Industrial Health 2010, **48**, 675–681 **Original Article**

Influence of Mono-axis Random Vibration on Reading Activity

M.K. BHIWAPURKAR[1], V.H. SARAN[1], S.P. HARSHA[1], V.K. GOEL[1]* and Mats BERG[2]

[1]Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, Roorkee-247667 (Uttarakhand), India
[2]Department of Vehicle Engineering, Royal Institute of Technology, Stockholm, Sweden

Received May 23, 2009 and accepted June 30, 2010

Abstract: Recent studies on train passengers' activities found that many passengers were engaged in some form of work, e.g., reading and writing, while traveling by train. A majority of the passengers reported that their activities were disturbed by vibrations or motions during traveling. A laboratory study was therefore set up to study how low-frequency random vibrations influence the difficulty to read. The study involved 18 healthy male subjects of 23 to 32 yr of age group. Random vibrations were applied in the frequency range (1–10 Hz) at 0.5, 1.0 and 1.5 m/s^2 rms amplitude along three directions (longitudinal, lateral and vertical). The effect of vibration on reading activity was investigated by giving a word chain in two different font types (Times New Roman and Arial) and three different sizes (10, 12 and 14 points) of font for each type. Subjects performed reading tasks under two sitting positions (with backrest support and leaning over a table). The judgments of perceived difficulty to read were rated using 7-point discomfort judging scale. The result shows that reading difficulty increases with increasing vibration magnitudes and found to be maximum in longitudinal direction, but with leaning over a table position. In comparison with Times New Roman type and sizes of font, subjects perceived less difficulty with Arial type for all font sizes under all vibration magnitude.

Key words: Random vibration, Reading activity, Word chain, Font type, Reading difficulty

Introduction

Whole-body vibration has been shown to affect both reading speed and reading accuracy in many studies[1–3]. Lewis and Griffin[4] studied the effects of vibrations on reading performance for two different seating conditions: leaning back in a helicopter seat and sitting upright on a flat seat. They concluded that vibrations in the lateral direction (y-axis) only give little motion transmitted to the head. They also pointed out that it was possible to predict the relationship between seat motion and decrements in reading performance.

The vibrations transmitted are affected by various parameters such as posture, vibration level, and frequency[5]. It was also reported that the human body behavior under two directional random vibrations could not be approximated by superposition of one directional random vibration[6]. The current trend in vibration research is to use multi axis values[7, 8]. Corbridge and Griffin[9] studied the effect of whole-body vibrations on the performance of human activity and concluded that the reading and writing performance decreased between 1.25 Hz and 8 Hz and its severity increased with increasing vibration magnitude and duration. It was reported by Wollstrom[10] that only a few studies were found on how vibration influences train passengers' activities.

In a field study on Swedish trains, Khan and Sundstrom[11] found that the vibration levels were found to be satisfactory according to ISO 2631-1, even though about 60% of the passengers were found to be disturbed by vibrations or motions in the train. It was also noticed that reading (80%) and writing by hand (25%) were two of the most common sedentary activities performed during travel. The study also reported that the choice of posture is strongly linked to the activity that is being performed. In a recent subjective study conducted in the laboratory, Khan and Sundstrom[12] studied judgments of perceived difficulty to read and write under two sitting positions (leaning against the backrest and leaning over a table) at two levels of sinusoidal vibrations that were applied at nine discrete frequencies (0.8–8.0 Hz). It was reported that subjects perceived greater difficulty while reading and writing on the table than while leaning back. It was also reported that frequencies up to 5 Hz had a maximum influence on the perceived difficulty.

It has been observed that font sizes 10, 12 and 14 in Times New Roman and Arial types are some of the most extensively used in Newspaper and other printed material. The purpose of this study was to examine the effect of vibrations along three orthogonal directions independently, on the reading difficulty and also to examine the influence of sitting posture (i) with backrest support and text placed on lap and (ii) without back support and text placed on the table.

*To whom correspondence should be addressed.
E-mail: goelvfme@iitr.ernet.in

Subjects and Methods

Subjects

The study involved 18 healthy male subjects of 23 to 32 yr of age group and with normal eyesight (normal visual acuity 6/6 vision). All participants were fluent in English and educated to either graduate/post graduate students or research scholars. The subjects participated voluntarily under informed written consent and were given a small remuneration. Ethical approval was obtained from IIT Roorkee Human Ethical Committee.

The anthropometric effects were taken care of by restricting the variations in body measures. In order to limit small variations among the participants, persons who fulfilled the anthropometric inclusion criteria in Table 1, were only recruited for the study. In direct association to the experiment all subjects were required to fill in a questionnaire on their personal background: level of education; experience of traveling with train; fitness; reading habits; and musculoskeletal disorders[13] to assure the suitability of subjects for experimental task.

Two seated postures were chosen for the laboratory study from the various postures that were reported in a field study on train passengers while traveling[11]. In the first posture the seated person leans against the back of the seat, with the text material held on his lap. In the second posture the seated person leans forward with the text material placed on the table, Fig. 1. The distance of 48 (SD ± 2) cms was maintained from the subject's eyes to the reading material in both the subject's posture. The variation in distance was due to variability in anthropometric parameter of subjects.

Table 1. Anthropometric requirements and results

	Seated Height [cm]	Seated Weight [kg]	Arm Length [cm]	Lower Leg length [cm]
Mean	44	54	64.1	47.9
Median	44	52	70.0	49
SD	0	8.07	9.24	2.23

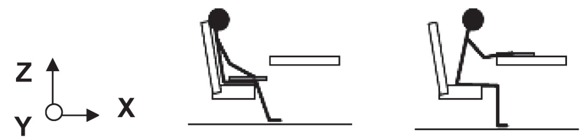

Fig. 1. Two Sitting Postures used in the study.

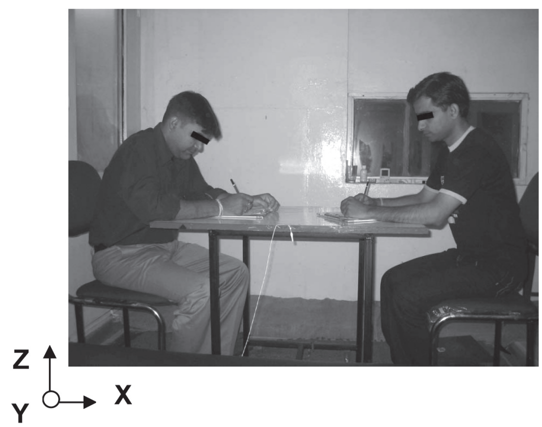

Fig. 2. Vibration simulator.

Experimental setup

The study was conducted in the vibration simulator developed as a mockup of a railway vehicle, in Vehicle Dynamics Laboratory, IIT Roorkee, India. The vibration simulator is located in a room with sound absorbing materials pasted on the walls to obtain reduced noise environment. It consists of a platform of size 2×2 m made up of stainless steel corrugated sheets, on which a table and two chairs having 14^0 angle of back rest with vertical, are securely fixed, Fig. 2. The weight of the platform is supported by four helical springs placed under its each corner. Three Electro-Dynamic Vibration exciters are used to create the desired longitudinal (X-axis), lateral (Y-axis) and vertical (Z-axis) vibration stimuli of the platform. Two uncushioned wooden chairs are rigidly attached with the platform for seating the test subjects. Each vibration exciter has a force capacity of 1,000 N with a stroke length of 25 mm (p-p) and can generate Gaussian random vibration, a type of broadband random vibration. For simplicity and safety reasons the internal positioning accelerometers of the shakers were continuously used for motion feedback. The onboard vibrations of the platform were measured on line by using a tri-axial accelerometer (KISTLER 8393B10), the signal sent to the Labview Signal Express software via a data acquisition card (NI 6218).

The simulator provides a sparse but comfortable train atmosphere with appropriate working illumination well above 200 lux. Both direct and indirect light sources assure constant and well-distributed illumination at all seats and tables. The test subjects are seated on the seats on the Vibration Simulator, mounted on platform in such a way these are excited at same frequency content as the platform, below 10 Hz. This range is critical since it coincides with the most vulnerable range for reading[14].

Test signals

In a separate study carried out on travel by Indian trains, vibration levels were measured along three directions viz, x-, y- and z-axis for different types of trains (passenger, express and superfast), different class of travel (chair car, sleeper class and A.C. two tier) and different track conditions (good track and worn out track). The measurements indicated that vibration levels varied from 0.6 to 1.4 m/s^2 depending on the various operating parameters such as track condition, speed etc. To cover all the travel conditions, vibration levels of 0.5, 1.0 and 1.5 m/s^2 rms (unweighted) were chosen in the laboratory study as these are similar to those generally encountered during train travel. In addition, control (static) condition with no vibration was presented before the start of experiment. Therefore, (three vibration magnitudes × two seating postures × three vibration directions) total 18 conditions were presented for each subject.

In the study, for each subject's posture, a continuous random Gaussian signal over the frequency range 1–10 Hz was generated using random vibration controller along three independent directions, Table 2, for which the well-known expo-

Table 2. Vibration levels in three axes acting independently

	Longitudinal direction (X-axis)	Lateral direction (Y-axis)	Vertical direction (Z-axis)
Vibration magnitudes (m/s^2) rms (unweighted)	Control	Control	Control
	0.5	0.5	0.5
	1.0	1.0	1.0
	1.5	1.5	1.5

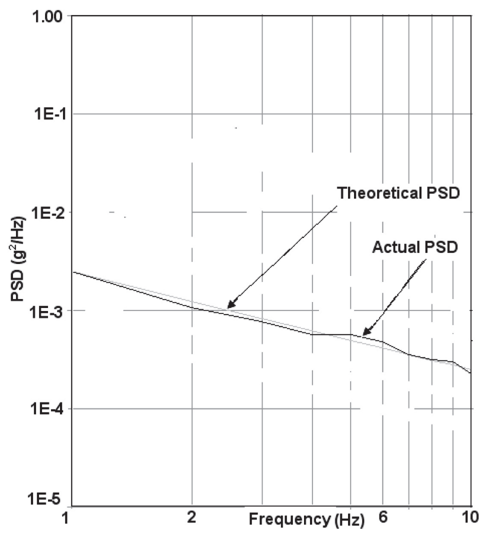

Fig. 3. Power spectral density curve.

1	2	3	4	5	6	7
Not difficult at all	Very Weak	Weak	Moderate	Strong	Very strong	Almost impossible

Fig. 4. Seven-point discomfort judging scale.

nential equation and bell-shaped curve defined the statistics. Power spectral density curve (g^2/Hz) of the signal generated by the exciter (theoretical PSD) and vibration measured from platform (actual PSD) over the frequency spectrum of interest is shown in Fig. 3.

The test subjects were asked to give their subjective opinion on a seven point scale printed adjacent to each word chain about difficulty to read under each vibratory condition. An ordinal judgment scale was used with seven points anchored with adjectives and numerical had assigned correspondingly, from 'Not difficult at all' at 1, to 'Almost impossible' at 7, Fig. 4.

Reading task

For the reading task, a word decoding test called 'Word chains' is usually used. The word chains are chosen since reading comprehension is known to be preceded and largely governed by proper encoding of the letters and words in the text, Johansson[15].

According to Adams[16], decoding is a part of the orthographic process that in turn couples the words with the phonetics of speech and the representation of meaning. In this manner, both decoding and phonetic analysis are affected by the reader's vocabulary, strategic ability and knowledge of the world[17]. When decoding has become an automatic skill it can free mental resources for the process of comprehension. The context has a major influence in supporting the comprehension since it provides a strategic base for the reading[18].

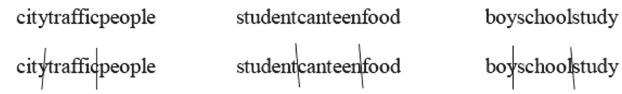

Fig. 5. Examples of word chains for the reading task.

The word chains are constructed as three words written together without space separation, Fig. 5.

The length of chains is given in such a way that the subjects can decode it within 30 s in absence of vibration. A text whose context is familiar and enjoyed by the reader will most likely be selected because the context and style of such texts would affect people differently. The chains were printed on white A4 size paper with three different sizes (10, 12, and 14 point) of Times New Roman font and Arial font. Therefore 6 such word chains are given. The postures, direction of vibration and vibration magnitudes were further combined into 108 sets of the word chains was used to prevent learning effect. The subjects were instructed to make a vertical pencil mark where the words should be separated by a space character. This procedure was repeated for all the test conditions. The reading task was to be performed silently, since the study was conducted on two subjects at a time.

Time is a very conservative measure of performance for reading task but the slow readers will manage and even perform well in complicated reading tasks if only given adequate time[19]. The variation in the number of words read will consequently be due to mainly in differences in reading skill rather than a measure of vibration effect. Therefore limitation of time was not provided. The instructions for the reading task included "You are about to read word chains. You shall mark with your pen where the words should be separated. Imagine yourself that you have to proof-read a text for a friend or a colleague".

Test procedure

Each participant began the experiment by filling out a general questionnaire about his personal information. Then a brief introduction about the experiment was given to each participant. After that, the participant performed the experiment task. The study involved about one hours of test each day and to avoid error caused by fatigue, each participant was given two days to finish the task.

The test was conducted on two subjects at a time. Each subject was exposed to a total 18 test conditions with a 1-min break between consecutive sessions. A control (static) condition with no vibrations was also used. The test conditions were presented in random with Latin Square Design to minimize order effects. The test subjects were instructed to occupy themselves with the prescribed task during the vibration exposure and rate their perceived difficulty of reading on a seven point scale. When the vibration faded out, the subjects were given an intermediate 10 s pause to rate their perceived

Table 3. Within-subjects effect of test parameters in "repeated measures test"

Source	Type III Sum of Square	df	Mean Square	F	Sig. (p)	Partial eta squared	Observed power
Vibration (V)	1426.31	1.18	1207.64	31.97	0.001	0.86	0.99
Direction (D)	199.84	2	99.92	7.44	0.01	0.59	0.85
Posture (P)	15.31	1	15.31	45.76	0.001	0.90	0.99
Font Type (T)	21.09	1	21.09	29.23	0.003	0.85	0.98
Font Size (S)	65.19	2	32.59	39.98	0.00	0.88	1.0
V × D	71.68	6	11.95	2.74	0.03	0.35	0.79
V × P	11.67	3	3.89	6.04	0.007	0.55	0.89
V × T	7.47	3	2.49	8.17	0.002	0.62	0.97
V × S	22.25	6	3.71	22.18	0.00	0.82	1.00

difficulty. This procedure was repeated for all the font sizes and types. The experiment took each participant about 2.1 h.

Response Data Analysis

A full factorial analysis of variance (ANOVA) was performed to evaluate subject's response. The results of the statistical analyses in terms of probability value i.e. p-value and data R^2 are given. The statistical significance was considered for $p<0.05$. The statistical package for social sciences (SPSS Inc., Chicago, USA, version 16) was used for all statistical analysis. The within-subjects design was used for the ANOVA of all the independent variables: vibration magnitudes (0.5, 1.0 and 1.5 m/s^2 rms); seated postures (with backrest support and leaning over the table); vibration direction (X-, Y- and Z-axis); font types (Times New Roman and Arial); font sizes (10, 12 and 14 pt.).

The repeated-measures design is well suited since the judgments from each participant were collected repetitively for all the test conditions. All the collected responses were manually coded and analyzed with the statistical software SPSS. 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 was chosen since it is not dependent on the number of factors for explaining the main effects or interactions. The advantage of this measure lies in its ability to avoid masking effects from the most powerful variables in the analysis. Observed power was calculated to increase the certainty of correct detection of an observed effect. In the range from 0 to 1, an observed power of 0.95 would mean a 5% chance of detecting an effect that is not true.

Results

In the within-subject test, general effects on the perceived difficulty were found for all the independent variables, i.e. vibration magnitude, direction of vibration, seated posture, font types and font sizes (Table 3). The table shows only the independent and interacted variables which were found to be significant ($p<0.05$).

Furthermore, Table 3 shows significant interaction effects for some parameters up to the second level indicating that all the main parameters are significantly responsible for the judgment of difficulty. In general, the observed power takes high

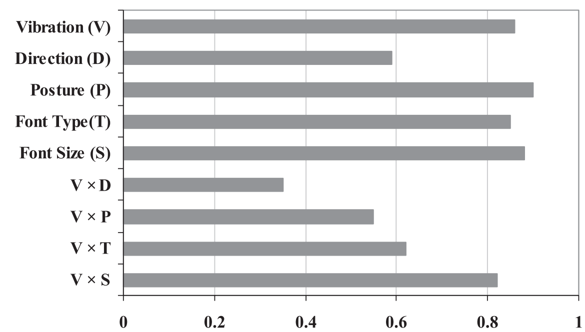

Fig. 6. Pareto chart of the partial eta squared for the significant variables.

values for all the independent variables. However, the interaction effect from the two levels onward does not have a significant effect on the perceived difficulty. The results also show that the highest contribution comes from the three independent factors namely posture (P), vibration magnitude (V) and font size (S). The contribution of the font type and the interactions (V × S) is also found to be higher.

A Pareto chart is shown in Fig. 6 to display the importance of the estimated effects between the variables. The diagram clearly shows that the subject's posture and font size are the variable that contributes the most to the perceived difficulty, and that vibration magnitude and font type come close second.

The mean (± SD) value of the rated perceived difficulty for reading activity are plotted as a function of vibration magnitude for vibration directions, font type, font size and seated postures. The responses show a clear dependence on vibration magnitude, vibration directions, font type, font size and seated postures.

To understand the effect of vibration directions on perceived difficulty to read, the mean values of level of reading difficulty for Times New Roman and Arial 10-point size font for X-, Y- and Z-direction were plotted against vibration magnitudes (see, Figs. 7 and 8). The result reveals that the perceived difficulty in all three direction of vibration increases with the increase of vibration magnitudes, suggesting a proportional relation to the experienced perceived difficulty. It was observed that the difficulty perceived while reading on table was much higher for vibration stimulus in longitudinal direction as compared to other two direction of vibration, for both font types ($p<0.05$, $R^2=0.93$).

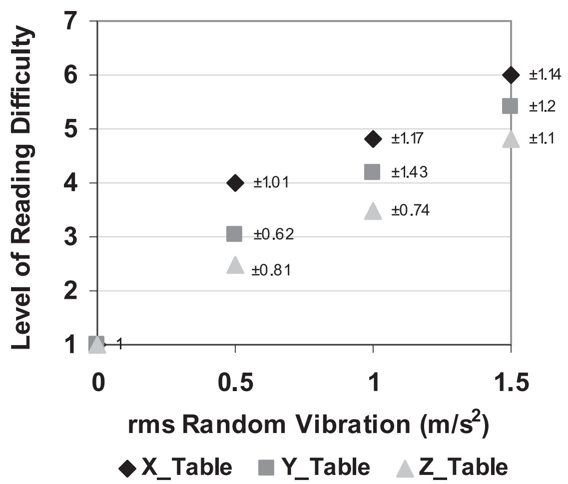

Fig. 7. Influence of vibration on perceived difficulty for reading Times New Roman font (10- point) in X, Y and Z direction.

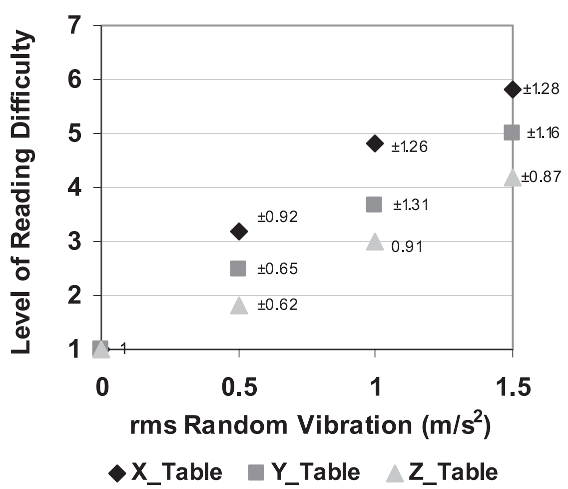

Fig. 8. Influence of vibration on perceived difficulty for reading Arial font (10- point) in X, Y and Z direction.

While comparing the font sizes of Times New Roman and Arial type for longitudinal direction, the mean values of level of difficulty of all font sizes (both Times New Roman and Arial) for longitudinal direction were plotted against vibration magnitudes (see, Figs. 9 and 10). The result reveals that the font size does matter in performance of reading task for both types of font. The maximum perceived difficulty was found with 10 point font of both Times New Roman (p<0.05, R^2=0.92) and Arial type (p<0.05, R^2=0.97). It was also observed that the perceived difficulty increases with an increase in intensity of vibration stimulus for all the font sizes.

For the same posture i.e. reading on table, direction of vibration (i.e. longitudinal) and for 10 point font size, Fig. 11 shows that the Times New Roman font causes a slightly higher difficulty in the reading task at 0.5 m/s^2 when compared to the Arial font (p<0.05, R^2=0.94). Further the perceived difficulty increase with an increase in intensity of vibration stimu-

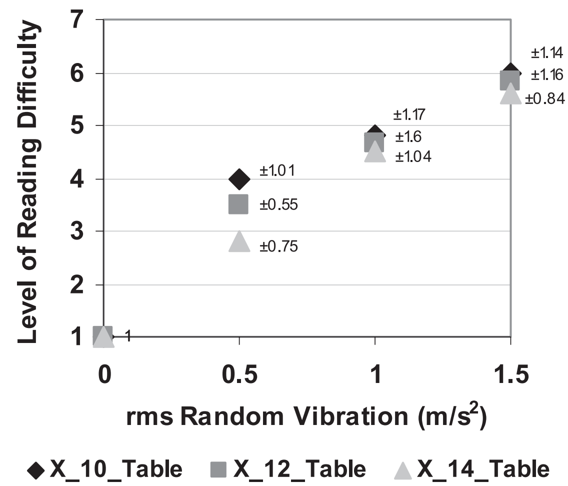

Fig. 9. Influence of vibration along X-direction on perceived difficulty for reading all Times New Roman font sizes.

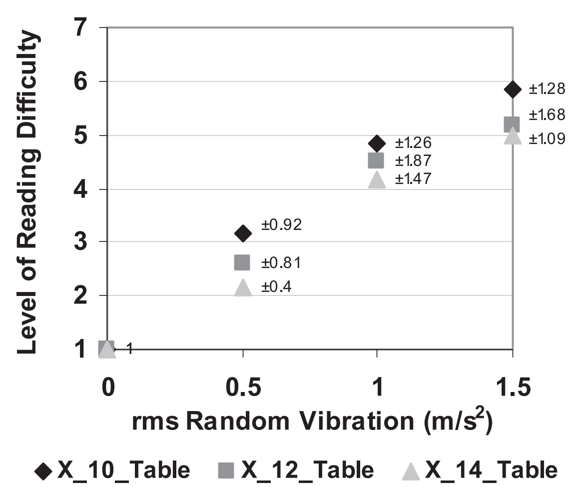

Fig. 10. Influence of vibration along X-direction on perceived difficulty for reading all Arial font sizes.

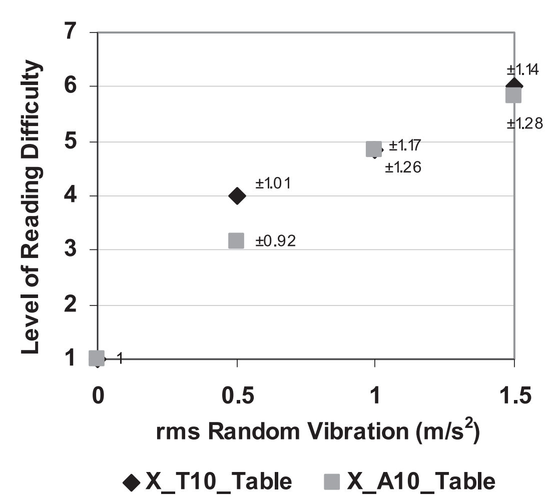

Fig. 11. Influence of vibration on perceived difficulty for reading Times New Roman and Arial font of size 10.

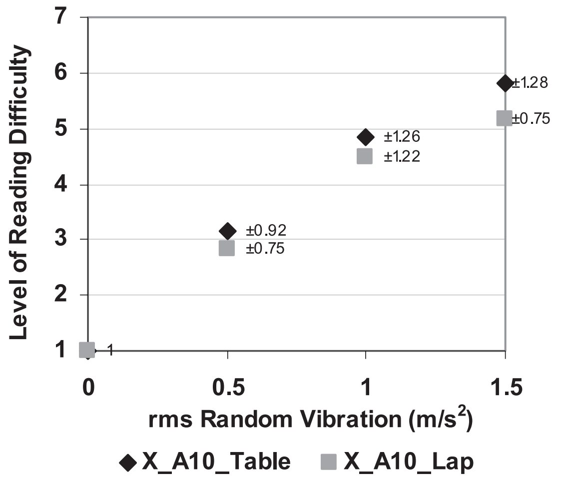

Fig. 12. Influence of vibration on perceived difficulty for reading Arial 10 font in both posture.

lus for both the font type, but no significant difference was observed in perceived difficulty between the two font types at 1 & 1.5 m/s^2 vibration stimulus (p>0.05).

While comparing the effect of subject's posture in longitudinal direction for Arial 10 point font which has less difficulty level, Fig. 12 reveals that a higher level of difficulty was observed when reading task was performed leaning over a table with text placed on table (X_A10_T) as compared to backrest support with text material on the Lap (X_A10_L) (p<0.05, R^2=0.9).

Discussions

The significant difference between the two seated postures used in this study can be explained by two different aspects, i.e. the support of the upper body and the vibration of the reading material with table. While reading with the material on the lap, the upper body is supported by the back of the seat, and the legs are supported by the floor. The muscles of the thighs help to reduce the vibration oscillation of the material on the lap. As compared with a no backrest posture, the backrest posture was known to slight reduction in head motion at about 5 Hz for frequencies up to 10 Hz[20] with consequent reduction in vision impairment. On the other hand, while working with material on the table, the upper body will lack support from the back of the seat and the reading material will attain an oscillation that is almost equal to that of the table. Therefore possibility is thus greater for the body to move out of phase with the table and material. While the reading task is similar between the two postures, the difference is significant. This implies that the table posture has a stronger influence on the perceived difficulty.

Typically, the presentation of Times New Roman and Arial font has been displayed in 10-, 12-and 14-point sizes on the printed paper. The size that is used is often determined at least in part by the x-height (the height of the torso for lowercase letters, or simply the height of a lowercase 'x') of that particular style (typeface). For example, Arial, which has a proportionally larger x-height than Times New Roman, is often displayed in a smaller text size - such as a 10-point size - whereas Times New Roman is often displayed in a 12-point size, giving them approximately the same x-height and general appearance in height. To a certain degree, larger text sizes are considered more readable than smaller sizes. Participants also perceived Times New Roman for both 10- and 12-point sizes as significantly more difficult to read as compared to Arial font, even though 10-point Arial and 12-point Times have approximately the same x-height. The results can be used in determining the optimal font sizes for presenting English characters under vibratory environment.

The performance of the reading task is mainly affected by the visual acuity on the retina and the cognitive decoding of individual words. This is confirmed by the subjects' response reported in Fig. 11. It was seen that the degree of reading difficulty at 0.5 m/s^2 was greater in Times New Roman than for Arial font. However at higher vibration levels of 1.0 and 1.5 m/s2 the degree of difficulty was nearly the same for the two font types.

In this study, however, the output response had to be silent and was therefore made by manually making a mark in the text. Unfortunately, the vibrations sometimes hampered the precision of the manual marking more than the reading. Therefore this manual operation might have caused a conflict for the test subjects when rating the level of difficulty for reading.

Conclusion

None of the present standards used by the industry (ISO 2631-1 or ENV 12299) considers the passengers' activity when evaluating ride comfort. These issues are necessary to emphasize since several train passengers perform sedentary activities during travel.

The present paper investigated the perceived difficulty to read under mono axis random vibration exposure along longitudinal, lateral and vertical axes for frequencies between 1 to 10 Hz at 0.5, 1.0 and 1.5 m/s^2 rms. In the study two font styles with three font sizes 10, 12 and 14 points were considered. The study confirmed the maximum perceived difficulty obtained for reading Times New Roman of font size 10 point, but only while working on a table. For mono axis random vibration stimuli applied independently, the subjective ratings suggest that reading difficulty is significantly increased in stimulus applied in longitudinal direction. Stimuli in lateral and vertical axis produced similar results, but the effect was less severe than that with longitudinal axis. For the range of vibration amplitudes which are commonly observed in the railway trains, it was found that Times New Roman font poses a greater level of difficulty as compared to Arial font in reading activity.

In this study, the response of the subjects was obtained in silent condition and by manually making a mark in the word chain. Unfortunately, the vibrations sometimes hampered the precision of the manual marking more than the reading activity. Therefore this manual operation could also be a source of difficulty. For the chosen font sizes and styles in the present study, the font size for reading activity comfort should have a minimum value of 10 point for Arial font, while for Times New Roman; the font size should not be smaller than 12 point. The results showed significant differences depending on postural conditions. The subjects reported greater difficulty while reading on the table than with lap.

Acknowledgements

The financial assistance received from EU-Asia link project, SIDA and DST India (No. SR/S3/MERC-50/2005) for the research work is duly acknowledged. We also wish to thank all the participants for participating in the experiment and openly discussing their opinions.

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