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AVIATION, SPACE & ENVIRONMENTAL MEDICINE

Psychomotor Performance After Forward-Facing Impact

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An experiment to assess psychomotor performance before and after forward-facing (-G_x) impact was conducted using the AFAMRL Horizontal Decelerator Facility. There were 10 volunteer subjects who participated in 50 tests at 4 impact levels (0 G or sham, 8 G, 10 G, and 12 G). Two initial head positions were explored at the highest impact level. The manikin psychomotor task, a complex reaction time and accuracy task, was used to evaluate performance. Linear and angular accelerations were measured at the head. Although there was a weak correlation between angular head acceleration and prolonged post-impact reaction time, no compelling statistical evidence was found to support the hypothesis that psychomotor performance is degraded with increasing impact severity at these test levels. The highest test level explored in this study may not have been sufficient to produce a change in performance or, alternatively, the manikin task may not have been sufficiently sensitive to measure a change in performance if one was present. In addition, significantly lower angular head acceleration was observed at the 12-G test level when the head was rotated forward initially rather than prepositioned upright against the headrest. The potential for temporary stunning of aircrew members during operational crash landings or ditchings may be reduced by rotating the head forward prior to an imminent crash if time permits.

TRANSIENT NEUROLOGIC disturbances resulting from forward-facing whole-body impact experiments involving human subjects have been reported by several investigators. In his classic high acceleration rocket sled experiments, Stapp (14) observed scintillat-

ing scotomata, blurred vision, ophthalmodynia, frontal headache, and temporary loss of consciousness. Rhein and Taylor (11) noted that subjects were stunned and disoriented for 10 to 15 s following 20 G ($800 \text{ G} \cdot \text{s}^{-1}$) impacts on the Daisy Decelerator. This was followed by a period of euphoria and loquaciousness. Other findings immediately following impact included increased muscle tonus as evidenced by an increase in briskness of the deep tendon reflexes (15), gross involuntary muscle movements, decreased muscle coordination, and tremulousness. These immediate post-impact effects resolved within 10 min, and no long-term neurologic effects were observed.

Such experimental observations have prompted concern that transient neurologic disturbances occurring among military aircrew members following aircraft crashes or ditchings may subsequently compromise timely aircraft egress. In fact, there are several anecdotal reports to justify this concern (9). For example, ditchings of United States Navy aircraft have been witnessed in which the mishap crewmembers survived the crash impact and appeared to be conscious following the event, but made no apparent effort to egress the aircraft and became drowning casualties. Autopsies revealed neither external trauma to the head nor brain tissue damage which could explain this inappropriate crewmember behavior. Presumably, the involved crewmembers incurred mild concussion as a result of the inertial response of the head to the whole-body impact. These crewmembers were temporarily incapacitated and, therefore, failed to egress the aircraft in a timely fashion.

No significant neurologic symptoms have been observed at test levels commonly explored in forward-facing impact experiments today within the USAF

Voluntary informed consent was provided by all subjects who participated in this test program in accordance with the human use guidelines in Air Force Regulation 169-3.

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or the USN. However, some subjects have reported momentary stunning immediately after higher level exposures in the range of 10 G peak ($9 \text{ m} \cdot \text{s}^{-1}$). It is thus conceivable that subtle behavioral disturbances may occur at these or higher test levels and, further, that they may be manifest by a decrement in psychomotor performance.

Reader (8,9) reported a degradation in performance after -G_x impact, but his study was limited by several factors, including a small subject sample and the type of psychomotor task used. Subsequently, he evaluated a manikin psychomotor task which was potentially more useful in impact testing. Accordingly, the purpose of the present study was to assess psychomotor performance by means of this manikin task before and after forward-facing impacts at varied levels of severity. Due to more precise control of impact conditions and a larger subject sample, other shortcomings of the earlier study were eliminated in this test program.

METHODS

The manikin psychomotor task (10) was provided by Reader to assess pre- and postimpact performance in this study. Developed by the Royal Air Force Institute of Aviation Medicine, United Kingdom, the manikin task is a complex reaction time task designed as a laboratory analog of real-world performance in modern military systems. It is simple and reliable and has a high measure of differential stability. Plateau performance is easily achieved by subjects and, thereafter, maintenance of this performance level is independent of the frequency of practice.

A manikin figure is presented on a video display in one of four possible orientations: upright or inverted and facing toward or away from the subject. The arms of the manikin are outstretched laterally toward a circle on one side and a square on the other. A control symbol (either a circle or a square) is shown at the bottom of the screen. The task is to determine whether the control symbol appears to the left or to the right with respect to the manikin. The subject holds a switch in each hand and responds to the presentation by pressing the appropriate switch.

Allowing for the four manikin orientations and all possible combinations of symbols, 16 manikin presentations of varying difficulty may be presented to the subject. The timing and sequence of these presentations are controlled by computer. Each image disappears immediately after subject response or after 2 s, whichever occurs first. There is a 1-s pause between presentations. There are 96 manikin presentations in a fixed sequence which constitute one performance period, but each period begins at a random location in the sequence. A complete task consists of four performance periods separated by 2-min rest intervals. Therefore, the time required to complete the entire task is 25.2 min. In this study, the first and second performance periods were accomplished before impact, and the third and fourth periods were completed after impact. Each experimental exposure was timed so that the first manikin figure in the third performance period

was presented to the subject approximately 2 s after impact.

After minimal training with the manikin task, subjects typically achieve nearly 100% accuracy in their responses to the presentations, but reaction time continues to decrease asymptotically. In this study, subjects were required to achieve plateau performance in terms of reaction time by participating in repeated training sessions prior to the impact tests. By definition, plateau performance was reached when the total reaction time was within $\pm 5\%$ of the mean reaction time of the previous two training sessions. This performance level varied from subject to subject.

In order to achieve the objective of this study, a controlled experiment was designed in which volunteer subjects were exposed to different levels of forward-facing impacts on a decelerator facility. The test conditions investigated are shown in Table I. A sham or false test was included to assess the influence of anxiety on manikin task performance. The remaining test conditions were planned with the expectation that different head accelerations would be produced in each condition, permitting an evaluation of psychomotor performance as a function of head acceleration. Subjects were first exposed to orientation tests at nominal 8-G and 10-G levels to familiarize them with the test procedures and the impact experience. Then, the experimental test conditions A-E were accomplished in a randomized sequence with subjects being informed of the impact level prior to each test. Subjects were told to expect a sham test at any time during the program. The sham, of course, was not revealed to subjects in advance and was followed in the randomized sequence by at least one 12-G test. All acceleration profiles were approximate half-sine waveforms. Approximate times to peak sled acceleration associated with each test level were: 8-G level, 60 ms; 10-G level, 57 ms; and 12-G level, 53 ms.

TABLE I. EXPERIMENTAL CONDITIONS.

Test Condition Designation	A	B	C	D	E
Planned Sled Acceleration (G)	0	8	10	12	12
Planned Velocity Change ($\text{m} \cdot \text{s}^{-1}$)	0	8.1	9.2	10.2	10.2
Initial Head Position	*	Up	Up	Up	Forward

Accelerations and velocities are nominal impact test levels.

*Head position in cell A was that of next 12-G test in randomized sequence, either up or forward. Up indicates head was upright braced firmly against headrest; forward indicates head was rotated forward and downward with upper torso braced against shoulder straps of restraint.

The test facility used for this program was the Horizontal Decelerator Facility at the Air Force Aerospace Medical Research Laboratory (AFAMRL). Each experimental run included an acceleration phase and a coast phase. Initially, the test vehicle or sled was accelerated along the 64-m track by expending mechanical energy stored in a flywheel. After achieving sufficient velocity, the test vehicle then coasted to the impact area under the influence of approximately 0.4 G due to friction between the sled and track.

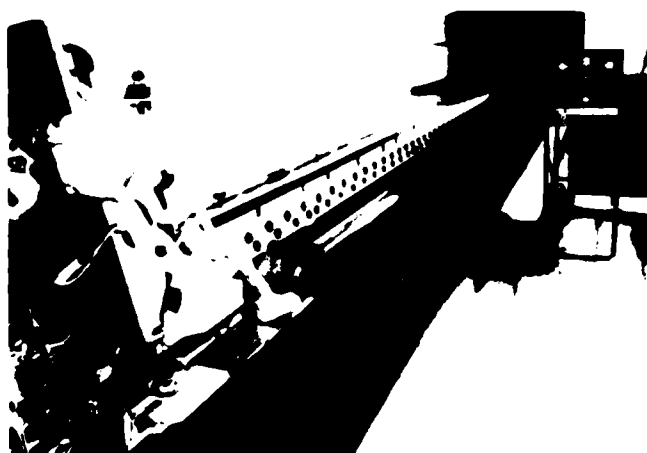


Fig. 1. Experimental Set Up. Video displays were arranged in the launch area (A, left) and impact area (B, right) to be in identical positions relative to the subject in both locations. To facilitate viewing of the displays, lights in the test areas were dimmed while the task was being completed.

During the coast phase, the instantaneous sled velocity was compared to a model or programmed velocity for that test condition and excess velocity was reduced by activating sled-mounted brakes, producing decelerations less than 1 G. This approach assured that the test vehicle arrived at the impact area with the appropriate terminal velocity. A piston mounted on the front of the sled then penetrated a fluid-filled cylinder which was mechanically programmed to produce the desired deceleration profile.

Two video displays for presenting the manikin task were set up adjacent to the sled, one in the launch area and one in the impact area (Fig. 1). The 43-cm diagonal screens of these displays were located approximately 2.35 m from the subject's head in order to approximate a 10° visual angle. The video displays were positioned to the right of the subject at an approximate 25° angle. The microcomputer controlling the manikin images was also located off the test vehicle, while the response switches remained with the subject on the sled during the experimental run. All pre-test preparations and procedures for the sham test were identical to the other test conditions, but the sled was not launched after the countdown procedure, and the third and fourth performance periods of the manikin task were completed in the launch area.

The test seat used in this study was designed with standard USAF ejection seat geometry. The seat back was reclined 13° from vertical, and the seat pan was inclined 6° above the horizontal. The seat was comprised of smooth wood surfaces, and no seat cushions were used. The headrest of the seat structure was positioned so that its contact plane was 2.5 cm aft of the seat back plane. The vertical position of the headrest was varied in order to provide adequate head support for the subjects. Once determined for each subject, this vertical headrest position was held constant during the test program.

A conventional double shoulder strap and lap belt configuration with an added negative G or crotch strap was used for all tests in this study (Fig. 2). The shoulder straps of this restraint were an adjustable MB-6 harness constructed of 4.5 cm wide type I polyester webbing,

and the lap belt was an HBU configuration constructed of 4.5 cm wide type III polyester webbing (MIL-W-25361C). The negative G strap, which was made of 4.5 cm wide 25.4 cm long type I polyester webbing, was added to the conventional restraint in order to reduce the tendency toward subject submarining and associated painful coccyx injury particularly at the higher test



Fig. 2. Restraint Harness Configuration. A standard double shoulder strap and lap belt arrangement with an added negative G or crotch strap was used in all tests in this study.

levels. The precise locations of the strap anchor points were the same as in a previous study (6). To accommodate the added negative G strap, a modified type MA-1 harness buckle was used. Prior to each experiment, the restraint harness was pretensioned to 89 ± 22 N as measured by load cells at the lap belt and shoulder strap attachment fittings. Pretension in the fixed-length negative G strap could not be adjusted.

The 10 male subjects who participated in this study were obtained from the AFAMRL Impact Acceleration Stress Panel (5). Prior to participation, the subjects, who were all active duty officers and enlisted personnel at Wright-Patterson Air Force Base, OH, were required to meet stature, weight, and sitting height criteria for pilot candidates. They successfully completed a USAF Flying Class II evaluation, pulmonary function tests, electroencephalogram, exercise treadmill test, and a complete battery of screening X-rays of the skull, chest, and spine. Thus, the selection method was designed to yield a subject sample comparable to the USAF flying population in terms of age and anthropometry (13), but was presumed to represent a subgroup with a lower susceptibility to impact injury in the experimental situation. Characteristics of the subjects participating in this study (means $\pm$ S.D.) are summarized as follows: age, 25.7 ± 3.7 years; weight, 83.1 ± 9.3 kg; height, 179 ± 6.8 cm; and sitting height, 94.2 ± 3.3 cm.

In order to participate, subjects were also required to see the manikin presentations with the unaided eye from a distance of 2.35 m since no contact lenses or glasses were permitted during the experiment. To obtain a sufficient subject sample from those available to participate, a liberal visual acuity criterion of 6/30 for uncorrected distant vision was used. Three subjects had 6/6 uncorrected distant vision in both eyes, three other subjects had 6/21 distant vision or worse in one or both eyes, and the remaining four subjects had uncorrected distant vision between these extremes. The distant vision of all subjects was correctable to 6/6.

For test conditions B, C, and D, subjects were instructed to assume identical body positions with head upright against the headrest, maintaining a mild to moderate amount of cervical muscle tension, and arms relaxed and resting against anterior thighs (Fig. 3a). In test condition E, however, the initial position of the head was as far forward and downward as possible with subjects permitted to tense the musculature of the upper torso and arms (Fig. 3b). Helmets were not used in this study in order to assure that the head response to impact was due to the mass of the head alone and to reduce the likelihood of cervical muscle strain. Before each experiment, subjects were instructed to attempt to respond to all manikin presentations as quickly as possible. The restraint

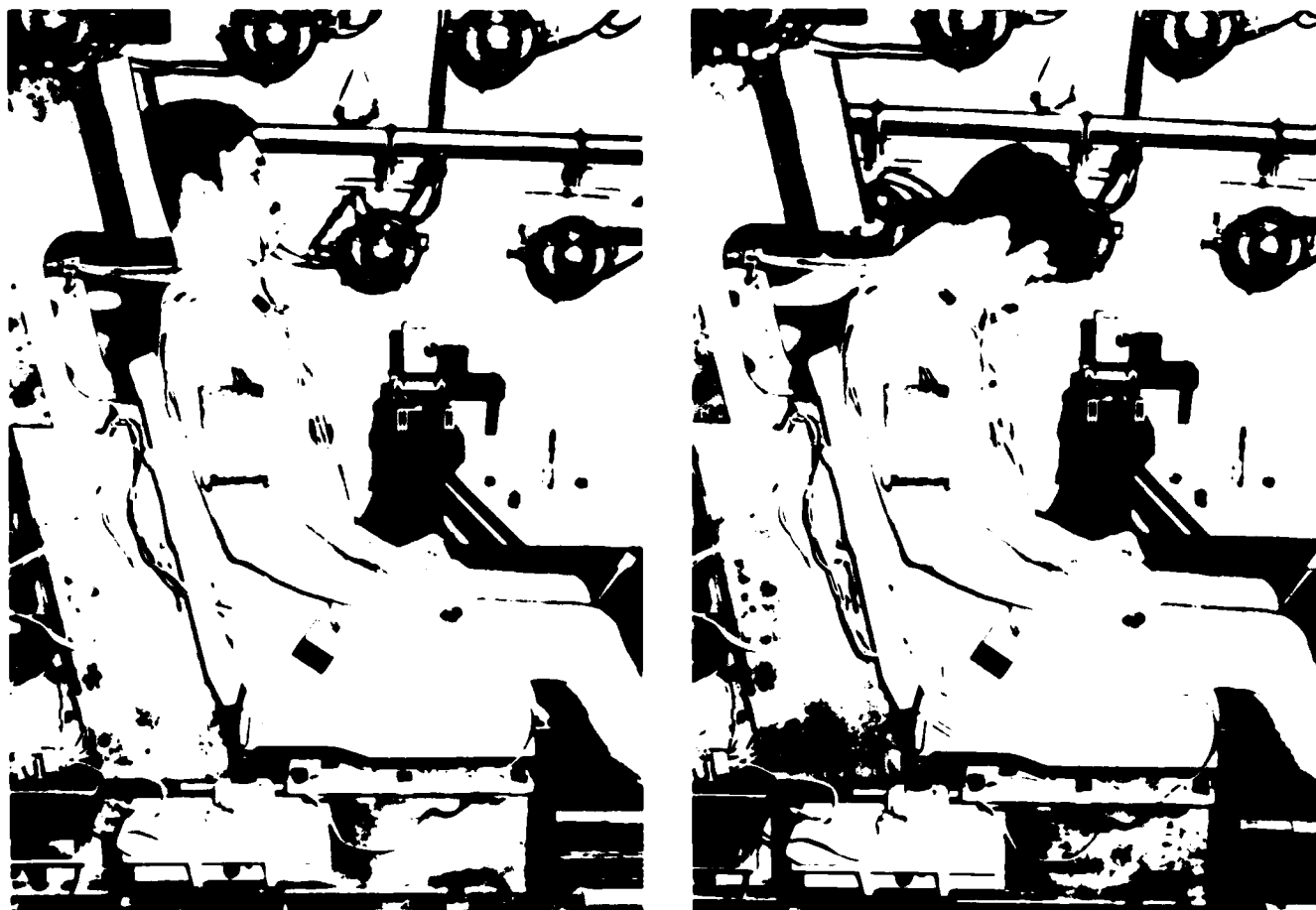


Fig. 3. Initial head positions before impact. (A, left) Head was positioned upright and braced firmly against the headrest in test conditions B, C and D. (B, right) Head was rotated forward and downward as subject braced upper torso against shoulder straps in test condition E.

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harness was pretensioned prior to the first performance period of the manikin task and was released after the fourth and last period. The dental appliance used for measuring head acceleration was placed in the subject's mouth after the the second performance period of the manikin task, just prior to countdown, and was gently removed by a medical technician during the third period. During the experiment the activity of all test personnel was restricted in order to minimize auditory and visual distractions of the subject.

The test fixture, restraint harness, and subject were instrumented to obtain pertinent objective data. Measured parameters included acceleration of the test vehicle and seat, velocity of the test vehicle, loads reacted at the seat, and loads measured at the restraint harness attachment points. Accelerations of the head and chest of the subject were measured by triaxial translational accelerometers (Endevco Model 2264) and by angular accelerometers (Endevco Model 7302A). Photogrammetric data were obtained by two high-speed motion picture cameras mounted on the test vehicle. The left-handed coordinate reference system for acceleration was used, with +X anterior, +Z cephalad, +Y right, and positive rotation about the Y axis being counterclockwise when viewed from the right.

Acceleration-time histories of the head and chest were evaluated by calculating the associated Gadd severity indices (3). These single parameters were obtained by computing a weighted integral of the acceleration-time function over the interval of the impact and were used to compare the overall severities of the impact responses.

Electronically measured and computed data, including the performance data from the manikin task, were

processed by computer. The results were statistically evaluated using the Wilcoxon paired-replicate rank test (16), and the Friedman two-way analysis of variance by ranks (12). These techniques were selected to compare the peak values of parameters and to establish the statistical significance of observed trends in the data. For both tests the 90% confidence level, assuming a two-tailed test, was chosen as the level of statistical significance for analysis of the performance data, while the 95% confidence level was selected for analysis of the impact parameters.

Following each experimental level impact, the subject completed a post-test questionnaire designed to evaluate his subjective impressions of test anxiety, manikin task performance, and impact response. Subjects were asked to evaluate various test-related sensations on a seven-integer scale from -3 to +3, with zero indicating a neutral response. For example, anxiety was assessed as relatively low or relatively high, and head displacement as relatively small or relatively large. The numbers of subjects giving more favorable and less favorable responses to the same question in comparable test conditions were noted.

RESULTS

Prior to the experimental level impacts, subjects participated in several manikin task training sessions in order to achieve asymptotic performance. The 10 subjects required from 3 to 13 training sessions with an average of 7.4 sessions to achieve plateau performance according to the established definition.

Selected impact input and response parameters are shown in Table II. Data presented are means $\pm$ S.D.

TABLE II. INPUT DESCRIPTORS AND HEAD RESPONSE DATA.

Measured Parameter	Cell B 8 G/Up	Cell C 10 G/Up	Cell D 12 G/Up	Cell E 12 G/Forward
Input Descriptors				
Sled Acceleration (G)	-8.04 ± 0.11	-9.96 ± 0.25	-11.8 ± 0.20	-11.7 ± 0.43
Sled Velocity ($\text{m}\cdot\text{s}^{-1}$)	8.17 ± 0.04	9.15 ± 0.13	10.0 ± 0.09	9.91 ± 0.18
Linear Head Acceleration (G)				
-X Axis	-10.2 ± 2.2	-12.8 ± 3.1	-15.3 ± 3.1	-11.2 ± 3.5
-Z Axis	-1.9 ± 2.8	-4.0 ± 4.3	-8.4 ± 6.5	-16.6 ± 3.8
Resultant	10.6 ± 2.5	13.7 ± 3.9	17.3 ± 6.2	20.0 ± 4.7
Head Severity Index				
	24.9 ± 11.1	49.8 ± 29.6	71.8 ± 30.0	61.3 ± 20.1
Angular Head Acceleration ($\text{rad}\cdot\text{s}^{-2}$)				
- R_y	-340 ± 197	-469 ± 147	-594 ± 212	-282 ± 102
+ R_y	218 ± 120	403 ± 171	501 ± 136	324 ± 178

The same 10 subjects participated in each test condition.

Data presented are means $\pm$ S.D. for peak accelerations, velocities, and severity indices.

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for peak accelerations, sled velocity, and head Severity Index. The same 10 subjects participated in each test condition.

Appropriate comparisons among test conditions were made using the Wilcoxon paired-replicate rank test ($2\alpha \leq 0.05$). First, the effects of changes in sled acceleration and velocity at impact were demonstrated in Wilcoxon comparisons B-C, C-D, and B-D. As expected, significant differences in sled acceleration and velocity change at impact were shown in all comparisons, indicating a progression in impact severity from test condition B to test condition D. Statistically significant differences in all head response parameters were also observed in all comparisons, showing the expected progression in linear and angular head accelerations and in head severity index.

Second, the effects of head position were demonstrated in Wilcoxon comparison D-E. No statistically significant differences were noted in sled acceleration or velocity change at impact, indicating satisfactory matching of impact parameters in these two test conditions. The -Z axis head acceleration was significantly higher with the head rotated forward initially than with the head positioned upright against the headrest. Review of the acceleration traces revealed

relatively high amplitude and short duration spikes in the Z axis head acceleration in test condition E, probably due to the forward initial position of the head which results in relatively small head displacement during impact. In addition, with the head rotated forward and downward, the Z axis linear accelerometer is oriented along the direction of impact, to some extent accounting for the higher Z component acceleration observed. The mean resultant head acceleration was higher in test condition E, while the Gadd head Severity Index was higher in test condition D, but neither difference was statistically significant. As expected, angular head accelerations (both $-R_y$ and $+R_y$) were significantly higher with the head upright than with the head rotated forward. These data highlight the limitations of measurements made with linear accelerometers and the importance of obtaining angular accelerations of the head whenever possible.

The psychomotor performance data from the manikin task are presented in terms of accuracy (Table III) and reaction time (Table IV). Separate statistical analyses of error and reaction time data were carried out by means of the Wilcoxon paired-replicate rank test using the liberal 90% confidence level for a two-tailed test in order to avoid overlooking findings. For each

TABLE III. PSYCHOMOTOR PERFORMANCE: SUBJECT ACCURACY.

Task Period	Number of Errors				
	Cell A Sham	Cell B 8 G/Up	Cell C 10 G/Up	Cell D 12 G/Up	Cell E 12 G/Forward
1 - Baseline	2.1 ±1.5	1.4 ±1.6	1.3 ±1.2	1.3 ±1.2	1.9 ±1.1
2 - Pre-Impact	1.4 ±1.5	2.0 ±1.7	1.8 ±1.6	1.4 ±1.3	1.6 ±1.8
3 - Post-Impact	2.9 ±2.0	2.0 ±1.8	1.7 ±1.3	2.0 ±1.4	3.3 ±3.0
4 - Recovery	2.1 ±2.0	1.6 ±1.4	1.1 ±1.1	1.5 ±1.7	1.7 ±1.8

Errors are the sum of incorrect responses and failed responses for each performance period of 96 presentations.

Values are means ± S.D.

TABLE IV. PSYCHOMOTOR PERFORMANCE:
SUBJECT REACTION TIMES.

Task Period	Reaction Time (in seconds)				
	Cell A Sham	Cell B 8 G/Up	Cell C 10 G/Up	Cell D 12 G/Up	Cell E 12 G/Forward
1 - Baseline	68.3 ±10.4	66.5 ±9.0	68.8 ±11.0	66.9 ±9.7	65.7 ±9.9
2 - Pre-Impact	69.3 ±11.4	66.5 ±7.8	69.4 ±9.9	68.3 ±11.3	66.1 ±9.5
3 - Post-Impact	72.5 ±13.8	69.7 ±9.4	70.7 ±9.8	70.4 ±12.3	67.9 ±11.7
4 - Recovery	70.1 ±12.3	66.7 ±10.1	68.1 ±8.8	67.4 ±11.8	66.7 ±10.3

Values are means ± S.D.

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test condition, comparisons between data obtained in different performance periods were completed. These included comparisons between periods 1-2, 1-3, 1-4, 2-3, 2-4, and 3-4. A larger number of errors and/or longer reaction times in the third or post-impact period were anticipated in test condition D and possibly in test condition C. Thus, the pre-post impact comparisons 1-3 and 2-3, as well as comparison 3-4 were most important in the evaluation of test results.

As previously noted, subject accuracy in manikin task performance typically improves rapidly during the training sessions to nearly 100% and, thereafter, is maintained at that level. For all responses in this study, subjects recorded greater than 98% accuracy. Furthermore, small variation among the mean number of errors in the various performance periods was demonstrated (Table III). The largest error value, occurring in the post-impact period of test condition E, may be attributed to one subject's inadvertent release of his left-hand response switch at the time of impact. As a result, the subject could not respond to the first six manikin images. These failed responses were recorded as errors, although the subject noted that he recognized the presentations during this time and would have been able to respond correctly if he had the left response switch. Given the uniform accuracy in all performance periods, it is not surprising that analysis of these error data by the Wilcoxon rank test was unremarkable in terms of statistically significant findings.

Small variation among the mean performance period reaction times in the various test conditions was also observed in this study (Table IV). The mean values ranged from a low of 65.7 s to a high of 72.5 s. For each test condition, the reaction time in the post-impact or third period was slightly longer than the reaction times in the three other performance periods. There were four reaction times greater than 70 s. These occurred in the third performance period of test conditions C and D (expected findings) and in the third and fourth performance periods of test condition A (unexpected findings).

Wilcoxon analyses of these reaction time data revealed no statistically significant differences in the control comparisons 1-2, 1-4, and 2-4 in any test condition. These findings were expected since no significant differences among reaction times in the baseline, pre-impact and recovery performance periods

were anticipated. Additional Wilcoxon comparisons indicated that reaction time in the post-impact period was significantly longer than reaction time in other performance periods in some cases (Table V). However, the distribution of these statistically significant differences did not meet our expectations.

For example, the statistically significant differences in comparisons 1-3 and 2-3 in test condition A were presumably due to the effect of subject anxiety on performance since subjects were told to expect a 12-G impact prior to a planned sham test. If this were true, however, similar statistically significant differences would be seen in comparisons 1-3 and 2-3 in test conditions D and E. Even larger differences might be expected if an additional decrement in performance occurred as the result of impact. In fact, however, no statistically significant differences were seen in three of these four comparisons. The findings in the sham condition, therefore, may be a manifestation of the Yerkes-Dodson law which relates performance to arousal for simple and complex tasks (7). For both types, performance increases with increasing arousal to a maximum; then, with further increase in arousal, performance decreases. A mental let-down or state of low arousal may have occurred in period three of the sham condition causing failure of the subject to adopt an appropriate mental set to accomplish the task, leading to a performance decrement.

In view of the findings in test condition A, the absence of statistically significant differences in the pre-post impact comparisons (comparisons 1-3 and 2-3) in test conditions C and D were unexpected. Although statistically significant differences were found in comparison 3-4 in both of these test conditions, a similar finding occurred in test condition B as well. The significant decrease in reaction time observed in the recovery period compared to the post-impact period in these three test conditions may be the result of increased subject arousal in anticipation of manikin task completion.

These same reaction time data were also evaluated using the Friedman two-way analysis of variance by ranks. This analysis revealed no meaningful trends in the data.

Correlations between reaction time and the various measures of head response were sought using a linear regression analysis technique (method of least squares).

TABLE V. COMPARISONS AMONG PERIOD REACTION TIMES.

Periods Compared	Percent Increase in Reaction Time During Period 3				
	Cell A Sham	Cell B 8 G/Up	Cell C 10 G/Up	Cell D 12 G/Up	Cell E 12 G/Forward
1 and 3	6*	5	3	5	3*
2 and 3	5*	5*	2	3	3
3 and 4	3	4*	4*	4*	2

Values are percent increases in the mean reaction times shown in Table IV for the indicated comparisons.

*Difference in reaction times is statistically significant by the Wilcoxon paired-replicate rank test ($2\alpha \leq 0.1$).

Analysis of data from test conditions B, C, D, and E showed a weak correlation between reaction time and $+R_y$ head acceleration at 95% confidence ($df = 38$, $r = 0.343$), indicating that longer reaction times were associated with higher angular head accelerations. Of course, correlation does not necessarily imply causation. No further correlation between reaction time and other head response parameters such as linear head acceleration or head Severity Index was found.

Data obtained from subject questionnaires demonstrated few statistically significant differences between pairs of test conditions, although the observed trends were consistent with expectations. For example, at least 7 of 10 subjects experienced lower pre-test anxiety in test condition B than in any of the other test conditions. However, these findings were statistically significant in the A-B and B-D comparisons only. Recall that the subjects were anticipating a 12 G impact prior to the sham test (condition A).

The subjects judged that head displacement was smaller in test condition E than in test conditions B, C, or D to a statistically significant degree, but a significant difference in perceived head displacement was not demonstrated in the B-C, B-D, or C-D comparisons. Moreover, no significant differences were found in neck or back discomfort experienced during the various impacts.

One subject reported being slightly dazed immediately post-impact in test conditions C, D, and E while another subject was stunned momentarily in test condition E. No other adverse neurologic effects were noted, the only medical findings being expected abrasions, contusions, and minor cervical muscle strains.

Unfortunately, several technical problems were encountered in this study requiring 12 tests to be repeated. Data from 10 tests were lost due to computer-operator error, one test was repeated because the impact level was unacceptably low, and another was repeated due to data collection problems. Excluding the performance data from the 12 repeated tests, however, did not alter our conclusions.

DISCUSSION

This study produced no convincing statistical evidence that psychomotor performance as measured by reaction time to the manikin task is degraded with increasing levels of whole-body impact up to 12 G ($10.2 \text{ m} \cdot \text{s}^{-2}$). Nearly all increases in post-impact reaction time (Table V) were within the 5% tolerance established for plateau performance. Furthermore, the pre-post impact differences observed at the higher test levels were not statistically significant. The correlation found between longer reaction times and larger $+R_y$ head accelerations is provocative and suggests that higher angular head acceleration may, in fact, cause a measurable performance decrement. However, scientific evidence supporting that contention has not been provided in this study.

In the single previous investigation of psychomotor performance following forward-facing impact, subjects were also exposed to four conditions (0 G or sham, 5 G, 10 G, and 12 G) and performance was measured before

and after the events with a step tracking task developed by Gibbs. The study (8,9) purportedly demonstrated a degradation in performance at the highest test level, but was subject to several critical limitations. For example, two different groups of four subjects were evaluated, one at the 10-G level and the other at the 12-G level, so that the test results were highly dependent on subject variability. Also, the tracking task chosen was not entirely appropriate for its intended purpose since it required considerable motor skill but relatively little cognitive effort. Finally, the impact velocity change associated with the nominal 12-G test level was $6 \text{ m} \cdot \text{s}^{-1}$ and, on the average, approximately $2 \text{ m} \cdot \text{s}^{-1}$ lower than the velocity change associated with the 10-G test, leading to concern that these two test conditions may not have been adequately dissimilar in terms of their overall impact severity to produce measurably different head-neck responses. Given these limitations, it is less surprising that our own test results did not confirm the findings of the previous study.

Although the manikin psychomotor task requires greater cognitive effort than the Gibbs tracking task, the former may also not be an appropriate task for this application. Conceivably, the manikin task may not be sufficiently sensitive to detect a performance decrement, even at the highest test level explored, if such a decrement exists. This would appear to be particularly true in the case of a highly transient neurologic disturbance. Consider that a single performance period of the manikin task requires approximately 4.8 min to complete. This duration is probably too long to permit precise quantification of the effect of a presumably transient neurologic disturbance which may resolve in seconds. The prolonged reaction times required by the subject to respond to the first few manikin images immediately following impact are averaged with the more rapid reaction times required for subsequent presentations as the subject recovers. The net outcome is that any early performance decrement is diluted by the normal performance which follows.

Perhaps an evaluation of psychomotor performance for a shorter period of time following impact would reveal a measurable performance deficit. This could be accomplished by programming the manikin task sequencer to present the images in blocks of 16 non-repeated presentations so that each block would contain all 16 possible presentations and would be of difficulty equivalent to other blocks or segments. Performance during immediate post-impact segments could then be compared to performance in later segments within the same period. Unfortunately, the manikin task sequencer was not programmed to initiate the presentations at the beginning of a segment in this study. The data, therefore, are not amenable to a more refined analysis.

It may also be true that the impact test levels examined in this study were not sufficiently high to produce a decrement in psychomotor performance, implying a defect in the initial hypothesis. It is certainly significant that only a few tests resulted in subjects being momentarily dazed following impact. The impact levels selected for evaluation in this study were extremely conservative compared to the previous

human impact tests which have produced neurologic symptoms (11,14,15). Our tests were also conservative with respect to impact levels recently demonstrated to produce irreversible neurophysiologic changes in Rhesus monkeys (1).

Despite the apparent benignity of these forward-facing impacts conducted in a laboratory setting without helmets, similar impact experiences in the operational setting may be associated with a greater likelihood of injury. This is true because the added mass of the flight helmet increases the forward inertial response of the head during the impact, resulting in higher cervical tension and possibly higher head acceleration. If the neurologic consequences (such as concussion) associated with aircraft crashes and ditchings are to be minimized, the principles of biomechanical protection require that head motion relative to the torso and peak head accelerations during impact be minimized.

A variety of techniques have been suggested to limit head motion during forward-facing impact. Approaches have included actively restraining the head posteriorly or mechanically impeding forward motion of the head by deploying an air bag, for instance, anteriorly. Such methods, however, are not yet available options in current aerospace operational equipment.

In the absence of other alternatives, the simplest and perhaps most effective technique for reducing head motion is to preposition the head forward and downward prior to an anticipated -G_x impact. As shown in this study and others (2), prepositioning of the head in this manner significantly reduces the angular head acceleration experienced during the event. This pre-impact bracing posture could be assumed by aircrew members confronted with imminent crash or ditching situations.

CONCLUSION

In this study, 10 male volunteers were exposed to forward-facing whole-body impacts up to a maximum test level of 12 G (10.2 m · s⁻²). The manikin psychomotor task was used to evaluate subject performance in terms of reaction time and response accuracy before and after each impact. Our hypothesis that psychomotor performance is impaired with increasing impact severity was not supported by analysis of the data from this experiment. Nevertheless, it is likely that the more severe -G_x impacts associated with some survivable aircraft crashes or ditchings may result in significant degradation of aircrew member performance. Conceivably, the occurrence of adverse effects such as temporary stunning or concussion may be minimized by the crewmember prepositioning his head forward and downward prior to anticipated crash impacts.

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