Original Article

PERFORMANCE ON HAND AND FOOT OPERATED CONTROLS UNDER LOW FREQUENCY VIBRATION

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Vertical vibration transmission in seated subjects for an erect posture is maximum in the frequency range 5-6 Hz. However, performance on push-pull types of hand operations and on rudder pedal for foot operations is affected most in the frequency range 3-7 Hz. Frequencies of maximum vibration transmission do not necessarily correspond to maximum effect on push-pull performance.

Keywords : Vibration Transmissibility, Resonance, Visual Performance, Manual Performance.

The effects of vibration on human performance have been the subject of experimental studies (1,4,5,9,10) over a number of years. In some studies the effort has been directed to establish relationship between performance and vibration parameters whereas in others the attempt has been towards solving specific applied problems. Differences in the methodologies and tasks used by workers make it difficult to generalise the effects of vibration on performance. However, it has been seen that low frequency vibrations affect human visual performance tasks (2,3,8,11,12,16). It has been deduced that at some low frequencies near about the first and second resonances the effects are maximum.

Tasks which involve vision but do not demand fine visual acuity such as perceptual discrimination and simple motor response are also affected by low frequency vibration (14). Pattern recognition, monitoring, tracking and other co-ordinated tasks are all affected by low frequency vibration. The vibration effects on the above stated tasks are said to be related to vibration transmission phenomena suggesting thereby maximum decrement in tasks performance around resonance frequency.

In the present paper effects of low frequency vibration on push-pull type of performance have been studied at frequencies near about the maximum vibration transmission frequencies.

Materials and Method

An electro-hydraulic vibrator was used in the present study. The vibration simulator is unidirectional and produces vertical vibration in the frequency range of 2 - 20 Hz. The working and details of the vibrator have been reported earlier (15).

An aircraft seat, suitably modified to provide bucket type contour was fitted on to the vibrating platform so that it vibrated at the same frequency and intensity as the platform. The bucket of the seat could be filled completely by compressible and non-compressible fibreglass cushions. A cockpit structure with window built around the vibrating platform simulated a cockpit environment.

Vibration frequency and intensity (G amplitude) on the seat and on the subjects were measured using KD-35 and KD-35A accelerometers coupled with RFT model SM 211 vibration meter. Vibration meter has a flat frequency response of 2 - 15 KHz. Output of vibration meter was fed to a two-channel Encardiorite pen recorder.

Strain gauge load cells were used for measuring forces involved in rudder pedal and hand push-pull operations. Load cells were made for responding upto 200 Kg and had a linear response. Two load cells, one for each foot were mounted firmly on the back of a foot rest of rudder pedal with the help of moderately hard springs. Similarly, two load cells were mounted at the back of a push button and a pull handle. Push button and pull handle were fixed on to iron rods which in turn were bolted to the cockpit structure. The rudder pedal and hand operation tasks were within easy reach of all the subjects who participated in the study.

A digital panel meter (DPM) recorded the forces via a control unit. The control unit had a four-way selection switch which enabled recording of any particular load cell measurement.

Equipment Calibration : The accelerometers and the vibration meter were calibrated on a standard electromagnetic shake table. Recordings of vibration meter and accelerometers were standardised for known vibration amplitudes between 0.2 and 1.0 G in the frequency range 3-12 Hz. Also, constancy of the vibration frequencies and amplitude was checked. Load cells and DPM were checked for linearity by applying known loads under static and dynamic conditions.

Experimental Procedure : Vibration transmission at the shoulder level was determined by recording the vibration intensity and frequency at the platform level and on the shoulder. An accelerometer was strapped on the shoulder of the subject with the help of double sided cloth tape whilst the other was mounted on the seat. Frequency range of 3 to 12 Hz and two fixed amplitudes, viz., 0.4 G and 0.5 G peak were employed. Recordings on frequencies below 4 Hz and above 8 Hz were discontinued after trial runs with subjects since transmission was found to be very low. Vibration transmission was determined for subjects sitting erect under the following conditions :

Sitting directly on the seat (SD).

Sitting on a compressible cushion (CC).

Sitting on fibre glass cushions (FGC).

Sitting on fibre glass cushion together with a fibre glass back rest (FGC+BR).

Transmissibility of vibration was also determined at the thigh level.

Force Measurements: In order to see the effect of vibration on rudder pedal and hand operated controls, subject sat directly on the seat in a comfortable erect posture and operated the rudder pedal with left and right toe pressures respectively. Subject was asked to exert maximum pressure without changing the posture or leaning backwards or forwards. Similarly, subject was asked to operate the pull handle and push button with the right (RHO) and left (LHO) hands respectively. In push button operation, subject pushed the button with the index fingers of both hands. Readings on the DPM were continuously recorded as the subject operated the rudder pedal and push-pull handles with and without vibration.

Frequency range between 3 to 7 Hz at an amplitude of 0.5 G was employed in place of frequencies of maximum transmission for different subjects.

Under vibration condition, only one reading each was taken on rudder pedal and hand operation. Under no vibration condition, several readings were taken to determine the basal performance. Subject was rested between frequency settings. For half the subjects, basal recordings were taken after the vibration trials. For the other half, basal readings without vibration were taken prior to vibration exposure.

Subject Details : Eight volunteers, who were healthy, well motivated and had previous experience with vibration exposure took part in the study. Details of the subjects are given in Table I.

Results

Tables II and III give the mean values of vibration transmissibility at shoulder and thigh levels for subjects under the experimental conditions of SD, CC and FGC respectively for frequency ranges of 4 to 8 Hz at 0.5 G amplitude.

Table I. Anthropometric measurements of subjects

Subject	Sex	Age (Yrs)	Height (Cm)	Weight (Kg)	Finger Reach (Cm)	Thigh Length (Cm)	Knee Height (Cm)
MKV	M	37	168.5	80.0	82	60.0	56
EMI	M	39	171.0	65.0	85	58.0	53
DTS	F	26	161.0	41.5	78	58.0	52
BR	M	28	173.0	54.0	80	62.0	44
NRC	M	42	166.0	62.5	77	57.0	53
SRK	F	42	161.0	59.5	72	53.0	54
NCM	M	26	163.0	66.0	80	60.0	52
NSB	M	39	174.0	67.0	86	58.5	56

Table II. Mean value of vibration transmissibility at shoulder level

Frequency	Transmissibility values for vibration amplitude 0.5 G			
(Hz)	SD	CC	FGC	FGC+BR
4.0	.61 + .15	.58 + .07	.60 + .08	.60 + .09
4.5	.71	.66 + .11	.64 + .08	.69 + .09
5.0	.95 + .23*	.77 + .17*	.75 + .17	.82 + .13*
5.5	.82	.81 + .18*	.77 + .17	.82 + .15*
6.0	.85 + .19	.79 + .11	.83 + .19*	.76 + .09
7.0	.66 + .12	.70 + .17	.66 + .23	.72 + .10
8.0	.50 + .13	.47 + .16	.48 + .17	.56 + .15

* - Indicates maximum values.
SD - Subject sitting directly on seat
CC - Subject sitting on compressible cushion
FGC - Subject sitting on fibre glass cushion
FGC+BR - Subject sitting on fibre glass cushion together with fibre glass back rest.

Table III. Mean value of thigh level transmissibility vibration amplitude 0.5 G

Frequency (Hz)	Transmissibility values for SD	CC	FGC
4.0	.61 + .12	.48 + .03	.48 + .04
4.5	.64 + .12	.65 + .09	.56 + .06
5.0	.72 + .14	.67 + .15	.68 + .10
5.5	.74 + .12*	.71 + .13	.72 + .10
6.0	.71 + .09	.72 + .09*	.71 + .09
7.0	.71 + .17	.71 + .09	.75 + .15*
8.0	.66 + .14	.69 + .10	.63 + .11

* Indicates maximum values

Table IV. Mean values of force exertion on rudder pedal for different experimental conditions under vibration.

Experimental conditions	Left toe operation			Right toe operation		
	Basal (Kg)	Max. (Kg)	Min. (Kg)	Basal (Kg)	Max. (Kg)	Min. (Kg)
SD	23.06 +6.5	25.7 +4.7(7)	22.7 +8.0(6)	23.0 +5.8	25.3 +3.4(4)	24.7 +4.2(7)
CC	19.2 +6.5	22.5 +6.1(5)	20.5 +4.8(5)	20.5 +6.1	23.0 +6.3(5)	22.0 +7.0(6)
FGC	21.6 +6.3	24.2 +6.6(6)	21.6 +8.0(3)	21.6 +5.9	25.3 +6.5(5)	22.0 +8.1(6)
FGC+BR	23.2 +6.9	26.0 +5.7(5)	24.2 +7.3(7)	23.4 +5.4	28.6 +6.6(6)	25.0 +5.4(7)

( ) Values indicate vibration frequencies where maximum and minimum values were noted.

Table V. Mean values fot hand operations for different experimental conditions under vibration.

Experi-mental condi-tions	Left hand operation			Right hand operation		
	Basal (Kg)	Max. (Kg)	Min. (Kg)	Basal (Kg)	Max. (Kg)	Min. (Kg)
PULL						
SD	26.2 +8.0	30.2 +14.4(3)	24.8 +9.8(6)	22.5 +7.8	30.2 +12.8(6)	23.5 +9.3(7)
CC	22.0 +6.3	25.7 +11.5(4)	20.1 +9.3(3)	22.4 +11.2	28.2 +12.1(4)	23.6 +11.2(5)
FGC	28.9 +14.2	30.9 +11.9(3)	19.4 +10.0(4)	23.0 +9.7	24.2 +10.3(7)	18.8 +8.6(4)
FGC+ BR	21.7 +8.0	26.3 +7.8(6)	22.8 +9.0(5)	18.9 +7.9	25.3 +11.6(6)	22.0 +11.4(7)
PUSH						
SD	3.7 +1.8	4.7 +1.3(3)	3.5 +1.7(5)	4.4 +2.0	5.3 +2.4(5)	4.4 +1.9(6)
CC	3.7 +2.5	4.5 +2.4(5)	2.9 +2.0(6)	4.4 +2.4	6.3 +3.6(4)	5.1 +3.8(6)
FGC	4.0 +2.0	5.1 +3.2(5)	3.2 +1.0(4)	3.6 +1.6	5.5 +4.4(5)	3.2 +1.0(4)
FGC+ BR	3.7 +0.9	4.7 +4.0(7)	3.2 +1.4(5)	4.0 +1.7	6.0 +2.9(7)	4.2 +2.0(3)

( ) Values indicate vibration frequencies where maximum and minimum values were noted.

Table VI. Mean difference of force in various operations in comparison to no vibration values (n=8)

Frequency (Hz)	Experimental condition							
	LHO				RHO			
	SD	CC	FGC	FGC+BR	SD	CC	FGC	FGC+BR
PULL								
3.0	4.0	-1.9	2.0	1.6	5.7*	2.6	-1.0	6.0
4.0	2.7	3.7	-9.5	3.8	2.5	5.7	-4.3	4.4
5.0	1.9	-0.2	-2.4	1.1	5.4	3.5	-1.5	4.4
6.0	-1.5	-0.1	-3.4	4.6	7.7	1.1	-0.4	6.4
7.0	-0.5	-0.8	-4.7	4.3*	1.0	4.0	1.1	3.1
PUSH								
3.0	1.0*	-0.4	-0.4	0	0.8	1.2	1.5*	0.3
4.0	-0.1	0.2	-0.8	0	0.7	2.0	0.2	1.4
5.0	0	0.9*	-0.6	-0.5	0.9*	1.2	1.9	0.7
6.0	0.9	-0.75	1.1	0.8	0	0.7	-0.1	0.6
7.0	0.7	0.7*	0.5	1.0	0.8	0.9	1.0	2.0
RUDDER PEDALS								
3.0	1.0	3.0	-0.1	2.4*	2.2	2.0	3.2	3.2@
4.0	0.2	2.9	2.5	2.2	2.4	1.7	1.3	3.5*
5.0	1.8	3.2*	1.0	2.8*	2.4	2.6@	3.8*	2.6*
6.0	-0.8	2.1	2.6@	2.6*	1.9	1.6	1.0	3.2@
7.0	2.2	1.9	0	1.0	1.7	2.4	1.8	1.6

RHO - Right Hand Operation
LHO - Left Hand Operation

* $P < 0.05$
@ $P < 0.01$

Tables IV and V compare the mean values of rudder pedal and hand operations for subjects under experimental conditions of SD, CC, FGC and FCC+BR.

Table VI compares the performance on hand pull and push, and rudder pedal operations with and without vibration.

Discussion

Mean values of vibration transmission at shoulder and thigh levels were maximum between 5 to 6 Hz. Shoulder level transmission (maximum) was more than the thigh level transmission (maximum). Shoulder level maximum transmission was more for SD condition whereas thigh level maximum transmission was not much affected by experimental conditions.

For rudder pedal operation, maximum and minimum values were found to be between 3 and 7 Hz whereas statistically significant performance change was seen in the case of FGC+BR between 3 to 6 Hz. In case of hand pull operation, there is statistical significance on performance change in the case of FGC+BR at 7 Hz (LHO). For the push operations, statistical significance is seen in SD and CC at 3,5 and 7 Hz (LHO).

Comparing Tables II to V, it is seen that frequencies of maximum vibration transmission are not necessarily the frequencies of maximum or minimum performance on rudder pedal and hand operated controls. It is further noted that hand pull and push operations are affected by vibration between 3 to 7 Hz at 0.5 G amplitude. However, the changes brought about by vibration are neither consistent nor uniformly significant. Same is the case with hand-push operation. In the case of rudder pedal operation between 5 to 6 Hz significant change in the performance is seen for the condition FGC+BR whereas for other experimental conditions no consistently significant effects are observed.

In our study, vibration transmission maximum has been observed in the frequency range 5 to 6 Hz although magnitude of vibration transmissibility found is small.

It has been reported (6,7,13,14) that perceptual motor tasks in which reaction time measure was taken as the indicant of performance, low frequency vibration did increase the response time. Performance on tracking tasks involving hand and foot operation (6,10,14) has been shown to suffer under low frequency vibration, the greatest decrement being at frequencies from 3 to 10 Hz. A relationship between whole body resonance in Z axis and performance has been reported (7). In the present study, the effects of vibration were felt by all subjects though without any quantitative reflection of the same on performance aspects. If one takes time element as a quantitative measure for completion of a given task there may be some relationship. The time frame to be taken is debatable since it has been shown that there is no emperical support to the notion that performance deteriorates over time as an effect of vibration (4,7).

Subjects perhaps maintain their performance through compensatory measures though at a physiological cost (1). Thus it is more appropriate to carry out thorough biomechanical and physiological studies to bring out the effect of vibration on any kind of task.

References

1. Anders K and Wikstrom BO: Whole body exposure time and acute effects-review. Ergonomics 3:535, 1985.

2. Dennis JP: The effect of whole body vibration on a visual performance task. Ergonomics 8:193, 1965.

3. Dennis JP: Some effects of vibration upon visual performance.J Appl Psychol. 49:245, 1965.

4. Griffin MJ and Lewis CH: A review of the effects of vibration on visual acuity and continuous manual control- Part I. Journal of Sound and Vibration 56:383, 1978.

5. Guignard JC and Irving A: Effects of low frequency vibration on man. Engineering 190:364, 1960.

6. Harris CS and Shoenberger RW:Effects of frequency of vibration on human performance. J Engg Psychol. 5:1, 1966.

7. Holland CL: Performance effects . long term random vertical vibratio Human Factors 9:93, 1967.

8. Lange KO and Coermann RR: Visu acuity under vibration. Human Facto 4:291, 1962.

9. Lewis CH and Griffin MJ: A revi of the effects of vibration on visu acuity and continuous manual control Part II. Journal of Sound and Vibrati 56:415, 1978.

10.Linder CG: Mechanical effects o vibration on human beings. Aerospac Med. 33:939, 1962.

11.Lippert S: in Human Vibration Resea rch. Pergaman Press, 1963.

12.O' Brient CR and Ohlbaum MK: Visua acuity decrements associated with whol body + Gz vibration stress. Aerospac Med. 41:79, 1970.

13.Parks DL: Defining human reactio to whole body vibration. Human Factor 4:305, 1962.

14.Shoenberger RW: Perceptual and moto skills. Monogr Suppl I-V, 34:127, 1972.

15.Verma SP, Verghese CA and Kapoor SP: Effects of vibration as encountered in low altitude flights. AFMRC Project No. 571/74: Sept 1977.

16.Vyawahare MK, Sant JS, Shakuntala D and Verghese CA: Dynamic vision under vibration and changes with curvature of transparencies. Aviation Med. 22:107, 1979.