THE USE OF LOWER BODY NEGATIVE PRESSURE AS A MEANS OF -Gz Protection

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The development of more maneuverable aircraft may expand the acceleration envelope to include both +Gz and -Gz acceleration. Currently human unassisted physiologic tolerance to sustained -Gz acceleration is approximately -2.5 Gz. The purpose of this study was to investigate the use of Lower Body Negative Pressure (LBNP) as a means of increasing -Gz tolerance. Ten subjects were seated at a zero degree seatback angle with their head outward away from the center of rotation in a human centrifuge. The subjects were exposed to -50, -100 mm Hg gauge pressure as well as ambient pressure while experiencing -1.0, -1.5, and -2.0 Gz plateaus for 30 seconds in duration. The tests were conducted on the Dynamic Environment Simulator, a three axis man rated centrifuge located at Wright-Patterson AFB, OH. Electrocardiographic data showed that significant decreases in heart rates occurred at -2.0 Gz with ambient suit pressure. Comparing the same -Gz level with -100 mm Hg, heart rates increased by 56% indicating that blood was being pooled in the lower body during the -Gz exposure. In addition, subjective data indicated that subjects experienced a decrease in cephalad pressures with the aid of LBNP for all -Gz exposures. LBNP at pressures between -50 to -100 mm Hg appears to be a viable means of counteracting the adverse physiologic effects of -Gz acceleration.

INTRODUCTION

The maneuvering capabilities of future aircraft will present new challenges to the acceleration protection community. Some of these new found capabilities are being brought on by the development and incorporation of composite materials into the airframes of the future. The aircraft of tomorrow may expose pilots to moderate levels of positive and negative acceleration in all six degrees of freedom. From a historical point of view, researchers working in the area of acceleration protection, have shown that man can tolerate moderate exposures to gravitational forces in most degrees of freedom.

This early work also revealed that -Gz (foot to head) acceleration was the least tolerated. Acceleration in the -Gz direction is not only the least tolerated, but also an area where the least amount of G protection research has been performed over the past forty years.

In an effort to try to expand the operational envelope for future fighter aircraft, as well as to increase the technological envelope of future aircraft design, the Harry G. Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB has developed and tested a negative G-suit. This suit used the concept of Lower Body Negative Pressure (LBNP) as a means of pooling blood in the lower half of the body preventing the large autotransfusion of blood toward the head that is typically seen during exposures to -Gz acceleration.

SUBJECTS

Ten healthy young men (age: mean 28.1 years, S.D. 3.48 years; weight mean 69.9Kg S.D. 14.2 Kg; height: mean 170.1 cm, S.D. 6.46 cm), members of the Acceleration Stress Panel at Wright-Patterson AFB, were used as subjects. The subjects were given detailed information and instructions concerning the experimental conditions before obtaining their consent.

METHODS AND MATERIALS

The negative G-suit concept involved an in-house development effort to design and build two sizes of Lower Body Negative Pressure (LBNP) suits (Figure 1). Each suit is constructed from polyethylene and a Kydex hard shell infrastructure; a neoprene-impregnated nylon material formed the soft shell outer surface of the suit as well as the waist seal. Latex rubber boots at the distal end of the legs formed the seal at that end of the suit. One inch diameter evacuation ports and 1/8 inch diameter pressure monitoring ports were located on the anterior left and right thigh sections of the suit.

Evacuation of the suit was accomplished through a 1 inch diameter wire reinforced hose which connected the suit to a vacuum source. The vacuum was a commercial grade 13 ampere vacuum motor capable of creating a 22 cubic foot per minute flow rate. Suit pressures were measured by an Omega pressure transducer and controlled using a 24 v DC electronic solenoid valve. Both the valve and pressure transducer were patched through the slip rings (two or more continuous conducting rings capable of transferring data using brushes to pick up or deliver current) of the Dynamic Environment Simulator (Figure 2) the AAMRL human centrifuge, and interfaced with a Zenith 148 (Z-148) computer. The Z-148 monitored and controlled suit pressure by opening and closing the solenoid valve.

Each subject was exposed to -100, -50, and 0 mm Hg LBNP while accelerated to -1.0, -1.5, and -2.0 Gz. All levels of LBNP and -Gz were randomized using a 3x3 matrix, each subject was limited to no more than three -Gz exposures per day.

A typical series of tests consisted of the test subject being instrumented with a three lead EKG then donning the LBNP suit. The waist seal was accomplished using benzoin adhesive on the skin then adhering the suit to the prepared area. This process was completed by wrapping elastic bandage material around the subject's waist. The subject then donned a PCU-15 harness (used for emergency egress).

Upon entering the cab, the subject was seated (Figure 3) with his head facing outboard from vertical. The subject was then secured into the seat for the experiment. The seat was preset to a reclined seat back angle of 65 degrees. The gondola was then offset another 25 degrees so as to align the subject in a longitudinal axis in relation to the centrifuge arm.

The vacuum pump was started with the valve controlling evacuation of the suit turned off. After the vacuum reached maximum operating speed the valve was then opened and the computer maintained and controlled suit pressure to the designated level of negative pressure. An eight channel Cleveite strip chart recorder and a PDP-11 computer recorded the drop in suit pressure as well as heart rate and Gz level. Within 10 - 15 seconds the subject was accelerated to the desired -Gz level at a rate of 0.1 G/sec. The duration of the plateau lasted 30 sec after which time the subject was decelerated at the same 0.1 G/sec offset rate. LBNP was maintained and EKG data were recorded throughout the exposure. Each exposure was videotaped and voice communications were maintained and also collected.

RESULTS

An analysis of variance was performed using heart rate percent of pre-baseline for LBNP on as the dependent variable. Factors used were pressure, -Gz, and subject (random). If an F-test was significant, paired t-tests were used for pairwise comparisons. T-tests were also used to determine whether percents were significantly different from 100%. Significance was determined at the .05 level.

The use of the negative G-suit and the application of -50 and -100 mm Hg LBNP, successfully protected all 9 subjects from the adverse physiological effects of -Gz acceleration.

Heart rate data in the form of percent change from baseline for all -Gz levels and pressures are illustrated (Figure 4). These data show a significant reduction of the effect of -Gz on heart rate when LBNP is applied. By taking the percentage of the mean heart rate at -2 Gz at 0 mm Hg and -2 Gz at -100 mm Hg an average

increase of 56 beats per minute is observed within this condition.

In addition to the heart rate data, subjective data were also collected. These data showed that subjects experienced less cephalad pressure when LBNP was applied for all -Gz levels compared to the unprotected condition.

DISCUSSION

Efforts to protect against -Gz acceleration in the past have used pressure of the head and/or neck mechanically or pneumatically from a helmet as a method to decrease the baroreceptor response to -Gz acceleration (5,11). Other methods have included the use of arterial occlusion cuffs on the lower extremities in an effort to decrease cephalad venous pressure with -Gz. These have been somewhat successful in reducing measured venous pressure (5,11). The adverse physiological effects of -Gz includes the increase in cephalad (headward) venous pressures that cause many of the painful sensations of facial pressure, sinus pain or pressure. The increase in cephalad arterial pressures affects the carotid sinuses and other baroreceptors in the wall of the aortic arch causing a reflex increase in vagus nerve impulse which decreases heart rate (10). The baroreceptors are very sensitive to large changes in arterial pressures especially from baseline values (4) and -Gz acceleration has been shown to cause periods of asystole, sinus arrest (6,11), and occasional incapacitation (2,7) from baroreceptor stimulation.

LBNP causes many cardiovascular changes which counteracts adverse physiological effects of -Gz. LBNP decreases right and left heart volumes, and shifts 500 - 1,000 cc of mostly venous vascular volume towards the pelvis and legs (14) decreasing the load on the baroreceptors.

LBNP involves the application of reduced atmospheric pressure to the lower portion of the body. This results in pooling of blood in the lower extremities and lower portion of the abdomen and a reduction in the central venous blood volume. The stress imposed by this blood volume loss results in circulatory reflexes that attempt to compensate for these changes. One example of these compensatory changes is increased heart rate (8,14).

When LBNP is applied to the lower body the vascular transmural pressure difference increases are directly related to the level of reduced atmospheric pressure. This decrease in pressure leads to expansion of capacitance vessels (or veins) and pooling of blood and some plasma filtration into the extravascular spaces. Measurements of the amount of blood that pools during LBNP vary. Musgrave, et al., measured leg volume changes at -40 mm Hg LBNP and reported pooling of 500 - 600 cc of blood in the legs (9). In general studies have shown that approximately 500 to 1,000 cc of blood is pooled during -30 to -50 mm Hg LBNP depending on individual physiology and experimental technique (14).

As blood is pooled in the lower extremities blood returning back to the heart is reduced and causes a reflex increase in heart rate. The changes in cardiovascular parameters with low level LBNP are similar to those seen in patients who are hypovolemic from hemorrhage (14,8). In a study conducted by Frey *et al.*, women exhibited a higher increase in heart rate response to LBNP when compared to heart rates of men (1).

Tripp *et al.*, have used LBNP in a 45 and 90 degree head down tilt study with echocardiography, and have demonstrated the efficacy of LBNP with 45 and 90 degrees head down tilt to pool blood caudally and to qualitatively cause the same LBNP response as when subjects are supine. The measured cardiac volumes were decreased with LBNP at both levels of tilt. Although 90 degrees of tilt without LBNP demonstrated little effect on measured cardiac volumes *per se*, the unloading effect on the venous and arterial baroreceptors as well as the anecdotal improvement in subjective symptoms gave evidence that LBNP may protect against higher magnitude -Gz (12).

Future development of the LBNP -Gz suit concept will include modifications to the present suit design and testing of this equipment at higher -Gz levels to define human tolerance limits using varying magnitudes of negative pressure.

CONCLUSION

The -Gz protection suit developed at the Harry G. Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB provides its users protection from the adverse physiological effects of -Gz acceleration. The suit, when operated at pressures of -50 and -100 mm Hg, causes blood to pool in the lower extremities preventing the large headward shift of blood concomitant with -Gz acceleration. This can be seen in the increased heart rate response at the varying -Gz levels and the positive comments from the subjective survey of the test subjects.

The negative G-suit has applications not only in preventing the headward shift of blood during -Gz acceleration, it also has application in the zero G environment of space.

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BIOGRAPHIES

Lloyd Tripp is an Aeromedical Technician in the Acceleration Effects Branch, Biodynamics and Bioengineering Division of the Armstrong Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH. He is currently enrolled in the Human Factors Engineering program at Wright State University. He has co-authored several papers dealing with increasing man's tolerance to +Gz acceleration and holds a patent for an anti-ballooning anti-G suit. He has also developed a negative Gz acceleration protection suit.

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FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

CREW ESCAPE TECHNOLOGIES INITIAL CENTRIFUGE TESTS

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The Crew Escape Technologies (CREST) program is an effort to expand the envelope of safe escape from aircraft in an open ejection seat system. The program was initiated in 1984 with the Boeing Military Airplane Company and provides for the development of a prototype ejection seat system to be tested on the high speed sled facility at Holloman AFB, NM in late 1989. These tests for the CREST program were performed on the Dynamic Environment Simulator (DES), a three axis man-rated centrifuge located at Wright-Patterson AFB, OH (1). The test objective was to evaluate three CREST candidate harnesses against the standard PCU-15/P harness. Specifically, was the restraint system comfortable and did it provide adequate restraint during adverse flight conditions? The PCU-15/P is used with the ACES-II escape system in such aircraft as the A-10, B-1, F-15 and F-16. The three candidate harnesses were the Air Force IH-1 (IH-1), a seat mounted X-band 45 degree (SM-45), and a seat mounted X-band 90 degree (SM-90). Seven test conditions were simulated on the DES; -1.0 Gx (eyeballs out), -1.0, -1.5, & -2.0 Gy (eyeballs right), and -1.0, -1.5, & -2.0 Gz (eyeballs up). Nine subjects completed the test series. Each subject was run on the DES four different days. The first day they tested the SM-90 harness, second the PCU-15/P, third the SM-45, and last the IH-1. Measurements included shoulder and hip displacement, subjective comments, and photographic coverage. At -2.0 Gy the mean shoulder displacement for the four harnesses ranged from 6.4 to 15.5 cm with mean hip displacements from 3.7 to 10.4 cm. At -2.0 Gz the range of mean shoulder displacement was from 4.2 to 10.9 cm and for the hip from 2.1 to 6.6 cm. Overall the PCU-15/P allowed significantly more shoulder and hip displacement than any of the other harnesses. While superior to the PCU-15/P, the IH-1 allowed more hip movement during -Gz than the SM-45 and SM-90 and more displacement of both the shoulder and hip during -Gy. There were no significant differences in displacement between the SM-45 and SM-90. In the subjective ratings there was a clear preference for the SM-45 over the PCU-15/P during all test conditions and for the SM-90 over the PCU-15/P during -Gy and -Gz. There were no significant differences in the subject ratings between the SM-45, SM-90, and IH-1.

FIGURE 1. A subject wearing the SM-45 harness while undergoing -2.0 Gz testing on the DES.

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