Tolerance To Transverse (+Gx) and Headward (+Gz) Acceleration After Prolonged Bed Rest

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ABSTRACT

Tolerance to the transverse (+Gx) acceleration of a simulated Gemini re-entry profile was determined before and after 4 weeks of absolute bed rest. Tolerance to headward (+Gz) acceleration was studied before and after 4 weeks of absolute bed rest and 2 weeks of modified bed rest.

As judged by the degree of physical discomfort, the ability to respond to a central light, or the presence of electrocardiographic abnormalities, tolerance to +Gx was unaffected by 4 weeks of absolute bed rest. In each subject studied, heart rates during peak acceleration were higher after bed rest than before.

As judged by the level of acceleration at which central vision was lost, no significant change in tolerance to headward (+Gz) acceleration of rapid onset was observed after 2 weeks of modified bed rest or after 4 weeks of absolute bed rest. After each type of bed rest, the majority of the subjects had decreased tolerance to headward (+Gz) acceleration of gradual onset, but the mean decrease was not statistically significant.

Mean heart rates at equivalent levels of +Gz were significantly higher after both periods of bed rests. The only arrhythmia of clinical importance noted was the appearance of bursts of premature atrial contractions during G.O.R. + Gz in 1 subject after 2 weeks of bed rest.

IT IS GENERALLY BELIEVED that tolerance to transverse (+Gx) acceleration will be unaffected by a 30-day flight in the Manned Orbiting Laboratory. No studies seeking objective support for this opinion have been performed, however.

The use of prolonged bed rest to simulate the cardiovascular effects of prolonged space flight has been discussed previously.[6] This paper presents an investigation of the effects of 4 weeks of absolute bed rest on tolerance to transverse (+Gx) acceleration. In addition, the effects of 4 weeks of absolute bed rest and 2 weeks of modified bed rest on tolerance to headward (+Gz) acceleration are described.

METHODS

Subjects were 22 healthy male volunteers 17 to 23 years old who had just completed 8 weeks of basic training in the United States Air Force. The conditions of bed rest for the 4 week and 2 week studies have been described previously in detail.[5,6]

A transverse (+Gx) acceleration profile identical to one of several proposed for the re-entry profile in the Gemini flights was produced on the human centrifuge (Fig. 1). Peak acceleration was 10.6 G, and the duration of acceleration above 1G was approximately 175 seconds. The angular configuration of the couch was identical to that planned for the Gemini flights. Subject conformation to the couch was achieved by the use of an evacuated latex rubber bag filled with microballoons (0.5 μ in diameter). The centrifuge was stopped if the subject failed to see a central light.

Tolerance to headward (+Gz) acceleration was determined during rapid onset runs (R.O.R.) and gradual onset runs (G.O.R.). In the R.O.R. the rate of acceleration was 1 G per second, and peak G was sustained for 15 seconds. Peak G was increased in 0.2 G increments until central vision was lost. In the G.O.R. the rate of acceleration was 0.07 G per second (1 G every 15 seconds), and acceleration was continued until central vision was lost.

Subjects were monitored during all centrifuge runs by television, voice intercom, and oscillographic recording of the electrocardiogram. Electrocardiograms and levels of acceleration were recorded on paper. Two indoctrination sessions for both +Gx and +Gz were performed on the human centrifuge prior to control runs before bed rest.

Eleven subjects underwent 4 weeks of absolute bed rest. The subjects did not leave the bed, and sitting was prohibited. Baths were given by medical technicians. Each subject ate and drank lying on his side. Bed pans and urinals were used in bed. Tolerance to +Gx and +Gz was determined before and after bed rest. After bed rest the subjects were transported by stretcher to the human centrifuge. +Gx and +Gz were performed on separate days, the subjects remaining in bed between tests.

Eleven subjects underwent 2 weeks of modified bed rest. They were allowed to sit in bed during meals and urination and to leave the bed for bowel movements. Tolerance to +Gz was determined before and after bed rest.

RESULTS

The degree of subjective physical discomfort during

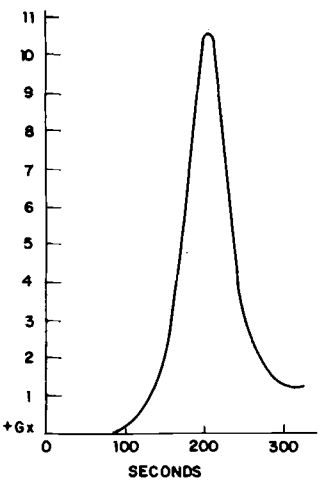

Fig. 1. Gemini Re-entry Profile.

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+Gx was no greater after 4 weeks of bed rest than before bed rest.

A number of subjects experienced visual impairment at peak +Gx or during the initial phase of deceleration of the centrifuge, but visual impairment was no more common or greater in degree after bed rest than before (Table I). Some subjects noted a progressive narrowing of vision similar to that experienced during +Gz, but others observed a generalized blurring of vision. In one subject blurring of vision occurred in one eye only.

TABLE I. VISUAL SYMPTOMS DURING +Gx BEFORE AND AFTER FOUR WEEKS OF BED REST

Subject	Before Bed Rest	After Bed Rest
A	No visual symptoms	Dimming of peripheral vision
B	Slight generalized visual blurring	Dimming of peripheral vision
C	No visual symptoms	No visual symptoms
D	Loss of peripheral vision	No visual symptoms
E	Generalized visual blurring of left eye	Slight generalized visual blurring
F	Loss of central vision	Loss of central vision
G	Loss of central vision	Loss of central vision
H	Loss of central vision	No visual symptoms
I	Dimming of central vision	Dimming of peripheral vision
J	No visual symptoms	No visual symptoms
K	No visual symptoms	Dimming of central vision

No abnormal electrocardiographic changes were observed during +Gx before or after bed rest. The presence in 1 subject of 1 premature ventricular contraction at 8 G was the only cardiac arrhythmia observed. Heart rate at peak +Gx was higher after bed rest than before in each subject tested (Table II).

TABLE II. HEART RATES AT 10.6 +Gx BEFORE AND AFTER FOUR WEEKS OF BED REST

Subject	Before Bed Rest	After Bed Rest
A	94	120
B	88	100
C	105	145
D	94	110
E	96	105
F	75	150
G	78*	125
H	90	130
I	84	140
J	84	120
K	115	140
Mean	91.2	125.9

*10.4 +Gx—Profile aborted because of loss of central vision

After bed rest, mean heart rate at peak +Gx increased 34.7 beats per minute ($P<.001$).

As judged by the level of acceleration at which central vision was lost, no significant change in tolerance to R.O.R. +Gx was noted after 4 weeks of absolute bed rest (Table III). In the gradual onset runs 8 of the 11 subjects showed decreased tolerance to +Gz after bed rest and 3 showed increased tolerance. The mean decrease of 0.34 G was not statistically significant.

TABLE III. LEVEL OF +Gz RESULTING IN LOSS OF CENTRAL VISION BEFORE AND AFTER FOUR WEEKS OF BED REST

Subject	Rapid Onset Runs Before	Rapid Onset Runs After	Gradual Onset Runs Before	Gradual Onset Runs After
A	3.4	3.6	4.5	4.7
B	3.9	3.4	4.1	4.6
C	3.9	4.4	4.7	4.9
D	3.2	2.8	4.1	4.0
E	—	—	3.7	3.5
F	4.0	4.0	5.4	3.6
G	3.0	3.0	4.4	3.9
H	2.8	2.8	3.8	3.4
I	3.8	3.8	4.4	4.3
J	3.6	3.4	5.6	4.3
K	3.6	3.6	4.4	4.1
Mean	3.52	3.48	4.46	4.12

In each subject tested, heart rate during equivalent levels of +Gz was higher after bed rest than before in both the rapid onset runs and the gradual onset runs (Table IV). After bed rest, mean heart rate increased 22.3 beats per minute ($P<.001$) in the R.O.R. and 26.2 beats per minute ($P<.001$) in the G.O.R.

TABLE IV. HEART RATES DURING EQUIVALENT LEVELS OF +Gz BEFORE AND AFTER FOUR WEEKS OF BED REST

Subject	Rapid Onset Runs G	Rapid Onset Runs Before	Rapid Onset Runs After	Gradual Onset Runs G	Gradual Onset Runs Before	Gradual Onset Runs After
A	3.4	110	150	4.5	125	150
B	3.4	105	135	4.1	110	140
C	3.9	130	155	4.7	145	170
D	2.8	115	130	4.0	125	145
E	—	—	—	3.5	97	150
F	4.0	112	130	3.6	105	150
G	3.0	105	118	3.9	105	122
H	2.8	110	125	3.4	125	148
I	3.8	113	150	4.3	132	155
J	3.4	110	125	4.3	125	150
K	3.6	115	130	4.1	138	140
Mean		112.5	134.8		121.1	147.3

A few cardiac arrhythmias were noted after deceleration. Before bed rest, one subject developed atrial rhythm after both the R.O.R. and the G.O.R., and another exhibited A-V dissociation and premature ventricular contractions after the R.O.R. After bed rest, one subject developed premature ventricular contractions after both the R.O.R. and the G.O.R.

As judged by the level of acceleration at which central vision was lost, no significant change in tolerance to R.O.R.+Gz was noted after 2 weeks of modified bed rest (Table V). In the gradual onset runs after bed rest 7 of the 10 subjects tested showed decreased tolerance, 2 showed increased tolerance, and 1 showed no change. The mean decrease of 0.46 G was not statistically significant.

TABLE V. LEVEL OF +Gz RESULTING IN LOSS OF CENTRAL VISION BEFORE AND AFTER TWO WEEKS OF BED REST

Subject	Rapid Onset Runs Before	Rapid Onset Runs After	Gradual Onset Runs Before	Gradual Onset Runs After
A	3.6	4.6	6.4	5.9
B	4.2	4.2	—	—
C	3.8	3.8	5.2	4.6
D	3.6*	3.6	5.3	5.0
E	5.0	4.4	6.7	4.2
F	3.8	3.4	5.2	4.9
G	3.6	2.6	5.4	3.7
H	3.2	2.6**	5.3	4.5
I	3.6	3.2	3.6	5.0
J	3.4	3.4**	4.8	5.5
K	3.4	3.6	5.0	5.0
Mean	3.75	3.58	5.29	4.83

*Loss of peripheral vision only
**Dimming of peripheral vision only

In the R.O.R. after 2 weeks of bed rest 8 subjects had higher heart rates and 2 had lower heart rates than before bed rest (Table VI). In the G.O.R. all subjects had higher heart rates after bed rest (Table VI). After bed rest, mean heart rate increased 13.8 beats per minute ($P<.05$) in the R.O.R. and 23.9 beats per minute ($P<.001$) in the G.O.R.

One subject developed atrial rhythm after decelera-

TABLE VI. HEART RATES DURING EQUIVALENT LEVELS OF +Gz BEFORE AND AFTER TWO WEEKS OF BED REST

Subject	Rapid Onset Runs G	Before	After	Gradual Onset Runs G	Before	After
A	3.6	130	138	5.9	175	180
B	4.2	115	135	—	—	—
C	3.8	150	180	4.6	180	190
D	3.6	123	150	5.0	140	180
E	4.4	150	170	3.0*	165	185
F	3.4	122	145	4.9	173	185
G	2.6	125	145	3.7	125	175
H	2.6	145	130	4.5	168	180
I	3.2	140	165	3.6	145	180
J	—	—	—	4.8	140	190
K	3.4	150	130	5.0	180	185
Mean		135.0	148.8		159.1	183.0

*Heart rates evaluated at 3.0 +Gz because subject developed bursts of premature atrial contractions at higher levels of acceleration after bed rest.

tion from a R.O.R. before bed rest. Another subject exhibited bursts of premature atrial contractions during and after a G.O.R. after bed rest.

DISCUSSION

No intolerance to the transverse acceleration of re-entry of the earth's atmosphere has been reported in American and Soviet space flights. The longest flight, however, has been only 5 days in duration. The absence in the present study of adverse cardiovascular effects during transverse acceleration after 4 weeks of absolute bed rest adds for the first time a measure of objective support to the opinion of many authorities that space flights of similar duration will not decrease tolerance to the transverse acceleration of re-entry.

It should be noted, however, that heart rates during peak acceleration were greater in each subject after bed rest than before. Raab et al[8] have emphasized that bed rest and physical inactivity result in an increased resting heart rate and an inefficient myocardium secondary to an accentuated catecholamine activity. Raab points out that catecholamines decrease the myocardial cell's ability to utilize oxygen, thus increasing myocardial irritability and predisposing the heart to arrhythmias.

Hypoxemia has been demonstrated during transverse acceleration.[7,9] Though no significant cardiac arrhythmias were observed in the present study, it is possible that more sustained levels of high transverse acceleration resulting in more prolonged hypoxemia might provoke serious cardiac arrhythmias in the deconditioned individual.

The absence of a significant change after bed rest in tolerance to headward acceleration of rapid onset, as judged by the G level at which central vision was lost, conforms with the work of Meehan and Jacobs.[4] They found no change in 15 second G tolerance in normal subjects after exposure to 4 weeks of "essentially bed rest conditions."

Tolerance to headward acceleration of rapid onset probably depends primarily on reflex arteriolar constriction stimulated by a fall in carotid sinus pressure.[1] The preservation of rapid onset G tolerance during prolonged bed rest suggests that reflex arteriolar constriction of an acute nature is not affected significantly by bed rest.

Reflex venoconstriction has been demonstrated after the onset of headward acceleration.[3] The maintenance of cardiac filling by venoconstrictive reflexes is considered essential to the higher G tolerance attained in headward acceleration of gradual onset.[1] The small changes in tolerance to headward acceleration of gradual onset observed after bed rest in this study suggest that initial venomotor reflexes stimulated by gravitational changes may not be seriously impaired by prolonged bed rest.

In the same subjects, syncope and pre-syncopal symptoms and signs were much more common during orthostasis on the tilt table after bed rest than before.[5,6] Though subjects on the tilt table are exposed to only 1 vertical G, the time of exposure to a gravitational change is much longer than during a gradual onset run on the centrifuge. After 4 weeks of bed rest no one fainted on the tilt table before the 6th minute of orthostasis. If the major physiologic deficiency responsible for orthostatic intolerance after bed rest were known, this apparent time dependency might be explained.

During +Gz (R.O.R. and G.O.R.) Graveline[2] observed higher heart rates after 1 week of partial immersion in water than before immersion. In the present study, heart rates were higher after bed rest during both R.O.R. and G.O.R. +Gz. Whether this signifies a decrease in the efficiency of the heart for a given G load, an attempt of the heart to compensate for deficient peripheral vascular mechanisms, or both, is not known. As noted above, in most subjects the overall cardiovascular response to +Gz (R.O.R. and G.O.R.) after bed rest adequately maintains G tolerance as measured by the level at which central vision is lost.

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