Original Article

Vertical Vibration Transmission at Head Level

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Vertical vibration transmission from seat to head level was determined in 15 male subjects in low frequency range of 3-9 Hz. A helicopter seat was used and vibration amplitudes of 0.5 m/sec.^{2}, 1.0 m/sec^2, 1.5 m/sec^2 and 2.0 m/sec^2 (RMS) were administered. Transmissibility decreased with frequency beyond resonance frequencies which occured between 3.5-5.0 Hz. Resonance frequency as well as amplitude showed a decrease with the increase in vibration magnitude. However, transmissibility around resonance was always in excess of 200 percent for all vibration amplitudes. Chronic low levels of vertical vibrations encountered in long duration flights as well as in other kinds of military transports, thus, cannot be dismissed lightly form the view point of operational efficiency.

Key words : Transmissibility, resonance, wholebody vibration.

In the multistress environment of military flying, vibration stress is always present to some degree. The exact magnitude of vibration stress is variable and a function of type of aircraft, flying and ambient environmental conditions. Helicopter crew subjected to intense vertical vibration consider it a problem whereas, others facing chronic low level vibration in different kinds of military transportation tend to dismiss it as an inherent occupational nuisance only. This is primarily due to the fact that as a non-specific stress, vibration hardly brings about any immediate noticeable pathology demanding strong reactions. This has, in fact led to non-specification of vibration problem in a proper perspective in quantitative term vis a vis other aviation stresses.

It is well known and established that vibration affects manual, psychomotor and coordinated performance [1,2]. In a multistress environment of vibration, heat and noise, vibration more than any other stress degrades performance[3]. Also, it is established that low frequency vibrations in the band 3-10 Hz i.e. band covering the first resonance in human body and spreading on either side of resonance, gives rise to problems. Thus, determination of actual vibration transmission to head level, which is the seat of eyes , is a must for seated person. For most of aircrew or pilot performance, sensory input through eyes is important. In the present study, vibration transmission from seat to head of upright seated subjects was determined in a helicopter seat.

Material and Method

The vibration simulator at IAM, simulating vibrations in the vertical axis was used in the study. A helicopter cockpit was firmly installed on the vibrating platform. The seat cushion and adjustable back pad recommended from an earlier study[4] were used along with the seat. The seat was fitted with a four point harness system. However, in the present study, subjects were not harnessed.

The vibration amplitude and frequency at the platform level, seat level and head level were measured by means of flat frequency response accelerometer (Type SI 120A), vibration indicators and filters. Fibre glass moulded head shells were made in different sizes. They were fitted with very thin crushable foam lining. Circular mild steel plates were embedded at the centre of the shells to fix the accelerometer. There were no air gaps and shells could be donned snugly on the head with the help of nylon chin straps.

Vibration simulator was checked for its consistency in terms of amplitude and frequency for a period of one hour in the frequency band 3-12 Hz at RMS amplitudes ranging between 0.5 to 2.0 m/sec^2. Vibration amplitudes were compared at the platform level and seat level with a 79 Kg subject sitting on the seat. There were no noticeable differences, at the platform and seat level.

All subjects, who participated in the present study, were given vibration runs to accustom them with vibration produced by the simulator. In the actual experiment, subject sat on the seat with comfort cushion and adjusted the back rest for his maximum comfort. However, he was instructed to sit relaxed upright without slouching. He was to continuously gaze at the lines drawn on the wall facing him to make sure that he was not losing the upright relaxed posture. Fibre glass shell was firmly secured on subject's head and accelerometer was installed. Chin straps were tightened and head gear adjusted so that the accelerometer was always vertical and there were no gaps between subject's head and the head shell.

Vertical vibrations in the range 3.5-9.0 Hz at an interval of 0.5 Hz were administered for fixed RMS amplitudes of 0.5 m/sec^2, 1.0 m/sec^2 and 2.0 m/sec^2. For experimental convenience, frequency was fixed and amplitude varied. Out of a total of 15 subjects, the starting frequency for eight subjects was 3.5 Hz which was raised till 9.0 Hz at 0.5 Hz increment. Whereas, for the remaining seven subjects, starting frequency was 9.0 Hz and it was stepped down to 3.5 Hz at 0.5 Hz interval. Amplitude of vibrations was varied in steps of 0.5 m/sec^2 and higher or lower amplitudes were administered randomly. But each amplitude was given at least twice. Average values of vibration amplitude at the head level were taken for the purpose of transmission calculations. To avoid any diurnal effect on vibration transmission, the experiment was conducted between 9-11 am for all subjects. Fifteen male volunteers participated in the study.

Results

Table I gives the average age and weight of the subjects. Age varied between 22-41 years and

Table - I Subject Characteristics (n = 15)

	Average	SD	Range
Age (years)	31.06	4.91	22-41
Weight (kg)	65.30	8.73	54-82

weight between 54-82 kgs. Table II, III, IV and V give average transmissibility values at the Head level for vibration magnitudes of 0.5 m/sec^2, 1.0 m/sec^2, 1.5 m/sec^2 and 2.0 m/sec^2 respectively. Transmissibility values decreased to less than 100% between 8.5-90 Hz for 0.5 m/sec^2 and between 7.0-9.0 Hz for 1.0 m/sec^2, 1.5 m/sec^2 and 2.0 m/sec^2 vibration amplitude. Transmission at the head level was maximum for 0.5 m/sec^2 amplitude. Table VI gives the average of the maximum transmissibility and resonance frequencies. Here again, the maximum values decreased from 2.83 ± 0.34 at 0.5 m/sec^2 to 2.40

Table-II Mean head level vibration transmission at 0.5m/sec^2

Frequency (Hz)	Transmissibility		
	Mean	SD	Range
3.5	1.83	0.24	1.45 - 2.44
4.0	2.58	0.42	1.70 - 3.24
4.5	2.66	0.41	2.00 - 3.44
5.0	2.16	0.50	1.30 - 2.90
5.5	1.96	0.42	1.20 - 2.45
6.0	1.84	0.27	1.44 - 2.56
6.5	1.58	0.25	1.25 - 2.15
7.0	1.39	0.29	0.94 - 2.00
7.5	1.22	0.27	0.84 - 1.70
8.0	1.12	0.27	0.74 - 1.50
8.5	1.01	0.22	0.70 - 1.40
9.0	0.92	0.23	0.60 - 1.36

Table-III Mean head level vibration transmission at 1.0m/sec^2

Frequency (Hz)	Transmissibility		
	Mean	SD	Range
3.5	2.19	0.28	1.63 - 2.85
4.0	2.55	0.38	1.97 - 3.30
4.5	2.07	0.39	1.45 - 2.75
5.0	1.69	0.36	1.00 - 2.17
5.5	1.52	0.26	1.12 - 1.85
6.0	1.50	0.23	1.12 - 2.15
6.5	1.32	0.26	0.92 - 1.80
7.0	1.12	0.24	0.77 - 1.45
7.5	1.01	0.23	0.72 - 1.45
8.0	0.99	0.22	0.68 - 1.45
8.5	0.89	0.20	0.48 - 1.35
9.0	0.84	0.19	0.50 - 1.27

Table-IV Mean head level vibration transmission at 1.5m/sec^2

Frequency (Hz)	Transmissibility		
	Mean	SD	Range
3.5	2.19	0.31	1.55 - 2.80
4.0	2.42	0.39	1.67 - 3.13
4.5	1.72	0.37	1.08 - 2.37
5.0	1.46	0.31	0.82 - 1.93
5.5	1.38	0.21	1.03 - 1.78
6.0	1.35	0.21	0.98 - 1.80
6.5	1.18	0.25	0.78 - 1.57
7.0	1.02	0.23	0.71 - 1.40
7.5	0.94	0.23	0.55 - 1.40
8.0	0.89	0.22	0.52 - 1.25
8.5	0.82	0.16	0.42 - 1.03
9.0	0.79	0.17	0.45 - 1.07

Table- V Mean head level vibration transmission at 2.0m /sec²

Frequency (Hz)	Transmissibility Mean	SD	Range
3.5	2.29	0.31	1.65 - 2.75
4.0	2.28	0.34	1.70 - 2.85
4.5	1.71	0.34	1.03 - 2.25
5.0	1.42	0.26	0.85 - 1.78
5.5	1.32	0.16	1.00 - 1.65
6.0	1.24	0.23	0.90 - 1.75
6.5	1.09	0.22	0.83 - 1.45
7.0	1.00	0.22	0.64 - 1.23
7.5	0.92	0.18	0.58 - 1.23
8.0	0.87	0.18	0.46 - 1.14
8.5	0.80	0.16	0.39 - 1.07
9.0	0.76	0.16	0.36 - 0.98

Table VI Mean of Maximum Transmissibilities and Resonance Frequencies

Amplitude of vibration in m/sec² (rms)	Transmissibility			Resonance Frequencies (Hz)		
	Mean	SD	Range	Mean	SD	Range
0.5	2.83	0.34	2.15-3.44	4.35	0.31	4.0-5.0
1.0	2.59	0.37	2.00-3.30	3.90	0.28	3.5-4.5
1.5	2.48	0.33	2.00-3.13	3.85	0.23	3.5-4.0
2.0	2.40	0.29	1.95-2.85	3.73	0.26	3.5-4.0

Table-VII Comparison of Resonance values and Frequencies for Different Vibration Magnitudes (t Value)

Comparison	Resonance	Frequencies
a_1 vs a_2	1.85	4.17***
a_1 vs a_3	2.86**	5.02***
a_1 vs a_4	3.73***	5.93***
a_2 vs a_3	0.86	0.53
a_2 vs a_4	1.57	1.72
a_3 vs a_4	0.71	1.34

** $p<.01$ *** $p<.001$

$a_1 = 0.5$ m/sec² $a_2 = 1.0$ m/sec² $a_3 = 1.5$ m/sec² $a_4 = 2.0$ m/sec²

± 2.0 m/sec² indicating somewhat weakening of resonance. Resonance frequency also decreased progressively from 4.35 Hz to 3.73 Hz for amplitude variation from 0.5 m/sec² to 2.0 m/sec². Resonance frequency range was between 3.5-5.0 Hz. Table VII gives the comparison of resonance values and resonance frequencies for different amplitudes of vibration respectively.

Discussion

Vibration transmission at head level decreased with the increase in magnitude of vibration input as well as with frequency. Also, the resonance weakened with increase of vibration magnitude. There was a slight decrease in the frequency at which the resonance occured.

Beyond resonance, vibration transmission decreases is well known. Moreover, whole body vibration is usually known to have maximum transmission between 3-7 Hz, representative value being 5 Hz [1-3]. However, in our study, vibration transmission at head level for unrestrained subjects was maximum in the frequency range 3-5 Hz. For progressively higher magnitudes of vibration, frequency was shifting towards 3 Hz. Involuntary muscle tensing is one of the causes attributable to increase in body rigidity and decrease in compressibility giving rise to weakening of resonance. This also shifts the resonance to lower frequency. Thus beyond a certain magnitude of vibration, body rigidity may become constant and restraining may not have much effect.

Although, there was intersubject variation in head level transmission values with four subjects showing maximum transmissibility of over 300%, the average transmission values were less than 300%. This is a finding similar to other workers.[6-12]

Subjectively, magnitude of 2.0 m/sec² was considered uncomfortable by all the subjects whereas, 0.5 m/sec² was considered negligible. Aircrew too, consider .3 g RMS (3 m/sec²) vibration amplitude as heavy, 0.1-0.15 g RMS as slightly moderate and 0.05 g RMS (.5 m/sec²) as negligible.[13-15]

From our study, however, it is seen that low frequency and low level of vibration (3-5 Hz 0.5 m/sec²) gives rise to maximum transmission. This transmission of vibration at the eye level may affect visual performance. In a vibration enviornment therefore, transmissibility of 300% at 0.05g will have the same effect as a transmissibility of 50% at 0.3g. At higher amplitudes of vibration, decrease in the resonance is significant as compared to the lowest amplitude (0.5 m/sec²) value. Also, there is a significant drop in the resonance frequency. This indicates a non linear behaviour of body elasticity even at relatively lower amplitudes of vibration between 0.5m/sec^2 to 2 m/sec^2.

Thus it is most pertinent that vibration environment be thoroughly checked for frequency and amplitude contents to determine the effect on performance alteration. A disturbing note is that the chronic low amplitudes of vibration which are considered negligible by aircrew in the aircraft and resorted to in laboratory experimentations may not be all that negligible particularly when low frequencies and operational efficiency effects are involved.

It is concluded that vertical vibration transmission at the head level is maximum in the low frequency range of 3-5 Hz. Lower amplitude of vibration gives rise to maximum transmissibility and, therefore, a chronic vibration environment even with low amplitude at lower frequency may have a much larger say in affecting performance involving visual elements.

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