HEAD ACCELERATION AND PSYCHOMOTOR PERFORMANCE

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SUMMARY

Concussion resulting from head acceleration could explain the poor survival rates in some types of accidents. Experiments have been conducted on a decelerator using a tracking task to determine whether high head acceleration could affect psychomotor performance.

Human subjects were exposed to impact acceleration of 0 (sham), 5, 10 and 12-Gx facing forwards. Measurements were made of the linear and angular accelerations experienced at the head and a step tracking task was used to examine psychomotor performance. Electro-encephalographs were also recorded.

Both the linear and angular accelerations at the head were increased at the higher levels of impact acceleration. At $-5G_x$ there were no significant differences in psychomotor performance when compared with controls, but at $-10G_x$ and, especially $-12G_x$, significant differences were found. The EEG activity did not vary significantly and no concussive effects were observed in any subject.

These results suggest that impairment of psychomotor performance severe enough to jeopardise survival could be produced by high accelerations of the head, though neither linear nor angular acceleration appear to have special significance.

INTRODUCTION

Survival in impacts depends on many factors, of which the most significant is probably the magnitude of the forces of impact. However, there have been many aircraft accidents where the estimated forces of impact were below normal physical tolerance, yet the occupants made no attempt to escape from the wreckage. In these accidents, no head impact occurred which could account for the lack of purposive action, yet the occupants either drowned following water entry, or were incinerated in a post-crash fire. No post-mortem evidence could be produced to explain the inactivity of the occupants following impact. Pilots have been observed to be "dazed and semi-conscious" in such incidents.

Head Acceleration

Ommaya et al (1966) observed that the whiplash effect (rapid extension and flexion of the neck) could cause concussion, and that limiting neck movement by means of collars raised the threshold for concussion. Subsequent work (Genaralli et al, 1972) suggested that angular acceleration was more effective than linear acceleration in producing concussion. Some impact experiments involving human volunteers have produced similar effects; for example Snyder (1970) reports "stunning and confusion" after some forward facing impacts.

In order to determine whether head acceleration could produce a syndrome in man similar to that seen in experimental concussion in animals, an experiment was devised to expose subjects to gradually increasing impact forces. However, concussion would be likely only as a result of high levels of acceleration and these would be both dangerous and difficult to impose upon human subjects. Lower levels of acceleration, while not inducing clinical concussion, should produce changes in behaviour, and these should be detectable with some form of psychomotor task. In addition, such a task might be related to the ability of a pilot to escape from an aircraft following impact. The task used was that devised by Gibbs (1966). EEG activity was also recorded.

METHODS

The experiments were conducted on the linear decelerator at the RAF Institute of Aviation Medicine (Dutton, 1973) using 26 male members of staff.

A metal seat frame was mounted facing forwards on the decelerator. The supporting surfaces were made of moulded fibreglass, a five point restraint harness was fitted and an arm rest was placed on the right side. An accelerometer was bolted to the carriage structure.

Metal bite plates were constructed and covered with dental impression material which was then moulded to each subject's dental bite. Two linear accelerometers were mounted on these plates in the vertical and horizontal planes together with an angular accelerometer recording in the saggital (pitch) plane. EEG electrodes were placed on the right side of the scalp of the subjects; one pair on the front-parietal area and the other on the occiput. After amplification, the output from the accelerometers and EEG electrodes passed by a trailing lead to a central recording console. Data were recorded on a 14 channel FM tape recorder and on an ultra-violet light galvanometer recorder.

The psychomotor task was presented to the subjects by two identical 21 inch TV monitors, connected in parallel, positioned at each end of the decelerator track so as to be in an identical position relative to the subject before and after impact. The task was generated by a PDP 8 digital computer and consisted of a spot light which could be positioned above any one of five arrow pointers arranged in a horizontal line. A movable vertical cursor line was also presented, the position of which was controlled by a small hand controller mounted on the arm rest. The task presented a spot in any of the five positions in random order and required the subject to move the cursor to occlude the spot. The spot then re-appeared in a different position. The task was conducted for periods of 4 minutes. Four separate periods were grouped with 2 minute rest periods to make a total session of 22 minutes. On those trials in which the subjects experienced impact, this occurred immediately before the third period of tracking. Thus, there were two 4 minute periods before impact and two after. Each subject also performed other sessions of tracking as controls without impact. The decelerator building was darkened, and noise and distraction were minimised. All the subjects were exposed to a lengthy training programme using the psychomotor task until their performance stabilised.

The experiments were conducted in separate phases. Phase 1 used a deceleration impulse set at 5.3G peak, with an overall duration of 0.6 sec.

The velocity before impact was 8 ms^{-1}. In Phase 2, the peak was set at 10.6G with an impulse duration of 86 ms, but with a similar velocity before impact. Phase 3 used an impulse with 12.5G and a 71 ms duration. However, the speed before impact was slower (6 ms^{-1}). The limitations of the decelerator mechanism did not allow similar rates of onset, durations and velocity changes to be maintained through the series.

In order to examine whether apprehension could affect tracking ability, some subjects were prepared for deceleration, but the run was aborted. Psychomotor performance was analysed as in the real impacts. As the value of this investigation depended on the subject not knowing whether a deceleration would occur or not, only half the subjects could experience a 'sham' run. This was conducted on a randomized double blind basis. This constituted the fourth phase (to be referred to as phase 0) and 9 subjects participated.

Eighteen subjects took part in the first phase, four in the second and four in the third. As the experiments were spread over a considerable period, staff changes prevented the same subjects participating in all phases.

RESULTS

Accelerations

The mean accelerometer data for the three phases of the experiments are presented in Table 1. The table shows that the peak accelerations of the head (both linear and angular) increased with increased deceleration.

EEG Data

The EEG data were replayed from magnetic tape into a hybrid digital analogue computer and analyser using a method devised by Byford (1964). The data were filtered into four frequency bands, and each band was then squared to increase the signal to noise ratio and to convert all data to positive values. The information in each band was then integrated and plotted against time. Changes in activity of the EEG were thus shown as changes in slope of the lines, whilst artifacts presented as vertical steps. All traces showed step changes at the moment of impact, but no significant alterations of slope.

Subjective Comments

There were few subjective comments. In phases 2 and 3, two runs produced slight headache and two runs caused neck stiffness which persisted for twelve hours. Approximately half the subjects noted a feeling of isolation immediately after deceleration. They felt detached from their surroundings, but this feeling did not persist beyond one minute.

Psychomotor Task Data

The psychomotor performance of the subjects was recorded as the "latency time" and "movement time" for each response. Latency time is the time interval from a fresh spot appearing until the subject first moved the cursor line to follow it, whilst "movement time" is the time interval between the start of movement and occlusion of the spot. In addition, whenever the subject initially moved the cursor in the opposite direction from that required, an error was recorded. Finally, the total number of spots successfully occluded in four minutes was recorded. This was the first index of performance to be used in the analysis (Table 2).

The data are grouped into the 4 phases (including the sham runs as phase 0) and mean values are given. Comparisons are made of the scores obtained from the 3rd period (just after impact, or sham) with mean values from the 1st, 2nd and 4th period of the same session. In addition, scores from the 3rd period are compared with those of the 3rd period of the control sessions. Coefficients of probability (p) are given for the significance of differences between adjacent figures in the table.

When the scores of the third period are compared with the means of periods 1, 2 and 4, significant drops are seen in phase 2 ($p = 0.01$) and phase 3 ($p = 0.05$). When comparing scores from the third period with those from the third period of a control session, only the differences obtained in phase 3 are significant ($p = 0.001$).

No significant differences appear in the sham runs, or in phase 1 (5.3G).

A further analysis was made to see whether impact affected the number of errors made. Mean values showed no significant difference between deceleration and control sessions. Unlike the total number of hits, the number of moves in error was unaffected by impact.

Latency times were also analysed. Latencies from successive groups of ten moves were meaned and each value was then compared with the appropriate figure for the other sessions. An analysis of variance showed that while there were small differences in the groups of means and overall mean values between decelerations and controls, these differences were not statistically significant.

Movement time data were analysed in a similar way and as with the latencies, movement time did change slightly with deceleration, but the changes were not significant.

An analysis was also conducted to compare individual measures of performance with individual accelerations. No significant correlations emerged when using all the data from phases 1, 2 and 3. However, the data from phase 1 did show significant correlation between psychomotor decrement and head vertical ($+G_z$, $r = 0.56$, $p = 0.02$) and forwards peak angular ($+R_y$, $r = 0.51$, $p = 0.05$) head acceleration with psychomotor performance decrement. Data from phases 2 and 3 showed significant correlation between peak head horizontal linear acceleration ($+G_x$, $r = 0.52$, $p = 0.05$) and performance decrement.

DISCUSSION

Objective

The object of the experiments was to measure the psychomotor performance of human subjects before and after exposure to different conditions of head acceleration achieved by varying the impact deceleration of a seat.

Accelerometer Data

Analysis of the records showed that the individual dental impression, when held by the clenched teeth, prevented any movement relative to the teeth and reliable recordings of head acceleration were obtained. The data in Table 1 shows that as the seat deceleration increased, the head vertical and horizontal linear acceleration also increased, but at a greater rate. The head angular acceleration also increased with seat deceleration, but at a lesser rate.

EEG Variance

Before impact, the EEG showed considerable interference from the electric winch and switch gear of the decelerator which caused step changes in the EEG variance curves. In the latter part of the periods of tracking there was no interference and the EEG variance graphs showed little artifact and the data were reliable. However, the graphs after impact were essentially straight lines so they did not show any significant effect due to acceleration. Moreover, at no time during the decelerations was there any significant impairment of consciousness. The impact was brief and subjects appeared alert throughout.

Psychomotor Performance

Many methods exist for examining human performance. No method has found universal acceptance, but this is expected as there are many different aspects of human performance. The most appropriate measure of a pilot's ability to escape from a cockpit after impact would involve an exact simulation of that task. Proving the reliability and repeatability of such a task would be so difficult as to make it not worthwhile.

A task requiring visual, psychological and motor aspects was sought. A potential candidate was a tracking task which had been used under a wide range of conditions, including hypoxia. Hypoxia can cause unconsciousness, but mild hypoxia can produce changes in behaviour similar to concussion, and Denison et al, (1974) showed that the decrement in subjects' performance correlated well with changes in inspired oxygen tension. Moreover, the EEG activity of the subjects had also been related to psychomotor performance when assessed in this way.

The initial comparison of performance was between the third period of the deceleration and control sessions. The mean number of hits achieved in the 4 min periods was reduced by 2.3 in phase 1, by 6.3 in phase 2 and by 14.2 in phase 3. 'Sham' runs reduced the number of hits by 2.5. Only the reduction in phase 3 was statistically significant ($p = .001$).

The next comparison was between the third periods of the deceleration sessions and the other three periods of the same sessions. Here the reductions were:- sham, 0.9; phase 1, 1.9; phase 2, 11.8; phase 3, 8.0. Only differences in phases 2 and 3 were significant ($p = 0.01$ and 0.05 respectively). Errors, latencies and movement times did not show any clear effect due to deceleration.

The data from the psychomotor task demonstrate that deceleration can impair performance immediately following impact, but that performance recovers within a few minutes (i.e. by the 4th period of the session). Increasing the deceleration of the carriage increases the performance deficit. Below 10.6G, no significant decrement could be demonstrated. There is a small effect, probably due to apprehension, as shown by the sham runs, and this effect is similar to that seen at 5.3G, but neither effect was statistically significant.

The analysis of individual performance and acceleration data does not support any clear distinction between the effects of linear as opposed to angular head acceleration, but suggests that both probably have some effect on psychomotor performance. More work with many more subjects would be required before firm conclusions could be drawn.

These experiments have shown that the ability of a subject to perform a simple tracking task is impaired after deceleration, but that at the impact levels imposed, the effect is transitory. At much higher levels, the effect could be more pronounced and longer lasting, even to the extent of unconsciousness. This would obviously impair the ability of a crewman to escape the wreckage of an aircraft and jeopardise his survival. More work is required to quantify this risk.

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TABLE 1 ACCELEROMETER DATA

Phase	Seat Acceleration				Head Acceleration			
					Linear		Angular	
	Peak	Onset	Duration	Velocity Change	Vertical	Horizontal	Forwards	Rearwards
	G	G/sec	ms	ms^{-1}	G	G	rads/sec^2	
1	5.3	148	583	8.3	4.4	7.7	254	193
2	10.6	475	86	8.1	20.9	14.8	279	213
3	12.5	475	71	6.0	24.8	26.9	385	275

TABLE 2 PSYCHOMOTOR PERFORMANCE

Phase	Session	Number of 'hits' in periods		
		3rd	Mean of 1st, 2nd & 4th	
0 (sham)	Mean of controls	127.5	NSD	128.5
		NSD		NSD
	Sham impact	125	NSD	125.9
1	Mean of controls	133.2	NSD	134.0
		NSD		NSD
	Impact	130.9	NSD	132.8
2	Mean of controls	139.8	NSD	138.9
		NSD		NSD
	Impact	133.5	p = 0.01	145.3
3	Mean of controls	147.7	NSD	145.5
		p = 0.001		NSD
	Impact	133.5	p = 0.05	141.5

The coefficient of probability (p) is given for the significance of the differences between adjacent values. NSD = No significant difference.