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THE EFFECTS OF PROLONGED ACCELERATION ON THE HUMAN BODY IN THE PRONE AND SUPINE POSITIONS

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AERO MEDICAL LABORATORY

JULY 1952

WRIGHT AIR DEVELOPMENT CENTER

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SECURITY INFORMATION

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Aero Medical Laboratory

July 1952

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

McGregor & Werner, Dayton, O.
100 May, 1953

RESTRICTED

FOREWORD

This project was performed under RDO's 695-72 "Physiology of Rocket Flight" and 695-66 "Position, Prone, Pilot, Flying", by personnel of Wright Air Development Center using the Aero Medical Laboratory human centrifuge. Capt. E. R. Ballinger and Lt. C. A. Dempsey, who are the authors of this report, served as Project Scientists for RDO's 695-72 and 695-66 respectively. Acknowledgement is made of the assistance of R. U. Whitney, centrifuge operator, R. F. Managan, T/Sgt., USAF, assistant centrifuge operator, E. E. Martin, Capt. USAF for technical assistance and Drs. J. P. Henry and O. H. Gauer for their suggestions and advice.

ABSTRACT

Two acceleration problems of equal interest were studied simultaneously on the Wright Air Development Center human centrifuge at the Aero Medical Laboratory. Data were obtained in regard to both the evaluation of the prone bed at various accelerations and the concomitant determination of the physiological tolerance to prolonged periods of acceleration in semi-prone and supine positions. The duration of runs depended upon the acceleration, ranging from 15 minutes at 3 g, 8 minutes at 4 g, etc. to 2 minutes at 10 g. There was no appreciable difference in tolerance in the semi-prone or supine positions with accelerations up to 10 g. However, the necessity for a well-constructed bed and head-supporting helmet, primarily for the comfort of the subject, was repeatedly demonstrated. In properly designed prone and supine beds, 23 unprotected subjects were able to tolerate accelerations up to 10 g for 2 minutes with only a small amount of discomfort. The security classification of the title of this report is UNCLASSIFIED.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

for ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

The aeromedical problems associated with accelerations encountered in flight have dealt until recently with a relatively short-term application of g force, such as that found during conventional aircraft maneuvers which usually last less than 15 seconds. However, with efforts being directed toward the incorporation of high degrees of maneuverability into modern and future highspeed aircraft, typical combat maneuvers could present dangerous difficulties for the conventionally seated, g-suited pilot. Radial accelerations may be sufficiently high to cause him to black-out and may also be of sufficient duration to make black-out and its associated conditions major combat hazards. For instance, an aircraft traveling at a velocity of 200 miles per hour could execute a 180° turn in 5.7 seconds by pulling 5 g of radial acceleration. However, for an aircraft traveling at 1000 miles per hour, 28 seconds of 5 g radial acceleration would be necessary to perform the same maneuver ($t_2 = \frac{V_2 t_1}{V_1}$).

Present fighter aircraft are stressed to a minimum of 7.3 g and a maximum of 11 g. Thus, our modern aircraft can already withstand g forces which are above the range of protection afforded the pilot in the conventional seated posture by the g-suit. Such forces, if sufficiently prolonged in duration, will cause marked fatigue, shortness of breath, edema of soft tissue and petechial hemorrhages in dependent limbs of subjects in the prone or supine position. Hence, it was in anticipation of possible future requirements for even higher accelerations of even longer duration that this study was undertaken.

COMPARATIVE ACCELERATION TOLERANCES

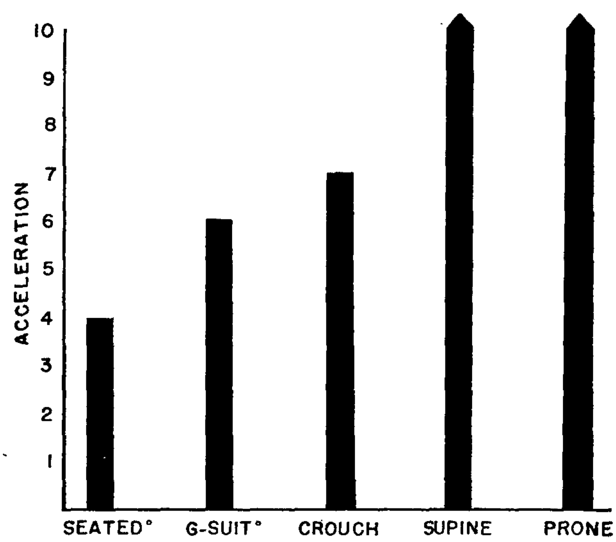

Figure 1

Since it was known that the postural protection of the supine or semi-prone position is considerably greater against g force than that afforded by other devices (Fig. 1), the conventional seat and the g-suit were discarded and the subject was placed in a semi-prone or supine position on the floor of the centrifuge cab. Runs were made at accelerations ranging from 3 through 10 g. Since our interest was in part directed toward determining the peak g tolerable for the average subject for an appreciable period of acceleration, it was decided to use as our criterion for the duration of the runs the approximate time needed to achieve gravitational escape velocities at accelerations between 3 and 10 g. It is believed that this period probably represents the longest exposure to acceleration that might be expected to be encountered for a number of years. Most of the subjects were non-rated personnel of average pilot age, and many had no previous experience as subjects on the human centrifuge. The subjects ranged in height from 5 feet 3 inches to 6 feet 1 inch and from 135 to 215 pounds in weight, and were therefore representative of 90% of the Air Force population in regard to height and weight.

SECTION I

METHOD OF CONDUCTING STUDIES

These acceleration studies were carried out on the Wright Air Development Center centrifuge at the Aero Medical Laboratory. The centrifuge has a 20 foot radius and is capable of producing 20 g. Although it is operated from the control room, either the center observer or the electrocardiogram observer in the instrumentation room can make emergency stops. The cab carrying the subject is so constructed as to swing outward under acceleration.

The subject was in voice contact with the centrifuge operator and the observer riding center. He was equipped with a hand-grip containing three switches and confronted by a light panel and buzzer system. He was instructed as to which switch operated the center light, the peripheral light and the buzzer, and during the run he was required to talk to the observer and to answer any combinations of light and buzzer signals by use of the proper switch. Failure to respond to the signals resulted in immediate stopping of the centrifuge. During acceleration in the prone position studies, tape recordings were made of the voice of the subject, who was required at various times to read word lists and to perform memory association tests prepared by the Psychology Branch of the Aero Medical Laboratory.

Direct-writing electrocardiograms were taken during accelerations in excess of 5 g with the subject in the supine position. Because of mechanical difficulties at high accelerations, the patterns frequently were not clear. However, heart rate was easily discernible, and in those cases where good patterns did result, no abnormalities were seen.

In the supine position an ordinary cotton mattress provided sufficient comfort up to 6 g acceleration. Above 6 g a semi-supine bed (Fig. 2) was

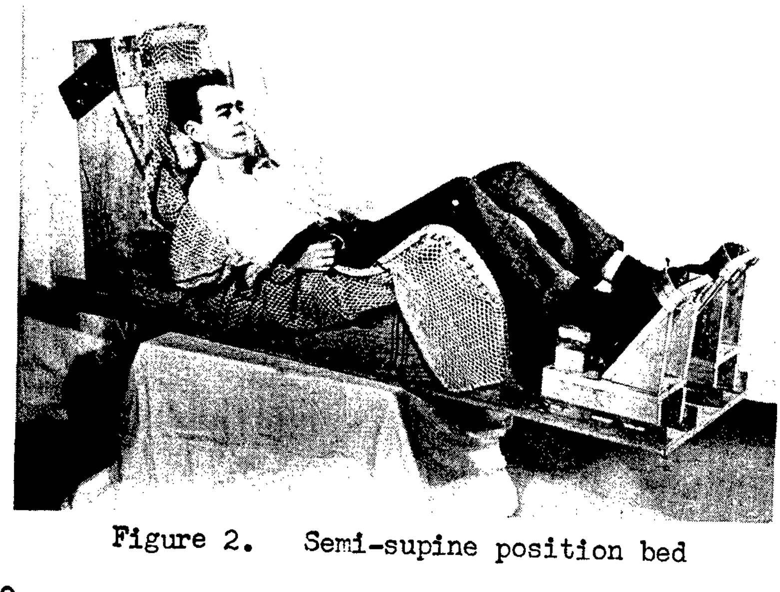

Figure 2. Semi-supine position bed

used. In the prone studies the prone position bed (which is described in Section III) was used, but at accelerations greater than 2 g the chin rest became uncomfortable and the prone position helmet (Fig. 3) was used.

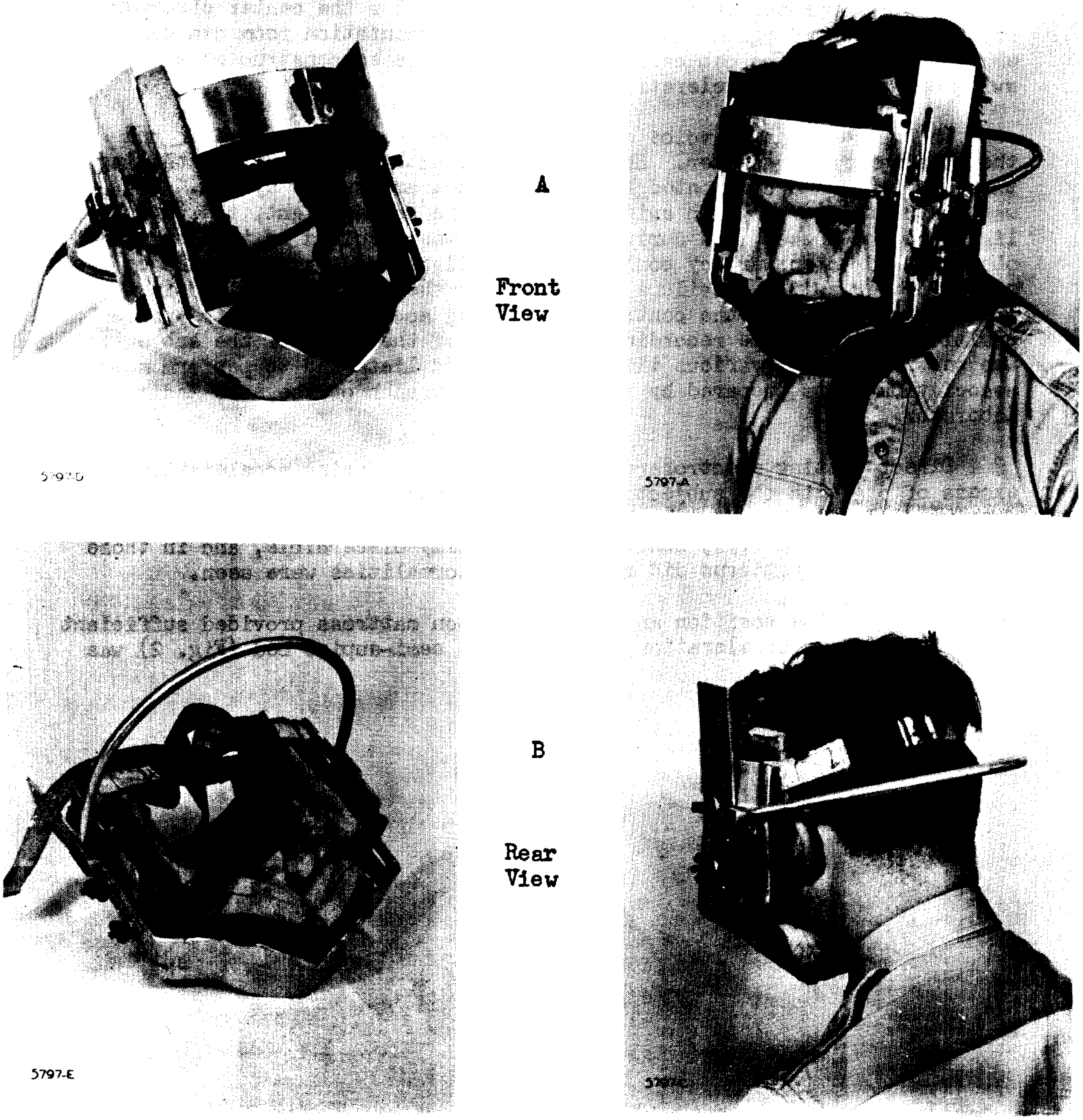

Figure 3 Prone Position Helmet

This helmet is constructed of aluminum with a layer of foam rubber, cut to face contour, on the inside. The jaw support area is adjustable to fit various face lengths, and nylon straps fit over the head to hold the helmet in correct face position. The entire assembly is supported by a counter-balanced weight located on the right rear side of the bed. The helmet carries the complete head load and permits easy neck movements while under high g forces.

The gravitational escape velocity-time curve at accelerations from 3 to 10 g (Fig. 4) was used because it seemed to represent the probable limit of duration of accelerations for aircraft maneuvers in the next few years.

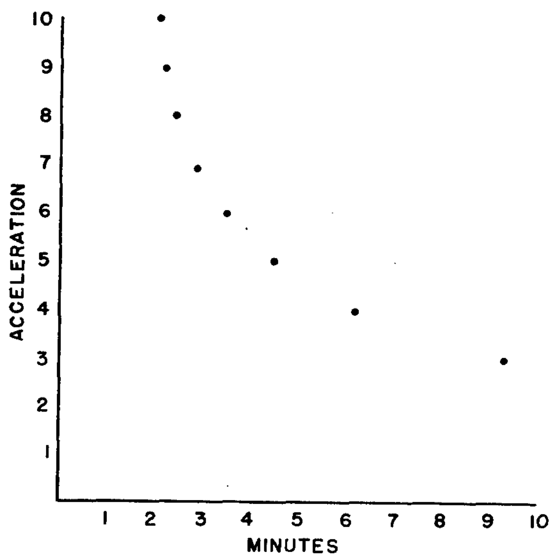

Figure 4. Gravitational Escape Velocities

The data concerning each series of accelerations from 3 to 10 g are presented in this report on a basis of each acceleration, with no conscious effort being made to integrate the whole. In Section IV, "Evaluation of Tolerance to Prolonged Acceleration", an attempt is made to compare the various accelerations in regard to physiological findings.

SECTION II

SUPINE STUDIES

The terms vertigo, dizziness and giddiness will be seen frequently in this report and are not intended by the authors to be used interchangeably. For our purpose, vertigo will be considered an apparent sense of motion, either of the surrounding environment (objective vertigo) or of the subject (subjective vertigo), and may be either rotational, linear, tilting, spinning or tumbling in character. Dizziness is intended to describe a groggy or drunken sensation accompanied by incoordination and lack of equilibrium and not associated with any particular sense of objective or subjective motion. Giddiness is used in this report to indicate closely allied feelings of light-headedness, pallor and upset stomach or anorrexia with or without any frank nausea and not associated with loss of equilibrium.

A. ABSOLUTE SUPINE POSITION

At 3 g acceleration the supine bed consisted of an ordinary cotton mattress, upon which the subject lay flat with head very slightly pillowed. The subject was within verbal, light signal and buzzer contact of the observer who rode the center of the centrifuge and had the subject under his complete view during the entire run. Ten men were subjected to 15-minute periods of 3 g accelerations each. While this duration was considerably greater than the previously described 3 g escape velocity time of 9 minutes and 31 seconds, the longer time was chosen to exaggerate any possible time factor in the production of giddiness. Nine individuals completed the 15-minute, 3 g acceleration. One subject with a history of air, car, and swing sickness failed to complete the 3 g run.

The chief complaint of all subjects during the run was that of monotony. All reported a marked objective vertigo occurring simultaneously with any head motion and ceasing immediately as the movement of the head was halted. Eye motions alone caused no untoward symptoms. Subjects preferred to move their arms and legs occasionally to relieve areas of pressure in the calves, elbows and buttocks. Although there was no prescribed schedule of motions at different g-levels, it was found that all normal motions of the extremities could be performed except for stiff-kneed leg raising. There was no diminution of accuracy or speed in answering light signals during the 3 g run. Respiration was not difficult; speech was good despite a sense of fullness or a lump in the region of the glottis experienced by most of the subjects. Post-run fatigue was slight if present at all.

The symptoms of each subject following the 3 g run were similar in nature and varied only in degree. Most subjects experienced a desire to lie perfectly still for 5 to 15 seconds after the centrifuge cab had come to a halt. This desire became more marked following higher accelerations and at 8 - 10 g the subject was content to lie still for as long as a minute before arising. During this brief period, motion of the head through an arc exceeding 10 - 15 degrees produced no simultaneous vertigo, but within the next several seconds a marked but transitory giddiness, pallor and nausea frequently occurred. The subject was capable of arising and getting out of the cab unassisted, but he walked with a slightly drunken gait. However, within 1 to 3 minutes equilibrium was fully restored and he was able to walk a line and stand on one foot with or without eyes closed. The feeling of giddiness persisted sometimes for as long as an hour.

The 4 g accelerations were of 8 minutes' duration, followed in each case by a deceleration to 3 g for 1 minute in order to obtain better comparisons. In contrast to the results in the 3 g run, none of the 9 subjects, all of whom completed this trial, complained of monotony. This is perhaps due in part to the number of other complaints, many of which were found to increase in intensity at higher levels of acceleration. Interestingly enough, however, most subjects preferred the 4 g 8-minute mild discomfort to the 15-minute period of monotonous 3 g acceleration. The main complaint was a feeling of fullness in the throat, accompanied by a constant but controllable desire to cough and clear it, and was in part relieved by elevating the head 5 to 10 degrees by using a small pillow. A second common complaint was discomfort along the lower border of the rib cage, extending bilaterally from the epigastrium to the mid-axillary line. It occurred late in each run, was increased on inspiration and diminished by abdominal-type breathing, and did not amount to pain. Inspiration at 4 g was slightly laborious. However, there were no complaints of fatigue. As with the 3 g acceleration, all normal motions of the extremities save for stiff-kneed leg raising were possible but increasingly difficult. Post-acceleration complaints were similar to those at 3 g and consisted of dizziness and subsequent giddiness.

Immediately on reaching the 4 g mark, one subject in the supine position experienced an extremely sharp stabbing chest pain located in the lower portion of the right side anteriorly. The pain was pleuritic in type, causing the subject to gasp, but disappeared immediately before he could signal the observer. He completed this run and had no ill effects, but he was dropped from any further tests at higher accelerations. It is believed that this episode was probably due to a pulling or tearing of a tiny pleural adhesion.

All nine subjects successfully completed the 5 g acceleration for 5½ minutes. The feeling of pressure along the lower rib border anteriorly was increased, but of more concern to the subjects was discomfort due to a sense of pressure over the lower third of the sternum and rather marked inspiratory effort. At this point we became interested in relieving these symptoms and considered whether pressure breathing might assist the inspiratory effort and, by aiding the inflation of the rib cage, also reduce the discomfort from pressure on the sternum and lower rib border. Accordingly, the 5 g accelerations were repeated with the subjects using pressure helmets that could be manually varied in pressure up to 25 mm Hg. Results of these comparative runs showed little improvement. While the discomfort of the lower rib border was alleviated, the sense of chest pressure occurred over the middle third of the sternum and seemed to increase in severity with an increase in breathing pressure. Inspiration was slightly less labored. Post-acceleration complaints again resembled those of the 3 g acceleration.

The 6 and 7 g accelerations ran for 4½ and 3½ minutes, respectively. Eight subjects were used. Although the chest pain occurring in the 5 g runs was not of the coronary type, nevertheless electrocardiograms were taken during each supine run above 5 g. A moderate increase in heart rate of 10 - 15 per second was evident; however, there were no pattern abnormalities observed. One subject who failed to answer the light signals after 4 minutes of the 6 g run, complained of severe chest pain over the sternum, extending into the left shoulder. This pain could be duplicated by pressure on the sternum during the examination that followed.

Seven subjects completed the 6 g run. All experienced considerable chest pain and marked difficulty with inspiration, coupled with moderate shortness of breath at the end of the $4\frac{1}{2}$ minute period. Speaking was very difficult due to the decreased amount of pulmonary ventilation. Several words were all that could be spoken following one inspiration. Discomfort in the completely supine position at 6 g was sufficient to interfere with accuracy and promptness in answering light signals, and when the acceleration was increased to 7 g, it became obvious that we had reached the functional limit of the subject in this position. Following the 7 g run, most of the subjects complained of muscular soreness in the chest lasting for several hours. All subjects failed to complete $2\frac{1}{2}$ minutes at an 8 g acceleration.

B. SEMI-SUPINE POSITION

The failure of any of the subjects to complete an 8 g run of $2\frac{1}{2}$ minutes' duration was entirely due to physical discomfort. Hence at this point numerous trials were made in order to determine the most comfortable supine position of the head, arms, trunk and legs. As a result of these trial and error attempts, the supine position,was modified in the following manner: The body was flexed at the hips so that the head, chest and abdomen were raised to an angle of approximately 20 degrees above horizontal and the neck was slightly flexed by pillowing the head so that a heart-to-eye distance of 7 inches in the vertical plane resulted. The knees were propped up to the level of the head, and thus a semi-supine or reclining position was obtained (see Fig. 2). With a firm but comfortable support holding the subject in this position, we again attempted the 8 g runs. With this relatively small change in body position the 8 g acceleration was easily accomplished, and the subjects registered no complaints of chest pain. Respiration was not difficult and shortness of breath not apparent. Accuracy and promptness in response to signals were satisfactory, in marked contrast to the performance during the 6 and 7 g runs in the completely supine position. At 8 g acceleration, movement of the subject was primarily limited to hand, wrist and ankle action. With considerable effort the arms could be flexed. The head could be turned but not raised. Similarly, the position of the legs could be changed only by rotation at the hip. Post-acceleration incidence and duration of giddiness was not excessive.

The 9 g acceleration for 2 minutes and 20 seconds was accomplished by all subjects. Results compared favorably with the physical stress of the previous 5 and 6 g runs in the completely supine position. Complaints, therefore, were similar and consisted of epigastric discomfort, moderate shortness of breath and speech difficulty due to decreased volume of complementary and supplementary air. Response to light and buzzer signals was unimpaired. Post acceleration giddiness was similar to that previously experienced.

Two out of three subjects went the full 2 minutes and 6 seconds of the 10 g acceleration on the first attempt. Their complaints consisted of moderate shortness of breath, slight to moderate epigastric pain and mild to moderate difficulty with the throat musculature in breathing and swallowing. Speaking could be done only with great effort, and then only one or two words could be uttered per breath. Understanding of the spoken word was moderately difficult. There was no impairment of response to light and buzzer signals. No visual disturbances occurred, and the subjects remained mentally clear.

The runs were discontinued above 10 g, not because it was believed that this figure represented the highest tolerable acceleration but rather because the experiment had been completed as planned.

SECTION III

PRONE STUDIES

The initial runs from 3 g to 6 g were accomplished with the semi-prone position bed (1) (Fig. 5).

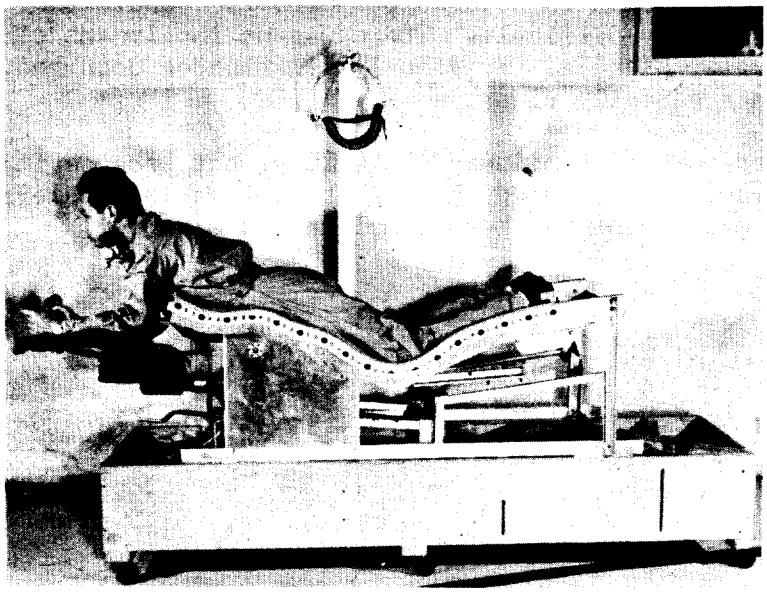

Figure 5. Semi-prone Position Bed

The only modification of the bed was the use of the head support helmet instead of the chin rest. This change was made because actual flight test of the jaw rest had proved it unsatisfactory at forces ranging from 1 to 3 g in intensity.

Thirteen subjects rode the centrifuge for 15 minutes at an acceleration force of 3 g. Three subjects out of the total group failed to complete the 15-minute period; two of these experienced giddiness with nausea, while the third suffered vertigo. At this g level the major complaint was of pooling of blood in the lower forearm and hands and subsequent petechia. Secondary complaints consisted of general monotony, nasal drip and dryness in the mouth. All subjects reported varying degrees of vertigo occurring simultaneously with head motion. Body and extremity movements were accomplished without any appreciable difficulty. Respiration was heavy in the early stages of the test and became difficult from the 10-minute period until completion of the run. All subjects moved their arms and legs occasionally to relieve pooling of blood in lower forearms, legs and other areas of the body. The symptoms of each subject following the 3 g run were similar and varied only in degree.

The 4, 5 and 6 g tests did not produce any appreciable change in complaints or symptoms, only an increase in severity. However, petechiae became a major problem at these higher g values and ranged in intensity from marked to severe (Fig. 6). To remedy this problem, the arms were repositioned from the vertical to the horizontal position (Figs. 7 & 8),

Figure 6. Petechiae of Left Arm

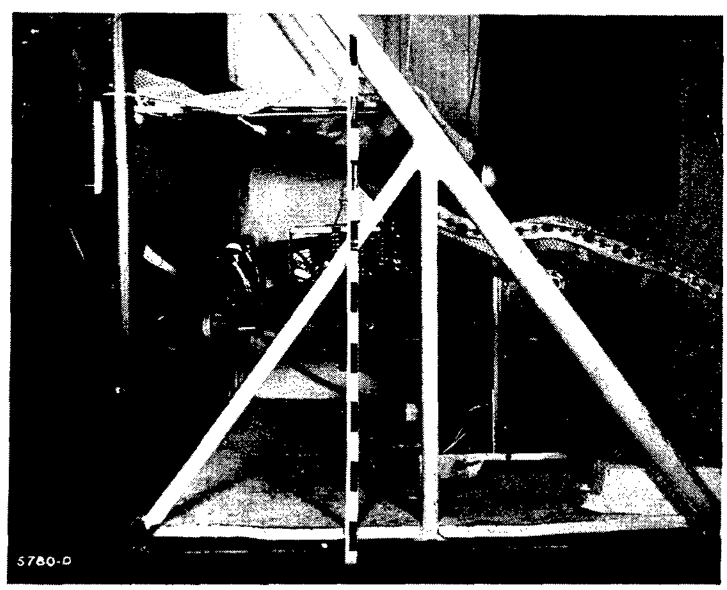

Figure 7. Semi-prone bed with modification to reposition arms to horizontal

Figure 8. Subject in modified semi-prone position

thus placing the hands and lower forearms in the same horizontal plane as the heart. The authors reasoned that this move would lower both the quantity and pressure of blood in the lower arms and hands. Tests thereafter proved this plan of action to be very satisfactory. Figure 9 shows a subject in this position during an actual g run.

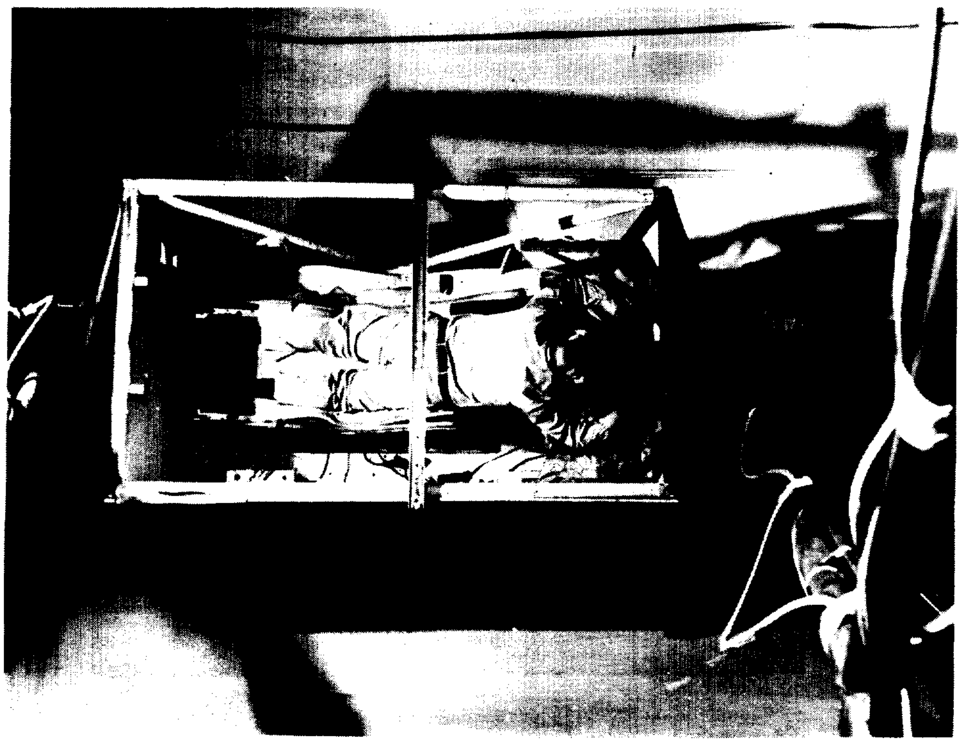

Figure 9. Subject in modified semi-prone position during actual g run.

The 8 g test called for 2 minutes of exposure, and all thirteen subjects successfully completed the run. General complaints are listed in the relative order of their importance.

1. Pooling of Blood in the Knees and in Several Instances Moderate Cases of Petechiae.

The pooling of the blood could be relieved temporarily by exerting pressure against the foot rest. This procedure moved the knee up from its "bottom of the well" position, thus permitting the blood to flow into the feet. When the pressure was relieved and knees moved back onto position, the blood immediately started to pool again.

2. Difficulty in Breathing.

Usually the subjects experienced a very marked shortness of breath while under g stress but returned to normal within a very few minutes after completion of run.

3. Nasal Drip and Mouth Watering.

These conditions generally began around 3 g and increased in intensity as the g force went up. The complaint did not produce any pain but only annoying discomfort.

4. Sagging Lower Eye Lids.

This complaint was mentioned by five subjects, but had not been experienced in any previous run by any subject. It was reported to be very annoying but did not interfere with the reading test or signal light response.

5. Dizziness after Run.

Six subjects experienced this condition. The best remedy was lying quietly on the bed for a minute or two until equilibrium was reestablished. Marked signs of pallor and vertigo were generally observed during this period.

At this g level the subject could move his body and extremities only with great effort and in general moved only to relieve pressure areas in the legs and body.

A total of nine subjects participated in the 10 g run for a period of two minutes. Four subjects completed the run, and one went for one minute and thirty seconds. The remaining four completed only one minute of time before the run was stopped. The five subjects who failed to complete the run were stopped because they all complained of severe choking in the lower throat. An analysis of stature and weight of the various subjects gave the answer to the choking problem. The subjects who did not complete the run ranged in size from 5 feet 11 inches, 190 pounds to 6 feet 1 inch, 208 pounds. These men were observed to ride low and to the rear in the bed when a value of 8 g was exceeded. In this position the throat pressed on the forward edge of the bed, resulting in the choking condition. The subjects who did complete the 2 minute period ranged in size from 5 feet 7 inches, 135 pounds to 5 feet 10 inches, 185 pounds. This group appeared to ride high and slightly forward on the bed when acceleration was in excess of 8 g.

A nylon net was used for body support on the bed. This material has a smooth surface which allows the body to slide over it very easily. The present net will stretch when a load is applied and will continue to stretch as the force becomes greater. Thus, a heavy man will ride much lower in the bed than a lighter man.

To remedy the above situation a large sheet of foam rubber, 1 inch thick, was laid over the net (Fig. 10).

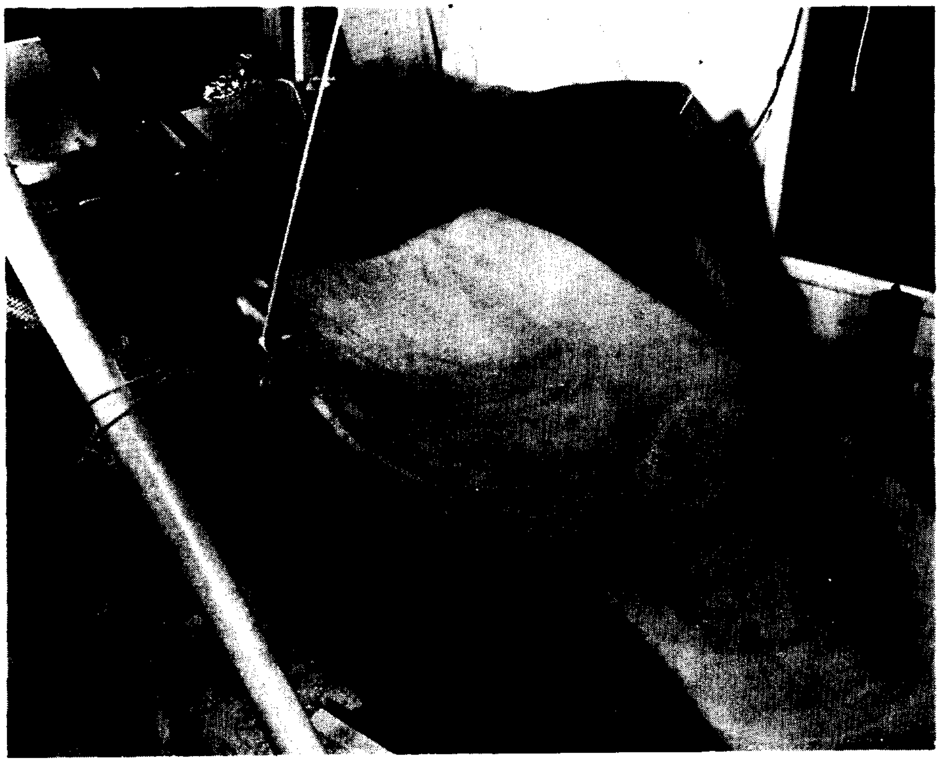

Figure 10. Foam Rubber Layer on Semi-Prone Bed

The foam rubber increased the subject's height above the net and also stopped any tendency to slide fore or aft on the bed. Later repeat runs at 10 g for 2 minutes proved this solution to be satisfactory and the 6-foot, 208-pound subject was capable of completing the run without the choking sensation. Complaints upon completion of the 10 g test were the same as those listed for 8 g with a generally higher degree of severity.

In addition to those runs performed for the tests as planned, two experimental runs to 12 g for 30 seconds were completed. Both subjects complained of tears in the eyes and subsequent examination by a physician confirmed the fact that tears had been present. Subjects were able to mo both extremities with difficulty during the runs, and no petechiae were o served in the arms or legs. Breathing was difficult, and both subjects experienced dizziness for 5 minutes after the runs.

SECTION IV

EVALUATION OF TOLERANCE TO PROLONGED ACCELERATION

Accelerations up to 10 g were tolerated by most untrained individuals for comparatively long periods of time in semi-prone and supine positions without g suit protection. At the highest of these accelerations there were normal vision and mental clarity. The subject conversed in monosyllables, responded to visual and auditory signals accurately, and retained relatively unimpaired mobility of the hand, wrist and ankle.

Since physical discomfort and difficulty in breathing have been the limiting factors in man's tolerance to prolonged acceleration, an evaluation of the prone and supine position will necessarily revolve about these two points. There are several complaints that are common to both prone and supine positions. These can be listed as vertigo, post-acceleration dizziness, giddiness, shortness of breath, difficulty in speaking and fatigue. Several other complaints are limited to only the supine position (chest pain, epigastric pain and fullness in the throat) while a few difficulties are experienced only in the prone position (edema of periorbital tissue, nasal drip, and petechiae on dependent limbs).

A. Vertigo

Movement of the head during acceleration results in the simultaneous onset of marked vertigo and disturbance of equilibrium. These unpleasant sensations result from the directional change of accelerative force upon the vestibular apparatus and vanish immediately as head motion is arrested.

B. Post Acceleration Dizziness and Giddiness

The dizziness immediately following the acceleration is similar to that experienced immediately after rotation in the Barany chair and can be largely eliminated by holding the head motionless for 15 - 30 seconds. The giddiness which is frequently an unpleasant after-effect of a prolonged acceleration is akin to motion sickness, and like mild episodes of the latter it may clear up completely after eating.

C. Chest and Epigastric Pain

The discomfort along the lower rib border with the subjects in the completely supine position was aggravated by inspiration, reduced by pressure breathing and the semi-supine position, and was not present in the prone studies. This probably indicates that the cause of the discomfort was tension on the anterior leaves of the diaphragm by the encroaching weight of the liver. The etiology of the sternal pain is unknown. That it is coronary appears unlikely since in some cases it could be simulated by pressure over the chest and also since there was no change in electrocardiogram pattern. This sternal pain, like the rib border pain, was diminished in the semi-supine position and absent in the prone position, but unlike the former, it was unaffected by respiration and was heightened by pressure breathing.

D. Throat

The desire to clear the throat and the sensation of fullness was no doubt due to sagging of the soft tissue in the region of the base of the tongue. An interesting feature was the cough common to most subjects following the higher accelerations in the supine and semi-supine positions. This cough occurs during the first 10-15 seconds after the cab has stopped or in some cases while it is still in the process of deceleration. The phenonenon has been noticed many times following 15-second runs at 4 - 6 g in the seated position with g-suit protection, but it rarely occurs after a prone acceleration.

E. Shortness of Breath

This symptom is common to the supine and prone position under high accelerations and is perhaps more pronounced in the supine. In part, of course, it is due to the increased difficulty of inspiration, resulting in diminished tidal air, and is evidenced by the inability to speak more than several words per breath. However, the subjects frequently reported that while they felt that they were breathing deeply and regularly, they were, nevertheless, very short of breath. Hence, it is the opinion of the authors that there may be other limiting factors perhaps equally important, such as the increased physiological and psychological stress imposed by high accelerations. Also the possibility of a shift of the pulmonary circulation toward the lowermost areas of the lung should not be overlooked. Further studies with motion picture x-ray may clarify the matter.

F. Edema of the Soft Tissues and Petechiae

In the prone position studies, edema of the periorbital tissue and nasal mucosa occurred in sufficient degree to be moderately uncomfortable. In the completely prone position (i.e. body entirely horizontal) this occurred at 3 g acceleration. However, in the semi-prone bed, edema appeared only at accelerations above 7 g. The edema lasted several hours and sometimes caused a frontal sinus headache.

CONCLUSIONS

From the foregoing experiments, it is concluded that the limiting factor of human tolerance to prolonged acceleration above 12 g will be marked hypoxia, as indicated by the degree of respiratory difficulty already present in accelerations at the lower g levels, and that the physical discomforts can be largely eliminated by proper modification of the semi-prone and supine positions.

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