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HUMAN TASK PERFORMANCE THROUGHOUT PROLONGED HIGH G EXPOSURE

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FOR THE DIRECTOR

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13. ABSTRACT (Maximum 200 words)

In this research, human subjects repeatedly endured prolonged high-G simulated aerial combat to the point of loss of vision or physical exhaustion. Some profiles included over twenty plateaus at 9 Gz. Measures of cognitive and neuromuscular function, mental workload, and physiologic status were taken throughout the exposures, as well as neuropsychologic examinations after the exposures. Results indicate that more advanced protective systems not only allow longer endurance, but provide adequate support for maintained cognitive performance throughout the extended exposure. Although measures were affected by the type of protective system the subject was wearing as well as individual ability and coping strategies, consistent target tracking task performance, rapid recall decision reaction scores, and sufficient arterial oxygen saturation were maintained throughout extended exposures to a point preceding termination by only a second or two. No neuropsychological decrement was demonstrated post exposure.

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PREFACE

This report documents an experiment conducted under Project/Task/Work Unit ILIRBB12 entitled "Performance in Closed and Open-Loop Control Simulations on the DES." The research was conducted in the Combined Stress Branch (AL/CFBS), Biodynamics and Biocommunications Division, Crew Systems Directorate, Armstrong Laboratory, Wright-Patterson AFB OH.

In addition, this report was presented as a paper of the same title by Dr. Chelette at the AGARD-AMP meeting on "Neurological Limitations of Flight" in Bonn, Germany, October 1995.

The authors wish to extend their appreciation to Deepa Naishadham and Charles Goodyear (Logicon Technical Services, Inc.) for their analysis efforts. The research was conducted in-house and supported by the research staff of AL/CFBS. Appreciation is expressed to the AL/CFBS staff for their technical support and to the Air Force volunteer subjects who made this research possible.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The recent deployment of positive pressure breathing for G (PBG) systems in the U.S. Air Force, as well as the pending deployment of advanced technology full-coverage anti-G suits, is resulting in greater physical endurance and, thus, longer duration high-G exposure [1]. Gz doses of greater than a million G-seconds are being anticipated [2]. Breathing pressures of 45 to 70 mmHg have been shown to increase G-endurance time by increasing intrathoracic pressures, reducing the mechanical effects of increased G on respiration, and reducing the effort needed to perform straining maneuvers [3, 4, 5]. There have been only a few experiments concerning crew task performance with these advanced suits in the military arena [6, 7, 8] and very little has been published in the open literature.

BACKGROUND

In 1944, the first experiment documenting impairment of cerebral function during exposure to G forces described subjects with confusion and momentary memory loss [9]. Frankenhauser's 1949 report documented increased reaction times to a multiplication task during 2-10 minute exposures to +3 Gz [10]. Canfield et al., in their 1949 investigation of vision under G, showed increased reaction times to visual discrimination tasks during +3-5 G exposure for 15 seconds [11]. Chambers and Hitchcock demonstrated increased errors in a memory task during 90 second exposures at +6-7 Gz in 1963 [12]. In 1968 Little, Leverett, and Hartman also observed tracking decrements during accelerations of +5-9 Gx [13]. Piranian showed increased tracking error during exposure to +5 Gz [14]. Frazier et al., and Darwood et al., both in 1990, showed increased error in time and weight estimation tasks, respectively, during long duration centrifuge exposure but only up to +4 Gz [15,16]. Albery et al. used a maze solving task [17] and then later used a dual tracking task [18] and documented an decreased performance with increased G stress over a 60 second period.

In contrast, there are several studies that have shown no significant performance decrement under G. Canfield, Comrey, and Wilson in 1948 found no effect on a memory matching task during exposures up to +5 Gz [19]. Again in 1950, Canfield et al. had consistent performance up to +5 Gz on a visual reaction time task [20]. Creer found no tracking task decrements at any acceleration level up to 6 Gz for 2.5 minutes using a heavily damped control tracking task. Between +6 and +9 Gz, performance dropped rapidly, attributed primarily to the serious visual degradation occurring above +7 Gz [21].

Grether reviewed the effects of acceleration on performance, and concluded that both simple and choice reaction times to visual signals generally increase during increased levels of +Gz. However, these effects tend to diminish or disappear as humans become more accustomed to acceleration environments [22].

Another very important factor, is the lack of standardized G profiles and exposure times. Seat geometry, centrifuge gimbal geometry, onset capabilities, and G gradients resulting from various centrifuge arm lengths, all combine to make results from various experiments difficult to compare [23]. In addition, tremendous variability in the backgrounds, training, ability, and motivation of subject participants has created a wide range of results [24].

The study of cognitive performance during prolonged 3-4 minute conscious exposures to very high G levels (+9 Gz) has only recently become possible with the deployment of advanced protective equipment. Some research has investigated the loss of cognitive function in these extreme conditions as related to G-induced loss of consciousness [25,26,27,28] but little is known about the effect on task performance during continuous conscious exposure to high G.

APPROACH

Studies conducted prior to 1980, and cited above, limited the stress to lower G levels and short durations. During the early 80s it became obvious that the new generation of fighter aircraft were being used in conditions of sustained 7 and 8 Gz and, in some configurations, 9 Gz. As G-LOC awareness grew, research and training focused on prevention and/or detection of G-LOC. Through improved pilot technique at the anti-G straining maneuver and, more recently, improved protective equipment, the 1990s has become the decade of prolonged exposure to high sustained acceleration. The approach taken in the study described herein was to allow centrifuge research subjects to endure prolonged exposure and continuously measure their cognitive performance. A multiple task paradigm was used in which subjects were performing a primary target tracking task (tail chase) while simultaneously monitoring a rapid choice reaction task. Eight subjects were asked to continue in an alternating 5 to 9 Gz profile until they lost eye level blood pressure and their peripheral vision or until physical exhaustion.

METHODS

An open-loop primary tracking task, with the Rapid Communication (RAPCOM) secondary performance task superimposed, was presented on a 175 degree horizontal by 60 degree vertical field-of-view visual display inside the centrifuge cab. RAPCOM is a performance task that displays to a subject a series of rapidly changing symbols [29]. The RAPCOM window was superimposed over the chase aircraft. A continually cycling sequence of frames appeared in the window displaying letters, symbols, and shapes. The task was to attend to the symbols while performing the primary task and to indicate when a predesignated, or target, symbol was present. Tracking error and RAPCOM reaction time, percent correct, and misses were tabulated. Subjects underwent alternating +5 Gz to +9 Gz peaks (Simulated Aerial Combat Maneuver, or SACM) with 5 sec plateaus until loss of vision or physical exhaustion (Figure 1). Pulmonary function tests were also conducted pre- and post-exposure for suit condition effects. Oxygen saturation values were collected with a Nellcor pulse oximeter during all high-G exposures. Stroop [30] and PIN [31] neurological tests were conducted before and after exposures. The Stroop Neuropsychological Screening Test is a reliable instrument that has been shown to correctly differentiate 79-92% of brain damaged subjects from normal control subjects. It involves a color task and a color-word task [32]. The PIN test provides a measure of manual dexterity, speed, and visual acuity with 93-98% concordance with estimates of manual dominance based on self-report, writing hand, or questionnaire. The individual pushes a pin through a patterned set of holes to make indentations in the trial sheet [31]. Subjective opinions concerning workload and suit conditions were also elicited from the subjects with the Subjective Workload Dominance (SWORD) questionnaire [33, 34].

Six anti-G suit conditions were evaluated under this simulated air-to-air combat task. They are shown in Figure 2 and included:

1) standard issue CSU-13B/P air-filled suit
2) standard suit with the current Combined Advanced Technology Enhanced Design G Ensemble (COMBAT EDGE),
3) air-filled Advanced Technology Anti-G Suit (ATAGS)
4) ATAGS with COMBAT EDGE
5) Advanced Protection System (APS) full-coverage air-filled suit (developed by Northrop)
6) Atlantis Warrior full coverage water-filled suit (developed by McDonnell Aircraft)

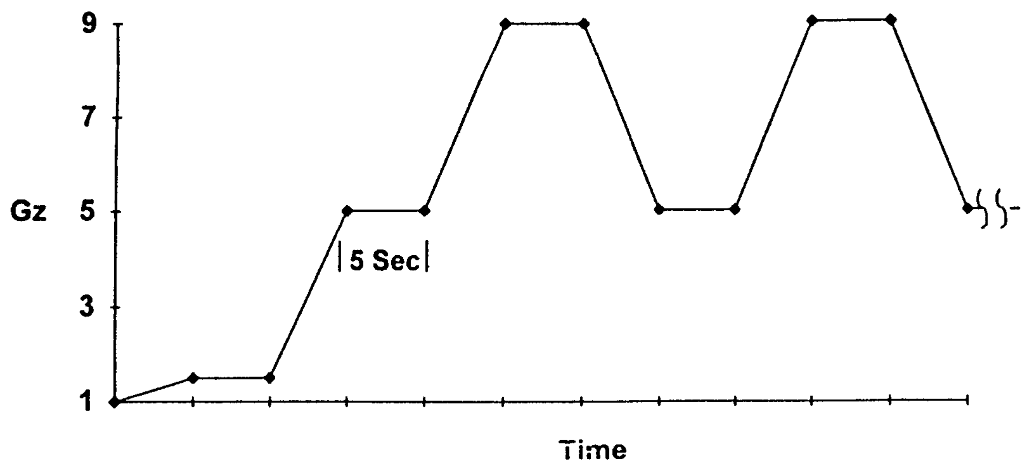

Figure 1. 5 to 9 G Simulated Aerial Combat Maneuver (SACM).

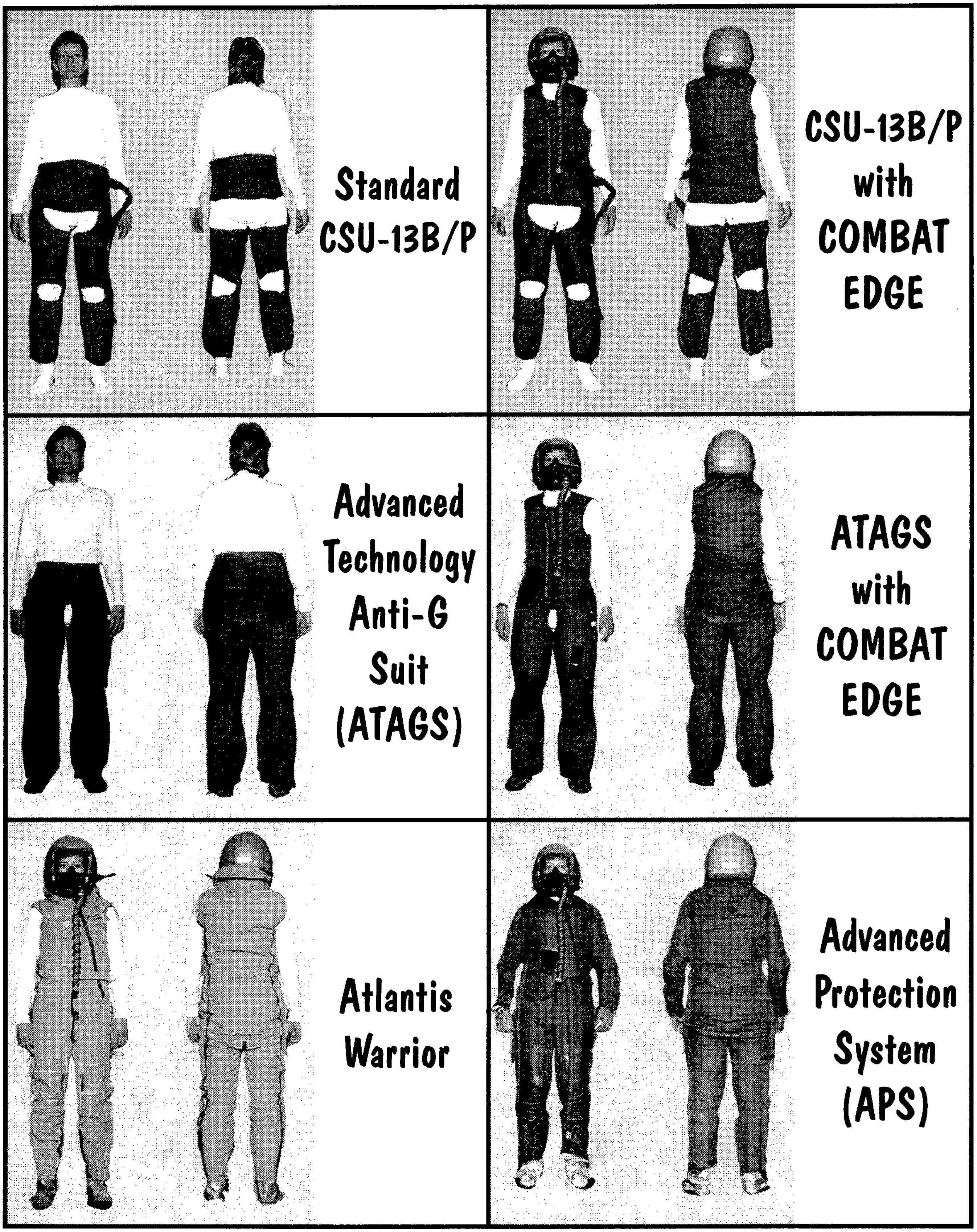

Figure 2. Front and rear views of six anti-G protective ensembles.

RESULTS

The mean number of +9 Gz peaks endured by suit condition, percent body coverage of each suit, and PPB conditions were measured as follows and shown in Table 1.

Table 1. Anti-G Suit Comparisons (N=6) (Note: N=4 for Atlantis Warrior).

Suit Condition	Mean Number 5-9 G Peaks Endured	% of Body Coverage by Suit	Positive Pressure Breathing (PPB) System?
Standard Suit	4.2	30-35	NO
ATAGS	5.3	40-45	NO
Standard with COMBAT EDGE	7.3	55-60	YES
Atlantis Warrior	7.8	65-70	YES
Advanced Protection System (APS) - Northrop	13.0	85-90	YES
ATAGS with COMBAT EDGE	15.2	55-60	YES

The standard suit and ATAGS were statistically comparable in terms of G-endurance, followed in increasing endurance by the standard with COMBAT EDGE and the Atlantis Warrior, which in turn were followed by the APS and ATAGS with COMBAT EDGE. The reasons given for stopping the 5 to 9 G SACM by the subjects included: 1) loss of peripheral vision (31%), 2) exhaustion/fatigue (26%), 3) total loss of vision, blackout (14%), and 4) other reasons (29%). Data from six subjects were analyzed. The data from two of the subjects were not analyzed as these subjects performed only 1-4 9-G peaks throughout five of the six suit conditions and were considered non-representative subjects. Data from only four of these six subjects are available on the Atlantis Warrior suit since the unique suits fit only four of the six subjects. The Subjective Workload Dominance (SWORD) questionnaire showed increased ratings of workload as the number of +9 Gz peaks endured increased, as well as suit condition effects. Oxygen saturation decreased as time at high-g increased (Figure 3). Results of the pulmonary function tests showed that reductions in lung volumes were surprisingly minimal (4-7%) across most suit conditions. Atlantis Warrior, the water-filled suit, compromised lung capacity by 15% prior to G exposure because the water-filled vest exerted pressure on the subjects' lungs and reduced total lung capacity. The Stroop and PIN tests showed no effects concerning suit condition, but did show a very large order effect.

SWORD ratings showed an increase in workload as the number of +9Gz peaks endured increased. SWORD showed the standard CSU 13 B/P suit generated the highest workload during G exposure, compared to the other five suits. There were no significant differences among the other five suit conditions (Figure 4).

Further analysis was completed in order to fully characterize the interactions of suits with strategies and G effects. This data analysis was focused on the sensitivity of the performance metrics to effects of training, fatigue, strategy, and the wide range of subject ability. Results indicate that well trained subjects will maintain both primary and secondary task performance with consistent results throughout the exposure with infrequent catastrophic failure occurring fairly suddenly at the end (Figure 6). Initially no significant effects of suit conditions were found, however, positive pressure breathing (PPB) configurations provided better endurance than non-PPB configurations. Some subjects never performed at the level of the best subjects and coping strategies varied widely. Although performance of both primary and secondary tasks was decremented by Gz exposure (compared to normal gravity), some subjects were affected adversely by G onset and 9 Gz while others performed best at these times and rested during the offset and 5 Gz plateaus.

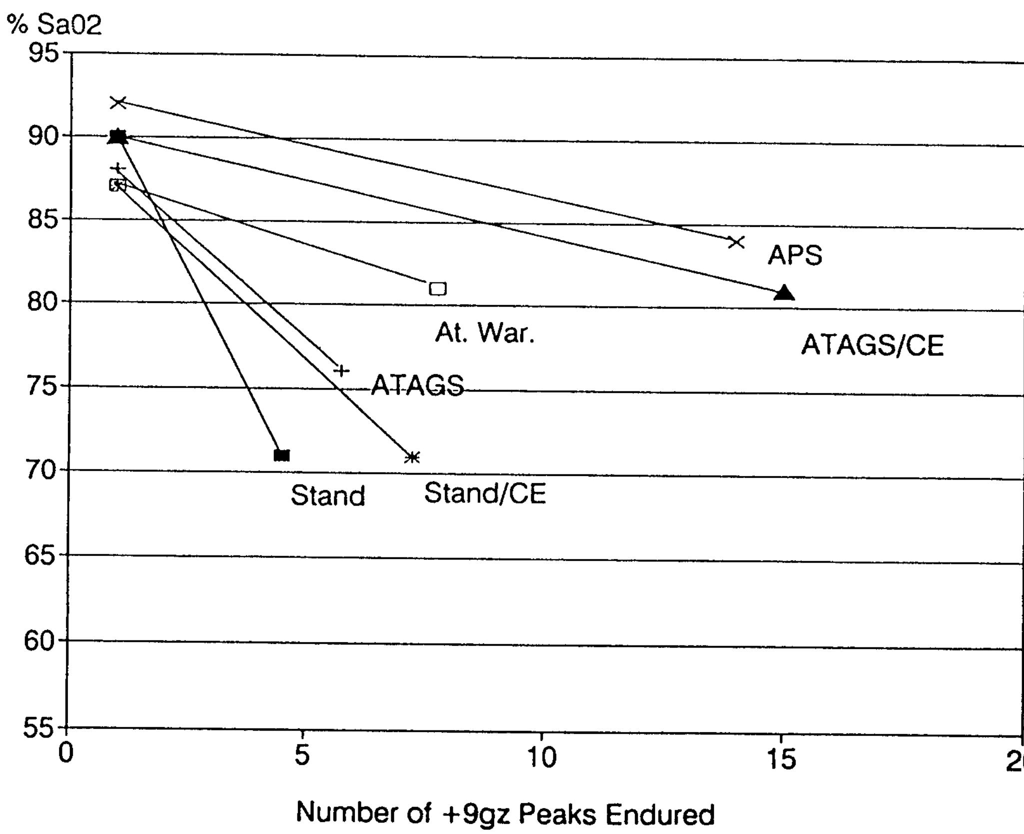

Figure 3. SaO_2 Versus Number of +9 Gz Peaks Endured.

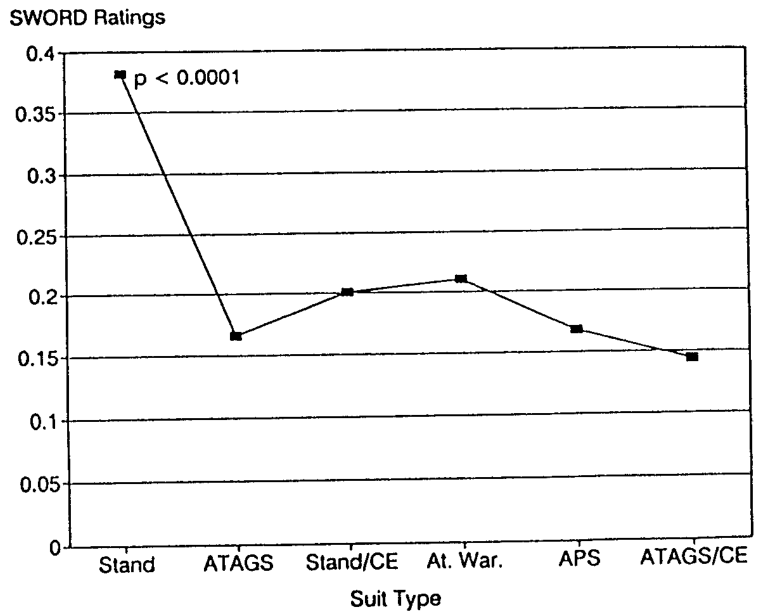

Figure 4. SWORD Ratings of the Six Suit Conditions.

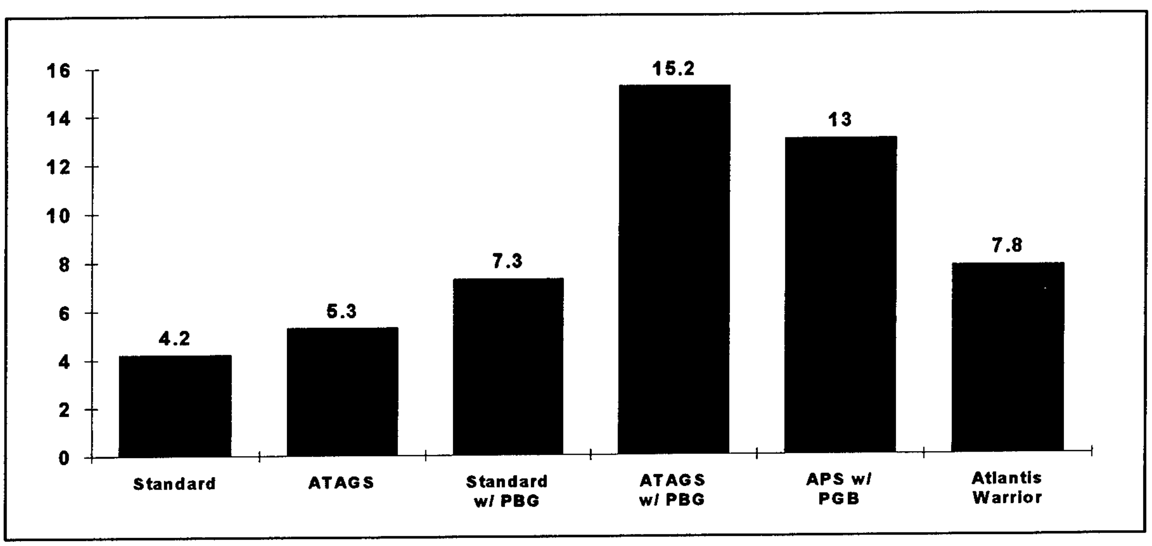

Figure 5. Mean Number of +9 Gz Peaks Endured (N=6). Minimum Significant Difference = 7.3 peaks.

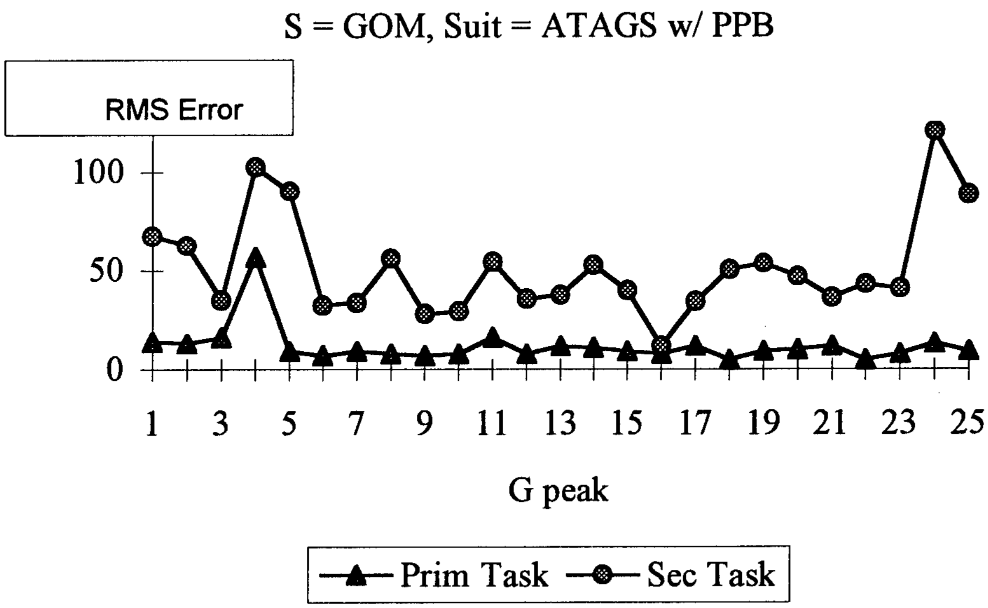

Figure 6. Tracking and RAPCOM Performance Over Prolonged High G Exposure.

DISCUSSION

One of the problems identified with an open-loop G profile was that there was no simple measure of comparison of subject exposure. As shown in Figure 6, subject GOM endured 25 peaks to 9 Gz while protected with ATAGS and PPB. Other subjects wearing ATAGS and PPB endured, on the average, 15 peaks. The higher the error the worse the performance. How does one compare task performance during these exposures? The first attempt was to divide each G exposure into a beginning, middle, and end. These three segments were then compared across all subjects, suit conditions, and exposures. Tracking error, reaction times, and error rates all increased, as expected, throughout the exposure. These results suggested that the dual task performance and physiological integrity of the subjects followed the same trends, regardless of G protection; the difference was that PPB protection allowed the subjects to perform the tasks longer with than without PPB. Tracking error, secondary task (RAPCOM) errors, and reaction times to the RAPCOM all increased from beginning to middle to end of the exposure.

It was decided to analyze the performance data during the first three peaks to 9 G, since all subjects (N=6) in five of the G protection ensembles were able to perform for at least three peaks, which corresponded to about the first 90 seconds of the 5 G to 9G SACM. Significant differences in tracking error, secondary task response, and reaction time to the secondary task were found when comparing the APS condition to the standard suit (tracking), ATAGS (reaction time to the secondary task), and Atlantis Warrior and ATAGS with PPB (percent incorrect on the secondary task).

The neurological tests, the Stroop and PIN tests should not be used in repeated measures experimental designs in the future. We found that as subjects obtained repeated exposure to these tests their performance increased. They were ineffective in determining any neuropsychological changes in the subjects due to G exposure. The Subjective Workload Dominance (SWORD) questionnaire showed increased ratings of workload as the number of +9 Gz peaks endured increased. According to the SWORD ratings, the standard suit condition generated the highest level of workload. This result is probably due to the fact that the standard suit provided the least amount of protection (Figure 3, 4).

Percent arterial oxygen saturation dropped throughout the exposures, but those suits that protected the subjects better helped maintain SaO_2 above 80%. What is shown in Figure 3 are the slopes of the $\%SaO_2$ dropoff as a function of the number of 9 G peaks. The beginning and ending $\%SaO_2$ for each suit condition is connected by a straight line to show the general slopes of the data. The standard suit was worst at helping the subjects maintain eye level arterial oxygen saturation.

CONCLUSIONS

In this research it was demonstrated that properly protected centrifuge subjects could perform simulated flying tasks while exposed to 9 G, in some cases, up to 25 times during a ten minute period. Most subjects were able to maintain dual task performance until the end of the exposure, when they stopped due to loss of vision, fatigue, etc. Although it was a simple matter of sorting out the acceleration protection capability of each of the six different anti-G suits during a 5 G to 9 G Simulated Aerial Combat Maneuver, comparing their task performances across suit conditions was more difficult. Since some G-suits protected subjects to 3 peaks to 9 G while others protected them to 25 peaks, it was difficult to compare the suits in terms of how they affected task performance. Comparing all the suits during the first three peaks yielded some significant differences in performance measures of primary task tracking error, secondary task error, and reaction time to the secondary task. The suit conditions which included positive pressure breathing allowed the subjects to endure more peaks to 9 G than did the non-PPB conditions. Subjects were able to perform the dual task quite adequately during those additional peaks.

In follow-on research, the flight simulation will be performed closed loop, with the subject in control of G exposure and simulated flight maneuvering. The exposures will be for a fixed time (e.g., 3 minutes) and comprised of several sorties. It is hoped that performance measurement across exposures and subjects will be easier than in the research described herein. This research does demonstrate that subjects are not only able to endure long duration high G exposures, but perform complex cognitive tasks throughout the exposure.

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