Effects of Simulated Weightlessness on Responses of Untrained Men to $+G_z$ Acceleration

by

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Running Head: $+G_z$ Acceleration After Simulated Weightlessness

Abstract

Space shuttle vehicle travel will expose crew and untrained lay personnel to headward acting ($+G_z$) acceleration stresses which may be as high as 4 G following periods of weightlessness. Previous studies, using bedrest as an analog of weightlessness, demonstrated the orthostatic intolerance and even syncope which occurs on re-exposure to a $+1\ G_z$ environment (70° passive tilt) following periods of simulated weightlessness, suggesting that post-bedrest exposure to still higher $+G_z$ acceleration stresses would exaggerate the undesirable responses. This study documents bedrest induced metabolic and physiologic changes in six untrained men exposed, following a two week period of simulated weightlessness, to possible $+G_z$ acceleration profiles anticipated for space shuttle vehicle travel. All subjects demonstrated decreased $+G_z$ tolerance following simulated weightlessness. While only one of six subjects could not tolerate the $+G_z$ profile in the control phase of the study, three of the six could not complete the post-bedrest study. The use of an inflated standard Air Force cutaway G-suit improved $+G_z$ tolerance in all subjects, but two of six subjects still failed to complete the profile. These findings are discussed in reference to the selection of untrained humans for space shuttle vehicle travel.

Indexing Words: Space Shuttle Vehicle
Lower Body Negative Pressure
70° Passive Tilt
Derived Maximal Oxygen Uptake
G-suit

It is anticipated that travel in the Space Shuttle vehicle will expose crew and lay personnel to headward ($+G_z$) acceleration stresses following periods of weightlessness of various durations. Depending on the choice of re-entry trajectory, the stresses may be as high as 4 G. Previous studies in this laboratory,[2,3] utilizing bedrest as an analog of weightlessness, have documented the orthostatic hypotension and even syncope which may occur on re-exposure to a + 1 G_z environment (70° passive tilt) following periods of simulated weightlessness, suggesting that post-bedrest exposure to even higher acceleration stresses would exaggerate the undesirable results. The present study was undertaken to quantitate the physiologic responses which would occur in untrained humans exposed to possible $+G_z$ profiles anticipated for space shuttle vehicle travel following two weeks of simulated weightlessness. Since a leading hypothesis attributes the post-bedrest decrease in orthostatic tolerance to pooling of blood and extracellular fluid in the extremities and pelvis in the presence of already diminished plasma and extracellular fluid volumes,[2,3] the modifying effect of an inflated standard Air Force cutaway G-suit on responses to $+G_z$ was also evaluated.

MATERIALS AND METHODS

Six healthy male volunteers, ages 24-27 years, served as subjects for this study. They were recruited from the Federal Correctional Institution, Lompoc, California, by permission of the U.S. Bureau of Prisons. Normality was established from a complete medical history and physical examination, by responses to a 20 minute 70° head-up passive tilt, and by standard laboratory studies of cardiac, renal, hepatic, and hematopoietic function. Informed consent was obtained after the details of the study were explained to each subject verbally and in writing.

Each volunteer was prescribed a specific diet throughout the study. The sodium, potassium, and caloric values of each diet were calculated in Subjects 1,2,3 and 4 from food content tables, and in Subjects 5 and 6 from chemical analyses of the strict metabolic diets consumed by them.

The study consisted of five phases which followed a 9-day diet equilibration period; a 14-day ambulatory control period (A 1-14); a 15-day bedrest period (B 1-15); a 14-day recovery period (R 1-14); a second 15-day bedrest period (B' 1-15); and a second 14-day recovery period (R' 1-14). During bedrest periods strict adherence to the horizontal position at all times was assured, and during the upright periods no exercise except walking was permitted.

Daily vital signs, body weight, and determination of oral intake and urine output were recorded. Twenty-four hour urine collections were made daily, and the urine analyzed for sodium and creatinine by standard laboratory methods. On Days A3, A9, B2, B14, R9, B'2, B'14, and R'12 plasma volume was determined by ^{125}I-RISA, extracellular fluid volume by ^{82}Br, red cell mass by ^{51}Cr, and total body water by $^{3}H_2O$.[13] Orthostatic tolerance in each phase of the study was determined by electrocardiographically measured heart rate and manually measured cuff blood pressure responses to 70° head-up passive tilt for 20 minutes in Subjects 1 and 2; and to application of lower body negative pressure (LBNP)[14,16] at -30mmHg, -40mmHg, and -50mmHg for successive five minute periods in Subjects 3,4,5 and 6. The relationship of these two orthostatic stress tests has previously been documented.[7] Following the orthostatic tolerance tests, cardiovascular system function was evaluated by calculation of maximal oxygen uptake derived at a heart rate of 180 by calculating the linear regression of simultaneous heart rate on oxygen consumption measured during supine bicycle ergometry at four different work levels.[18]

$+G_z$ stresses were achieved using a human centrifuge with a 25 foot radius located at the Ames Research Center, Moffett Field, California, a distance of about 35 miles from the USPHS Hospital in San Francisco. All subjects were transported from San Francisco to Moffett Field in the supine position during bedrest periods. All subjects performed three centrifuge training runs during the 9-day diet equilibration period, and data runs on Days A14, R1, R14, and R'1. The specific acceleration profile used was +2.1 G_z for 670 seconds, +3.2 G_z for 220 seconds, and +3.8 G_z for 185 seconds, with 10 minute rest and equilibration periods between different $+G_z$ levels. The upramp of each acceleration profile was 1.8 G/min. Seat back angles were adjusted immediately prior to each run to 30°, 19.5°, and 16.6° head above the horizontal plane for the +2.1 G_z, +3.2 G_z, and +3.8 G_z runs, respectively, in order to maintain the acceleration vector along the long axis of the body. In the runs at the completion of one of the two bedrest periods of each subject an Air Force cutaway anti-G garment CSU-3/P was worn as a countermeasure to the acceleration stress.

The suit was inflated to 13 inches of H_2O, 45 inches of H_2O, and 60 inches of H_2O for the +2.1, +3.2, and +3.8 G_z runs, respectively. During acceleration ECG, instantaneous heart rate, and Doppler flowmeter signals from the temporal arteries were recorded continuously on a Brush 8 channel direct writing recorder and an Ampex FR 1800 tape recorder. Acceleration tolerance was assessed by a subject's response to peripheral lights presented in a random fashion, by his ability to perceive a central white light of 15 foot candles luminence, and by the presence or absence of Doppler flow velocity signals from the superficial temporal arteries. Peripheral light loss (PLL), central light loss (CLL) or presyncopal symptoms were used as end-points to stop the run. Subjects were additionally monitored by observation on infrared television and by voice communication. The subjects were instructed not to perform straining maneuvers during acceleration studies.

All data were analyzed using standard statistical procedures employing the paired t test.[11] P values of < 0.05 were considered to document a significant difference.

RESULTS

Documentation of the "Weightless" State The sodium balance, calculated as the dietary intake minus the urinary excretion, is shown in Figures 1 and 2. These values neglect stool and insensible losses which should have been small and constant during all phases of the study.[1] The sodium balance was markedly negative on the first day of each bedrest period, mean values being -52 meq and -64 meq on B1 and B'1, respectively. On the second bedrest days, the balance was still negative but less so, being -7 meq (B2) and -26 meq (B'2). In contrast, the first two days of recovery periods were characterized by markedly positive sodium balances of 77 meq and 54 meq on R1 and R'1, respectively; and 29 meq and 32 meq on R2 and R'2, respectively. Figure 2, displaying the group means for each period of study, shows that the sodium balances were positive during the ambulatory control and recovery periods, and negative during bedrest periods. Statistically significant differences were found only in the comparisons of the second bedrest period and the first and second recovery periods. Two subjects had atypical rises in sodium balance in the first bedrest period, and the abnormally low total urine creatinine in one of these two subjects during this period suggests inaccurate urine collection. The atypical findings in these two subjects resulted in failure to show statistically significant differences between the first bedrest period and the ambulatory control and first recovery periods. The failure to achieve significant differences during the first bedrest period may also have been contributed to by the fact that some subjects did not reach full equilibration with the diet, since all subjects showed the expected responses in the second bedrest period. These results do point up the difficulties inherent in interpreting data from small numbers of subjects.

The fluid balance, calculated as the oral intake minus urine output, was significantly lower during bedrest than during upright activity periods (Figure 2).

The results of plasma volume (PV), extracellular fluid volume (EFV) and total body water (TBW) determinations are shown in Figure 3. The PV decreased significantly by the second bedrest days and continued to decrease throughout the bedrest periods. EFV and TBW also decreased during bedrest periods but more slowly, the decreases achieving statistical significance sometime after the second and before the fourteenth bedrest days. There were no significant differences in PV, EFV, or TBW between the ambulatory control and first and second recovery periods.

Detailed heart rate responses to 70° passive tilt in two subjects are shown in Figure 4. The heart rates are higher following the first bedrest period than during the ambulatory control or recovery period. During the tilt following the second bedrest period the subjects wore G-suits inflated to 43 inches of H_2O. This time the heart rates were actually lower than during the ambulatory control and recovery period studies. Subject 2, who experienced presyncope in both bedrest tilts, tolerated the tilt for five minutes longer with the inflated G-suit than without it. His detailed heart rate and blood pressure data are shown in Figure 5.

The maximum heart rate responses to LBNP are shown in Table 1. The group means at all levels of LBNP were higher following the bedrest periods than during the ambulatory control and recovery periods. The heart rates following the first bedrest period were significantly greater, at all levels of LBNP, than in the ambulatory control period. However, differences were not as significant when the first bedrest period was compared with the first recovery period, or when results following the second bedrest period were compared with both recovery periods. This suggests that not all subjects had returned to their ambulatory control status for these stresses by R13 or R'14, as illustrated by Subject 6's higher maximum heart rates on R13 than on A13 (Figure 6). However, the failure to show statistically significant differences between R13 and A13 and between R13 and R'14 suggests that some subjects had returned to ambulatory control status. Thus, in reviewing data from groups such as this with small numbers of subjects, individual results and group means ±SE (95%) must be considered along with P values in the interpretation of results.

The derived maximal oxygen uptakes, calculated by extrapolating the linear regression of the heart rate on the oxygen consumption to a heart rate of 180 are shown in Figure 2. These studies document significantly lower derived maximal oxygen uptakes following the bedrest periods relative to the ambulatory control and recovery periods. No significant differences were found between the ambulatory control and both recovery period studies.

Centrifuge Studies: The maximum heart rate responses during centrifuge studies are listed in Table 2. Since two subjects wore the G-suit in the run following the first, and four subjects in the run following the second bedrest period, the post-bedrest data are tabulated as days on which a subject wore (BR+) or did not wear (BR-) a G-suit.

The maximum heart rates in all subjects at all $+G_z$ levels, except for Subject 2 at $+3.8\ G_z$, were greater in the post-bedrest runs without

G-suit than in the ambulatory control and recovery period runs. Specifically, the maximum heart rates in the bedrest without G-suit runs exceeded those in the ambulatory control period runs by 20 to 48 (mean 32) beats/min at +2.1 G_z, by 8 to 34 (mean 20) beats/min at +3.2 G_z, and, with the one exception, by 12 to 53 (mean 25) beats/min at +3.8 G_z. They likewise exceeded those in the recovery period runs by similar values: 7 to 48 (mean 33) at +2.1 G_z, 11 to 44 (mean 24) at +3.2 G_z, and, with the one exception, 20-32 (mean 24) at +3.8 G_z. Further, the heart rate responses in the post-bedrest runs show a significant lowering of heart rate with the use of the G-suit. The post-bedrest maximum heart rates with the G-suit were lower than without the G-suit by 5 to 50 (mean 24) in the +2.1 G_z runs, by 4 to 50 (mean 22) in the +3.2 G_z runs, and with the one exception, by 0 to 40 (mean 21) in the +3.8 G_z run. In fact, the maximum heart rates in the post-bedrest runs with G-suit were in most instances very close to, and at times lower than, those in the comparable ambulatory control and recovery period runs. In Subject 4's +2.1 G_z run with G-suit, the G-suit spontaneously deflated early in the run. However, the run was completed, and it is noteworthy that in this instance the heart rate was essentially identical to that during the earlier post-bedrest without G-suit run. Subject 2's atypical maximum heart rate response at +3.8 G_z, i.e., lower in the post-bedrest without G-suit run than in the ambulatory control and recovery period runs, suggests increased vagal tone which may have been related to the presyncopal symptoms experienced in the immediately preceding

$+3.2$ G_z run. This subject also had much shorter time tolerance in the post-bedrest without G-suit run than in the other periods.

Statistical analysis of the group means of the maximum heart rates during centrifuge runs are shown in Figure 7 and Table 3. Since the G-suit deflated during Subject 4's $+2.1$ G_z run, this datum is excluded from the BR+ group and added to the BR- group. In the post-bedrest runs without G-suits (BR-) the maximum heart rates achieved were significantly higher than in the ambulatory control, recovery, and post-bedrest with G-suit (BR+) runs at the $+2.1$ G_z and $+3.2$ G_z levels, and higher than in the recovery and BR+ periods at $+3.8$ G_z. There were no significant differences in maximum heart rate responses between the post-bedrest with G-suit (BR+) and the ambulatory control or recovery period runs at all $+G_z$ levels, indicating that the use of the G-suit normalized the post-bedrest maximum heart rate response.

At the $+3.8$ G_z level, significantly higher maximum heart rates were not achieved in the post-bedrest without G-suit (BR-) run relative to the ambulatory control period. he lack of significance is attributable to Subject 3's very low maximum heart rate on A14, giving a large standard error.

Perhaps of greater practical significance than maximum heart rate responses is the fact that subjects who had previously terminated the post-bedrest runs prematurely were able to tolerate the runs for longer periods of time with the G-suit (BR+) than without it (BR-) (Table 4). It permitted Subjects 2 and 6 the 5 and 54 seconds, respectively, needed to complete the +3.2 G_z run; and Subject 1 the 55 seconds to complete the +3.8 G_z run. Also in the +3.8 G_z run it allowed Subject 2 102 seconds and Subject 6 124 seconds longer tolerance than in the post-bedrest without G-suit run. It is noteworthy that in all the episodes of PLL or CLL, the Doppler flowmeter had indicated "zero" flow for at least a few seconds prior to the development of visual impairment. Details of these flow studies have been published elsewhere.[9]

Although the G-suit had a beneficial effect on orthostatic tolerance, its use resulted in some complications. All subjects developed some asymptomatic petechiae of the feet and ankles, but Subjects 5 and 6 also developed painful purpuric edema of the toes and feet which gradually disappeared over a 12 hour period.

DISCUSSION

The findings in this study have demonstrated bedrest induced changes in body metabolism and physiologic responsiveness. The sodium balance and fluid balance were lower during bedrest than during upright activity periods. The plasma volume, extracellular fluid volume, and total body water all decreased during bedrest periods and returned to ambulatory control levels in the recovery periods. During 70° tilt and LBNP the heart rates were higher and the duration of tolerance shorter following bedrest periods relative to upright activity periods. Finally, the derived maximal oxygen uptakes were significantly lower following than during upright activity periods. All of these changes have been established in our laboratories to occur during periods of bedrest,[2] and the decrease in maximal oxygen uptake during bedrest confirms an earlier report.[10] For the purposes of this study, they document achievement of bedrest induced metabolic and physiologic changes prior to the post-bedrest centrifuge studies. Thus, the post-bedrest data obtained in the $+G_z$ profiles used here should accurately predict the responses of untrained passengers re-entering the earth's atmosphere in the Space Shuttle Vehicle using an identical $+G_z$ profile following a two week exposure to the weightless environment.

The centrifuge data obtained in this study have demonstrated that $+G_z$ tolerance, measured by maximum heart rate, time to visual impairment, and time to cessation of temporal artery flow deteriorates following bedrest simulation of weightlessness. In the unprotected post-bedrest state all subjects had higher heart rates than in upright activity period runs, and Subjects 1,2 and 6 were unable to tolerate the complete acceleration profile. The post-bedrest use of an inflated standard Air Force cutaway G-suit normalized the heart rate responses and prolonged the duration of $+G_z$ tolerance. It permitted Subject 1 to complete the $+G_z$ profile in the post-bedrest state, but Subjects 2 and 6 were still unable to do so.

If blackout and syncope are to be avoided, persons like Subjects 2 and 6 must be identified. Since admission into this study required an ambulatory subject to tolerate a 70° passive tilt, it is clear that this test of orthostatic tolerance will not be of high enough selectivity in ambulatory subjects. Further, the fact that Subjects 3,4,5 and 6 additionally tolerated the LBNP studies during the ambulatory control period indicates that LBNP in ambulatory subjects is also inadequately selective. The intolerance of Subjects 2 and 6 to tilt and LBNP following two weeks of bedrest suggests that performance of these tests following a two week bedrest period will identify some of the people at risk. Such a long bedrest period as part of a screening is obviously impractical. Since previous studies have demonstrated that decreases in plasma and extracellular fluid volumes [2] and diminution in 70° passive tilt tolerance [15] occur within 48-72 hours of bedrest, it is possible that orthostatic tolerance tests may achieve the required selectivity for higher risk subjects after an abbreviated period of bedrest.

The heart rate responses and tolerances to centrifugation documented in this study are similar to those obtained in studies with somewhat different protocols and aims. [4,6,8] Specifically, it has been shown that $+G_z$ tolerance, measured by several endpoints, deteriorates following periods of bedrest. [4,6] Further, the use of the inflated G-suit has been documented to give increased $+G_z$ tolerance in the control as well as the post-bedrest state, [8] although in the present study its use seemed to worsen petechial hemorrhages on the feet and ankles. It is possible that $+G_z$ tolerance in our subjects could have been increased to a greater extent than observed had the G-suits been tailored to the individual subject and had pressures in the G-suits been different. Others have found that subjects wearing the best fitting

G-suits, inflated almost to the point of discomfort at 1 G, had the best $+G_z$ tolerance,[8] although specific inflation pressures have not been published. Finally, it has been observed that muscle straining maneuvers may result in increased $+G_z$ tolerance,[8,17] suggesting that the performance of such a maneuver in our study might have supplemented the increased $+G_z$ tolerance afforded by the inflated G-suit alone.

The exact mechanisms for the observed post-bedrest decrease in $+G_z$ tolerance were not determined in this study. However, the results of previous studies suggest that multiple factors are responsible. Chief among these are net loss of body fluids, shifts in body fluid compartments and decreases in ventricular contractility.[2,3,12] Data concerning alterations in peripheral venous compliance remain controversial.[5] The improvement in acceleration tolerance with the G-suit is most consistent with the hypothesis that decreased plasma and extracellular fluid volumes and shifts in body fluid compartments are major factors. The G-suit, by compressing the leg veins and by preventing venous pooling, would augment cardiac performance through the Frank-Starling mechanism.

While acknowledging the fact that bedrest may be an imperfect analog of weightlessness and space flight, these studies strongly suggest that the cardiovascular responses of humans re-entering the earth's atmosphere in a space shuttle vehicle and exposed to $+G_z$ acceleration stress will be altered after a two-week exposure to weightlessness. Specifically, some untrained passengers re-entering the earth's gravitational field at these

$+G_z$ in the unprotected state will have higher heart rates and will experience visual impairment earlier than in the control state. Some passengers may even become syncopal. However, the wearing of the Air Force cutaway G-suit inflated to the pressures used here should normalize the heart rate responses and prolong the time to visual impairment in all passengers. Nevertheless, some lay personnel may still experience visual impairment or syncope. For the safe return of these individuals, additional G protection, e.g., muscle straining maneuvers or higher G-suit pressures, would have to be employed.

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Legends

Figure 1. Mean sodium balances during specified periods of the study (n = 6). The initial bedrest days are characterized by markedly negative balances; the inital recovery period days by markedly positive balances.

Figure 2. Sodium balance, fluid balance, and derived maximal oxygen uptake during specified periods of the study. (Means and 95% confidence limits, n = 6). The values are lower during bedrest than during ambulatory control and recovery periods.

Figure 3. Body fluid compartments on specific days. (Means and 95% confidence limits, n = 6). The plasma volume, extracellular fluid volume, and total body water are smaller during bedrest than during ambulatory control and recovery periods.

Figure 4. Heart rate responses to 70° passive tilt in two subjects during different periods of the study. Higher heart rates occurred during the post-bedrest without G-suit than during the ambulatory control, recovery, or post-bedrest with G-suit tilts.

Figure 5. Heart rate and blood pressure responses to 70° passive tilt in Subject 2. In the post-bedrest tilt using the inflated G-suit the heart rate is lower and the duration of tolerance longer than in the post-bedrest without G-suit tilt.

Figure 6. heart rate and blood pressure responses of Subject 6 to LBNP. Higher heart rates occurred following bedrest when compared with ambulatory control and recovery periods. Also, the heart rates in the recovery period are greater than in the ambulatory control period. Thus, complete recovery from bedrest has not occurred during the two week recovery period.

Figure 7. Maximal heart rates during centrifugation at various $+G_z$ levels in different study periods. (Means and 95% confidence limits, n = 6). The heart rates are higher in the bedrest without G-suit run (BR-) than in the ambulatory control (A), recovery (R), and bedrest with G-suit (BR+) runs. The heart rates in BR+ are lower than in BR-, and not significantly different from those on A and B.

Table 1

MAXIMUM HEART RATE DURING LBNP
Group Means and 95% Confidence Limits (n = 6)
(beats/minute)

		LBNP Magnitude		
Day of Study	Rest	-30mmHg	-40mmHg	-50mmHg
A 13	47 ±2.7	58 ±8.6	70 ±13	82 ±15
B 15	52 ±5.9	69 ±10	87 ±13	105 ±12
R 13	54 ±11	64 ±18	80 ±19	91 ±12
B'15	52 ±3.3	71 ±19	85 ±32	104 ±9
R'14	53 ±4.4	69 ±25	72 ±28	84 ±34

P Values

B vs A	< 0.05	< 0.005	< 0.02	< 0.005
R vs B	< 0.8	< 0.4	< 0.4	< 0.2
B' vs R	< 0.5	< 0.3	< 0.6	< 0.005
R' vs B'	< 0.3	< 0.4	< 0.05	< 0.10
R vs A	< 0.2	< 0.4	< 0.4	< 0.3
R' vs R	< 0.9	< 0.5	< 0.4	< 0.5

Table 2

MAXIMUM HEART RATES AT SPECIFIED $+G_z$ LEVELS
Individual Data
(beats/minute)

Subject	Day of Study	$+2.1\ G_z$	$+3.2\ G_z$	$+3.8\ G_z$
1	A14	116	148	156
	BR-	154	176	176*
	BR+	104	128	136
	R14	108	132	144
2	A14	128	168	184
	BR-	176	184*	176*
	BR+	146	176	188*
	R14	144	172	188*
3	A14	81	103	104
	BR-	107	137	157
	BR+	90	105	125
	R14	100	110	137
4	A14	110	138	143
	BR-	130	150	155
	BR+	129 †	138	155
	R14	106	125	135
5	A14	100	125	148
	BR-	137	143	165
	BR+	120	117	140
	R14	105	120	137
6	A14	140	168*	166*
	BR-	165	176*	190*
	BR+	160	172	180*
	R14	117	165*	170*

* Run terminated early because of visual impairment.

† G-suit spontaneously deflated during this run.

Table 3

MAXIMUM HEART RATE DURING CENTRIFUGE STUDIES
Group Means and 95% Confidence Limits (n = 6)
(beats/minute)

Day of Study	Rest	$+2.1\ G_z$	$+3.2\ G_z$	$+3.8\ G_z$
A 14	53 ± 7.9	112 ± 22	142 ± 27	150 ± 28
BR-	59 ± 7.1	143 ± 22	161 ± 21	169 ± 14
BR+	58 ± 3.2	124 ± 36	139 ± 12	147 ± 26
R 14	56 ± 9.3	113 ± 17	137 ± 16	152 ± 23

P Values

R14 vs A14	< 0.4	< 0.95	< 0.3	< 0.95
BR- vs A14	< 0.005	< 0.001	< 0.005	< 0.10
BR- vs R14	< 0.4	< 0.005	< 0.005	< 0.05
BR+ vs A14	< 0.3	< 0.2	< 0.6	< 0.7
BR+ vs R14	< 0.6	< 0.4	< 0.7	< 0.7
BR+ vs BR-	< 0.9	< 0.05	< 0.05	< 0.05

\+ With G-suit.

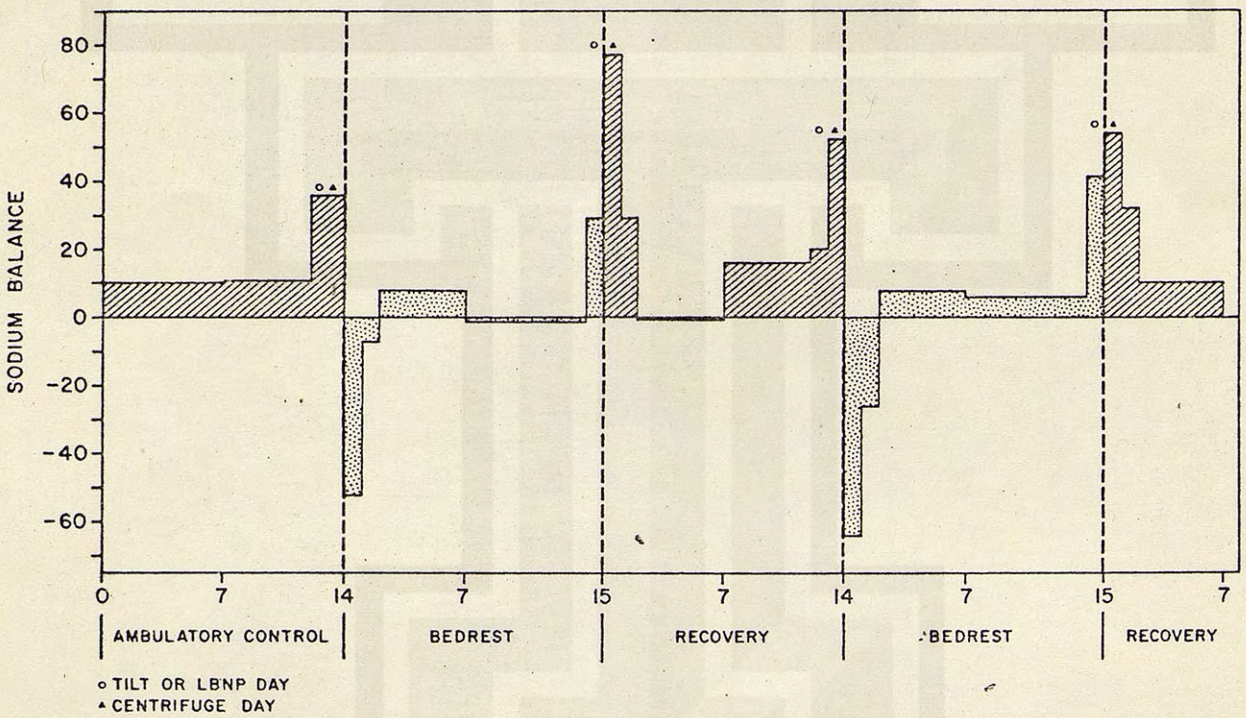
\- Without G-suit.

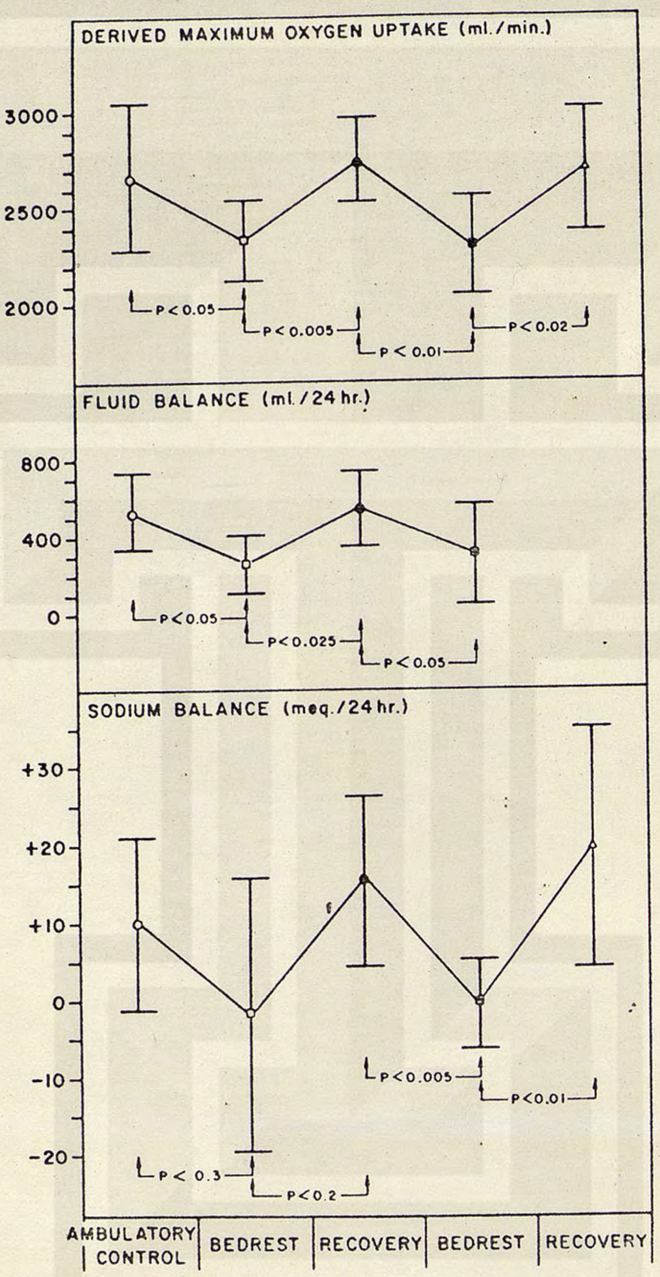
Table 4

DURATION OF TOLERANCE TO CENTRIFUGATION:
Post-Bedrest Runs With (BR+) and Without (BR-) G-Suit

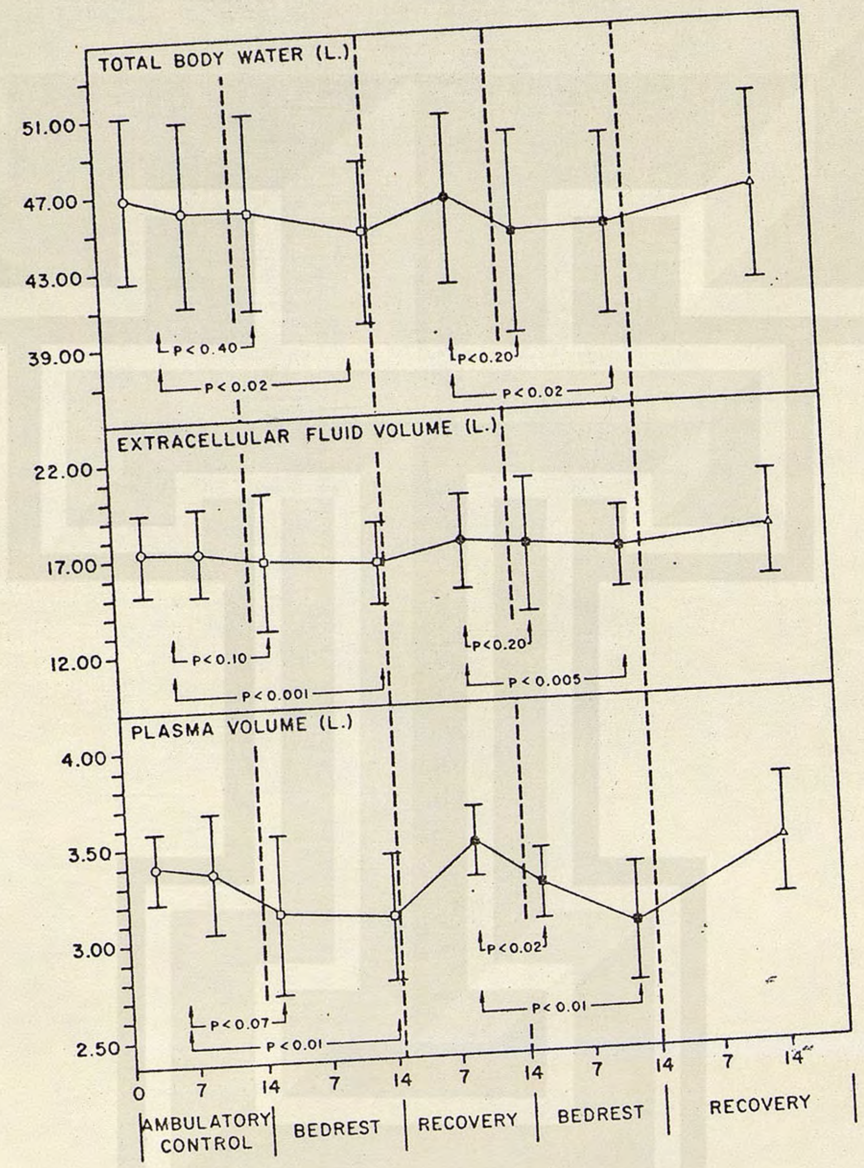
Subject	Day of Study	+2.1 G_z	+3.2 G_z	+3.8 G_z
1	BR-	670"	220"	130"
	BR+	"	"	185"
2	BR-	"	215"	42"
	BR+	"	220"	144"
3	BR-	"	220"	185"
	BR+	"	"	"
4	BR-	"	220"	185"
	BR+	"	"	"
5	BR-	"	220"	185"
	BR+	"	"	"
6	BR-	"	166"	41"
	BR+	"	220"	165"

SODIUM BALANCE (meq./24 hrs.)

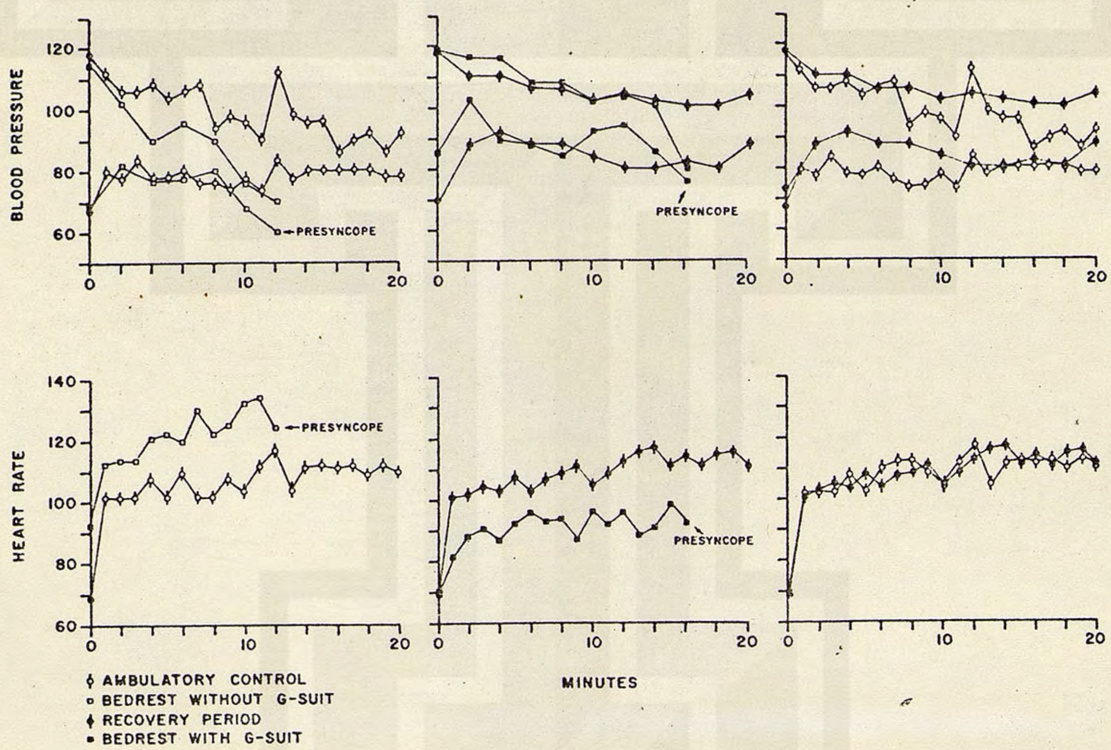



DERIVED MAXIMUM OXYGEN UPTAKE (ml./min.)
3000
2500
2000
P < 0.05
P < 0.005
P < 0.01
P < 0.02
FLUID BALANCE (ml./24 hr.)
800
400
0
P < 0.05
P < 0.025
P < 0.05
SODIUM BALANCE (meq./24 hr.)
+30
+20
+10
0
-10
-20
P < 0.005
P < 0.01
P < 0.3
P < 0.2
AMBULATORY CONTROL
BEDREST
RECOVERY
BEDREST
RECOVERY

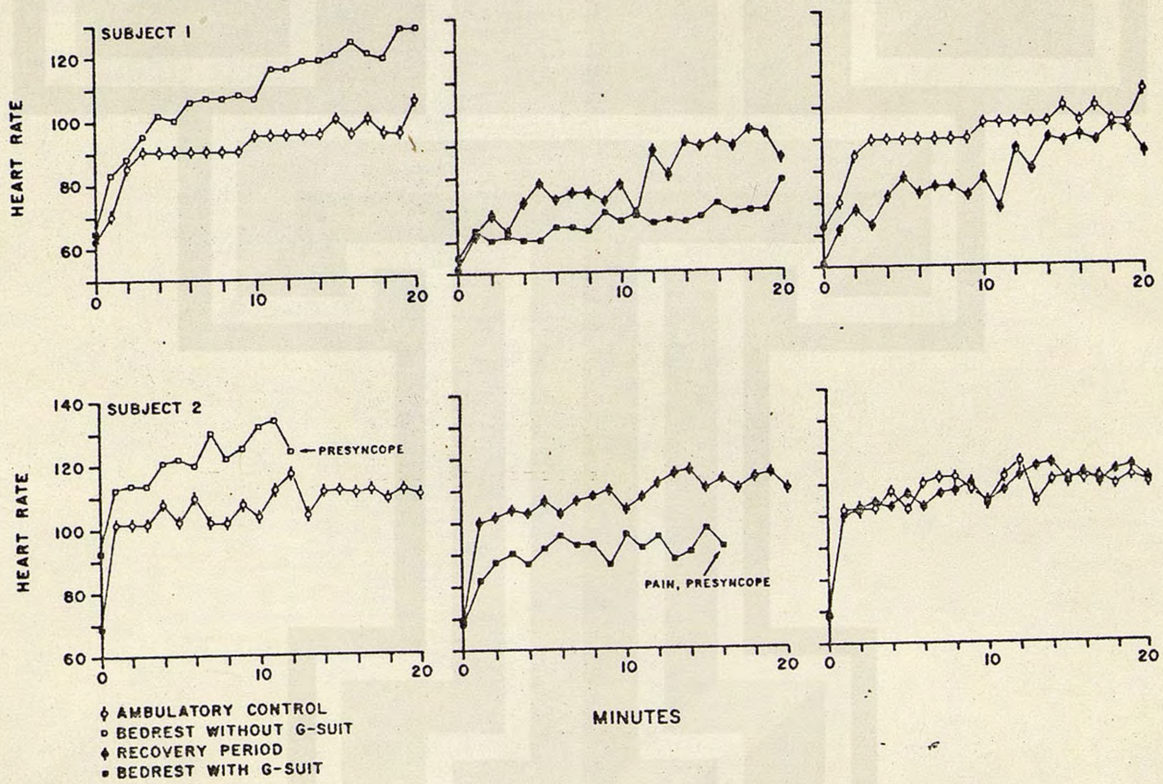
BODY FLUID COMPARTMENTS



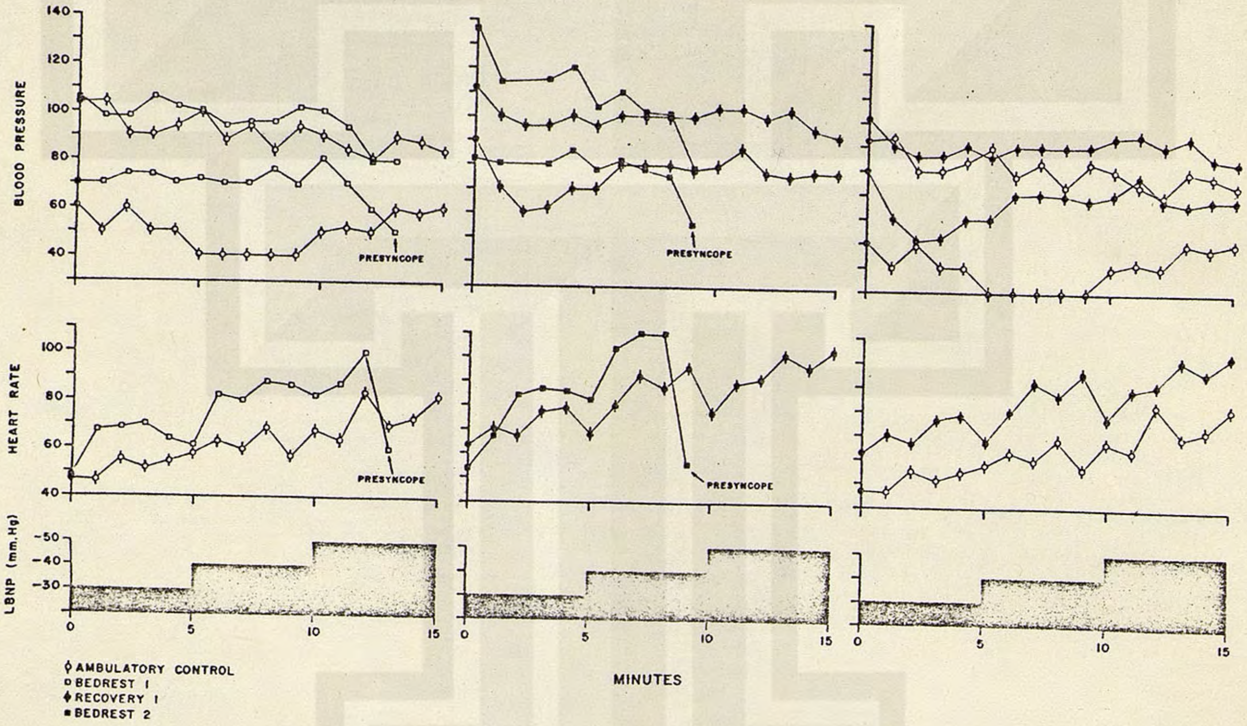
70° TILT: SUBJECT 2
BLOOD PRESSURE AND HEART RATE RESPONSES



HEART RATE RESPONSE TO 70° TILT



LBNP: SUBJECT 6
BLOOD PRESSURE AND HEART RATE RESPONSES



MAXIMUM HEART RATES DURING CENTRIFUGATION