Original Article

Effect of Vibration, Heat and Noise on Psychomotor Performance

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Psychomotor performance was studied under intermittent vibration of 6 Hz at 0.5 g amplitude, and heat and noise exposure of $60^0\ T_{db}$ with 20% rh and 85 dB(A) respectively. Stresses were administered individually as well as in various possible combinations. Performance on a psychomotor task was determined in four intervals within a total period of 1 h of experimentation.

Vibration degraded the psychomotor task performance significantly as an individual stress as well as in combination with other stresses of heat and noise. Heat improved the psychomotor performance after 30 min of continuous exposure. At the start of the exposure as well as after 45 min, noise also tends to improve the psychomotor performance. Noise and heat combined did not affect performance. The changes brought about by a combination of stresses of vibration, heat and noise on psychomotor performance were statistically similar to those seen under vibration and heat, and vibration and noise. However, performance degradation was somewhat higher with the combination of all the three stresses as compared to the effect brought about by linear combination of these stresses. Thus, a realistic stress combination simulation is suggested for performance efficiency studies in laboratory based experiments.

Vibration, the single most important stressor as far as visual and co-ordinated performances are concerned, needs to be simulated in laboratory studies using actual vibration data obtained from aircraft in operation.

Keywords: Aviation stress, aircrew performance, combined stresses, vibration simulator.

Military vehicle operations in general, and military flying in particular, subject the crew to environmental stresses of vibration, heat and noise. Vibration and noise are generated by engine, auxiliary equipment and dynamic interaction of the vehicle with the medium. In our country, the problem of heat stress is also considerable, particularly in the north[1-3]. These inherent stresses, either individually or in combination, are capable of producing physiological strain, the magnitude of which depends on the amount of stress, its duration and its interaction with other stresses.

Stresses of vibration, heat and noise may not unduly extend the physiological compensatory mechanism depending on the availability of stress reducing devices. However, presence of stresses may bring about changes in the overall performance of military crew. Thus, physical health is not endangered but performance efficiency may be.

There have been many laboratory based studies on vibration[4-13], heat[14-18] and noise[19-22] including their effect on task performance. However, actual inflight measurements of these stresses and laboratory studies on performance evaluation under combination of stresses are few and, for the most part, equivocal[23-28]. Also, findings on the effects of combined stresses on performance lack uniform indication due to difference in the absolute and relative levels of stress magnitudes used as well as procedural differences and choice of complexity of task. In the present study, effects of stresses of vibration, heat and noise on a psychomotor task involving visual and hand co-ordination have been evaluated to understand the effect of combination of stresses on performance efficiency.

Material and Method

Simulator

Vertical vibrations were simulated using an electrohydraulic vibrator which was developed at the Institute of Aviation Medicine, Bangalore (IAM) and has been in operation for a number of years. It consists of a mild steel platform which is actuated by a piston and cylinder. The platform is displaced vertically by the force of spindle oil. The system is capable of producing Z axis vibrations in the frequency range 2-15 Hz at various amplitude levels. Frequency and amplitude resolutions of 0.1 Hz and 0.05 g respectively are achieved. A bucket seat of mild steel is firmly mounted on the vibrating platform so that the seat is displaced at the frequencies and amplitudes of the platform. The seat is incorporated with a lap strap shoulder harness. The harness can be adjusted for various sitting heights. At the base of the seat, an accelerometer of flat response is fixed to monitor the seat vibrations. A vertical frequency of 6 Hz at 0.5 g peak amplitude is obtained at the seat level for simulation of the vibration stress. A double layered thermally insulated cockpit made of aluminium is built around the vibrating platform. The cockpit is fitted with a door and windows. The cockpit can be heated by means of 2 KW blower heater which is coupled with thermostat. Temperature in the cockpit is adjustable upto 70°C with an accuracy of ±1°C. Heat produced inside the cockpit is essentially dry heat since no humidification is provided. Air temperature of 60°C was used to simulate heat stress. Wet bulb temperature was recorded around 32.5°C.

A small adjustable wooden platform was fixed in the cockpit in front of the vibrating platform so that the equipment for performance testing could be kept on it within easy reach of the subject sitting on the seat. Since the wooden platform was not linked to the vibrating platform, vibrations reaching the equipment were essentially through the operator's hands only.

A cassette mounted pre-recorded magnetic tape was played through a tape recorder and the output fed to the vibration simulator cockpit through a 8 ohm sound column placed behind the vibrating seat. The noise generated was essentially mixed frequency noise whose level was raised till 85 dB(A) was obtained at the head level of the subject sitting on the seat. The noise level was measured using a sound level meter.

Performance Test

NRC stressalyer: To have a quantitative measure of psychomotor performance involving eye-hand co-ordination, a psychomotor performance measuring equipment, the NRC stressalyser, was used. It is a subject-paced step input pursuit tracking performance measuring equipment [29]. The tracking unit of the equipment presents to the subject an illuminated target, which randomly changes position between five equidistant circumferentially arranged locations, when the subject covers a pointer carrying the pursuit element on the illuminated target for an uninterrupted period 200 msec. The control unit in auto mode offers 10 different programmes each consisting of 100 targets which are presented on the display tracking unit one after the other in succession, appearing randomly at any of the five positions of the tracking unit. The task for the subject consists of successively aligning the pursuit element within the illuminated target as it stops in between the five positions.

In the present study, the total time taken for completing one programme of 100 targets as recorded in the control unit has been taken as indication of performance measurement.

Experimental Protocol

The subjects were given 16 trials on the task to acquaint themselves with the working and to come to a steady performance level [30]. The tracking unit of the stressalyser was kept on the adjustable wooden table in the cockpit and the control unit was kept outside. Each subject was administered different programmes by the experimenter and once the practice trials were over, he was given three programmes in succession. The total average time taken for completing a programme was taken as his control performance. Before subjecting the personnel to the stress environment, the control performance was measured each time. Higher the task completion time, lower is the performance and vice-versa.

Performance under Vibration Stress

Each subject sat on the hard seat without any cushion or backpad and was strapped on to the seat. Each was exposed to vibrations for a total period of 30 min in four intervals of 7 min 30 sec each with a rest period of 10 min in between each interval.

Vibrations of 6 Hz frequency and peak amplitude of 0.5 g were started and continued for 7 min 30 sec during which the subject was given as many programmes as he could handle.

Performance under Noise

Noise level of 85 dB(A) was maintained at the subject's head level continuously for a period of one hour. Pre-stress performance was measured for all the subjects. In each test interval, three programmes were administered in a time of 7 min 30 sec with rest of 10 min.

Performance under Heat Stress

Temperature of 60°C T_{db} with relative humidity (rh) of 20% was simulated in the cockpit. The subject was exposed to heat stress continuously for one hour. The experiment time was broken into four intervals and in the first 7 min 30 sec interval, the subject was administered 2-3 programmes and the average time per programme was also determined before exposing the subject to heat.

Performance under Combined Vibration and Heat Stress

Heater blowers were kept continuously on till a temperature of 60oC Tdb with rh of 20% was achieved. Vibrations at 6 Hz and 0.5 g were administered for a period of 7 min 30 sec. During this time, the subject performed at the stressalyser and the average time per programme was determined. Heat stress was kept continuously on and three more vibration exposures given with a rest interval of 10 min in between. The performance during each combined stress exposure of 7 min 30 sec duration was determined.

Performance under Vibration and Noise

Noise was kept on for the full duration, whereas vibration at 6 Hz and 0.5g was given for 7 min 30 sec duration. Four such intervals were given and performance score on time per programme was determined. A rest period of 10 min was allowed in between two vibration exposures.

Performance under Heat and Noise

In this case, heat and noise were kept continuously on at Tdb 60o+1oC with 20% RH and 85 dB(A) respectively, at the subject's head level. The subject carried out the psychomotor tasks on the stressalyser in four intervals of 7 min 30 sec with a rest period of 10 min each in between two intervals of work.

Performance under Combined Stresses of Vibration, Noise and Heat

To see the effect of combined stresses of vibration, noise and heat, heat and noise stresses were kept continuously on for the entire interval at 60oC Tdb with 20% rh and 85 dB(A) respectively. Vibration was administered at 6 Hz and 0.5 g at regular intervals. Vibration stress was operative in 4 intervals of 7 min 30 sec each. Performance under combined stresses was determined during the intervals of vibration exposures. Rest period of 10 min was allowed in between two vibration exposures.

Analysis

The average time taken per programme was calculated for each subject without stress and under stress and the group average value of time has been taken to draw inferences. For each experimental situation, the performance time during work intervals has been compared against the respective control. Student 't' test was used to obtain significance levels.

Detailed analysis of variance was carried out and Fisher's ratio determined for various degrees of freedom (Table IV).

Results

Vibration

Against a control time of 152.7 ± 18.6 sec per programme, the performance time in all the four vibration intervals showed significant increase (Table I). In the first vibration exposure intervals, increase in performance time was 30.8%. In the subsequent vibration exposures, the increase over the control time was not as large due to vibration adaptation. Thus, there is a definitive decrease in the psychomotor performance under vibration.

Heat

Exposure to heat stress brought about a decrease in the average time required to complete a programme thereby indicating a better psychomotor performance (Table I). This was true in all the four intervals. However, a significant decrease in time ($p < 0.05$) was evident only after 30 min of continuous heat exposure. Performance time showed a slight increase in the 4th interval compared to the 3rd, showing thereby a possibility of performance decrement if performance evaluation were carried out beyond one hour time.

Noise

Immediately on encountering noise of 85 dB(A), the psychomotor performance time reduced (Table I). However, on further continuation in the noise environment, the performance time steadily decreased so that after over 50 min of noise, performance was significantly better as compared to the control ($p < 0.001$).

Vibration with Heat and Vibration with Noise

Psychomotor performance was significantly lower as compared to the control in all the four intervals, more so in the first two exposure intervals (Table II). The trend in the performance decrement was similar to that observed in the case of vibration exposure alone. However, the percentage increase in the performance time under vibration with heat and under vibration alone was of different magnitude (Table III) not conforming to a straight forward linear combination.

Heat and Noise

The stress of heat and noise together did not bring about significant changes in performance time, as compared to the control, in all the four test intervals although there was a progressive decrease in the timings (Table II). Here again, the percentage decrease in the time was not equal to the sum of the percentage decrease under heat and noise. The stress combination of heat and noise failed to elicit psychomotor performance change in a significant manner.

Vibration, Heat and Noise

Under the combined stresses of vibration, heat and noise, control time of 149.7 ± 19.7 sec per programme was modified to 204.7 ± 16.2 sec, 187.7 ± 23.0 sec, 179.3 ± 20.6 sec and 172.5 ± 19.5 sec respectively in the four work intervals. Performance significantly decreased under combined stresses (Table II) and the percentage increase in the performance time was much larger than that suggested by the linear combination of percentage time changes due to individual stresses (Table III). The first encounter with the combined stresses has been translated into maximum decrease in the psychomotor performance.

Discussion

Performance on the stressalyser involves visual, vigilance and co-ordination elements. Since the task is subject-paced, the total time taken for completing the task of aligning the pointer on the illuminated spot is a good indicator of performance efficiency. Smaller the time, better is the efficiency. Proper acquisition of the task visually, overcoming efficiency. Smaller the time, better is the efficiency. Proper acquisition of the task visually, overcoming error and doing it correctly are integrated aspects in any task accomplishment.

From a detailed analysis of variance of task completion time (Table IV), it is clear that subjects showed differences in performance from interval to interval. Also, it is seen from interaction (A x B), that the learning process was over and the subjects were indicating performance change due to stress application only. Significant interaction B x C showed that interval and situation together could change subject performance. That the experiment was well conducted with negligible error is brought about by a nonsignificant interaction A x B x C.

Decrease in the psychomotor performance due yto vibration is atributable to co-ordination loss brought by differential body deformation. Earlier work at IAM 8,10,13,27 and elsewhere 5-7,11,12 together with the present findings confirm that low frequency vibration is capable of reducing visual, tracking and speech performances.

A marginal improvement of performance under heat stress has been reported by Poulton et al [31] and Ramachandran [32]. However results of Grether [17] and Yoram [18] differ. Our simulation of 36.6° C of Effective Temperature (ET) which is much higher than ET of 29.5° C of suggested by Yoram [18], above which psychomotor performance in terms of speed, co-ordination and vigilance is suposed to decrease.

Noise level of 85dB(A) decreased psychomotor performance only in thge first work interval; performance betterment was seen thereafter. Our earlier study[33] and Poulton's work [28] are in line with the present trend of psychomotor performance change.

Under the combined stress, Grether et al [23,24] had shown that vibration along (vibration 5Hz, 0.3g) affected tracking and choice reaction time. In our case too, vibration, by and large, stands out as a single stress capable of reducing vigilance, tracking and co-ordination. Heat and noise combination by itself may not cause performance decrement. In fact, it may improve the performance upto certain extent if the time duration does no5t exceed one hour. However, the stress combination of vibration, heat and noise brings about noticeable decrement in performance than warranted by combining linearly the effects caused by the individual stresses.

Stress magnitude in our experiments, particularly of vibration and heat, was quite severe and around the value which may be attained only in acute conditions. Also, noise level was taken at 85 dB(A), i.e, at DRC level. Thus, it is possible, as shown by Stave [34], that in actual flight conditions or realistic flight stress simulations, efficiency of psychomotor performance and other tasks may not show much deterioration. Also, in the absence of low frequency vibration, performance decrement may not take place at all.

Vibration seems to affect various kinds of performance by a large measure and as such accurate determination of vibration spectrum in various types of military transportation is a must. This will enable to carry out detailed studies on the effect of combined stresses on long and short term performances.

Table - I Psychomotor performance on exposure to different stresses (n=6)

	Time (sec) per programme [m ± (sd)]		
	Vibration	Heat	Noise
Control	152.7 (18.0)	154.8 (14.4)	150.5 (21.4)
I Interval	199.8 (37.0) **	151.0 (8.5) NS	154.5 (22.7) **
II Interval	178.3 (22.4) ***	147.0 (11.7) NS	150.3 (22.6) NS
III Interval	177.3 (27.3) **	144.8 (11.4) *	149.7 (22.1) NS
IV Interval	172.0 (25.6) **	146.0 (11.6) NS	146.8 (21.4) ***

Table - II Psychomotor performance under combined stresses (n=6)

	Average Time (sec) per Programme [m ± (sd)]			
	Vibration + Heat	Vibration + Noise	Heat + Noise	Vibration + Heat + Noise
Control	150.0 (20.8)	151.7 (19.3)	149.8 (14.3)	149.7 (19.8)
I Interval	187.8 (21.3) ***	190.7 (27.2) ***	147.8 (12.9) NS	204.7 (16.2) ***
II Interval	177.0 (26.7) ***	181.8 (25.0) ***	146.7 (11.2) NS	187.7 (23.0) ***
III Interval	170.7 (27.2) **	174.0 (26.4) **	144.0 (10.5) NS	179.8 (20.6) **
IV Interval	177.3 (26.9) **	171.3 (26.3) **	145.0 (10.4) NS	172.5 (19.5) **

Table - III Percentage change in the average time per programme

Stress	Task Interval			
	I	II	III	IV
Vibration	30.8	16.0	16.1	12.6
Heat	-2.0	-5.0	-6.5	-5.7
Noise	2.7	-0.1	-0.5	-2.4
Vibration +Heat	25.2	18.0	13.8	15.5
Vibration +Noise	25.6	19.6	14.7	12.9
Heat + Noise	-0.7	-2.1	-3.9	-3.2
Vibration + Heat + Noise	36.7	25.4	19.7	15.2

Table - IV Detailed analysis of variance of psychomotor task completion time

Source of Variation	Sum of Squares	Degrees of Freedom	Estimate of Variance	F
Between subjects (A)	62203.0	5	12440.6	358.35 ***
Between intervals (B)	14240.0	4	3560.0	102.54 ***
Between situations (C)	37179.0	6	6196.5	178.49 ***
Interaction - AxB	838.0	20	41.9	1.21 NS
Interaction - AxC	10840.5	30	361.35	10.41 ***
Interaction - BxC	12752.0	24	531.33	15.30 ***
Interaction - AxBxC	4166.0	120	34.72	1.01 NS

NS = Not significant; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

REFERENCES

1. Dikshit MB: Heat stress in high speed low level flight. Aviation Medicine 1980; 24:31-35

2. Gupta VK: Field studies on thermal stress in fighter operation in Assam valley. Dept Proj Report 13, IAM IAF, Bangalore, 1970

3. Verghese CA, Sinha KC: Thermal evaluation of hot cockpit under simulated heat load condition of various IAF aircraft in use. AFMRC Report 190/65, DG AFMS, New Delhi, 1968

4. Anders K, Bengt OW: Whole body vibration, exposure time and acute effects - a review. Ergonomics 1985; 28:535-544

5. Chaney RE, Parks DL: Tracking performance under vibration. Tech Report D3-3512-6, Wichita Keensaw Boeing Co, 1964

6. Coermann RR, Majid EB, Lange KO: Human performance under vibration stress. Human Factors 1962; 4:315-324

7. Dennis JP: Effects of whole body vibration on visual performance. Ergonomics 1965; 8:193-205

8. Kapoor SP: Visual acuity under low frequency vibration. Aviation Medicine 1977; 21:24-30

9. Oborne DJ: Vibration at work. In: The Physical Environment at Work. Editor: DJ Oborne, London, John Wiley & Sons, 1983

10. Sant JS Varghese CA, Vyawahare MK, et al: Effects of vibration on external visibility and dynamic perception. AFMRC Report 1013/77, DG AFMS, New Delhi, 1979

11. Shoenberger RW: Effects of vibration on complex psychomotor performance. Aerospace Med 1967; 38:1264-1269

12. Shoenberger RW: Human responses to whole body vibration on perceptual and motor skills. Aerospace Med 1972; 43:127-160

13. Verghese CA: Speech distortion caused by low frequency vibration. AFMRC Report 888/77, DG AFMS, New Delhi, 1980

14. Allnutt MF, Innes LG: Mental performance in condition of mild heat. Report 422, IAM, Farnborough, 1962

15. Allnutt MF, Allen JR: The effect of core temperature elevation and thermal sensations on performance. Ergonomics 1973; 16:189-196

16. Colquhoun WP: Effects of raised ambient and event rate on vigilance performance. Aerospace Med 1969; 40:413-417

17. Grether WF: Human performance at elevated environmental temperature. Aerospace Med 1973; 44:747-755

18. Yoram E, Karen G, Joseph M, et al: Psychomotor deterioration during exposure to heat. Aviat Space Environ Med 1980; 51:607-610

19. Broadbent DE: Noise paced performance and vigilance tasks. Brit J Pyschol 1953; 44:295-303

20. Broadbent DE, Gregory M: Effects of noise and signal rate upon vigilance analysed by means of decision theory. Human Factors 1965; 7:155-162

21. Kryter KD: The effects of noise on man. New York, Academic Press, 1970

22. Stevens SS: Stability of human performance under intense noise. J Sound and Vibration 1972; 21:35-36

23. Grether WF: Effects on human performance of combined environmental stresses. AMRL-TR-70-68, Wright Patterson AF Base, Ohio, 1970

24. Grether WF, Harries CS: Effects of combined heat, noise, vibration on human performance and physiological function. Aerospace Med 1971; 42:1092-1097

25. Harries CS, Shoenberger RW: Combined effects of noise and vibration on psychomotor performance. AMRL-TR-70-74, Wright Patterson, AF Base, Ohio, 1970

26. Harries CS, Sommer HC: Combined effects of noise and vibration on mental performance. AMRL-TR-70-20, Wright Patterson AF Base, Ohio, 1971

27. Jumbe JJ: The influence of heat stress on decrement of visual acuity. Student's Dissertation, IAM IAF, Bangalore, 1977

28. Poulton EC, Edwards RS: Interaction and range effects in experiments on pairs of stresses - mild heat and low frequency noise. J Experimental Psychol 1974; 102:621-628

29. Buck L: Skilled Performance on NRC Stressalyser. LTR-CS-130, Canada, National Research Council, 1974

30. Buck L, Green G, Nyde F: NRC Stressalyser Operating Handbook. LTR-CS-174, Canada, National Research Council, 1977

31. Poulton EC, Kerslake D: Initial stimulating effect of warmth upon perceptual efficiency. Aerospace Med 1965; 36:29-32

32. Ramachandran N, Banerjee PK: Perceptomotor performance under acute heat stress as commonly encountered in high speed low level flying. Dept Proj Report 108, IAM IAF, Bangalore, 1980

33. Ramachandran N, Vyawahare MK: Effects of combined stresses of low frequency vibration and noise on psychophysiological function. AFMRC Report 1132/79, DG AFMS, New Delhi, 1982

34. Stave AV: The effects of cockpit environment on long term pilot performance. Human Factor 1977; 19:503-514