Industrial Health 2011, **49**, 410–420 **Original Article**

Quantitative Evaluation of Distortion in Sketching under Mono and Dual Axes Whole Body Vibration

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Received July 21, 2010 and accepted December 16, 2010
Published online in J-STAGE June 21, 2011

Abstract: Performance of sedentary activities such as reading and writing, in trains is known to be affected by the vibrations. An experimental study was therefore initiated to investigate the interference perceived in sketching task under low frequency random vibration in both mono and dual axes. Thirty healthy male subjects participated in the study. Random vibration stimuli were excited in various axes in frequency range of 1–20 Hz at magnitudes of 0.4, 0.8 and 1.2 m/s^2. The task required the subjects to sketch the given geometric figures such as circle, rectangle and triangle under vibration environment in two subject postures (sketch pad on lap and on table). Three performance methods were used to measure the effect of vibration stimuli and posture. They consisted of two specifically designed objective methods for percentage distortion measurement and one subjective method using Borg CR10 scale. The results revealed that the percentage distortion and difficulty in sketching increased with an increase in vibration magnitude and was found to be higher for vibration in Y- and Z-axis. Similar trend was observed for percentage distortion and difficulty in sketching for dual axes also. The perceived difficulty and impairment in sketching performance was greater while sketching on lap for X-axis, while the effect was just the reverse for other axes.

Key words: Whole body vibration, Multi axis vibration, Distortion in sketching

Introduction

Although vibration studies in military applications have been well documented, it has evoked comparatively smaller attention as far as the issues of general public interest are concerned. A few such studies include the effects of vibration on drinking[1, 2)], effects of vibration on writing[2, 3)] and effects on reading[4–6)]. However, these studies are based on mono axes vibration and have not considered the multi axis vibration which may be much closer to train vibration.

Whole body vibration transmission is known to be affected by various parameters such as posture, vibration magnitudes, and frequency as reported by Griffin[7)]. It was also reported that the human body behavior under two directional random vibrations could not be approximated by superposition of one directional random vibrations[8)]. Some biodynamic studies[9–11)] have considered the effects of multi-axis vibrations rather than limiting the tests to single axis vibration. However, activity comfort under dual axes vibration, specifically for the sketching task has not been reported in the literature, to the best knowledge of the authors.

Various national and international standards provide guidance on the measurement, evaluation and assessment of whole-body vibration in respect to perceived discomfort but the standards differ in evaluation and assessment of vibration[11)]. These standards are usually used as a tool for the train operators and manufacturers to ensure vibration levels in respect to ride comfort. Limits and procedures for the evaluation of discomfort caused by whole body vibration are given in standards such as ISO 2631-4, ENV 12299[12, 13)]. However, these standards have very little use in determining the extent of difficulty caused by vibrations in performing sedentary activities like reading and writing.

The effect of vibrations on the writing ability cannot

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be quantified directly, whereas the difficulty experienced in working with the pen/pencil can be fairly estimated in terms of the difficulty encountered in sketching activity. For the present study, simple geometric figures such as circle, triangle, square and rectangle were chosen, since they may be independent of individual's skills.

The objective of this study was to quantitatively evaluate the distortion while sketching in vibration environment by two objective methods viz, (Area method and RMS method) and compare with the level of difficulty assessed by subjective evaluation method. Sketching performance was measured in terms of distortion in sketching by specifically designed two objective methods, namely RMS and Area method and subjective evaluation of sketching difficulty. It was hypothesized that vibration magnitude and subject postures would affect sketching performance and that this would also be reflected in the sketching distortion and perceived difficulty in sketching task.

Methodology

Subjects

Thirty healthy male subjects with age in years (22.9 ± 4.6), weight in kg (68.9 ± 12) and height in cms (173.8 ± 5.9) volunteered for this study under informed written consent and were given a small remuneration for participation. All subjects were Institute students with almost identical educational qualifications and familiarity with sketching. Necessary approval was obtained from Institute Human Ethical Committee. All the subjects had normal vision either with or without glasses. None of them had any previous history of neuromuscular disorders.

Subject postures

Two subject postures were used in the study, namely the lap posture and table posture. In the lap posture, the seated subject leans against the back of the seat, with the sketch material held on his lap. In the table posture, the seated subject leans forward with the sketch material placed on the table, Fig. 1. The two subject postures were chosen based on previous studies[5, 14], which reported that a majority of train passengers preferred to adopt either of the two seated postures for writing activity. The experiments were conducted using a rigid seat with a configuration representative of that used for Indian train passenger compartment seats. The seat consisted of a 42 × 42 cm^2 flat seat and the height of the seat from floor is 48 cms.

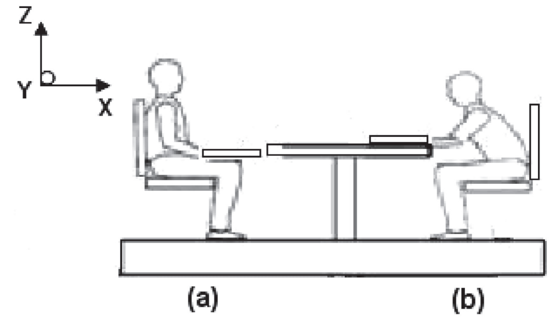


Fig. 1. Subject postures used in the study (a) Lap posture (b) Table posture.

Vibration environment

The study was conducted on a vibration simulator, developed as a mock-up of passenger rail vehicle[6]. The simulator consists of a platform on which a table and two chairs with rigid wooden seats have been securely fixed, Fig. 1. The backrests of the chairs were flat, rigid, and vertical. The seat, the backrest, and the table are not in resonance condition within the frequency range studied (up to 20 Hz) in any of the three axes. Three Electro-Dynamic Vibration shakers have been connected to the platform in three orthogonal axes, which can provide both independent and simultaneous vibration stimuli. Continuous monitoring of the vibration signal is achieved by measuring onboard vibrations of the platform on line by using a tri-axial accelerometer (KISTLER 8393B10). The simulator offers a controlled train environment with a working illumination about 250 lux using both direct and indirect light sources, providing a well-distributed illumination at all seats and tables.

Vibration stimuli

In the present study, the vibration stimuli consisted of a continuous Gaussian random signal over the frequency range 1–20 Hz which was generated using random vibration controller, for which the well-known exponential equation and bell-shaped curve defined the statistics. This range is considered critical since the structural dynamics of a passenger railcar usually gives rise to several resonance peaks in the frequency range of 0.5 to 20 Hz[15]. Power spectral density curve (g^2/Hz) of the signal generated by the exciter over the frequency spectrum of interest is shown in Fig. 2.

The vibration magnitudes were selected based on a recent field study conducted on various Indian railway passenger trains[14]. The vibration magnitudes measured from floor of passenger compartment were found to be in the range of 0.2–0.67 m/s^2 rms in longitudinal direction (X-axis); 0.23–0.83 m/s^2 rms in lateral direc-

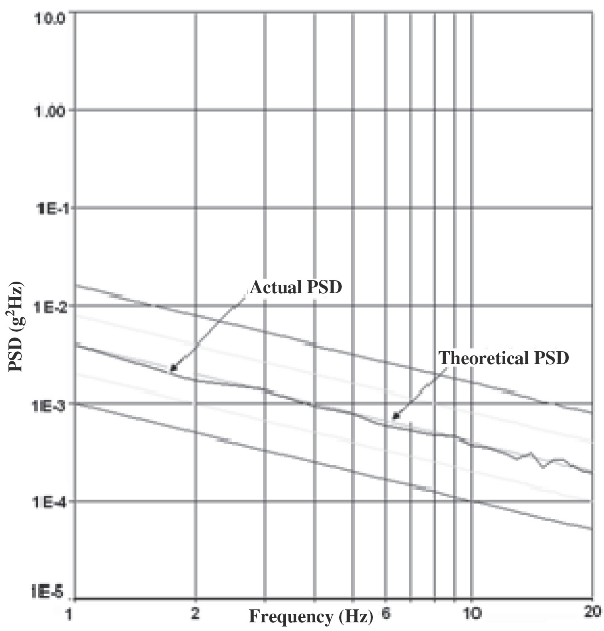


Fig. 2. Power spectral density (g^2/Hz) curve.

Table 1. Vibration stimuli in three axes acting independently and simultaneously

Stimulus	Vibration Magnitude (m/s^2, unweighted)			
	X-axis rms	Y-axis rms	Z-axis rms	rss = ∑axes
1	0.4	—	—	0.4
2	0.8	—	—	0.8
3	1.2	—	—	1.2
4	—	0.4	—	0.4
5	—	0.8	—	0.8
6	—	1.2	—	1.2
7	—	—	0.4	0.4
8	—	—	0.8	0.8
9	—	—	1.2	1.2
10	0.25	0.32	—	0.4
11	0.5	0.63	—	0.8
12	0.75	0.94	—	1.2
13	0.2	—	0.35	0.4
14	0.4	—	0.7	0.8
15	0.6	—	1.0	1.2
16	—	0.24	0.33	0.4
17	—	0.45	0.65	0.8
18	—	0.7	1.0	1.2
Static	—	—	—	—

rms = root mean square; rss = root sum of squares.

tion (Y-axis) and 0.38–1.2 m/s^2 rms in vertical direction (Z-axis). A quantitative comparison showed that the mean vibration magnitudes was found to be about 30% higher in the Y-axis and approximately 80% higher in Z-axis as compared with X-axis vibration. Therefore, in order to cover the entire range, three representative values viz. 0.4, 0.8 and 1.2 m/s^2 rss have been chosen for exciting the platform in mono and dual axes as shown in Table 1. The rss represents the root sum squared value, which is obtained from taking square root of the sum of the squares of the measured rms values in the X-, Y-, and Z-axis[16].

Experimental Task

The test subjects were seated in the vibration simulator and were provided an A4 size paper sheet with simple geometric figures such as circle, rectangle and triangle printed on it. The subjects were required to sketch on the given figure with the help of a ball point pen without lifting the pen, Fig. 3. Initially, the subjects were asked to sketch in a vibration-free environment (static condition). Next, the subjects were required to repeat the same task for each stimulus and posture, Table 1.

Evaluation of performance in sketching

Performance in sketching task was evaluated using a subjective method and two objective methods namely, Area method and RMS method. The two objective methods with different methodologies were used to evaluate distortion so as to establish which method compared better with the subjective results.

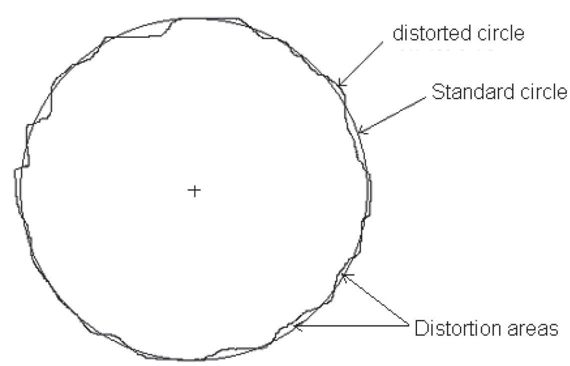


Fig. 3. Comparison of distorted figure sketched under vibration with standard figure.

Area Method

In this method, the area intersected between the standard figure and the distorted figure (figure sketched by subject) was calculated, Fig. 3. A normalized value was obtained by dividing it by the area of the standard figure and expressed as percentage distortion:

Percentage distortion =

$$\frac{\text{Area intersected between the standard figure and distorted figure}}{\text{Area of the standard figure}} \times 100$$

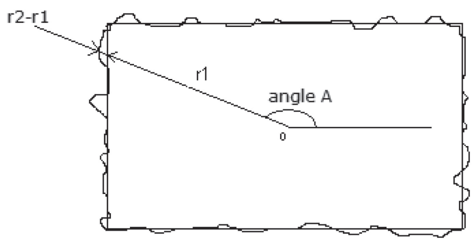


Fig. 4. Radial difference between distorted and standard rectangle.

Root Mean Square Method (RMS method)

In this method, the radial difference between the distorted figure and standard figure was computed at small intervals of angles with reference at the center of standard figure, Fig. 4. Mathematically, the normalized RMS distortion was expressed as:

$$\text{Percentage RMS distortion} = \sqrt{\frac{\sum_{i=0}^{i=359.9}\left(\frac{r_2}{r_1}-1\right)^2}{3{,}600}} \times 100$$

For better accuracy of calculation, computations were made at intervals of 0.1 degrees. A Matlab program was developed to calculate the percentage distortion by both the methods.

From global perspective, paper documents (sketch), which are an inherently analog medium, can be converted into digital form by the process of scanning. This process yields a digital image i.e. gray pixel. Using MATLAB programming the area of digital image of geometrical entity was selected. The distorted part of the area was converted into black color (off pixels), as shown in Fig. 3. The residual area of the enclosed geometrical figure remained in white color. This white colored area was measured in terms of number of "on pixels". The more the number of "on pixels", the larger was the white area. Distorted area was considered positive whether inside or outside the standard geometrical entity. The area of standard geometrical entity (white area) was also measured to calculate percentage distortion. In case of RMS method, only the difference between pixel value in radial distance of the two figures (distorted and standard figure) from the center of standard figure at different angles was computed.

Subjective evaluation

The Borg's CR-10 scale[17)] employed for subjective evaluation is presented in Table 2, which consists of 17 level points (9 labeled and 8 unlabeled). The scale is used by first finding the verbal label which best fits the stimulus attribute of interest, and then using the number scale to make adjustments to the rating. The value of 10 represents the maximum suggested intensity, but greater values can be chosen if the test subject so wishes. Due to its ease of use and reliability, the CR-10 scale has found wide application in the fields of physiology, psychology and ergonomics to rate sensations of pain, fatigue, physical exertion and discomfort.

Table 2. Borg CR10 scale

0	Nothing at all
0.3	
0.5	Extremely weak (hardly noticeable)
0.7	
1	Very weak
1.5	
2	Weak (light)
2.5	
3	Moderate
4	
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong (almost maximal)
*	Absolute maximum

Test Procedure

The study involved about one hour of test in a day to avoid the influence of fatigue. Before experiment started, each subject was asked to fill out a general questionnaire about his personal information. This was followed by a brief introduction about the experiment. The test was conducted on two subjects at a time. Each subject was exposed to overall 36 conditions, from a combination of six levels of vibration direction, three levels of vibration magnitudes and two levels of subject postures with a 1-min break between consecutive sessions. A static condition with no stimuli was also used. Each condition had an exposure time of one minute. The conditions were presented in random to minimize order effects. The test subjects were instructed to occupy themselves with the prescribed posture to perform the assigned task during the vibration exposure. During the 1-min break, the stimuli was stopped and the subjects were required to rate their perceived difficulty using Borg CR10 scale. This procedure was repeated for all the vibration stimuli and posture.

Statistical Data Analysis

A factorial analysis of variance (ANOVA) was performed to evaluate subject's response for which results at the $p<0.05$ level were considered as significant. The statistical package for social sciences (SPSS Inc., Chicago, USA, version 16) was used for all statistical analysis.

In the ANOVA, the within-subjects design was used for all the independent variables: vibration magnitudes, subject's posture and direction of vibration. Within-subject designs are alternatively called repeated-measures designs since within-subjects variables always involve taking repeated measurements from each subject for all the test conditions. Two other statistical measures were considered for interpreting the ANOVA, i.e. the estimate of effect size (partial eta squared) and the observed power. Partial eta squared is not dependent on the number of factors —it gives the contribution of each factor or interaction, taken as if it were the only variable, so that it is not masked by any other powerful variable. Observed power is the ability to detect an effect if there is one. In the range from 0 to 1, an observed power of 0.95 would mean a 5 percent chance of failing to detect an effect that is there.

A non-parametric Wilcoxon matched-pairs signed ranks test was also carried out on all the data to determine whether vibration magnitude, direction of vibration and subject's posture had a significant effect on sketching performance and perceived difficulty. The two-tailed test was used and statistical significance was accepted at 5% level ($p<0.05$).

Results

The mean values of level of difficulty and percentage distortion by both objective methods for all geometrical entities in mono and dual axes vibrations are shown from Figs. 5 to 10.

Sketching difficulty as subjective evaluation

The mean values of level of difficulty in each vibration direction for the two subject postures under mono and dual axes vibration are shown in Figs. 5 and 6. Also, the effect of subject posture is apparent from Fig. 6.

Influence of vibration magnitudes on perceived difficulty in Sketching

Figures 5 and 6 show the effect of vibration magnitudes on perceived difficulty in all the mono and dual axes for the two subject postures. It can be observed that the level of difficulty progressively increases with an increase in intensity of vibration stimulus. It was also confirmed by observing statistically significant difference ($p<0.05$) in level of difficulty between the range of given vibration magnitudes for the two subject postures in all the directions of vibration.

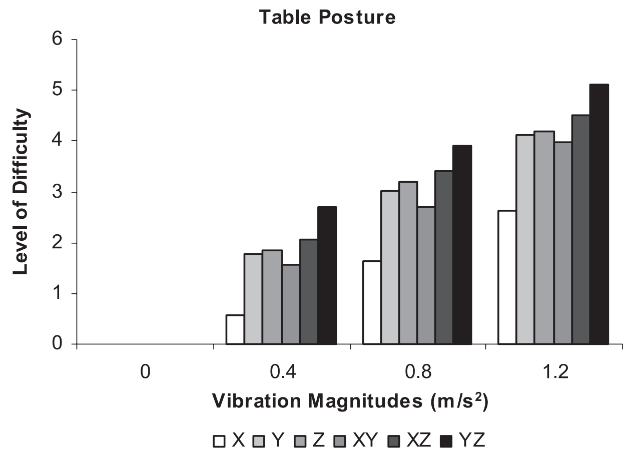


Fig. 5. Effect of vibration stimuli on perceived difficulty.

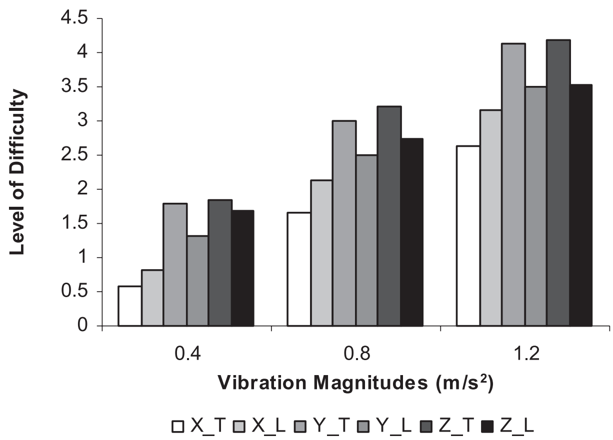
Influence of direction of vibration on perceived difficulty in Sketching

Considering vibration in all mono axes with table posture, the highest level of difficulty was observed with vibration in Z-axis and least difficulty in X-axis (Fig. 5). It was observed that the difference in level of difficulty between Y-axis and Z-axis vibrations was very small, consequentially their difference was found insignificant ($p>0.05$). However, the difference in level of difficulty was found significant for all other combinations of mono axes ($p<0.05$). Similarly, amongst all combinations of dual axes vibration, the highest level of difficulty was observed with vibration in YZ-axis and least difficulty in XY-axis (Fig. 5), also the difference in level of difficulty was significant ($p<0.05$).

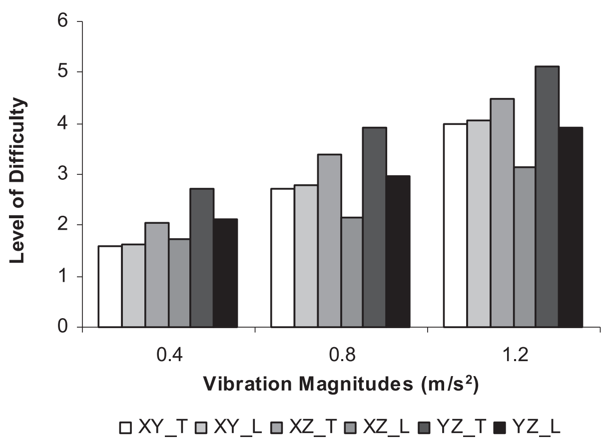
The effect of vibration in dual axes has been compared with its associated mono axes of same rss magnitude, in order to study their combined effect on sketching difficulty (Fig. 5). A higher level of difficulty was observed with dual XY-axis as compared to its associated individual X-axis ($p<0.05$) and comparable to Y-axis vibration ($p>0.05$). Similarly, vibration in dual XZ-axis resulted in higher level of difficulty than in X-axis ($p<0.05$), but effect was found to be similar to Z-axis ($p>0.05$). Moreover, the vibration in dual YZ-axis induced higher level of difficulty than individual Y- and Z-axis ($p<0.05$).

Influence of subject posture on perceived difficulty in Sketching

For vibration in X-axis, the level of difficulty was found to be higher with lap posture than with table posture (Fig. 6a) ($p<0.05$). In contrast, it was found to be comparatively greater for the table posture for vibration



(a)



(b)

Fig. 6. Effect of subject posture on perceived difficulty for (a) mono axes (b) dual axes.
Label X, Y, Z, XY, XZ and YZ denote vibrations in respective axis. Label 'T' and 'L' denote table lap posture respectively.

in Y-axis ($p<0.05$). The effect of posture for vibration in Z-axis was similar to that in Y-axis, but significant only at higher vibration magnitudes (i.e. 0.8 and 1.2 m/s^2) ($p<0.05$).

While subject posture had no significant effect on level of difficulty in dual XY-axis vibration ($p>0.05$), the table posture (Fig. 6b) shows greatest effect on perceived difficulty for vibration in both dual XZ- and YZ-axis ($p<0.05$).

Sketching performance as percentage distortion in Sketching

The mean values of percentage distortion in each vibration direction for both subject postures under mono and dual axes vibration are shown in Figs. 7 and 8 by RMS method and Figs. 9 and 10 by Area method.

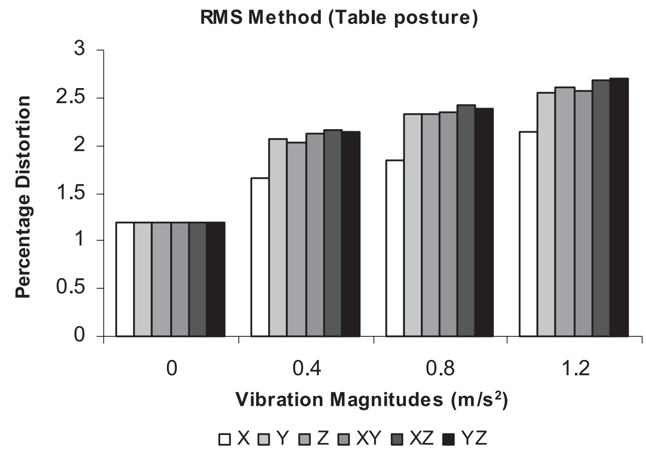
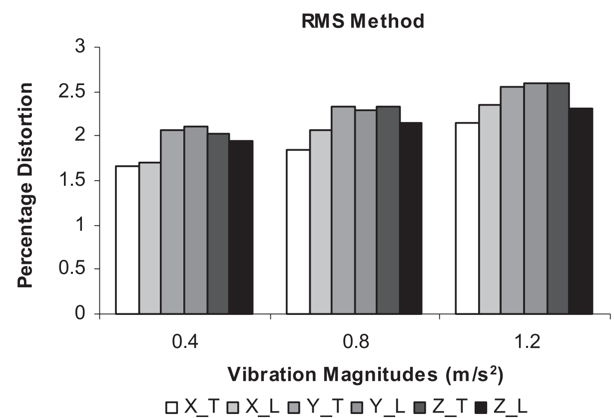
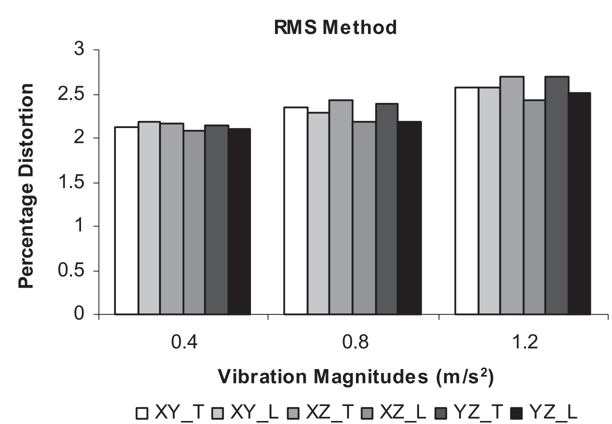


Fig. 7. Effect of vibration stimuli on percentage distortion.



(a)



(b)

Fig. 8. Effect of subject postures on percentage distortion for vibration in (a) mono axes (b) dual axes.

Influence of vibration magnitudes on percentage distortion

Figures 7 to 10 show the effect of vibration magnitudes on percentage distortion in sketching by both objective methods, in all mono and dual axes for the

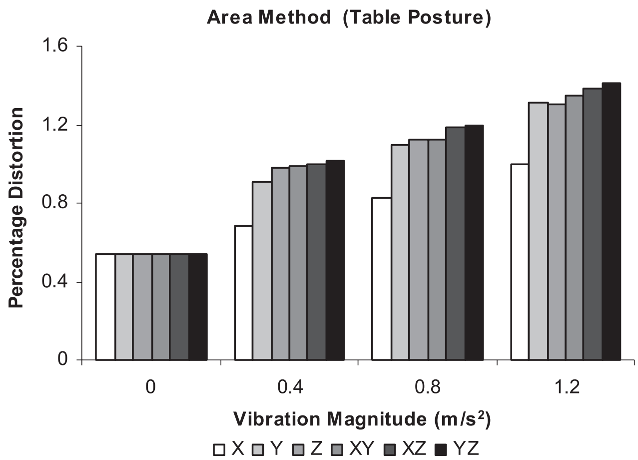


Fig. 9. Effect of vibration stimuli on percentage distortion.

two subject postures. It was observed that the percentage distortion in sketching increased with an increase in vibration magnitudes in all mono and dual axes for the two subject postures ($p<0.05$).

Influence of direction of vibration on percentage distortion

Considering mono axes vibrations in table posture, the percentage distortion in sketching was highest with vibration in Z-axis and least in X-axis (Figs. 7 and 9). It was found that effect of Z-axis vibration on percentage distortion was comparable to that of Y-axis and this was also true for the difference in percentage distortion being not significant between them ($p>0.05$). However, it was found significant for the remaining combinations of mono axes by both the objective methods ($p<0.05$). Moreover, among all the combinations of dual axes vibration, the difference in percentage distortion was not found significant ($p>0.05$).

The effect of vibration in dual axes has been compared with its associated mono axes, in order to study their combined effect on percentage distortion by both the objective methods (Figs. 7 and 9). It can be seen that the percentage distortion in sketching was higher with vibration in dual XY- axis as compared to X-axis ($p<0.05$), but the difference was insignificant between Y- and XY-axis vibration ($p>0.05$). Similarly, percentage distortion in sketching was found to be higher for vibration in dual XZ-axis as against that in X-axis ($p<0.05$). Nevertheless, difference in percentage distortion remained insignificant between XZ- and Z-axis vibration ($p>0.05$). Moreover, the vibration in dual YZ-axis showed insignificant difference in percentage distortion between Y- and Z-axis vibration ($p>0.05$).

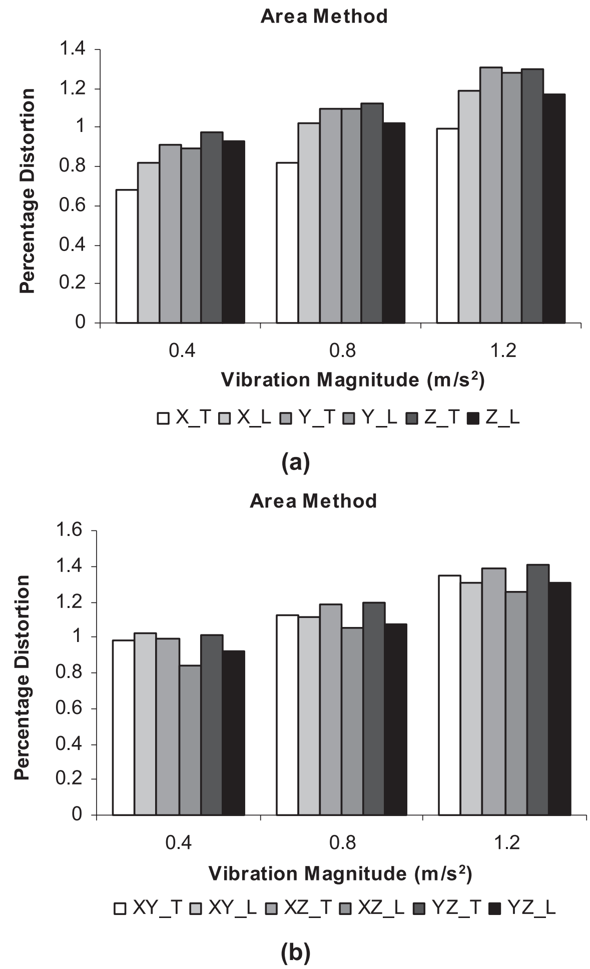


Fig. 10. Effect of subject postures on percentage distortion for vibration in (a) mono axes (b) dual axes.

Influence of subject postures on percentage distortion

While comparing the effect due to subject postures on percentage distortion by both the objective methods (Figs. 8 and 10), the effect of vibration magnitudes in Y-axis on subject postures showed no significance difference ($p>0.05$). The Fig. 10a shows that the percentage distortion by Area method for vibration in X-axis was greater for the lap posture as compared to table posture ($p<0.05$). Similar trend was found for difference in percentage distortion in both postures by RMS method, however it was found significant only at higher vibration magnitudes (i.e. at 0.8 and 1.2 m/s^2) ($p<0.05$). Reverse trend was observed for vibration in Z-axis, in which table posture produced higher percentage distortion as compared to lap posture. However, the difference in percentage distortion in both postures was significant only at higher vibration magnitudes (i.e. at 0.8 and 1.2 m/s^2) by both the objective methods ($p<0.05$).

As found for effect of vibration magnitudes in Y-axis on subject postures, the trend was similar in dual XY-axis vibration by both the objective methods (Figs. 8b and 10b) (p>0.05). For vibration in both XZ- and YZ-axis, the percentage distortion by Area method was found to be higher with table posture as compared to lap posture (p<0.05). Nevertheless, the percentage distortion by RMS method was found significant only at higher vibration magnitudes (i.e. at 0.8 and 1.2 m/s^2) (p<0.05).

Results from data analysis

The general effect of all the independent variables on the sketching performance in terms of subjective evaluation and percentage distortion was evaluated using within-subject test (Tables 3 to 5). Table 3 shows that all the independent and interacted variables exhibit significant value (p<0.05), indicating that all the main parameters are significantly responsible for the judgment of perceived difficulty. In general, the observed power was highest for all the independent and interacted variables. The results also show that the vibration magnitude has the maximum influence on the perceived difficulty, which is followed by the posture and subsequently direction of vibration. The two objective methods revealed that vibration magnitude was highest contributing factor (Tables 4 and 5), followed by direction of vibration. Comparing the two objective methods, the percentage distortion by RMS method revealed least effect on subject posture whereas it remained insignificant by Area method. Moreover, as far as the effect of interacted variables on percentage distortion is concerned, only one interacted variable (D × P) showed substantial contribution on sketching performance.

Discussions

Effect of vibration magnitude

The results (Tables 3 to 5) show that the vibration magnitude emerges as the highest influencing factor, on the perceived difficulty and percentage distortion in sketching and has good correlation with all the perfor-

Table 3. Within-subjects effect of test parameters for subjective Evaluation

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial eta Squared	Observed Power
Direction (D)	261.10	2.95	88.34	54.21	0.00	0.57	1.0
Vibration (V)	4,036.99	1.59	2,531.58	1,397.81	0.00	0.97	1.0
Posture (P)	44.28	1.0	44.28	174.04	0.00	0.81	1.0
D × V	95.24	6.76	14.08	15.98	0.00	0.28	1.0
D × P	71.31	3.82	18.68	60.19	0.00	0.59	1.0
V × P	21.65	2.12	10.21	33.48	0.00	0.45	1.0
D × V × P	37.83	7.73	4.89	13.96	0.00	0.25	1.0

Table 4. Within-subjects effect of test parameters for percentage distortion by Area method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial eta Squared	Observed Power
Direction (D)	610.04	3.56	171.28	18.98	0.000	0.345	1.0
Vibration (V)	1,1967.11	1.45	8,214.25	187.11	0.000	0.84	1.0
Posture (P)	7.19	1.0	7.19	1.06	0.308	0.029	0.172
D × V	256.29	8.19	31.28	4.04	0.000	0.101	0.993
D × P	267.33	5	53.46	17.64	0.000	0.33	1.0
V × P	41.65	2.21	18.83	2.23	0.109	0.06	0.466
D × V × P	105.48	7.94	13.29	2.44	0.015	0.063	0.896

Table 5. Within-subjects effect of test parameters for percentage distortion by RMS method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial eta Squared	Observed Power
Direction (D)	2,076.25	3.99	520.18	26.63	0.000	0.4	1.0
Vibration (V)	46,610.01	1.88	24,735.73	564.13	0.000	0.93	1.0
Posture (P)	73.76	1.0	73.76	5.0	0.03	0.111	0.58
D × V	775.37	9.08	85.35	5.24	0.000	0.116	1.0
D × P	451.09	5	90.22	10.99	0.000	0.215	1.0
V × P	122.78	2.27	54.10	3.47	0.03	0.08	0.67
D × V × P	274.23	8.85	30.99	2.40	0.012	0.057	0.917

mance measures. While comparing the subjective evaluation with percentage distortion by the two objective methods, the subjective evaluation revealed that the difficulty perceived was significantly affected by all vibration magnitudes and increased with an increase in level of vibration for both subject postures. The findings are consistent with those of Mansfield and Maeda[18], where subjective ratings of intensity increased with vibration magnitude for both single axis and dual axis vibration conditions. Similar outcome was reflected in percentage distortion in sketching performance by both the objective methods, which progressively increased with an increase in vibration magnitudes, for the two subject postures. The percentage distortion from RMS method was higher than that from Area method for both subject postures, which could be attributed to the difference in mathematical definition of the two objective methods.

Effect of subject postures

Among all independent variables, the subject posture emerged as the second highest influencing factor from subjective evaluation (Table 3). On the contrary, the two objective methods predict minimal and almost insignificant influence of subject postures on percentage distortion by RMS and Area methods respectively (Tables 4 and 5). The difference in results of two objective methods, although small can be attributed to the difference in their mathematical definitions.

In vibration environment, the posture becomes even more important as it helps in suppressing and compensating the motions to limit their effect on the performance of the work[19]. The posture has, thus, a vital role in transmitting vibrations to the different body segments, as well as to the working material.

For all vibration magnitudes in X-axis, both the perceived difficulty and degradation in performance by the two objective methods were found to be higher with lap posture as against table posture. In lap posture, since the upper body is supported by the backrest and the legs are supported by the floor, the vibration is transmitted to the head over a wide range of frequencies[20] which could affect vision. This outcome is consistent with Griffin and Hayward[4], who reported that the reading performance was greatly hampered in horizontal direction in presence of backrest.

The percentage distortion by both the objective methods remained unaffected in both the subject postures for vibration in Y-axis. However, subjective evaluation indicated that subjects perceived higher difficulty with table posture. For vibration in Y-axis, the upper body will lack support from the backrest and the sketch material may attain an oscillation that is almost equal to that of the table. The unsupported upper body is likely to move out of phase with the sketch material, thus disturbing the sketching task. Humans generally have the ability to compensate for adverse conditions and maintain a certain level of performance; however, this usually results in an increased workload[19]. In brief, the subjective evaluation indicated an increase in sketching difficulty with vibration magnitude while the sketching performance remained unaffected. This could suggest that the adaptation capabilities of the subjects to cope with the adverse conditions may have contributed to the unchanged sketching performance.

Considering the vibration in Z-axis, both the perceived difficulty and distortion in sketching were affected more in table posture. The effect was significant only for higher vibration magnitudes (i.e. at 0.8 and 1.2 m/s^2), suggesting that the adaptation capabilities of the subjects were adequate only to cope for effects of lower vibration magnitudes. This was also confirmed from considerable effect of interacted variable ($V \times P$) on perceived difficulty (Table 3). The lap posture could be considered a comparatively relaxed posture which would result in softening of the biomechanical system, which in turn reduces the seat to head transmissibility. As the muscles relax, the body stiffness reduces and the damping increases[21]. Therefore the sketching task in lap posture could be less affected by vibrations in Z-axis.

Considering the vibrations in dual axes, vibration in XY-axis revealed similar effect of subject posture on both perceived difficulty and distortion in sketching performance. The XZ- and YZ-axis exhibits greater difficulty while working on table as against lap posture. This could be due to higher impairment in performance and higher contribution of vibration magnitude in Z-axis alone.

Effect of direction of vibration

Among all independent variables, the direction of vibration emerged as the third highest influencing factor from subjective evaluation and was second highest by the two objective methods. The vibration direction had a significant effect on all performance measures, Tables 3 to 5.

Considering vibration in mono axes, the sketching task was greatly affected in Y- and Z-axis and least in X-axis, as evaluated by all performance methods. The adverse effects of Y-axis vibration may have arisen from increased movement of upper-body together with the head and, therefore more interference with vision. Similarly, in Z-axis vibration the sketching task may be impeded by simultaneous vibration of both the table and sketching material.

The effect of vibration in dual axes was compared with its associated mono axes, in order to study their combined effect on sketching performance by the three performance methods. A comparison of percentage distortion shows that the effect of vibration was similar for all dual axes and Y and Z mono axes. The subjective evaluation displayed similar trend except for dual YZ-axis vibration, which revealed greatest perceived difficulty among all mono and dual axes vibration. This could be explained by the higher impairment in sketching performance found for only Y and Z axes. The results of objective methods are fairly consistent with subjective evaluation for the above combinations. The results are also consistent with Lewis and Griffin[22], who reported that the effects of multi axis vibration have been found to be similar to that of single axis vibration, corresponding to the rss of the magnitudes in each axis.

Conclusions

The present study is significant since it attempts to quantify the effect of vibrations on the writing ability in terms of performance impairment in sketching activity. In this study, sketching task was assigned to subjects seated in two postures in vibration environment, and the difficulty perceived in sketching under mono and dual axes random vibrations was investigated using subjective evaluation and two objective methods. It has been observed that the percentage distortion and perceived difficulty increases with increase in vibration magnitudes. For the given vibration stimuli, a maximum distortion of about 2.5 percent by RMS method or 1.4 percent by Area method was observed. This is found to be equivalent to a rating of about 4 on the subjective rating scale, which implies that the sketching task is moderately affected.

Both Y- and Z-axis vibration produce maximum difficulty and distortion, whereas vibration in X-axis produces least difficulty and distortion. The effects of vibration in all the dual axes have been found to be comparable with vibration in Y- and Z-axis by both the objective methods. From results of subjective evaluation, difficulty perceived for XY-axis vibration was comparable to that for Y-axis vibration. Similar outcome was observed with XZ-axis and Z-axis. Moreover, the vibration in dual YZ-axis produces higher difficulty than that for individual Y- and Z-axis.

It was found that subject posture had a noteworthy effect on sketching task in all directions of vibration. The result revealed that the subjects perceived higher difficulty and impairment in sketching performance while working on lap for vibration in X-axis, which could be a consequence of vibration being transmitted to the head and thereby leading to visual interference. For Y-axis vibration, subjects perceived greater difficulty while sketching on table, but no postural difference was reflected from objective methods. While all performance measures reveal higher effect with table posture than the lap posture, for vibration in Z-, XZ- and YZ-axis, however, for vibration in XY axis, no significant postural effect was observed.

Acknowledgements

The financial assistance received from Department of Science & Technology, New Delhi (India) for the research work is duly acknowledged. We also wish to thank all the participants for participating in the experiment.

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