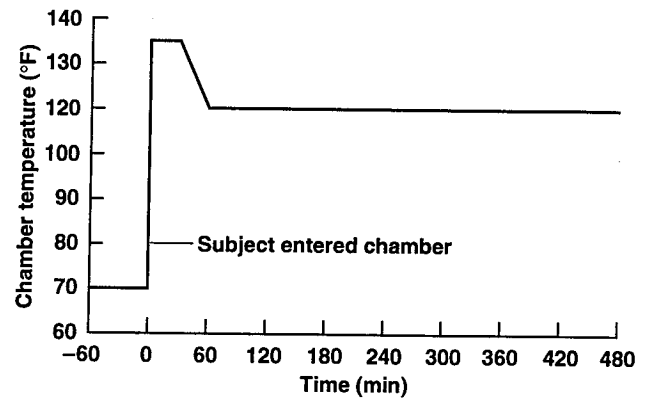


Figure 2. Ambient temperature profile inside chamber for the 8 hr test.

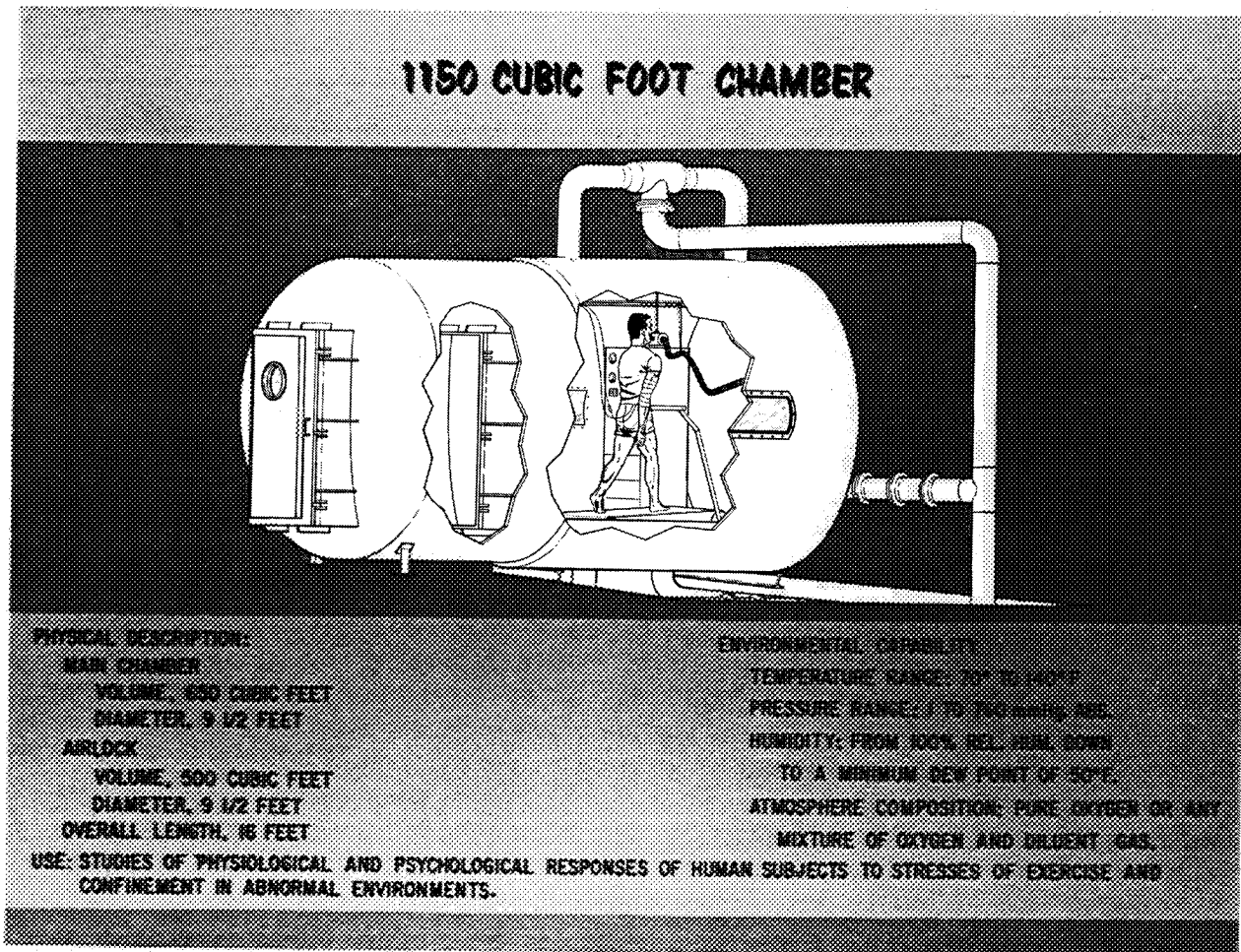


Figure 3. Specifications for the Ames 1150 cubic-foot environmental chamber.

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