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16. Abstract

Eleven male surrogates of general aviation pilots, 25-40 years old, were tested for altitude, +Gz, and fatigue tolerances with and without previous fasting for 24 h. Testing included 2 min of lower body negative pressure (LBNP) at -40 torr (equivalent to +2Gz) after 118 min at 3,810 m chamber altitude and, after returning to ground level pressure, ergometry of 50 watts (W) for 6 min. The fast had no statistically significant effect on altitude and fatigue tolerances. One subject, who tolerated 2 min of LBNP in the nonfasting condition, lost useful consciousness during this test in the fasting condition. Although the remaining 10 subjects tolerated 2 min of LBNP in both fasting and nonfasting conditions without statistically significant differences in quantitated parameters, 2 of them during fasting manifested symptoms usually associated with impending syncope. Pilots should be informed that a 24-h fast may reduce the margin for safe tolerance of $\geq$ +2Gz flight maneuvers.

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CARDIORESPIRATORY ASSESSMENT OF 24-HOUR CRASH-DIET EFFECTS ON ALTITUDE, +Gz, AND FATIGUE TOLERANCES

INTRODUCTION

Studies of acute starvation (up to 10 d) in healthy humans (4,5) have revealed that reductions in blood and plasma volumes occur during fasting despite the administration of supplementary water. The largest decrement in total body water occurs during the first day of fasting (4). Dehydration has been demonstrated to cause increased fatigability (23), and decreased tolerance to gravity (G) (20,22,29). Overnight fasting significantly decreased the tolerance of healthy men to a hypoxic altitude equivalent of 4,875 m mean sea level (MSL) (12). The tolerance of nonfasting healthy men to 1.5 min of lower body negative pressure (LBNP) equivalent to +2Gz was significantly reduced at the hypoxic altitude equivalent of 4,145 m MSL as compared to a sea level normoxic altitude equivalent (13). These findings (12,13) suggest the possibility of a decreased +Gz tolerance (+2Gz for 2 min) in healthy men under the combination of total food fasting and ambient air breathing at a 3,810 m MSL altitude.

The National Center for Health Statistics has reported that United States men, 18-75 years of age, were 1.4 kg heavier during a 1971-1974 survey than were men surveyed during 1960-1962 (1). An evaluation of the earlier survey revealed that about 70 percent of these men were overweight (11). The 1978 height and weight data for male general aviation pilots reflect a similar presence of overweight (8).

Dieting has become a fashionable means of reducing body weight. One popular version is the crash diet, which requires complete abstinence from all food intake for about 24 h. Because loss of body water is greatest during the first 24 h of such a diet (4), and because such loss of body water may possibly decrease altitude, +Gz, and fatigue tolerances (12,20,22,23, 29), this study was undertaken. The purpose of this investigation was to assess the effects of crash dieting on tolerance to fatigue under a submaximum physical workload, to LBNP (equivalent to +2Gz) and, to a moderate altitude (3,810 m). For this study, crash diet is defined as total abstinence for 24 h from the intake of food, but not water.

METHODS

Subjects. Paid, healthy male volunteers, 21-35 years old, who were 5-15 percent overweight were used. The weight-per-height norms of the Framingham Study (6) were used as the basis for calculating the 5-15 percent range of overweight. In order to qualify medically as a surrogate, each subject had to pass a physical examination, which was equivalent to third-class medical certification of a general aviation pilot. Those medically qualified signed a standard consent form after a thorough briefing. Each subject was then given a complete equipment and protocol orientation. This included a 0.5-h exposure in our hypobaric chamber to the pressure equivalent of a 3,810 m altitude MSL, during which the subject took a timed simple math test, and then underwent 2 min of LBNP equivalent to +2Gz (-40 torr relative to chamber pressure). After the chamber was returned to the pressure equivalent of ground level (GL) altitude (388 m), the subject underwent 4 min of pedal ergometry at the moderate load of 50 watts (W). During this protocol orientation, the subject was disqualified from subsequent participation if his arterial oxygen saturation (HbO_2) did not remain above 80 percent during the hypobaric exposure, useful consciousness was not maintained during the 2 min of LBNP at altitude and, his heart rate (HR) exceeded 150 beats per min (bpm) during the pedal ergometry. Additionally, disqualification resulted if the subject's single-lead electrocardiogram (ECG) manifested evidence of ischemia and/or arrhythmia at any time during the orientation. Age, height, and weight of the 11 subjects are shown in Table I.

Protocol and Parameters. Each subject participated in one experiment per week for 2 consecutive weeks. The experimental protocol is outlined in Table II. Each subject reported at 0745 after fasting overnight. He voided his urine, and donned a surgical scrub suit. His body weight, corrected for clothing weight, was measured. A venous blood sample was drawn and heparinized; blood glucose (25), hematocrit, and hemoglobin (19) were measured. The hematocrit and hemoglobin data, along with corresponding data from the blood sample drawn 24 h later, were used in calculating the percent change in blood and plasma volumes (7).

At 0800 the subject ate a standard breakfast. In the fasting experiment, the subject ate nothing further until 1300 on the next day. Only water and no-calorie soft drinks were permitted during the fasting period. Adherence to fasting was monitored at all times. In the control (nonfasting) experiment, the subject was fed a lunch at 1300, a dinner at 1800, a breakfast at 0800 on the next day, and was allowed to consume snack foods and drinks at any time. Drinks containing caffeine were withheld from all experimental sessions. During the first day of each experiment, the subject remained in an upright body position, and refrained from sleeping.

The subject went to bed at 2300 on the first day and arose at 0700 the next day. At 0745 he voided his urine, was weighed, and had a blood sample drawn. In the nonfasting experiment, breakfast was eaten at 0800. At 0830 the subject entered the hypobaric chamber and was instrumented for subsequent testing. The subject was seated upright in the LBNP box and sealed in it from the waist down. The LBNP box and its built-in pedal ergometer have been described elsewhere (15). Physiological measurements were recorded for 10 min at GL, after which the chamber pressure was reduced over a 10 min period to an altitude equivalent of 3,810 m. At altitude, four separate math tests were alternated with 10-min periods of resting physiological measurements as indicated in Table II. After 1 h and 48 min at altitude, 10 min of resting measurements were made, after which the subject was exposed to -40 torr LBNP for 2 min. The chamber pressure was then returned to GL pressure in 10 min. A 10-min period of resting measurements preceded pedal ergometry of 30 W for 2 min, and 50 W for 6 min. After ergometry testing, all sensors were removed. The subject voided his urine, was weighed and allowed to don his street clothes. He returned 6 d later at the same time (0745) for the second experiment session. To compensate for any effects of experimental order, half of the subjects were fasted in the first experiment session and the remaining

TABLE I. Vital Statistics

	Age (yr)	Height (cm)	Weight (kg)	No.
$\overline{X}$	27.1	177.7	89.6	10
SE	2.1	1.9	2.3	
†	32.0	186.7	97.2	1

$\overline{X}$ = Mean SE = Standard error of the mean

† = The one subject who was qualitatively incapacitated during LBNP testing at altitude after a total food fast of 24 h

TABLE II. Schedule of Experimental Protocol

Day 1		Day 2	
Time	Activity	Time	Activity
0745	Report in fasted overnight	0700	Arise
	Urine void		Ablutions
	Body weight		Dress
	Blood sample	0745	Urine void
0800	Breakfast		Body weight
1300	Lunch or Fast		Blood sample
1800	Dinner or Fast	0800	Breakfast or Fast
2300	Bedtime	0830	Sensor placements
		0930	LBNP seal check
		0940-0950	GL resting measurements
		0950-1000	Altitude ascent
		1000-1009	Ear oximetry
		1010-1025	1st math test
		1030-1045	2nd math test
		1050-1100	Resting measurements
		1105-1120	3rd math test
		1125-1140	4th math test
		1148-1200	LBNP procedure
		1200-1210	Altitude descent
		1215-1234	Ergometry procedure
		1235-1240	Sensor removal
		1240	Urine void
			Body weight
		1245	Release

half in the second experiment session. The data were pooled and statistically compared (26) on the basis of fasting versus nonfasting conditions. Statistical significance was based on a probability value of $p \leq 0.05$ (26).

Specific measurements made at altitude consisted of: (i) HR using a single-lead ECG; (ii) blood pressure (BP) using automatic auscultative sphygmomanometry; (iii) HbO_2 using an ear oximeter (24); (iv) pulmonary ventilation ($\dot{V}_E$), respiratory frequency (f), and tidal volume (V_T) using pneumotachometry of expired air; and (v) temporal artery blood flow velocity (TAFV) using a directional Doppler device (14). Oxygen uptake ($\dot{V}O_2$) was also measured during pedal ergometry by analysis of quantitatively collected expired air. Gas volume data were normalized for differences in body size and expressed as volume per kg of body weight. The CM_5 single lead (3) was used to monitor ECG function. The electrical signal from this ECG lead was fed simultaneously to: (i) an oscilloscope for visual monitoring of the ECG for ischemia and/or arrhythmia; (ii) a cardiotachometer for continuous indication of HR; and, (iii) a standard ECG recorder for periodic recording. Also monitored were the digital readout of the HbO_2 for any indication of hypoxemia, and the pulsatile signal of the TAFV for any flow-reversal indication of approaching syncope (14). At altitude, criteria for immediate termination of any experiment consisted of strong subjective symptoms of impending syncope (lightheadedness, nausea, and visual grayout, tunneling or blackout) accompanied by sustained hypotension and bradycardia, electrocardiographic evidence of ischemia and/or arrhythmia, TAFV reversal for at least 5 s and falling values of HbO_2 below 80 percent.

Because each subject used a valve mouthpiece during two ventilation measurements at altitude, three simple hand signals were taught to each one to communicate that "everything is OK," "subjective distress is present," or "stop the test." The same researcher remained in the hypobaric chamber with the subject during each experiment. Besides continuous direct observation of the subject, he was often asked if everything was OK. Each subject was given the unconditional option of stopping the experiment at any time. A staff physician, a positive-pressure mask source of 100 percent oxygen, and other emergency resuscitation equipment were always available on a standby basis.

Mainly to counteract the boredom of quiet sitting, a simple math test was administered twice during each of the 2 h at altitude. The temperature and relative humidity ranges in the hypobaric chamber for all experiments were 21.0°-$23.0^{\circ}C$ and 20.0-26.0 percent, respectively.

Altitude tolerance was assessed mainly on the basis of maintaining adequate HbO_2 levels. Fatigue tolerance was assessed mainly on the basis of quantitative shifts in cardiovascular and respiratory functions during the 50 W pedal ergometry load. The +Gz tolerance was assessed mainly on the basis of maintaining useful consciousness during the LBNP test.

RESULTS

In both the fasting and nonfasting experiments, 10 of the 11 subjects: (i) maintained an adequate HbO_2 during altitude exposure; (ii) tolerated

2 min of LBNP at altitude without loss of useful consciousness; and, (iii) easily tolerated pedal ergometry.

One of the subjects experienced syncope near the end of the LBNP test after 24 h of fasting, but was adequately tolerant to the same test in the nonfasting condition of both the control experiment and the preexperimental orientation session. The data from the other 10 subjects were pooled and analyzed statistically (26).

These 10 subjects lost an average of 1.2 kg of body weight in 24 h of fasting and gained an average of 0.4 kg in the 24 h of nonfasting. The difference between these two average weight changes was statistically significant ($p = 0.001$). During the next 4 h of the experiment session, an additional average weight loss of 0.4 kg occurred in the fasted subjects and a corresponding average weight loss of only 0.2 kg in the same subjects in the nonfasting control experiment. The difference between these two additional weight losses was also statistically significant ($p = 0.018$).

The blood glucose, hemoglobin, hematocrit, blood volume, and plasma volume data are summarized in Table III. The decrease in blood glucose associated with the 24-h fast was about 5 percent, and was not statistically significant ($p > 0.05$) when compared to the nonfasting condition. The blood glucose was assessed in this study to rule out the unlikely but possible occurrence of frank levels of hypoglycemia (18).

Although not statistically analyzed, the simple math testing at altitude revealed that fasting had no apparent adverse effect on this type of function.

DISCUSSION

In the nonfasting control condition, statistically significant physiological displacements (Tables IV-X) were caused by the altitude, ergometry and LBNP tests, per se. Although statistically significant physiological displacements occurred, these tests were adequately tolerated without loss of useful consciousness. As stated previously, intolerance to any of these three tests during the orientation session disqualified the subject from further participation.

Altitude Tolerance. The 2 h of altitude exposure was adequately tolerated in the fasting condition as reflected by the sustained presence of useful consciousness (math test capability), and by the absence of statistically significant differences between the fasting and corresponding nonfasting mean values for all measured parameters (Tables IV-VIII). The fasting mean values for HbO_2 at the end of the first and second h at altitude were 85.1 and 86.5 percent, and were essentially equivalent to those of the nonfasting condition. An HbO_2 value of 85 percent is regarded as being fully compensatory for the hypoxia of a 3,810 m altitude (17). The absence of any adverse effect on the performance of simple math is consistent with the HbO_2 data.

Fatigue Tolerance. The 6 min of 50 W pedal ergometry was adequately tolerated under the fasting condition as reflected by the ease of accomplishment and by the absence of statistically significant differences between the fasting

TABLE III. Blood Chemistry

		Glucose			Hemoglobin			Hematocrit		
		D_1 (gm/dl)	D_2 (gm/dl)	$\frac{D_2}{D_1} \times 100$	D_1 (gm/dl)	D_2 (gm/dl)	$\frac{D_2}{D_1} \times 100$	D_1 (%)	D_2 (%)	$\frac{D_2}{D_1} \times 100$
Fast	$\overline{X}$	86.8	82.3	95.1	13.9	14.6	104.7 *	40.4	42.3	104.8 *
	SE	1.8	0.8	1.9	0.2	0.3	0.7	0.6	0.6	1.0
Nonfast	$\overline{X}$	88.9	88.5	99.9	14.4	14.3	99.6	40.9	41.0	100.3
	SE	1.9	1.7	2.7	0.2	0.2	0.7	0.6	0.7	0.3

		% Δ Blood Volume $D_2/D_1 \times 100$	% Δ Plasma Volume $D_2/D_1 \times 100$
Fast	$\overline{X}$	95.6 *	92.5 *
	SE	0.6	1.1
Nonfast	$\overline{X}$	100.4	100.2
	SE	0.7	0.7

$\overline{X}$ = Mean SE = Standard error of the mean

D_1 = Day 1 D_2 = Day 2 Δ = Change

Alt. = Hypobaric chamber altitude of 3,810 m MSL

* = Statistically significant difference with a probability value of $p \leq 0.05$

TABLE IV. SBP and DBP

		SBP (mm Hg) GL	Alt. 2	Alt. 3	+2Gz	% Δ SBP: Alt. 2 / GL X 100	Alt. 3 / GL X 100	+2Gz / Alt. 3 X 100
Fast	$\overline{X}$	119.0	115.6	115.6	100.8	97.2	97.2	87.2
	SE	2.6	2.8	3.3	3.7	1.2	2.0	2.2
Nonfast	$\overline{X}$	123.8	124.1	121.3	110.3	100.2	97.9	91.0
	SE	0.9	1.2	1.4	1.9	1.0	1.4	2.1

		DBP (mm Hg) GL	Alt. 2	Alt. 3	+2Gz	% Δ DBP: Alt. 2 / GL X 100	Alt. 3 / GL X 100	+2Gz / Alt. 3 X 100
Fast	$\overline{X}$	69.4	69.5	66.1	62.8	100.8	95.7	94.4
	SE	3.0	2.6	3.0	4.1	3.1	3.3	2.5
Nonfast	$\overline{X}$	66.7	67.8	68.2	65.1	101.8	102.3	95.8
	SE	0.7	0.5	3.4	3.6	1.5	3.3	4.0

$\overline{X}$ = Mean SE = Standard error of the mean Δ = Change
SBP = Systolic blood pressure DBP = Diastolic blood pressure
GL = Ground level altitude (390 m MSL)
Alt. = Hypobaric chamber altitude of 3,810 m MSL
Alt. 2 = Ten-min resting period at 50-60 min of the first hour at altitude
Alt. 3 = Ten-min resting period at 48-58 min of the second hour at altitude immediately preceding the simulated +2Gz test
+2Gz = Two-min period of -40 mm Hg LBNP at 58-60 min of the second hour at altitude

TABLE V. PP and AP

		PP (mm Hg) GL	PP (mm Hg) Alt. 2	PP (mm Hg) Alt. 3	PP (mm Hg) +2Gz	% Δ PP: Alt. 2 / GL X 100	% Δ PP: Alt. 3 / GL X 100	% Δ PP: +2Gz / Alt. 3 X 100
Fast	$\overline{X}$	49.6	46.1	49.5	38.0	92.7	100.8	77.3
	SE	3.2	3.4	3.9	3.0	3.2	6.1	3.5
Nonfast	$\overline{X}$	57.1	56.2	53.2	45.2	98.5	93.1	85.0
	SE	2.0	2.9	3.6	3.8	3.4	5.4	3.8

		AP (mm Hg) GL	AP (mm Hg) Alt. 2	AP (mm Hg) Alt. 3	AP (mm Hg) +2Gz	% Δ AP: Alt. 2 / GL X 100	% Δ AP: Alt. 3 / GL X 100	% Δ AP: +2Gz / Alt. 3 X 100
Fast	$\overline{X}$	85.9	84.8	82.6	75.5	99.0	96.3	91.0
	SE	2.4	2.2	2.5	3.7	1.9	2.0	2.2
Nonfast	$\overline{X}$	85.7	86.6	85.9	80.2	101.0	100.2	93.5
	SE	1.7	1.9	2.6	2.9	0.7	1.7	2.9

$\overline{X}$ = Mean SE = Standard error of the mean Δ = Change
PP = Pulse pressure AP = Mean arterial pressure, calculated as the value of DBP + 1/3 PP
GL = Ground level altitude (390 m MSL)
Alt. = Hypobaric chamber altitude of 3,810 m MSL
Alt. 2 = Ten-min resting period at 50-60 min of the first hour at altitude
Alt. 3 = Ten-min resting period at 48-58 min of the second hour at altitude immediately preceding the simulated +2Gz test
+2Gz = Two-min period of -40 mm Hg LBNP at 58-60 min of the second hour at altitude

TABLE VI. TAFV and HR

		TAFV (cm/s)				% Δ TAFV		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{\text{Alt. 2}}{\text{GL}}$ X 100	$\frac{\text{Alt. 3}}{\text{GL}}$ X 100	$\frac{\text{+2Gz}}{\text{Alt. 3}}$ X 100
Fast	$\overline{X}$	4.7	4.0	4.7	3.4	86.8	101.2	74.5
	SE	0.6	0.5	0.5	0.4	8.1	8.7	4.0
Nonfast	$\overline{X}$	4.5	4.1	4.6	3.7	92.9	103.1	79.2
	SE	0.4	0.6	0.5	0.4	8.7	5.9	2.3

		HR (bpm)				% Δ HR		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{\text{Alt. 2}}{\text{GL}}$ X 100	$\frac{\text{Alt. 3}}{\text{GL}}$ X 100	$\frac{\text{+2Gz}}{\text{Alt. 3}}$ X 100
Fast	$\overline{X}$	73.3	78.2	82.4	94.5	107.1	112.9	114.0
	SE	3.6	4.3	4.0	4.7	3.5	3.8	4.0
Nonfast	$\overline{X}$	76.4	80.8	81.0	89.7	106.4	107.1	111.5
	SE	4.6	4.1	4.0	3.6	2.6	3.8	3.1

$\overline{X}$ = Mean SE = Standard error of the mean Δ = Change
TAFV = Temporal artery blood flow velocity
HR (bpm) = Heart rate in beats per min
GL = Ground level altitude (390 m MSL)
Alt. = Hypobaric chamber altitude of 3,810 m MSL
Alt. 2 = Ten-min resting period at 50-60 min of the first hour at altitude
Alt. 3 = Ten-min resting period at 48-58 min of the second hour at altitude immediately preceding the simulated +2Gz test
+2Gz = Two-min period of -40 mm Hg LBNP at 58-60 min of the second hour at altitude

TABLE VII. $\dot{V}_E$/kg, f, and V_T/kg

		$\dot{V}_E$/kg (l/min/kg)				% Δ $\dot{V}_E$/kg		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{Alt.\ 2}{GL} \times 100$	$\frac{Alt.\ 3}{GL} \times 100$	$\frac{+2Gz}{Alt.\ 3} \times 100$
Fast	$\overline{X}$	74.2	91.9	91.5	105.2	125.1	124.5	116.1
	SE	3.1	4.5	5.0	6.0	7.0	7.2	6.8
Nonfast	$\overline{X}$	76.8	92.4	95.4	98.3	120.7	125.0	102.9
	SE	3.0	4.4	3.7	5.0	4.4	4.8	3.6

		f (rpm)				% Δ f		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{Alt.\ 2}{GL} \times 100$	$\frac{Alt.\ 3}{GL} \times 100$	$\frac{+2Gz}{Alt.\ 3} \times 100$
Fast	$\overline{X}$	13.1	14.5	13.6	14.9	111.2	104.4	111.8
	SE	0.7	1.2	1.0	1.2	10.0	6.0	8.0
Nonfast	$\overline{X}$	13.0	13.8	13.7	13.8	108.9	108.8	102.5
	SE	0.8	1.0	1.0	1.2	10.4	11.8	7.9

		V_T/kg (ml/kg)				% Δ V_T/kg		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{Alt.\ 2}{GL} \times 100$	$\frac{Alt.\ 3}{GL} \times 100$	$\frac{+2Gz}{Alt.\ 3} \times 100$
Fast	$\overline{X}$	5.8	7.0	7.0	7.4	122.2	123.0	107.5
	SE	0.3	1.0	0.5	0.7	15.7	10.1	7.4
Nonfast	$\overline{X}$	6.1	6.8	7.1	7.5	115.9	121.6	105.8
	SE	0.4	0.3	0.4	0.5	6.6	9.1	7.0

$\overline{X}$ = Mean   SE = Standard error of the mean   Δ = Change
Alt. = Hypobaric chamber altitude of 3,810 m MSL   GL = Ground level altitude (390 m MSL)
$\dot{V}_E$/kg = Pulmonary ventilation per kilogram of body weight
V_T/kg = Tidal volume per kilogram of body weight
Alt. 2 = Ten-min resting period at 50-60 min of the first hour at altitude
Alt. 3 = Ten-min resting period at 48-58 min of the second hour at altitude immediately preceding the simulated +2Gz test
f (rpm) = Respiratory frequency in respirations per min
+2Gz = Two-min period of -40 mm Hg LBNP at 58-60 min of the second hour at altitude

TABLE VIII. HbO_2

		HbO_2 (% sat.)				% Δ HbO_2		
		GL	Alt. 2	Alt. 3	+2Gz	$\frac{\text{Alt. 2}}{\text{GL}}$ X 100	$\frac{\text{Alt. 3}}{\text{GL}}$ X 100	$\frac{\text{+2Gz}}{\text{Alt. 3}}$ X 100
Fast	$\bar{X}$	95.4	85.1	86.5	88.7	89.3	90.7	102.6
	SE	0.3	1.2	1.2	0.9	1.3	1.2	1.1
Nonfast	$\bar{X}$	94.6	85.0	85.3	87.5	89.9	90.2	102.6
	SE	0.6	0.8	0.8	0.9	0.6	0.6	0.6

$\bar{X}$ = Mean SE = Standard error of the mean Δ = Change
HbO_2 = Arterial oxyhemoglobin saturation
GL = Ground level altitude (390 m MSL)
Alt. = Hypobaric chamber altitude of 3,810 m MSL
Alt. 2 = Ten-min resting period at 50-60 min of the first hour at altitude
Alt. 3 = Ten-min resting period at 48-58 min of the second hour at altitude immediately preceding the simulated +2Gz test
+2Gz = Two-min period of -40 mm Hg LBNP at 58-60 min of the second hour at altitude

and corresponding nonfasting values for all measured parameters (Tables IX and X). The moderately low workload used approximated estimates of the average maximum workload encountered in general aviation flying (2).

Tolerance to LBNP (+2Gz). The effects of various magnitudes and durations of LBNP on human physiological functions have been reviewed comprehensively (29). When healthy young men are subjected to an LBNP of -40 torr, about 0.5-0.6 L of blood are shifted from the central blood volume by the pooling of blood in the lower half of the body. The acute loss of central blood volume gives rise to a complex barrage of reflexes that attempt to compensate for this loss and ensure an adequate continued perfusion of the brain (29). Vasoconstriction and increased HR are the two major reflections of this reflex defense against loss of consciousness (29). Symptomatically, the temporary adequacy of defense mechanisms is reflected by the behavior of initial symptoms, which either disappear or stabilize at very low levels of intensity. In extended durations of LBNP at -40 torr or greater, the reflex defenses eventually collapse, and syncope rapidly ensues (29). The main reason for eventual collapse is that, in addition to the pooling caused by LBNP, there also occurs a substantial time-dependent extravasation of plasma from the intravascular compartment (16). The syncopal response has been arbitrarily divided into two phases (20). Phase I (presyncope) is characterized by physiologic instability in which marked phasic variations occur in arterial blood pressure, while the mean pressure is slowly falling and HR continues to rise. Phase II (syncope) is characterized by a precipitous fall in both arterial pressure and HR leading rapidly to syncope (29). Phase I is characterized by the appearance and intensification of symptoms such as lightheadedness, dizziness, visual blurring, and pallor. Phase II is best characterized by the additional appearance and very rapid intensification of nausea and visual grayout, tunneling, and blackout (29). When healthy, nonfasted normally hydrated men are subjected to an LBNP of -40 torr at GL, the average time to the first appearance of presyncopal symptoms is 10-30 min (9,21,30).

One of our 11 subjects adequately tolerated the LBNP equivalent of +2Gz for 2 min at altitude in the nonfasting condition of both the control experiment and the preexperimental orientation session, but was incapacitated during the same LBNP test at altitude after the 24-h fast. In order of appearance and increasing intensity, the subject's symptoms were lightheadedness, visual graying, and visual tunneling. Because of his motivation to successfully complete the test, the subject withheld the hand signal for subjective distress until very nearly the end of the second min of LBNP. When the LBNP was terminated, the subject's face was pale and sweaty. Supplemental oxygen was administered immediately, and he recovered facial color and lucidity within 30 s. At the time of signaled distress, the recorded data revealed that: (i) the HR had peaked at 108 bpm, and was starting to fall precipitously; (ii) the BP had decreased markedly with a barely visible systolic signal at 52 torr; and, (iii) the pulsatile TAFV signal was barely discernible, and very close to zero. The HR, TAFV, and BP recovered in parallel with subjective recovery. The subject realized that he had "blacked out." From these data it is clear that, had the subject been piloting an airplane during an equivalent +Gz maneuver, he would not have been in control of the airplane during this incapacitation.

TABLE IX. Postaltitude Ergometry (10 Minute Resting Control)

		SBP (mm Hg)	DBP (mm Hg)	PP (mm Hg)	AP (mm Hg)	HR (bpm)
Fast	$\overline{X}$	115.7	69.4	46.2	84.8	75.8
	SE	2.8	3.1	3.9	2.3	3.9
Nonfast	$\overline{X}$	120.3	71.0	49.2	87.4	72.5
	SE	2.2	2.6	3.1	2.0	4.1

		$\dot{V}O_2$/kg (ml/min./kg)	TAFV (cm/s)	$\dot{V}_E$/kg (ml/min/kg)	f (rpm)	V_T/kg (ml/kg)
Fast	$\overline{X}$	2.8	5.4	74.8	13.2	5.8
	SE	0.1	0.4	2.9	0.8	0.3
Nonfast	$\overline{X}$	2.9	4.8	76.6	13.1	6.0
	SE	0.1	0.5	3.1	0.9	0.4

$\overline{X}$ = Mean SE = Standard error of the mean
SBP = Systolic blood pressure
DBP = Diastolic blood pressure
PP = Pulse pressure
AP = Mean arterial pressure, calculated as the value of DPB + 1/3 PP
HR (bpm) = Heart rate in beats per min
Alt. = Hypobaric chamber altitude of 3,810 m MSL
$\dot{V}O_2$/kg = Oxygen uptake per kilogram of body weight
TAFV = Temporal artery blood flow velocity
$\dot{V}_E$/kg = Pulmonary ventilation per kilogram of body weight
f (rpm) = Respiratory frequency in respirations per min
V_T/kg = Tidal volume per kilogram of body weight

TABLE X. Postaltitude Ergometry (50 W Load)

		SBP (mm Hg)	DBP (mm Hg)	PP (mm Hg)	AP (mm Hg)	HR (bpm)
Fast	$\overline{X}$	145.6	70.8	74.8	95.7	111.4
	SE	3.8	3.3	4.3	2.8	3.1
Nonfast	$\overline{X}$	152.7	72.3	80.4	99.1	110.0
	SE	3.4	2.6	3.9	2.2	3.1

		$\dot{V}O_2$/kg (ml/min/kg)	TAFV (cm/s)	$\dot{V}_E$/kg (ml/min/kg)	f (rpm)	V_T/kg (ml/kg)
Fast	$\overline{X}$	10.0	5.8	234.9	19.2	12.5
	SE	0.4	0.4	12.8	1.1	0.7
Nonfast	$\overline{X}$	9.5	5.5	236.1	19.9	12.2
	SE	0.5	0.5	13.8	1.2	0.9

$\overline{X}$ = Mean SE = Standard error of the mean
SBP = Systolic blood pressure
DBP = Diastolic blood pressure PP = Pulse pressure
AP = Mean arterial pressure, calculated as the value of DBP + 1/3 PP
HR (bpm) = Heart rate in beats per min
Alt. = Hypobaric chamber altitude of 3,810 m MSL
$\dot{V}O_2$/kg = Oxygen uptake per kilogram of body weight
TAFV = Temporal artery blood flow velocity
$\dot{V}_E$/kg = Pulmonary ventilation per kilogram of body weight
f (rpm) = Respiratory frequency in respirations per min
V_T/kg = Tidal volume per kilogram of body weight

In the remaining 10 subjects under the fasting condition, the 2 min of LBNP at altitude produced statistically significant displacements in systolic blood pressure (SPB), pulse pressure (PP), mean arterial pressure (AP), TAFV, HR, and $\dot{V}E$/kg which were greater in magnitude than the corresponding displacements in these 10 subjects under the nonfasting condition. Although the fasting displacements were greater and statistically significant, per se, the differences between them and the corresponding displacements under the nonfasting condition were not statistically significant.

Under the nonfasting condition, the same 10 subjects easily tolerated the 2 min of LBNP at altitude with either no symptoms, or with few symptoms which were mild, transient, or nonintensifying. Under the fasting condition, 8 of the 10 subjects postexperimentally reported an increase in the presence and/or intensity of symptoms during the LBNP. Two of these eight subjects felt that they were nearing syncope at the end of the 2 min of LBNP, because lightheadedness was present and increasing, nausea was commencing, and visual blurring and graying was present and progressing. Visual tunneling had commenced in one of these two subjects. Both of them fully recovered upon cessation of the LBNP.

Consistent with a comprehensive review of LBNP research findings (29), and with the subjective and objective data of this study, it appears reasonable to suggest that the threshold for syncopal intolerance to 2 min of -40 torr LBNP (+2Gz) possesses a distribution spectrum; and that in the fasting condition of this study, two subjects did not approach the threshold, six of them were approaching the threshold at individual rates, two were probably right at the threshold, and one exceeded the threshold. If the threshold of intolerance to this LBNP test was approximated during fasting by three of the subjects, whose adequate tolerance of the same test during orientation revealed their biased position in the more tolerant portion of the distribution spectrum of this function, then it follows that intolerance should probably occur more frequently in a random sample of general aviation pilots without this selection bias.

The decrements in both circulating blood and plasma volumes, which are caused by total fasting, constitute the primary physiological changes relevant to a potential decrease in +Gz tolerance. Several studies have reported decreased +Gz or LBNP tolerances as a consequence of reducing blood and plasma volumes by any of several means (10,20,22,28,29). In our study, the mean decrements in both blood and plasma volumes after the 24-h fast constituted statistically significant differences (Table III) from the corresponding changes which occurred in the nonfasting condition. In the one subject, who was incapacitated during LBNP after the 24-h fast, the blood and plasma volume decrements were of the same order of magnitude as the two subjects who felt that they were nearing syncope at the end of the LBNP test.

Intake of caffeine, which has a well-known diuretic action, was not allowed in both the fasting and nonfasting experiment sessions. Despite the fact that caffeine diuresis could possibly have caused a further decrease in the blood and plasma volumes, and hence possibly have made the fasted individuals more susceptible to syncope during the LBNP, we chose to omit it because of the interindividual and intraindividual variability in the ad libitum amount of its intake. As deduced from body weight data, the rate of water loss during the 4-h testing period after 24 h of fasting was approximately twice the corresponding rate under the nonfasting condition. Two of the 4 h of the testing period were spent at an altitude of 3,810 m. Caffeine intake immediately prior to or during flight at substantial altitudes after a 24-h fast could possibly synergize diuretic water losses disproportionately, and thereby decrease tolerance to applied +Gz. However, since this facet was not specifically tested in this study, the possibility of such an adverse effect must remain moot.

This study was confined to subjects who were substantially overweight, because overweight people are more apt to go on a crash diet than people of normal weight. In the context that young healthy men are normally able to withstand 10-30 min of -40 torr LBNP (+2Gz) before the first appearance of presyncopal symptoms (9,21,30), three of our subjects manifested a decreased tolerance to 2 min of -40 torr LBNP. **However, in the context of ordinary general aviation flying, a +2Gz maneuver (e.g., a 60° bank/turn) is not a common occurrence, and a 2-min sustained duration for such a maneuver would be even less probable.** A 2-min duration for our LBNP test was chosen as an arbitrary, but reasonable, test of the reserve capacity for +Gz tolerance. Our finding of some decreased tolerance to +2Gz in three of the subjects may have some relevance to general aviation pilots who engage in crop dusting or aerial acrobatics. The possible exposure to +2Gz is probably greater in these two types of flying. Because Luft and coworkers (16) have shown that, besides dehydration, blood and plasma volume decreases are also a function of LBNP duration, the multiple successive +Gz exposures of crop dusting and aerial acrobatics may have a cumulative decremental effect on +Gz tolerance. If either of these two activities are combined with relatively high environmental temperatures and/or fasting, the +Gz tolerance could decrease further. To our knowledge, the effect of the combination of fasting and heat exposure on the +Gz tolerance of pilots engaged in crop dusting or aerial acrobatics has not been studied. Our current findings indicate that pilots engaged in both of these types of flying would be prudent to avoid acute dehydrations of all types.

Luft and coworkers (16) have shown that even men of normal weight manifest decreased LBNP tolerance as a result of work-dehydration decrements in blood and plasma volumes. The two groups of healthy men of normal weight studied by these investigators (16) consisted of sedentary nonrunners and active long-distance runners. Although the LBNP tolerance of the five sedentary nonrunners was reduced after their plasma volumes had been decreased, they were still able to tolerate at least 2 min of -40 torr of LBNP. After a similar bout of work dehydration, two of the five runners tested were unable to tolerate 2½ min of -30 torr. Even in the normally hydrated state, the runners' average LBNP tolerance was 58 percent less than that of the nonrunners (16). One of the physiological adaptations to long-distance running is an increase in circulating blood volume. Unfortunately, because of a concomitant increase in circulatory pooling capacity, and a concomitant decrease in circulatory baroceptor sensitivity, the fully adapted normally hydrated runner is less tolerant than the normally hydrated nonrunner to applied +Gz (16,27). When such a runner incurs a plasma volume decrement, his +Gz tolerance decreases further, and to a disproportionately greater degree than that of the nonrunner (16,27). Neither the nonrunner nor the runner of normal weight is apt to manifest plasma volume decrements due to crash dieting, because neither one is apt to go on such a diet. Because jogging and long-distance running have become so popular, the number of such runners in the general aviation population may have also increased proportionately. Because the normally hydrated runner, who may also be a general aviation pilot, already possesses a decreased LBNP tolerance, acute decreases in plasma volume caused by any means may potentially decrease +Gz tolerance during flight. Regarding this potential vulnerability, two generating conditions, which may merit further research investigation are: (i) an uncompensated dehydration caused by a prolonged running session; and (ii) an overnight fast. Because the two main studies (16,27) revealing the disproportionate +Gz intolerance in runners were done at ground level altitudes, the +Gz tolerance may decrease further in the pilot/runner when tested at altitude. Such studies are currently under consideration.

SUMMARY

After 24 h of either fasting or nonfasting, 10 out of 11 subjects: (i) maintained an adequate HbO_2 during altitude exposure; (ii) tolerated 2 min of LBNP at altitude without loss of consciousness; and (iii) easily tolerated pedal ergometry. One subject was incapacitated (syncope) during the LBNP testing after fasting, but was fully tolerant to the same test in the nonfasting condition. Tolerance to infrequent less-than-+2Gz maneuvers encountered in ordinary general aviation flying would probably be unaffected by a 24-h fast. However, it appears reasonable to recommend that all general aviaton pilots (especially those engaged in crop dusting and aerial acrobatics) be informed through educational channels regarding the advisability of avoiding: (i) prolonged single flight maneuvers (e.g., a steep turn or a sharp pullup) in excess of +2Gz; or (ii) multiple frequent repetitions of maneuvers approximating +2Gz, immediately after a total food fast of 24 h or more.

REFERENCES

1. Abraham, S., C. L. Johnson, and M. F. Najjar: Weight by Height and Age for Adults 18-74 Years, VITAL AND HEALTH STATISTICS, Series 11, No. 208, 1979.

2. Balke, B., C. E. Melton, and C. Blake: Physiological Stress and Fatigue in Aerial Missions for the Control of Forest Fires, AEROSP. MED., 37:221-227, 1966.

3. Blackburn, H., H. L. Taylor, H. Okamoto, P. L. Mitchell, P. M. Rautaharju, and A. C. Kerkhof: Standardization of the Exercise Electrocardiogram: A Systematic Comparison of Chest Lead Configurations Employed for Monitoring During Exercise. In Physical Activity and the Heart, M. J. Karvonen and H. Barry (Eds.), Springfield, Illinois, A. H. Thomas, pp. 101-134, 1966.

4. Consolazio, C. F., L. O. Matoush, H. L. Johnson, R. A. Nelson, and H. J. Krzywicki: Metabolic Aspects of Acute Starvation in Normal Humans (10 Days), AM. JOUR. CLIN. NUTR., 20:672-683, 1967.

5. Consolazio, C. F., R. A. Nelson, H. L. Johnson, L. O. Matoush, H. J. Krzywicki, and G. J. Isaac: Metabolic Aspects of Acute Starvation in Normal Humans: Performance and Cardiovascular Evaluation, AM. JOUR. CLIN. NUTR., 20:684-693, 1967.

6. Dawber, T. R., F. E. Moore, and G. V. Mann: Coronary Heart Disease in the Framingham Study, J. PUB. HEALTH, 47:4, 1967.

7. Dill, D. B., and D. L. Costill: Calculation of Percentage Changes in Volumes of Blood, Plasma, and Red Cells in Dehydration, JOUR. APPL. PHYSIOL., 37:247-248, 1974.

8. Federal Aviation Administration: AEROMEDICAL CERTIFICATION STATISTICAL HANDBOOK, 1978.

9. Foux, A., R. Seliktar, and A. Valero: Effects of Lower Body Negative Pressure (LBNP) on the Distribution of Body Fluids, JOUR. APPL. PHYSIOL., 41:719-726, 1976.

10. Greenleaf, J. E., J. S. Bosco, and M. Matter, Jr.: Orthostatic Tolerance in Dehydrated, Heat-Acclimatized Men Following Exercise in the Heat, AEROSP. MED., 45:491-497, 1974.

11. Hannon, B. M., and T. J. Lohman: The Energy Cost of Overweight in the United States, AM. JOUR. PUB. HEALTH, 68:765-767, 1978.

12. Hartzell, W. G., and P. D. Newberry: Effect of Fasting on Tolerance to Moderate Hypoxia, AEROSP. MED., 43:821-826, 1972.

13. Heistad, D. D., and R. C. Wheeler: Effect of Acute Hypoxia on Vascular Responses in Man, JOUR. CLIN. INVEST., 49:1252-1265, 1970.

14. Krutz, R. W., Jr., S. A. Rositano, and R. E. Mancini: Comparison of Techniques for Measuring +Gz Tolerance in Man, JOUR. APPL. PHYSIOL., 38: 1143-1145, 1975.

15. Lategola, M. T., and C. C. Trent: Lower Body Negative Pressure Box for +Gz Simulation in the Upright Seated Position, AVIAT., SPACE, & ENVIRON. MED., 50:1182-1184, 1979.

16. Luft, U. C., L. G. Myhre, J. A. Loepky, and M. D. Venters: Specialized Physiological Studies in Support of Manned Space Flight, Annual Research Report, NASA, Contract: NAS 9-14472, Houston, Texas, 1976.

17. McFarland, R. A.: Human Factors in Air Transportation, McGraw-Hill, New York, p. 159, 1953.

18. Merimee, T. J., and J. E. Tyson: Stabilization of Plasma Glucose During Fasting, NEW ENG. JOUR. MED., 291:1275-1278, 1974.

19. Miale, J. B.: Laboratory Medicine - Hematology, Mosby Company, St. Louis, pp. 656-657, 1958.

20. Murray, R. H., J. Krog, L. D. Carlson, and J. A. Bowers: Cumulative Effects of Venesection and Lower Body Negative Pressure, AEROSP. MED., 38:243-247, 1967.

21. Musgrave, F. S., F. W. Zechman, and R. C. Mains: Comparison of the Effects of 70° Tilt and Several Levels of Lower Body Negative Pressure on Heart Rate and Blood Pressure in Man, AEROSP. MED., 42:1065-1069, 1971.

22. Myhre, L. G., U. C. Luft, and M. D. Venters: Responses of Athletes and Non-Athletes to Lower Body Negative Pressure and Acute Dehydration, MED. AND SCIENCE IN SPORTS, 8:53-54, 1976.

23. Saltin, B.: Aerobic and Anaerobic Work Capacity After Dehydration, JOUR. APPL. PHYSIOL., 19:1114-1118, 1964.

24. Saunders, N. A., A. C. P. Powles, and A. S. Rebuck: Ear Oximetry: Accuracy and Practicability in the Assessment of Arterial Oxygenation, AM. REV. RESP. DIS., 113:745-749, 1976.

25. Slein, M. W.: In H. V. Bermeyer: Methods of Enzymatic Analysis, Verlag Chemie, Weinheim, Germany (1965), and Academic Press, New York and London, p. 117.

26. Snedecor, G. W.: Statistical Methods, Iowa College Press, Ames, Iowa, 4th Ed., p. 54-88, 1956.

27. Stegemann, J.: Beziehungen Zwischen Trainingzustand und Orthostasetoleranz, CARDIOL., 61(Suppl. 1):255-256, 1976.

28. Stevens, P. M., and L. E. Lamb: Effects of Lower Body Negative Pressure on the Cardiovascular System, AM. JOUR. CARDIOL., 16:506-515, 1965.

29. Wolthuis, R. A., S. A. Bergman, and A. E. Nicogossian: Physiological Effects of Locally Applied Reduced Pressure in Man, PHYSIOL. REVS., 54:566, 595, 1974.

30. Wolthuis, R. A., G. W. Hoffler, and R. L. Johnson: Lower Body Negative Pressure as an Assay Technique for Orthostatic Tolerance: 1. The Individual Response to a Constant Level (-40 mm Hg) of LBNP, AEROSP. MED., 41:29-35, 1970.