Human Experiments in Subgravity and Prolonged Acceleration

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With the advent of rocket type aircraft that can freely probe the outer limits of the earth's atmosphere, the problem of subgravity will be extremely commonplace. If a rocket craft having attained an altitude of seventy miles and a velocity of five miles per second, were placed in a planetary orbit about the earth, the resultant weightless condition would be a constant environmental situation. What are the problems of this subgravity state? Gauer and Haber have postulated that the unusual proprioceptive impulses arising from the vestibular apparatus might result in a condition similar to motion sickness. A second more apparent problem is that of orientation in space and co-ordination in a weightless situation.

As the high altitude sounding rocket is the best available means of studying the effects of subgravity upon animals, so the jet aircraft is the best available means of studying the effects of subgravity upon humans.

In the summer of 1951 a series of jet flights designed to expose a pilot and passenger to periods of essentially zero gravity was accomplished through the co-operation of the Fighter Test Branch at Wright-Patterson Air Force Base. The aircraft was a modified F-80E with a prone position bed installed into the nose extension. This ship could be flown from the bed or from the conventional cockpit seat. First a brief explanation concerning how this is accomplished. The craft at full throttle in level or slightly descending flight, having reached a constant velocity is rather abruptly pulled up into an attitude vertical to the ground. At this point the power is reduced so that the craft describes a ballistic, rocket like trajectory, deceleration as it ascends, reaching zenith, and then accelerating in its descent at the rate of 32 feet per second. Further, it should be stated that while the aerobee rocket begins its zero *g* flight at a velocity of 1 mile per second, the jet enters this zero *g* pattern at about 1/6 that velocity. Hence, while the aerobee rocket gives a 3 to 4 minute zero *g* period, the F-80 gave only 15 to 25 seconds. Both the pilot and the passenger were instrumented to obtain heart rate and an electrocardiogram. The pilot's compartment was instrumented with accelerometers in three axes and recorded with an accuracy of plus or minus 1/50 *g*. During each flight the subjects were given eight to ten subgravity runs that averaged 15 seconds duration. The longest zero *g* run last-

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ed slightly over 20 seconds. Passengers and pilots were instructed during several runs to nod and shake their heads while in the zero *g* phase of the maneuver. No ill effects were noticed. However, when the subject continued the head motion during the 3 to 4 *g* pull-out, vertigo was frequently the result. As long as the subject was held firmly in place by his safety belt and had a point of visual reference, he was, with moderate effort, able to maintain his sense of orientation. However, it was the opinion of the participants that had they been unrestrained and blindfolded, disorientation might have been extreme. Co-ordination was unimpaired. The mild tendency to overreach could easily be controlled by looking at the object of the reaching maneuver. There were no significant alterations in heart rate or electrocardiogram during any of the runs. In summary, thirty zero gravity runs averaging 15 seconds each gave no suggestion of motion sickness, vertigo or in-co-ordination attributable to the sub-gravity state.

A second physiological problem in rocket type aircraft which I would like to present is that of prolonged acceleration. In order to attain the necessary altitude and velocity for a free ride through space, one must first undergo a certain acceleration for a certain length of time. The velocity thus attained is termed "escape velocity" and is that velocity which will free an object from the earth's gravitational field. The physiological problem of attaining escape velocities would be simple were it not for the mechanical one. For instance, a 3 *g* acceleration for 9½ minutes would give an escape velocity and is physiologically satisfactory, but mechanically, it is costly from the fuel economy standpoint. The reverse would be true however, of a 30 *g* acceleration for 44 seconds. This would give an escape velocity which might be mechanically sound but would certainly be physiologically unwise. A compromise must be made. It was the purpose of this second group of experiments to determine the optimum acceleration one could safely undergo in attaining this escape velocity. It was believed that this would represent the greatest length of acceleration one would be apt to experience in aircraft for many years. The human centrifuge at the Aero Medical Laboratory was used in performing these experiments.

TABLE I. ESCAPE VELOCITIES

Rate	*Time*	*Runs*	*Failed*
3g	9 min 31 sec	9	1
4g	6 min 21 sec	9	0
5g	4 min 45 sec	9	0
6g	3 min 48 sec	7	1
7g	3 min 10 sec	8	1
8g	2 min 40 sec	7	7
8g	2 min 40 sec	5	0
9g	2 min 20 sec	3	0
10g	2 min 6 sec	3	1

Table I illustrates the procedure followed and the results obtained. We began with a 3 *g* acceleration in the completely supine position. At this acceleration an escape velocity is effected in 9 minutes and 31 seconds. Nine subjects were run and eight runs completed. The common complaint was that of monotony. These runs were easily tolerated at 3 and at 4 *g* accelerations. The 4 *g* run in most cases was preferable to the 3 because of the shorter duration. At 5 *g* for 4 minutes and 45 seconds substernal pain developed in most of the subjects and this was coupled with a definite short-

TABLE II. CHIEF COMPLAINTS IN THE SUPINE POSITION

Rate	*Complaints*
3g	Monotony during and giddiness after accelerations
4g	Giddiness after accelerations
5g	Sub-sternal discomfort
6g	Severe sub-sternal discomfort
7g	Sub-sternal pain and shortness of breath
8g	Severe sub-sternal pain and shortness of breath
8g	Epigastric discomfort
9g	Severe epigastric discomfort and shortness of breath
10g	Epigastric pain and severe shortness of breath

ness of breath late in this 3 minute 10 second run. Following this and the higher accelerations the subjects frequently complained of muscular soreness of the chest lasting for several hours. Eight *g* represented the highest acceleration attempted in the completely supine position. Substernal pain. and the shortness of breath, despite active respiratory efforts, were most alarming to the subject. None of the subjects completed this 8 *g* run. At this point in the series of accelerations, in the attempt to relieve the shortness of breath and chest pain, the supine position was modified to a semi-supine or reclining seat with the chest and head elevated to an angle of 20 degrees. The knees were elevated to head level, and the eye to heart distance was approximately 7 inches in the vertical plane. The runs made in this position are indicated on the slide under the horizontal line between the two 8 *g* runs. In this position 8 *g* was tolerated by most of the subjects with relative freedom from chest pain and shortness of breath. At 9 *g* the runs were still tolerable but very definitely uncomfortable. Two out of three subjects went the full 2 minutes and 6 seconds of the 10 *g* run on their first attempt. Their complaints consisted of moderate shortness of breath, slight to moderate pain in the epigastrium and difficulty with the hyoid and glossopharyngeal musculature in breathing and swallowing.

It is interesting to note that by raising the head and chest to the 20 degree angle previously mentioned, the 8 *g* run was easily accomplished. The 9 *g* run in this modified supine position compared favorably with the previous 6 *g* run, while at 10 *g* in the modified position the complaints were comparable to the former 7 *g* acceleration.

As Table II points out, the chief complaints of the supine position at 3 *g* was monotony and giddiness. The incidence and duration of giddiness seemed to be most marked at lower accelerations. This may be due to the longer period of acceleration or may be the result of inexperience and lack of conditioning early in the series.

Substernal discomfort was characterized by a feeling of weight or pressure over the lower third of the sternum. When at higher accelerations the pressure became painful, there was radiation of the pain into the anterior portions of the chest bilaterally. When the semi-supine position was used this discomfort and pain was localized high in the epigastric region just under the tip of the xyphoid process. The mechanics of this pain and discomfort are thought to be muscular in origin. The etiology of the shortness of breath during the higher accelerations is probably a triad of emotion, decreased pulmonary ventilation and an altered pulmonary circulation.

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of prolonged accelerations, on the centrifuge at the Aero Medical Laboratory, we can make certain general observations. First that vertigo seems to be the result of head motion rather than from any particular position of the head during the accelerations. Second, the giddiness following each run was related more to the duration of the acceleration than to its intensity. Lastly, escape velocities can be tolerated at accelerations at least as high as 10 *g* in the semi-supine position. However, from the physiological point of view an accelerating thrust below 8 *g* probably represents the more acceptable acceleration.