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TRAIN PASSENGERS' ABILITY TO READ AND WRITE DURING LATERAL VIBRATION TRANSIENTS

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Abstract

In a passenger survey aboard Swedish Intercity trains a majority of the passengers reported disturbances due to vibration and shocks. Subsequent laboratory studies revealed that the difficulty of reading and writing displayed non-linear frequency characteristics for stationary vibrations in the lateral direction.

In the present study a train mock-up was used to investigate the effect of lateral vibration transients on passengers' ability to read and write. The subjects sat leaning against the backrest with the work material placed on their lap during the exposures. In order to limit the influence of anthropometric differences, 21 subjects were recruited according to predefined body measures. The study consisted of three experimental parts (A, B, C). Part A and B comprised of six discrete sinusoidal frequencies (1.25 - 5.0 Hz) with a stationary amplitude of 0.3 m/s^2. Each frequency was superimposed with transient peaks of three amplitudes (0.7, 1.0, 1.4 m/s^2). The transient peaks were one oscillation period long and had a sinusoidal shape. Each peak appeared randomly three times during the 25 s long sequences. The test subjects rated their experienced difficulty to read and write due to each transient vibration, using Borg's CR-100 scale. In part C, nine amplitude levels (0.43 - 0.7 m/s^2) were used for three frequencies (1.25, 2.0, 4.0 Hz). In this part the test subjects were instructed to press a button whenever their reading was disturbed by a vibration transient.

The results showed that occasional vibration transients cause lower levels of difficulty than stationary vibrations. Further did, only 35% of the shocks at 0.7 m/s^2 cause a disturbance while reading.

INTRODUCTION

To assure good ride comfort for train passengers, the manufacturers undertake certifying vibration measurements according to standards like ENV 12299 [2] or other ride indexes. However, none of the available comfort measures are known to consider the passengers’ activities or context of travel. In a recent field study among Swedish train passengers, about 60% of the passengers were disturbed by vibrations or motions in the train [7]. However, the vibration levels onboard the same trains, were measured and found to be "comfortable" according to both ISO 2631-4 [5] and the Wz (Ride Index), [8]. It was also found that two of the most common activities among the passengers were reading and writing. The same study reported that the choice of posture is strongly linked to the activity that is performed. From studies on truck drivers’ sitting positions it was found that different contexts of driving also had a great influence on the variation and choice of posture [11]. Other studies have shown how different contexts or actions would affect the experience of ride comfort [9,10]. All of these studies indicate the importance of considering the context and seated posture while undertaking vibration and comfort studies. It is further known that vibrations in trains are typically multi-directional, *i.e.* mainly vertical, lateral and roll [3,4]. Nevertheless, substantial studies on human responses to vertical vibrations frequently may be found in the literature. Therefore a research project was initiated to study how low-frequency lateral vibrations influence the train passengers' ability to read, write, drink, perform computer work, and experience comfort.

Prior to this project, an experiment was performed to evaluate the vibration standards ISO 2631-4 and Wz (RI) for reading and writing [14]. Even with a small number of test subjects and a 4-point disturbance judging scale, strong characteristics were found for how different frequencies interfere with reading and writing. Therefore, two extended laboratory studies were set up to develop the methodology and further investigate these problems. The first study used harmonic excitation which, however, rarely occurs in ordinary trains. Therefore, this second study used only occasional occurring acceleration peaks. The main hypothesis of the present study is that the reading and writing difficulty would show strong but different characteristics due to both vibration amplitude and frequency. It was further hypothesised that the experienced difficulty of reading and writing under occasional acceleration peaks is higher than when exposed to stationary vibrations of equal acceleration amplitude.

METHOD AND PROCEDURES

Design

As in a previous study [12] a factorial design was chosen. Sinusoidal frequency and acceleration amplitude were set as the two independent variables. A subjective measure of experienced difficulty of task performance was set as a dependent variable. To investigate the disturbance threshold for reading, a judgement task was added to the design.

Present study was designed as a 3x2 factor study with three experimental parts:

A. Reading while exposed to occasional acceleration peaks
B. Writing while exposed to occasional acceleration peaks
C. Judgement of reading disturbance from occasional acceleration peaks

The purpose of the first two parts of this study (A and B) was to investigate how different frequencies and acceleration amplitudes (of lateral shocks) influence the ability to read and write in terms of difficulty. The purpose of the third part (C) was to investigate to what extent the process of reading is disturbed by lateral shocks. Each of the three parts investigated the influence of both vibration frequency and acceleration. To control any learning effects the first two parts were issued in a balanced in order.

Equipment

The study was set up and performed at the Marcus Wallenberg Laboratory at the Royal Institute of Technology (KTH). For the experiment a shortened (Bombardier C20) metro carbody was equipped with tables, seats, ventilation and lighting, see Figures 1 and 2. The carbody was mounted on a wagon frame with four steel wheels running on two steel rails. A position controlled hydraulic cylinder was used to create the desired lateral motion.

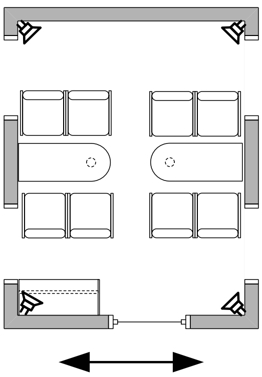

Figure 1 - Carbody layout

Figure 2 - Compartment interior

In order to simulate realistic conditions and to maintain a constant noise level, recorded interior noise from a passenger train (Bombardier X50, *Regina*) was played in the mock-up. Loudspeakers were mounted in each corner of the mock-up to give an evenly distributed background noise of 61 dB(A) during the experiment. The windows were all covered with semi transparent plastic film to prevent the subjects from getting visual cues of motion from the exterior.

Vibration Exposure

The basic design of the acceleration pulses was developed and successfully used in an experiment [13]. To create a simple shock-pulse, the sinusoidal background vibration was amplified during one oscillation period, as seen in Figure 3. In this way a controlled increase in acceleration is created meanwhile a sinusoidal motion is maintained.

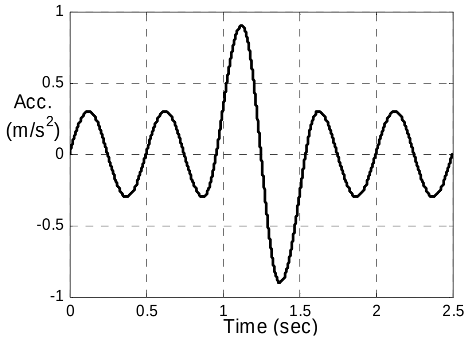

Figure 3 - Example of an acceleration transient used in the experiment [13].

In the two first parts of the experiment six discrete frequencies (1.25, 2.0, 2.5, 3.15, 4.0, 5.0 Hz) were presented with a stationary background amplitude of 0.3 m/s^2. Each frequency was superimposed with three transient acceleration peaks (0.7, 1.0, 1.4 m/s^2). The 3x6 vibration transients were presented to the subjects in a random order.

To introduce more amplitude levels in *part C*, only three discrete frequencies were used (1.25, 2.0, 4.0 Hz). Each frequency was presented at a stationary amplitude level of 0.3 m/s^2 in 3-minute sequences. During each sequence the nine amplitude peaks (0.433, 0.466, 0.500, 0.533, 0.566, 0.600, 0.633, 0.666, 0.700 m/s^2) were presented twice with a randomised order and interval.

Subjects

The study involved 21 healthy subjects (6 female, 15 male). The previous laboratory study [12] revealed large differences in anthropometric measures between the genders. These differences were, however, found to have non-significant influence on the overall results. This study aimed to control for the anthropometric effects by restricting the variations in body measures. In order to certify small variations among the participants, only persons who fulfilled the anthropometric inclusion criteria in Table 1, were recruited to the study.

Table 1 - Anthropometric requirements and results

	Seated Height [cm]	**Seated Weight** [kg]	**Arm Length** [cm]	**Low. Leg Length** [cm]
Criteria	***95-100***	***40-50***	***70-75***	***55-60***
Mean	95.0	49.3	73.0	54.0
Median	95.2	47.2	72.2	53.5
SD	2.2	5.5	3.4	1.7

In direct association to the experiment all subjects were required to fill in a questionnaire on their personal background: level of education; experience of travelling with train; fitness; reading and writing habits; and musculoskeletal disorders.

Tasks

In each part of the experiment the test subjects were given a different task, *A)* reading, *B)* writing and *C)* judgement of disturbance while reading. The writing task consisted of dictation from a tape-recorder, since this task needed to be free from influences from other processes than the physical hand writing. Each test subject was given a dictating machine with a footswitch for individual control of the speed. For the reading task, a word decoding test called "Word chains" [6] was chosen. *Word-chains* are constructed by three or more words written together without space separation, se Figure 4. The chains were printed on white A4 paper with a 14 point size Times New Roman font. The subjects were requested to make a vertical pencil mark where the words should be separated by a space character.

trainrunfast   bigcityline   sistermyhouse

train|run|fast   big|city|line   sister|my|house

Figure 4 - Example of Word Chains for the reading task

The test subjects were instructed to occupy themselves with the prescribed task during each of the 25 second long vibration sequences. When the vibration faded out the subjects were given a period of 10 s to rate their experienced difficulty to read or write during the last exposure. This procedure was repeated for all the 18 vibration stimuli and all ratings were made according to Borg's CR-100 scale. The CR-100 scale differs from ordinary magnitude estimation scales since it is verbally level-anchored [1]. This level-anchoring does not only permit determination of relative Stimuli-Response functions, but also provides "absolute" levels of intensity.

During the judgement of disturbance (*Part C*) each test subject was given a push button and a sample of a simple text to read. Subjects were instructed to press the button whenever their reading was disturbed by the occasional transients. Each push button was connected to a digital audio tape (DAT) recorder that simultaneously sampled the acceleration levels of the cabin and signals from the push buttons.

Posture

In a previous laboratory study [12] two main sitting postures were used in order to obtain a representative variation of the sitting positions of train passengers. In this study, however, only one posture was prescribed since the effect of posture was not of primary interest. Hence, the subjects were instructed to sit leaning against the back rest, with the text material placed in their lap.

RESULTS

Analysis of variance (ANNOVA) was performed with a *Repeated measures* model in the statistical software *SPSS*®. Differences due to gender and anthropometry were found to be insignificant ($p=0.18$ and $p=0.16$). The vibration frequency and acceleration did however show significant effects on the rated difficulty ($p<0.001$) for both reading and writing. Frequency characteristics for the reading and the writing task are presented in Figure 5 as means of experienced difficulty for the three acceleration peak amplitudes.

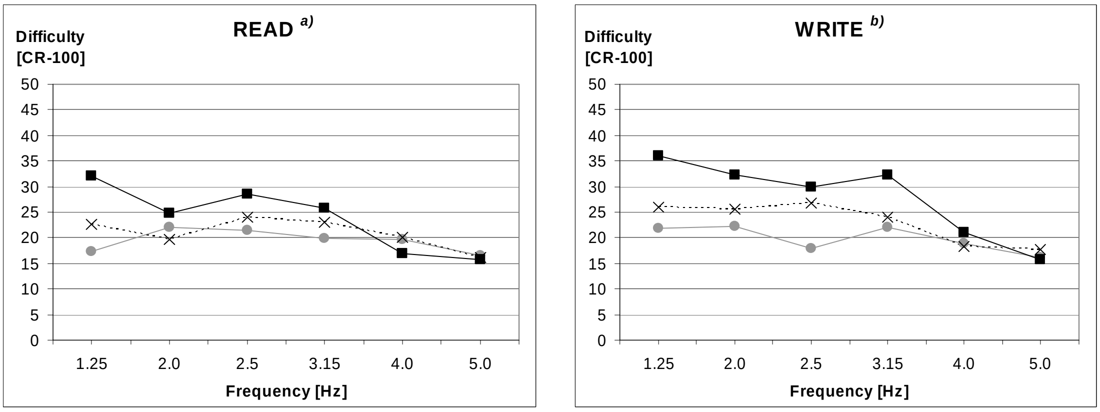

Figure 5 - Frequency characteristics for perceived difficulty to Read a) and Write b) at transient acceleration amplitudes (● 0.7 m/s², x 1.0 m/s², ■ 1.4 m/s²).

The rated difficulty shows clear dependence of frequency, amplitude and type of task. For writing the greatest difficulties are found at frequencies 1.25 and 3.15 Hz whereas the highest values for reading were found at 1.25 and 2.5 Hz. For writing, the characteristics are more equal for the highest and the lowest amplitude (1.4 and 0.7 m/s^2) than for the intermediate level 1.0 m/s^2. The maximum difficulty at 1.0 m/s^2 seems to be shifted down in frequency compared to the lowest and highest amplitudes.

An example of the push-button task responses is plotted in Figure 6. The results from the judgement of disturbance is presented as reading-disturbance-scores as a function of acceleration change (shock) in Figure 7. Regression lines are also plotted for each of the three frequencies.

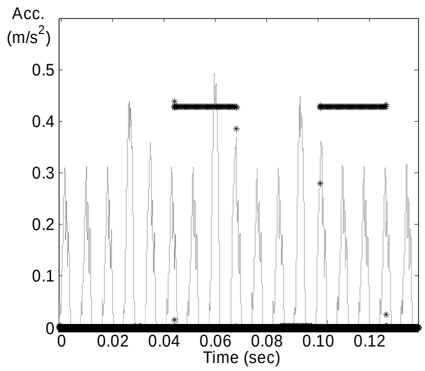

Figure 6 - Example of push-button response for reading disturbance

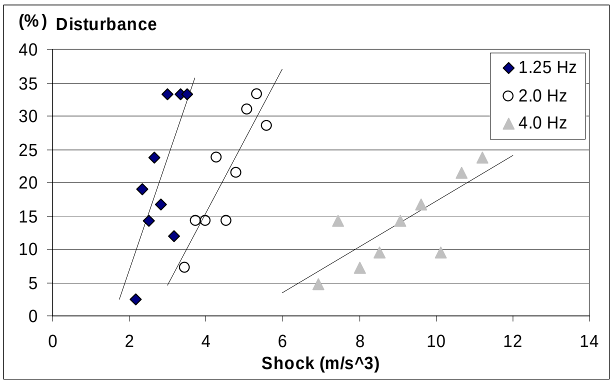

Figure 7 - Disturbances while reading as a function of shock amplitude.

Figure 7 shows that the disturbances increase as the amplitude increases for each frequency. Although the vibrations at 1.25 Hz have the lowest shock levels this frequency shows the steepest increase in disturbance. All three frequencies show high correlations between shock level and amount of disturbances (r^2 = 0.51 at 1.25 Hz; r^2 = 0.78 at 2.0 Hz; r^2 = 0.61 at 4.0 Hz). However, the highest amplitude peaks caused reading disturbances for only 14 of the 21 subjects.

DISCUSSION AND CONCLUSIONS

The results of this study show that the difficulty to read and write during occasional acceleration peaks is lower than during stationary vibration exposure. It was further found that the rated difficulty was influenced by the type of work, vibration amplitude and frequency. During the reading task, the number of disturbances increased proportionally with increasing acceleration amplitude. The vibrations at frequency 1.25 Hz were noted to cause steeper increase in disturbance than at 2.0 and 4.0 Hz.

In a previous experiment [12], the mean levels of rated difficulty of reading and writing were determined for stationary vibrations se Table 2.

Table 2 - Means of rated difficulty (CR-100) for reading under stationary and transient vibrations.

Vibration \ Frequency	1.25 Hz	2.0 Hz	2.5 Hz	3.15 Hz	4.0 Hz	5.0 Hz
Stationary at 0.8 m/s^2	40.1	49.4	51.3	49.8	45.7	47.8
Transient at 1.4 m/s^2	32.1	24.9	28.6	25.7	16.9	15.7

Although the amplitude levels of the stationary vibrations (0.8 m/s^2 *peak*) were lower than the acceleration peaks in the present study (1.4 m/s^2) the mean difficulty of reading and writing was rated 50% and 45% lower respectively. It is thus reasonable to assume that stationary vibrations cause considerable temporal fatigue effects even for durations less than 1 min.

This study obtained strong frequency dependence for the subjective ratings of difficulty, for both reading and writing. This frequency-dependence corresponds to previous results [14] but differ from that given in ISO2631-4 or ENV 12299. Hence, further studies are needed in order to develop more appropriate models or measures for assessment of how passengers' activities, like reading and writing, are disturbed by occasional acceleration peaks.

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