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HUMAN PERFORMANCE UNDER HIGH G ENVIRONMENTS: A COMPARISON OF UPRIGHT AND RECLINED SEAT CONFIGURATIONS

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13 ABSTRACT (Maximum 200 words)

The present study investigated human cognitive performance under high G in an upright seat and two reclined seats (PALE and Tilt-back). Subjects were required to perform a perceptual/motor and a classification task both separately and concurrently Data were gathered prior to G-onset, during varying levels of acceleration, and post-G. Results indicated that neither of the reclined seats were superior to the upright seat at high G levels. Perceptual/motor data revealed that the PALE seat has an advantage in post-G recovery, while the upright seat maintains better performance during acceleration for this measure. These results indicate that the physiological benefits of reclination do not easily translate into cognitive performance increments. Before a definitive study can evaluate the contributions reclination may make to pilot performance under severe levels of G-force, engineering issues surrounding the mechanization of reclined seating needs to be resolved

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CONTENTS

FIGURES

TABLES

ABSTRACT

The present study investigated operator performance based on sensory and cognitive task performance measures obtained during high G in both an upright seat and two reclined seats (PALE and tilt-back). Subjects were required to perform both a perceptual/motor and a classification task under varying levels of G. Data were gathered pre-G, during acceleration, and post-G. Results indicated that neither of the reclined seats were superior to the upright seat at high G levels. Tracking data showed that the PALE seat has the advantage in post-G recovery, while the upright seat maintains better performance during acceleration. However, the tracking results favoring the upright seat could be a function of engineering design problems inherent in the reclined seats, or lack of subject experience with responding during supination. The physiological benefits of reclination do not easily translate into behavioral performance increments. Before a definitive study can evaluate the contributions reclination may make to pilot performance under severe levels of G force, engineering issues surrounding the mechanization of reclined seating needs to be resolved.

INTRODUCTION

There is currently a lack of data on the operator's ability to perform flight and weapon system management functions under a high G environment. Available research has focused primarily on ways to extend man's ability to *physiologically* tolerate high acceleration environments, giving little or no attention to the effects of high G on behavioral performance measures (Lisher and Glaister, 1978). The interest in physiological improvement under high G, while important, does not address crucial human performance concerns. The ability to correctly track enemy targets and respond with appropriate countermeasures is dependent upon the operator's ability to perform both sensory and cognitive functions. There is insufficient information available to determine how these two functions operate under high G environments.

Numerous studies have shown that seat supination will increase G tolerance. Since the 1930s, investigators have known that reclining or supinating seating configurations can increase crewmember tolerance to Gz. Supination redirects the Gz vector to a chest-to-back direction and allows the heart to more easily pump blood to the eyes and brain, thus reducing blackout or G induced loss of consciousness (GLOC). A high angle (60 degrees or greater) of supination has been claimed to increased tolerance between 1.0 and 1.5 G (Crossley and Glaister, 1971; Burns, 1975; Lisher and Glaister, 1978). While physiological data associated with reclined seating are available, few human performance studies have been reported. Those that are available generally investigate psychomotor performance. Often these experiments are so complex, with too many uncontrolled variables being introduced that to extrapolate or analyze the data with any degree of confidence is questionable. One study, however, should be mentioned in that it was designed with relevant tasks with few uncontrolled variables (Smiles, 1972). That study used a simple two-dimensional compensatory tracking task measuring time-on-target, presented under acceleration to non-pilot subjects. Smiles' experiment suggested that a critical stress region was found to exist between 4 Gz and 6 Gz where, unlike other G levels, tracking performance during post G failed to return to within pre-G performance levels.

Since high G maneuvers account for only a small portion of any flight, sitting in an upright position for most of the mission is still the preferred position. The upright position provides the crewmember with accessibility to controls and displays, out-of-cockpit vision, and ejection path clearance. However, it does not provide the crewmember with sufficient tolerance to Gz. Two articulating seat designs, a tilt-back seat and a PALE (*P*elvis *A*nd *L*eg *E*levating) seat, change the crewmembers position from an upright configuration to a reclined position while under Gz, and then return to the desired upright position upon termination of acceleration. The tilt-back seat uses acceleration (Gz) force-induced actuation to tilt the subject and seat structure backwards about a pivot point under the seat. The PALE seat uses an automatic electrohydraulic repositioning system to supinate the subject by elevating the pelvis and legs, while maintaining a fixed head (design eye) position. Both seats move the crewmember from an upright position of 27 degrees of seat back angle to a reclined position of 67 degrees.

In order to assess performance under high G, an appropriate experimental methodology must be developed to capture subject data during very brief (perhaps 15 seconds or less) performance sessions. There is also the problem of interpreting the performance data. More specifically, are G-induced performance decrements due to visual narrowing and distortion (i.e. non-cognitive factors), cognitive processing deficits, or both? To more fully understand any G-induced performance changes, the sensory and cognitive components of performance need to be distinguished. Both of these problems, namely gathering data within brief performance periods and distinguishing between cognitive and non-cognitive factors, have been eliminated in a recent study which provided the background work for the current investigation (Deaton, Holmes, Hitchcock, and Warner, 1990).

The present study investigated operator performance changes on both sensory and cognitive tasks obtained during high G. Three seat configurations were compared: (1) an upright seat (27 degrees of reclination), (2) a PALE seat (67 degrees of reclination), and (3) a tilt-back seat (67 degrees of reclination). The rationale for including both reclined seating configurations centers on a potentially important difference between the two. As mentioned earlier, the PALE seat maintains a fixed design eye position, thus reducing major visual angle changes between the operator and his instruments during supination. However, one disadvantage of the PALE seat is the requirement for additional leg room due to the necessity to lift the pelvis, thrusting the lower body forward. The "real estate" on the next generation aircraft will be severely limited, and requiring additional cockpit space to actuate PALE seat movement could not be justified unless human performance advantages were apparent.

METHOD

Subjects. Subjects were eight adult males ranging in age from 24 to 35 years. Half of the volunteers performed tasks in the PALE/upright seat, (mean age=32.5), while the remaining subjects were assigned to the tilt-back/upright seat (mean age=29.5). All eight subjects had previously completed a U.S. Navy Flying Class II physical examination and had prior experience and training in the Naval Air Development Center Dynamic Flight Simulator (DFS) centrifuge. Prior to the study, all subjects were briefed of possible physiological hazards and completed informed consent forms.

Procedure. A tracking task and a classification task, developed in an earlier experiment (Deaton et al., 1990), were used to assess psychomotor and cognitive performance, respectively. The objective of the tracking task was to keep a set of crossbars centered via force stick inputs (see Figure 1). The cognitive task display consisted of four geometric symbols which were displayed to the subject until a response was recorded. Symbol sets were presented at an inter-stimulus rate of 0.6 seconds. The symbols used were a square, circle, a plus sign, and a triangle (see Figure 1). Associated with each symbol was a numerical value, namely one, two, three, and four, respectively. All values remained constant throughout the experiment in all of the conditions. Two difficulty levels were developed. In the easy cognitive task (Cog A), subjects were required to interpret the corresponding values associated with each symbol, and assess whether the majority of the symbols represented an "even" or "odd" number set. In the difficult version of the cognitive task (Cog B), subjects also made "even" or "odd" determinations. However, once the majority category was determined, subjects then calculated the numerical sum of the majority symbols' corresponding values and compared this sum to a given target value displayed below the symbol set. If the sum of the values was greater than the target value a specific manual response was made; if the sum was less than the target value, another button press was required. The target value was only presented during Cog B.

The symbol sets were randomly generated with the following constraints: (1) the symbols that comprised the set could not all be the same type; (2) the symbols that comprised the set could not all be different; these constraints were necessary because neither "odd" or "even" would be of a majority, and for the same reason, two-of-a-kind pairs of "odd" and "even" could not appear in the same set; (3) for Cog A, "odd" and "even" sets of symbols would appear in a random order; however, the overall session would have an equal ratio of "odd" and "even" sets; and (4) the same constraint as (3) was applied for Cog B, except 50 percent of the time the target value would be greater than the sum of the majority symbols, and 50 percent of the time it would be less.

All stimuli were displayed on a single 6 inch monochrome video monitor located 20 degrees left of center from the subjects' perspective at an approximate distance of 71 cm. The two tasks were positioned on the display so that the tracking task was displayed directly below the cognitive task. The computer program which generated the task display and collected subject response latency and accuracy, ran on a Zenith PC with an 80286 microprocessor operating at a 10 mHz clock rate. The error on the tracking task was sampled every fifth loop of the program, with a final summary calculation reported every 5 sec. Response times were reported to the nearest millisecond after every response.

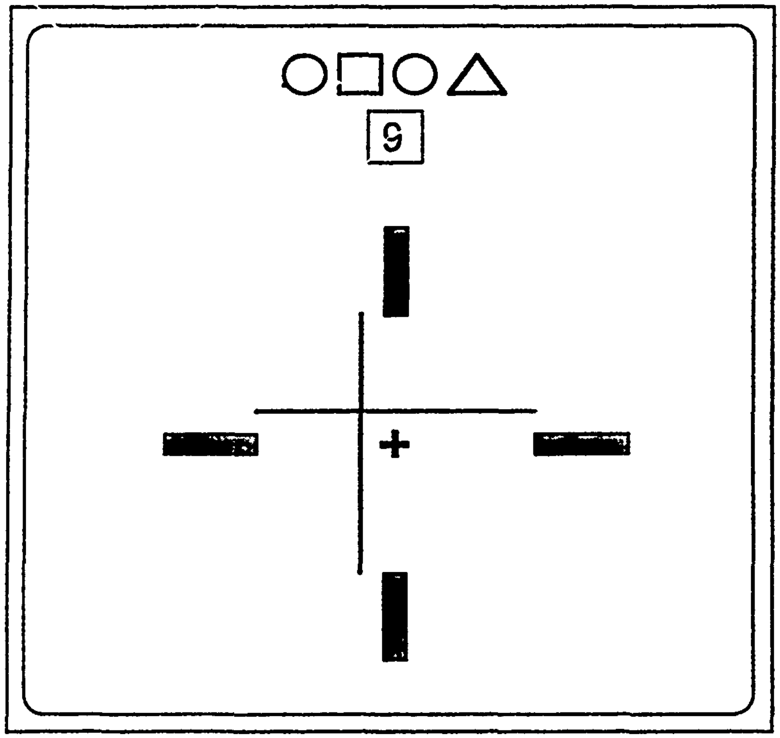


Figure 1. Dual Task Presentation Display

The height of the on screen symbols measured 0.4 cm, which resulted in a visual angle equal to .458 degrees. The compensatory tracking task was controlled with a force stick located in line with the right armrest.

Subjects underwent training in an adjoining laboratory prior to the experiment. Training consisted of five sessions, each comprised of five two-minute runs and five fifteen-second runs under each condition (tracking only; Cog A only; tracking paired with Cog A; Cog B only; and tracking paired with Cog B). Thus, both single and dual task measures were obtained during training as well as in the main experiment.

The study was conducted in two phases. Phase 1 consisted of a comparison between the upright seat and the PALE seat. This phase took place over a period of five days, with all five task conditions being presented in each of the two seat configurations. Subjects were inserted into the DFS once per day for approximately one hour for four of the days. The PALE seat began supination at 2.5G at a rate of 20 degrees per second to a seat back angle of 67 degrees. The upright seat had a fixed seat-back angle of 27 degrees. Phase 2 was initiated approximately six months after Phase 1, and consisted of a comparison between the upright seat and the tilt-back configuration. The tilt-back seat also began reclining at 2.5G at a rate similar to that of the PALE configuration to a seat back angle of 67 degrees. The testing procedure for both phases was identical.

Individual differences in tolerance to acceleration resulted in different maximum G end points and slightly different G profiles for PALE, tilt-back, and upright seats. Maximum G levels for each subject were obtained from an earlier study conducted at NADC which investigated physiological tolerances in each seat configuration. The previous study assessed G-maximum tolerance based upon a 60 degree of visual arc remaining criterion measured with a curved LED array. G levels ranged from 5.0 to up to a maximum 10.5 G's in some cases. Data runs were divided into three performance periods, consisting of: (1) 15 seconds pre-G, (2) 15 seconds under acceleration, and (3) 15 seconds post-G. Acceleration ($+G_z$) onset rates in period 2 were constant for all subjects on all runs for all G levels and were 1.5 sec. haversine-shaped. Physiological protection of the subjects was ensured through the use of medical instrumentation attached to the subjects. Anti-G suits and assisted positive pressure breathing (APPB) were employed. Additional subject-mounted equipment included a helmet used to support the APPB mask, and a breathing regulator.

The two versions of the cognitive task made it possible to plot performance as a function of task difficulty and G level. This method, similar to the logic involved in Sternberg's memory-search paradigm, made it possible to determine whether decrements were the result of cognitive or non-cognitive factors. That is, by plotting data associated with task difficulty and G level, one could assess whether the two plots were parallel or intersecting. An interaction of the two would be evidence that performance on the two tasks changed as a function of G level. Such an effect could only be due to cognitive features since it was only on the cognitive level that the two tasks differed. Cog A and B were essentially identical in terms of sensory requirements.

RESULTS AND DISCUSSION

Response latency (RT), percent correct, and in the case of tracking, root mean square error (RMSE) data, were submitted to a series of 2 x 2 x 3 (G-level x seat type x time period) factorial analyses of variance with repeated measures on the last factor. There were two levels of G (high/low), two seat types (PALE/upright or tilt-back/upright), and three time periods (pre-G, during acceleration, and post-G). In order to determine G level (high or low) the median value of each subject's G profile was used. Data below the median was collapsed and defined the low G category, while data above the median was combined to determine the high G level. Individual ANOVAs were calculated for both single task performance (tracking, Cog A, Cog B), as well as for dual task performance (tracking with Cog A, and tracking with Cog B). While a completely within subjects study involving all three seat configurations would have been preferable, subject availability necessitated using different subjects to assess PALE and tilt-back performance. Therefore, results will be reported separately for PALE and tilt-back seat configurations.

Cognitive Task Results for PALE Seat

Single Task Performance. Table 1 shows both percent correct and RT for single task cognitive performance for the PALE seat. Results showed there were little differences in reaction times or accuracy as a function of G level, time period, or seat type for single task performance (Cog A or B). None of the sources of variance were significant.

Dual Task Performance. Table 2 shows percent correct and RT for dual task performance involving both the cognitive task and tracking for the PALE seat configuration. None of the sources of variance for accuracy were significant. RT data, however, showed a significant main effect for seat type, $F(1,171)=4.85$, $p<.05$, when Cog A was paired with tracking. Figure 2 shows RT performance for both seats as a function of task difficulty. More specifically, response times were more rapid for the PALE seat when tracking was combined with the easy cognitive task (Cog A). Moreover, the main effect for seat type was significant when tracking was combined with the difficult cognitive task (Cog B), $F(1,160)=4.07$, $p<.05$. However, in this case, the upright seat demonstrated faster response latencies when tracking was combined with the difficult cognitive task. Thus, the advantage of the PALE seat for cognitive performance was more apparent for moderate levels of task difficulty (Cog A with tracking), while the upright seat configuration was preferable for tasks involving maximum task difficulty (Cog B with tracking). That Cog B was indeed judged by subjects as more difficult than Cog A was assessed in a workload analysis of similar data from a preliminary study (see Deaton et al, 1990).

TABLE 1
SINGLE TASK PERFORMANCE: COGNITIVE TASK
(PALE SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
PALE SEAT	97.33 .59	84.44 1.33	97.33 .60	92.67 1.50	98.22 .60	85.44 1.39	97.29 .59	93.04 1.25	97.33 .69	88.87 1.60	97.08 .64	90.26 1.73	97.43 .61	89.12 1.47
UPRIGHT SEAT	96.90 .65	83.70 1.36	98.00 .62	94.70 1.44	98.40 .66	90.00 1.36	98.75 .58	95.92 1.35	98.83 .63	89.67 1.43	97.42 .64	92.92 1.47	98.05 .63	91.99 1.40
MEANS	97.12 .62	86.57 1.35	97.67 .61	93.69 1.47	98.31 .63	87.72 1.38	98.02 .59	94.48 1.30	98.08 .66	89.27 1.52	97.25 .64	91.59 1.60		

NOTE: FOR EACH CELL, THE PERCENT CORRECT VALUE IS SHOWN ABOVE THE REACTION TIME VALUE.

TABLE 2
DUAL TASK PERFORMANCE: COGNITIVE TASKS
(PALE SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
PALE SEAT	94.71 .77	90.64 1.78	94.14 .84	88.27 2.19	94.17 .76	92.55 2.73	97.81 .68	95.00 1.81	95.89 .84	90.23 2.91	96.00 .78	85.72 2.70	95.45 .78	90.40 2.35
UPRIGHT SEAT	98.54 .88	92.00 1.88	94.63 .85	94.20 1.82	93.65 .96	85.10 1.78	97.27 .74	93.27 1.67	97.82 .89	89.46 1.80	94.40 .87	90.00 1.87	96.05 .87	90.67 1.80
MEANS	96.63 .83	91.32 1.83	94.39 .85	91.24 2.01	93.91 .86	88.83 2.26	97.54 .71	94.14 1.74	96.86 .87	89.85 2.36	95.20 .83	87.86 2.29		

NOTE: VALUES SHOWN ARE FOR THE COGNITIVE CONDITIONS WHILE PAIRED WITH THE TRACKING TASK. FOR EACH CELL, THE PERCENT CORRECT VALUE IS SHOWN ABOVE THE REACTION TIME VALUE.

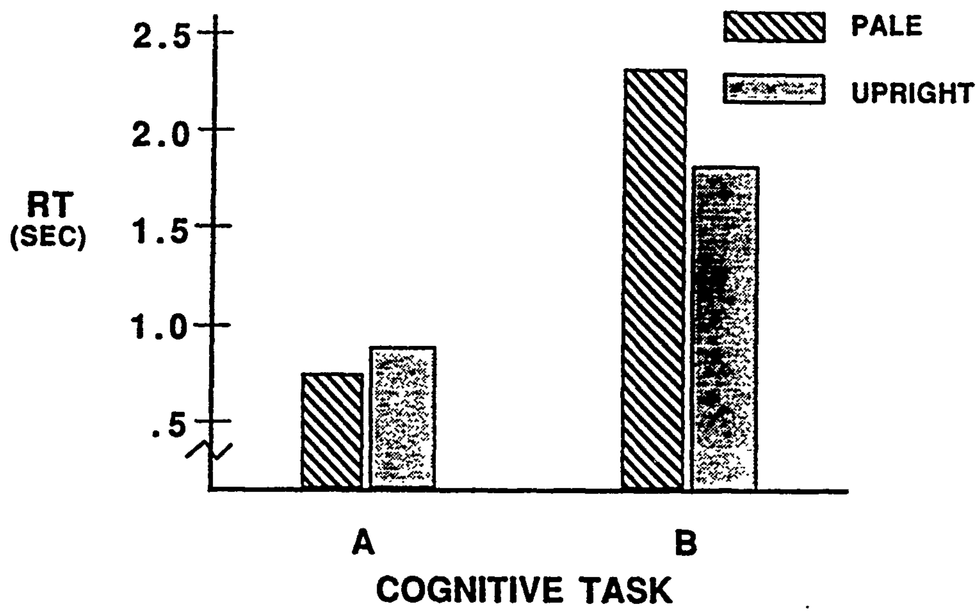


Figure 2. Cognitive Performance (RT) with Tracking as a Function of Task and Seat Type (PALE)

Tracking Task Results for PALE Seat

Single Task Performance. Table 3 shows RMS error for single task performance for the PALE seat. Tracking task performance was more diagnostic of seat differences than was cognitive performance. Results for single task performance showed significant main effects for seat type, $\underline{F}(1,318)=45.22$, $\underline{p}<.001$, G level, $\underline{F}(1,318)=22.75$, $\underline{p}<.001$, and time period, $\underline{F}(2,318)=43.86$, $\underline{p}<.001$. Tracking error was less in the upright seat and at lower G levels. Moreover, performance decreased as a function of time period. Newman-Keul post-hoc tests for time period showed significant differences ($\underline{p}<.05$) between: (1) pre-G vs. during-G, and (2) pre-G vs. post-G. Tracking performance during acceleration and post acceleration were not significantly different. The implication here is that tracking performance does not recover to pre-G levels after G offset for at least 15 seconds. Significant effects were also found for the seat type by G level interaction, $\underline{F}(1,318)=9.13$, $\underline{p}<.01$, the seat type by time period interaction, $\underline{F}(2,318)=8.52$, $\underline{p}<.001$, and the G level by time period interaction, $\underline{F}(2,318)=4.16$, $\underline{p}<.05$. Figure 3 shows tracking error as a function of seat type and G level. There was little difference between seats at low G; this was anticipated since seat reclination was identical (27 degrees) for both seats up to the 2.5 G level. The picture changes, however, at high G. Here we see that tracking error was significantly greater ($\underline{p}<.05$) for the PALE seat. The seat by time interaction will be discussed in reference to dual task performance since it was significant in both situations. The significant G level by time period interaction merely indicated that differences in performance between low and high G conditions were more pronounced during acceleration (period 2).

Dual Task Performance. Table 4 shows RMS error for dual task performance involving tracking with Cog A and tracking with Cog B. The ANOVA for tracking with Cog A showed a significant main effect for time period, $\underline{F}(2,171)=15.87$, $\underline{p}<.001$, and marginal effects for G level, $\underline{F}(1,171)=3.03$, $\underline{p}=.08$, and the seat by time period interaction, $\underline{F}(2,171)=2.50$, $\underline{p}=.08$. The ANOVA for tracking with Cog B

TABLE 3
SINGLE TASK PERFORMANCE: TRACKING (RMSE)
(PALE SEAT)

	LOW G			HIGH G			
PERIOD	P1	P2	P3	P1	P2	P3	MEANS
PALE SEAT	.318	.374	.388	.331	.459	.441	.385
UPRIGHT SEAT	.318	.338	.351	.315	.347	.379	.341
MEANS	.318	.356	.370	323	.403	.410	

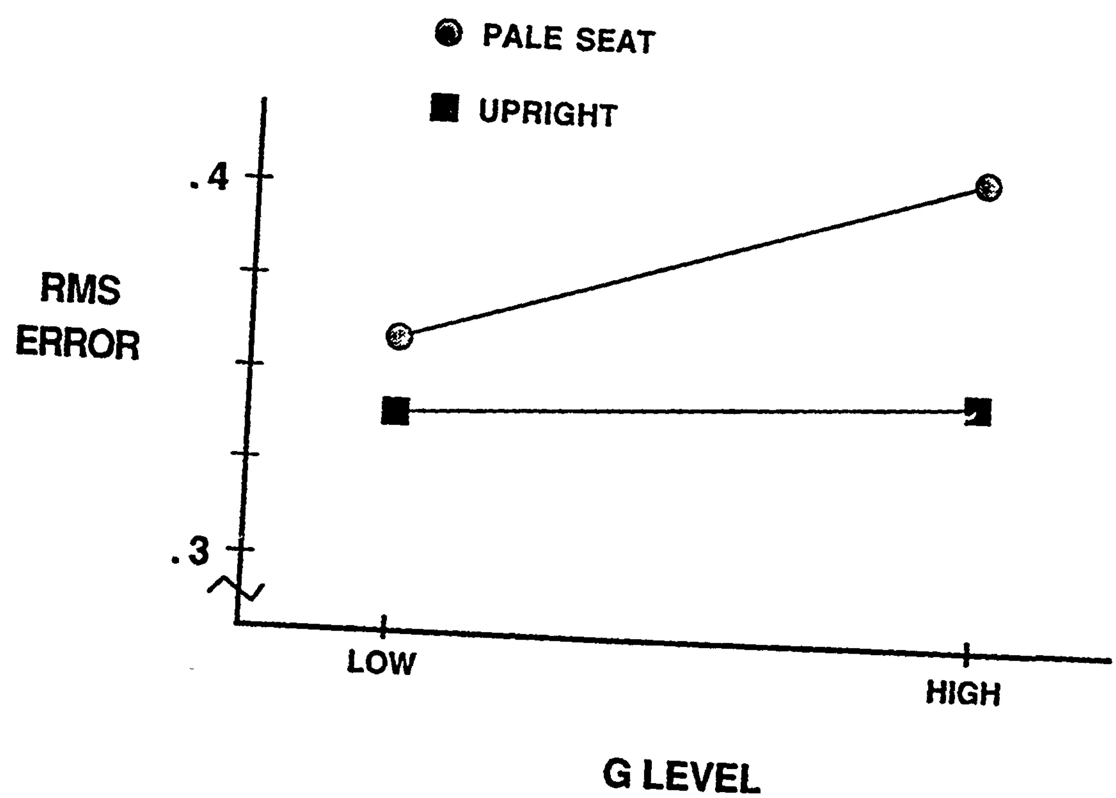


Figure 3. Tracking as a Function of Seat Type and G Level (PALE)

TABLE 4
DUAL TASK PERFORMANCE: TRACKING (RMSE)
(PALE SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
PALE SEAT	.355	.382	.436	.471	.371	.511	.372	.388	.476	.543	.460	.541	.412	.473
UPRIGHT SEAT	.351	.404	.428	.425	.450	.480	.371	.385	.449	.459	.449	.493	.416	.441
MEANS	.353	.393	.432	.448	.411	.496	.372	.387	.463	.501	.455	.517		

showed only the main effect for time period, $F(2,160)=11.88$, $p<.001$. Unlike single task performance, there were no significant seat differences. As was the case with single task performance, performance decreased over time. Deterioration in tracking performance experienced during-G was again maintained post-G. All post-hoc tests showed no significant difference between during-G and post-G performance. Differential effects were noted, however, as a function of seat types; hence, the marginal seat by time period interaction (tracking with Cog A). Figure 4, which shows tracking with Cog A as a function of seat type and time period, indicated that tracking performance improved somewhat post-G for the PALE seat while it continued to deteriorate over time for the upright seat. It may be that the real advantage of the PALE seat is not *during* G load; rather, it may be that any physiological improvements afforded by the reclined seat does not manifest itself behaviorally until G offset.

Cognitive Task Results for Tilt-back Seat

Single Task Performance. Table 5 shows single task performance for the cognitive task on the tilt-back seat. The only significant source of variance for percent correct for either Cog A or Cog B was time period, $F(2,155)=4.24$, $p<.05$ (Cog A). Post-hoc tests for time period showed a significant difference ($p<.05$) between pre-G and post-G. The difference between pre-G and during-G and between during-G and post-G were not significant. Like PALE seat performance, accuracy was not a diagnostic measure of seat performance differences.

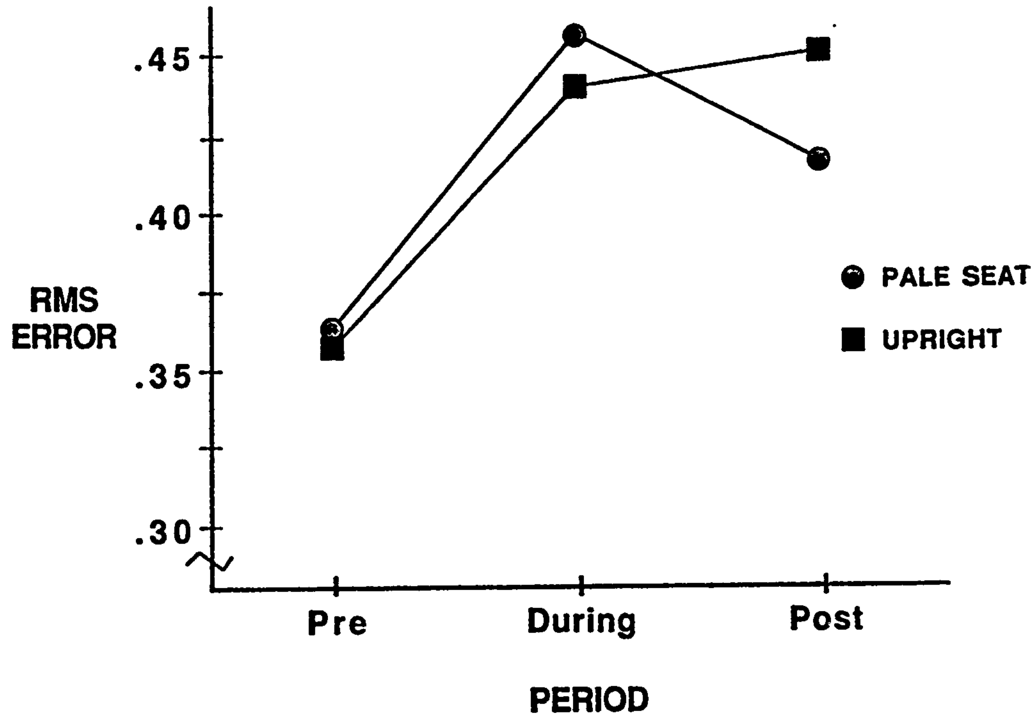


Figure 4. Tracking with Cog A as a Function of Seat Type and Time Period (PALE)

TABLE 5

SINGLE TASK PERFORMANCE: COGNITIVE TASK (TILT-BACK SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
TILT-BACK SEAT	97.69	92.64	95.97	85.86	98.10	93.79	93.67	91.96	96.33	86.05	92.05	88.36	96.14	89.78
	.59	1.69	.70	1.96	.68	1.91	.69	2.09	.97	2.79	.95	3.40	.76	2.31
UPRIGHT SEAT	100.0	94.73	98.27	95.64	94.64	93.82	99.20	95.86	95.50	92.00	93.30	92.43	96.82	94.08
	.87	1.73	.97	2.12	.97	2.81	.78	1.34	1.16	1.90	.98	2.41	.96	2.05
MEANS	98.85	93.69	97.12	90.75	96.37	93.81	97.94	93.91	95.92	89.03	92.68	90.40		
	.73	1.71	.84	2.04	.83	2.36	.74	1.72	1.07	2.35	.97	2.91		

NOTE: FOR EACH CELL, THE PERCENT CORRECT VALUE IS SHOWN ABOVE THE REACTION TIME VALUE.

Reaction time data, however, presented a different picture. For Cog A, the following sources of variance were significant: (1) seat, $F(1,155)=13.31$, $p<.001$, (2) G level, $F(1,155)=5.78$, $p<.05$, and time period, $F(2,155)=6.23$, $p<.01$. That is, overall RTs were more rapid for the tilt-back configuration (see Table 5). Not surprisingly, RTs were faster under low G conditions. Post-hoc tests for time period showed a significant difference ($p<.05$) between pre-G and during-G, and between pre-G and post-G. The difference between during-G and post-G was not significant.

Single task performance for Cog B showed the following significant effects: (1) time period, $F(2,150)=5.02$, $p<.01$, and (2) the seat by G level interaction, $F(1,150)=6.91$, $p<.01$. Post-hoc tests for time period showed a significant difference ($p<.05$) between pre-G and post-G only. Figure 5 shows the seat by G level interaction. Post-hoc tests indicated a significant difference ($p<.05$) for tilt-back across G level, while the mean RT for the upright seat did not statistically change across G level. There was a significant difference ($p<.05$) between seat configurations at high G levels. The difference between seats at low G was not significant. These data indicate some stability (perhaps slight improvement) in performance for the upright seat across G levels, while the tilt-back seat showed considerable decrements in RT as the level of G increased.

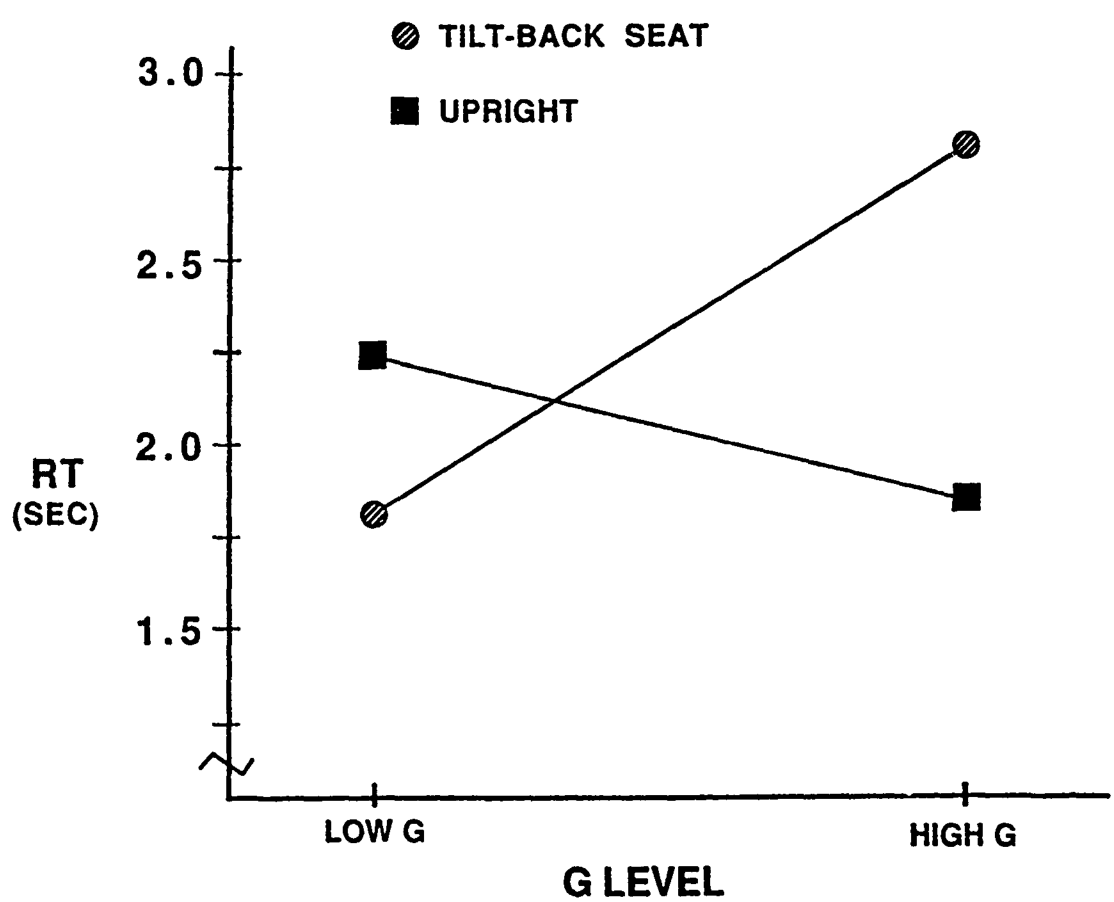


Figure 5. Cognitive Performance (RT) as a Function of Seat and G Level (Tilt-back)

Dual Task Performance. Table 6 shows dual task performance for the tilt-back configuration. There were no significant effects for percent correct or RT for Cog A with tracking. Percent correct for Cog B with tracking showed significant effects only for time period, $\underline{F}(2,138) = 3.73$, $\underline{p} < .05$. Post-hoc tests for period showed a significant difference ($\underline{p} < .05$) between pre-G and during-G and between pre-G and post-G.

TABLE 6
DUAL TASK PERFORMANCE: COGNITIVE TASKS (TILT-BACK SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
TILT-BACK SEAT	89.00 .87	91.86 1.73	93.64 .88	90.36 1.88	97.21 .87	93.43 2.41	97.13 1.26	97.13 2.14	92.87 1.17	88.74 3.09	93.70 1.06	83.04 3.62	93.93 1.02	90.76 2.48
UPRIGHT SEAT	98.18 1.05	92.57 1.72	95.36 1.15	96.43 3.03	94.46 1.12	81.86 2.04	99.00 .97	100.0 1.60	96.30 1.40	90.00 2.57	95.56 1.28	85.50 2.24	96.48 1.16	89.39 2.20
MEANS	93.59 .96	92.22 1.73	94.50 1.01	88.40 2.46	95.84 1.00	87.65 2.23	98.07 1.12	98.57 1.87	94.59 1.29	89.37 2.83	94.63 1.17	84.27 2.93		

NOTE: VALUES SHOWN ARE FOR THE COGNITIVE CONDITIONS WHILE PAIRED WITH THE TRACKING TASK. FOR EACH CELL, THE PERCENT CORRECT VALUE IS SHOWN ABOVE THE REACTION TIME VALUE.

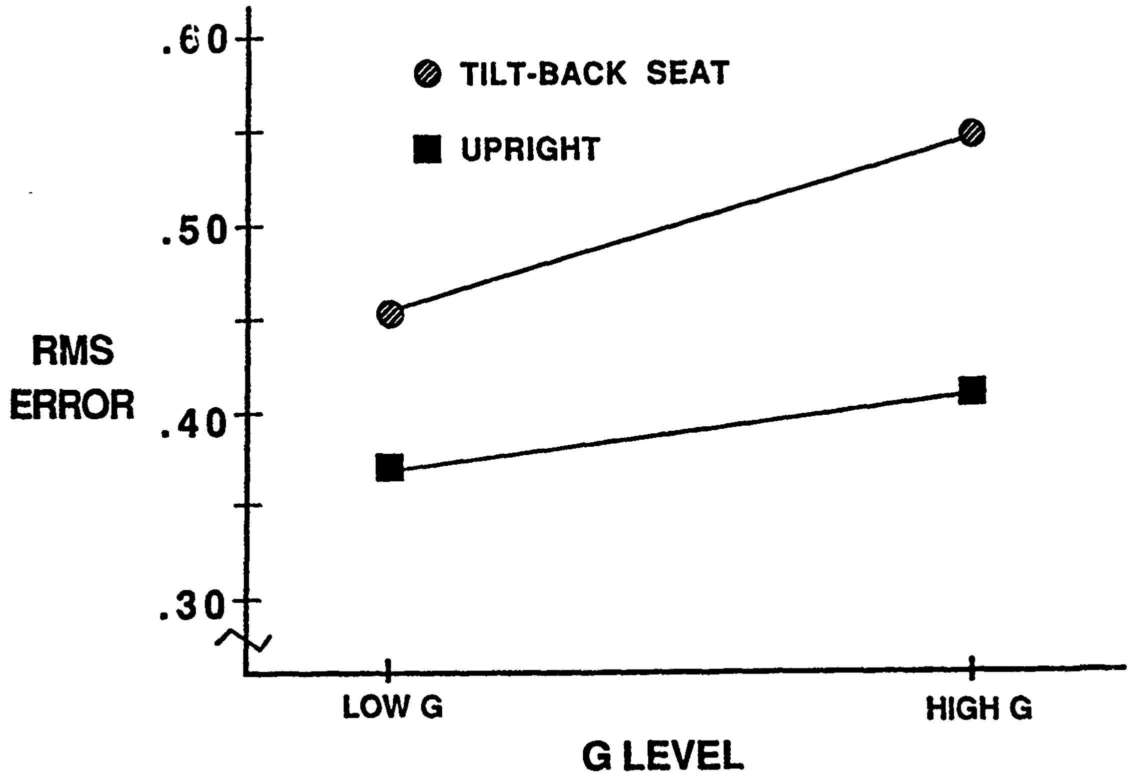


Figure 6. Tracking as a Function of Seat Type and G Level (Tilt-back)

The data for mean RT for Cog B with tracking showed significant effects for time period, $F(2,138)=4.53$, $p<.05$, and the seat by G level interaction, $F(1,138)=4.42$, $p<.05$. Post-hoc tests for time period showed a significant difference ($p<.05$) between pre-G and during-G and between pre-G and post-G. The significant seat by G level interaction for Cog B with tracking mirrors that found for Cog B alone (see Figure 5). That is, while there were no differences in cognitive performance (RT) at low G, the upright seat resulted in reduced RT at high G levels.

Tracking Task Results for Tilt-back Seat

Single Task Performance. Table 7 shows RMS error for single task performance on the tilt-back seat. RMS error for tracking showed significant effects for the following sources of variance: (1) seat, $F(1,291)=78.89$, $p<.001$, (2) G level, $F(1,291)=26.83$, $p<.001$, (3) time period, $F(2,291)=41.62$, $p<.001$, (4) the seat by G level interaction, $F(1,291)=7.65$, $p<.01$, (5) the seat by time period interaction, $F(2,291)=4.16$, $p<.05$, and (6) the G level by time period interaction, $F(2,291)=6.59$, $p<.01$. In general, tracking performance was best for the upright seat. Moreover, tracking error was greater at high G, and across time periods (post-hoc tests for period showed a significant difference between all periods). Figure 6 shows the seat by G level interaction. It is apparent from this figure that the effect of high G was more pronounced (increased slope) for the tilt-back seat. Figure 7 shows the seat by time period interaction. As was the case with the PALE seat, it was evident from this figure that deterioration in tracking performance continued post-G. The effect of G on performance seemed to be greater for the tilt-back seat configuration, especially when going from pre-G to acceleration. The G level by time period interaction merely indicated that performance differences between high/low G occurred during acceleration and were maintained post-G.

TABLE 7
SINGLE TASK PERFORMANCE: TRACKING (RMSE)
(TILT-BACK SEAT)

	LOW G			HIGH G			
PERIOD	P1	P2	P3	P1	P2	P3	MEANS
TILT-BACK SEAT	.402	.463	.500	.410	.612	.612	.497
UPRIGHT SEAT	.355	.396	.408	.348	.419	.474	.400
MEANS	.379	.430	.454	.379	.516	.543	

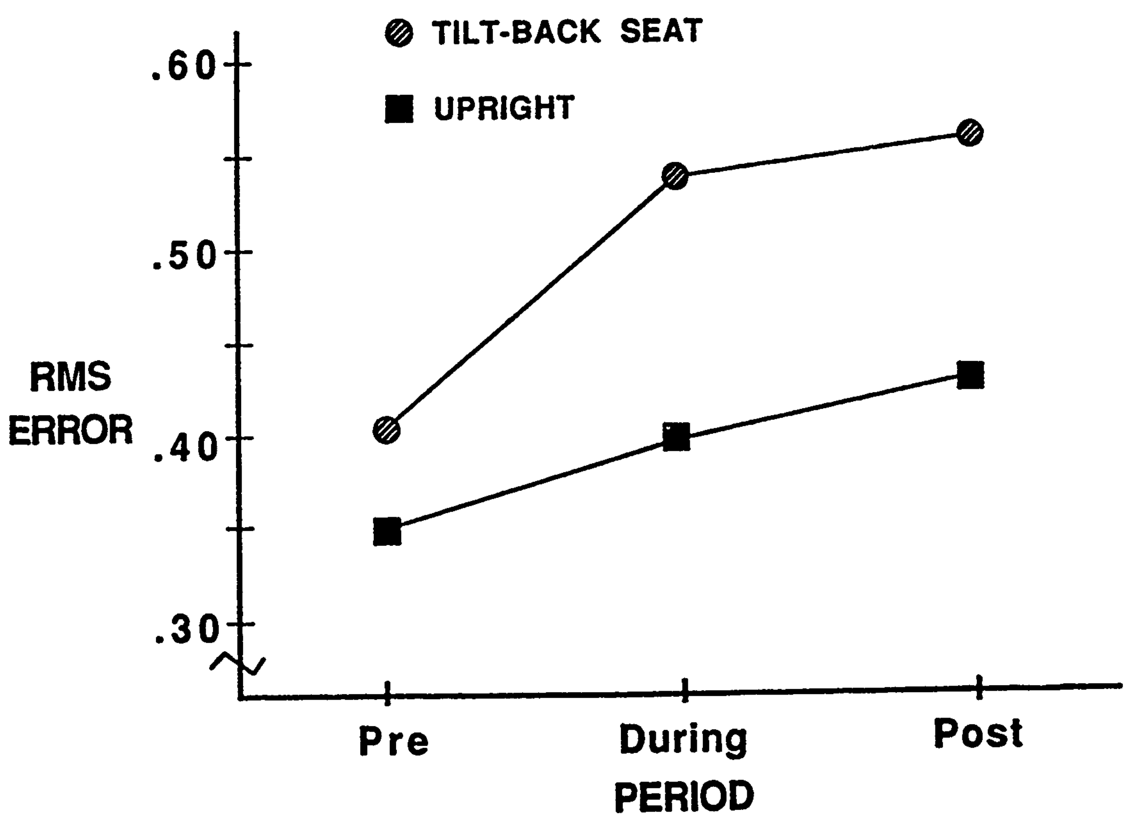


Figure 7. Tracking as a Function of Seat Type and Time Period (Tilt-back)

Dual Task Performance. Table 8 shows tracking performance in combination with Cog A and Cog B. RMS error for tracking with Cog A showed the following significant sources of variance: (1) seat, $F(1,161)=57.83$, $p<.001$, (2) G level, $F(1,161)=8.29$, $p<.01$, (3) time period, $F(2,161)=23.79$, $p<.001$, and (4) the seat by time period interaction, $F(2,161)=3.37$, $p<.05$. That is, tracking performance in the upright seat was better than the tilt-back, and also better at low G. Moreover, performance decreased as a function of time period, particularly for the tilt-back seat. Post-hoc tests for period showed what has been commonly found in this study; namely significant differences between pre-G and during-G, and between pre-G and post-G. Figure 8 shows the seat by time period interaction for tracking with Cog A. It is interesting to compare Figures 4 and 8. Figure 4 showed that the PALE seat may aid recovery in performance post-G. In contrast, Figure 8 demonstrates that tilt-back performance deteriorates more rapidly than the upright during acceleration and apparently continues that trend post-G. There was no recovery in performance for the tilt-back seat.

TABLE 8
DUAL TASK PERFORMANCE: TRACKING (RMSE)
(TILT-BACK SEAT)

	LOW G						HIGH G							
PERIOD	P1		P2		P3		P1		P2		P3		MEANS	
CONDITION	A	B	A	B	A	B	A	B	A	B	A	B	A	B
TILT-BACK SEAT	.447	.478	.550	.590	.584	.627	.439	.451	.645	.689	.656	.689	.556	.587
UPRIGHT SEAT	.363	.330	.397	.408	.451	.432	.389	.349	.468	.533	.485	.494	.423	.424
MEANS	.405	.404	.474	.499	.518	.530	.414	.400	.557	.611	.571	.592		

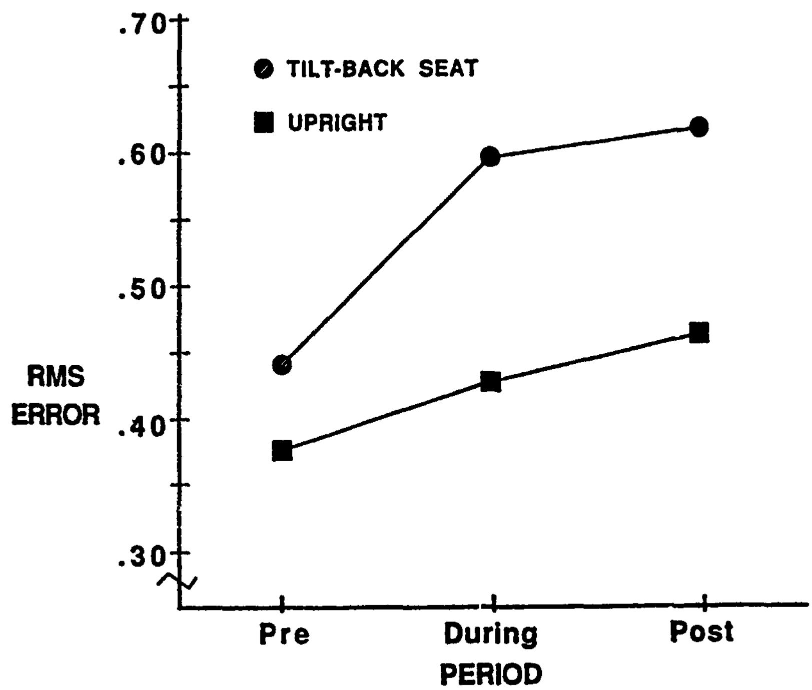
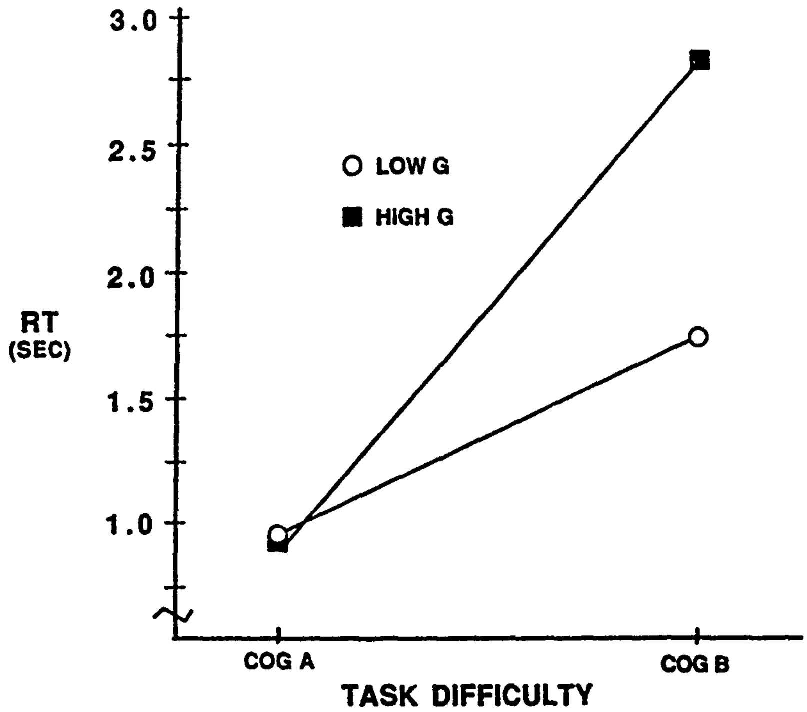


Figure 8. Tracking with Cog A as a Function of Seat Type and Time Period (Tilt-back)

The pattern for tracking performance with Cog B was similar to that above. The following significant effects were noted: (1) seat, $F(1,138)=89.76$, $p<.001$, (2) G level, $F(1,138)=10.81$, $p<.001$, (3) time period, $F(2,138)=36.20$, $p<.001$, and (4) the G level by time period interaction, $F(2,138)=3.85$, $p<.05$. Again, performance on the upright seat was better, as was that at low G. Again performance decreased over time in the same manner as did tracking with Cog A. The G level by time period interaction indicated that performance differences between low and high G conditions were greater during acceleration.

What conclusions can be drawn regarding whether decrements in performance were due to genuine cognitive deficits or due to sensory (non-cognitive) factors? Figure 9 shows performance as a function of task difficulty and G level for the tilt-back seat. (The tilt-back seat data were used for this analysis since subjects were experiencing the highest level G in this configuration. If decrements in performance were due to sensory rather than cognitive factors at high G, they would most likely appear in these data). The interaction of task difficulty and G level was significant, $F(1,208)=6.90$, $p<.01$. If only Cog A data were available, we would have erroneously concluded that G level does not affect task performance. However, with both tasks available, we can determine the precise relationship between G level and performance. We know the difference in performance for Cog B cannot be due to non-cognitive factors since both tasks have identical sensory requirements. The difference must be attributed to the additional cognitive (central processing) factors required in Cog B. The conclusion to be drawn from this graph is that deficits at higher levels of G are most likely due to cognitive decrements rather than, say, visual field narrowing (sensory factors). Had the lines been parallel, i.e., an equal difference in performance between low and high G levels, we would have concluded that the difference must be associated with a factor which is common to both tasks; namely, sensory features. Using the modified Sternberg methodology it can be concluded that the decrements seen at high G were truly the result of cognitive deficiencies.



Figue 9. Cognitive Performance (RT) as a Function of Task Difficulty and G Level (Tilt-back)

GENERAL DISCUSSION

Results of the present study indicated that, in general, percent correct was not very diagnostic of seat performance differences for either single or dual task situations. Due to the extensive practice afforded subjects, this result was not particularly surprising. Subjects were most likely trained to an asymptotic performance level and maintained this level throughout the main sessions as well.

RT data showed mixed results. There were no differences in performance between upright and PALE seats for single task performance; however, dual task performance showed faster response times for the PALE seat at moderate levels of task difficulty (Cog A with tracking). At the highest level of task difficulty (Cog B with tracking), the upright seat resulted in better performance. In contrast, tilt-back performance was best for the single task situation. No differences were found for dual task performance in terms of RT for the tilt-back seat. Performance on the tilt-back seat was always better or equal to the upright seat regardless of task difficulty. On the other hand, PALE seat performance was only better than the upright seat at moderate levels of task difficulty. While a direct comparison was not made between PALE and tilt-back configurations, the data suggest indirectly that the tilt-back seat may be preferable to the PALE seat (at least on the cognitive task as measured by RT). Assuming that the tilt-back seat is better than the PALE, it was nevertheless inferior to the upright seat at higher levels of G. The significant seat by G level interaction for Cog B and Cog B with tracking showed an advantage for the upright seat at high G. If we assume that pilots will be engaged in high G maneuvers during part of their flight regimen, the results indicate that upright seating is better than tilt-back, and certainly much better than the PALE seat. Now whether the advantage for the upright seat is merely the result of lack of experience in responding to a task from a reclined position should not be ruled-out. While subjects received extensive practice on all tasks, they did so on a fixed-based PC using normal upright seating. It is recommended that future studies include as part of the training protocol opportunities to respond in reclined configurations as well as upright.

Another interesting result is associated with the period effect for cognitive performance for the tilt-back seat. It would seem that post-G performance (as measured by both percent correct and RT) was not different from that seen during acceleration. That is, there was no recovery in cognitive performance post-G. This effect appears again in the tracking data, especially for the tilt-back seat. More of this will be discussed later in reference to tracking performance.

Tracking performance for both PALE and tilt-back seats were similar. That is, tracking performance was best for the upright seat, particularly when compared to PALE seat performance at high G. The interesting point here concerned the marginal seat by time period interaction for the PALE seat. The data showed that the PALE seat advantage is in post-G recovery. No such advantage was detected in the tilt-back seat. In fact, tilt-back performance continued to deteriorate post-G. It may be that by maintaining a fixed design eye position (PALE seat) combined with the physiological benefits of reclination aid recovery in performance during post-G periods. The tradeoff in improved post-G performance was, of course, the degradation in performance during acceleration. Whether the tradeoff is warranted needs to be considered. It makes sense to view performance during acceleration as the most important factor. Unless the operator successfully accomplishes his task safely during G, post-G recovery is irrelevant. In contrast to the mixed results seen with the cognitive task, it would seem that tracking performance was almost always better in the upright seat. It should be mentioned here that safety precautions required that performance periods be restricted to 15 seconds (at least during acceleration). Future studies will be presumably restricted to brief performance periods as well. However, it would be interesting to continue gathering post-G performance data for more extended time periods (perhaps 30 minutes or more). Anecdotal reports have mentioned that physiological consequences of high G (especially when loss of consciousness is involved) may have effects lasting 24 hours or more. Whether behavioral detriments also occur for such an extended period would have widespread implications for aircrew personnel.

The tracking results favoring the upright seat could be a function of engineering design problems inherent in the reclined seats rather than true perceptual/motor advantages. Preliminary reports from some subjects indicated that when the PALE seat moved back during G there was a tendency for the arm to slip back along the armrest. This movement could have affected tracking performance. Problems such as these need to be investigated in future studies incorporating reclined seating configurations.

The current study has shown that physiological benefits of reclination do not easily translate into behavioral performance increments. The relationship between reclination and performance is not clear. While performance differences may indeed exist between upright and reclined seating, it is crucial that the engineering issues mentioned above be resolved before a definitive study can evaluate the contributions reclination may make to pilot performance under severe levels of G force.

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