UNIVERSITY OF Southampton
Institute of Sound and Vibration Research

ISVR Technical Report

Effect of Fore-and-Aft,Lateral and Vertical Whole-Body Vibration on Typing

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ISVR Technical Report No 327

April 2009

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UNIVERSITY OF SOUTHAMPTON

INSTITUTE OF SOUND AND VIBRATION RESEARCH

HUMAN SCIENCES GROUP

Effect of fore-and-aft, lateral, and vertical whole-body vibration on typing

by

Mandy Lo and Michael J Griffin

ISVR Technical Report No. 327

April 2009

Abstract

Although many rail travellers use portable computers while travelling, the train environment has not been influenced by the desire to operate computers. Some trains provide power points and tables for portable computers, but an optimal design also requires understanding of how typing is disturbed by train motion. There are numerous studies of typing in static conditions and many studies of the interference of activities by vibration, but there have been few studies of the effects of vibration on typing. In the few studies previously conducted, the differing methods of measuring performance make it difficult to compare results.

An experimental study has been performed to understand the effects of vibration magnitude, vibration frequency and vibration direction on typing performance. With 12 seated subjects in each condition, the effects on typing performance of five vibration magnitudes (0.63, 0.80, 1.00, 1.25 and 1.6 ms^{-2} r.m.s.) of 30-s periods of sinusoidal vibration at each of twelve frequencies (0.50, 1.00, 1.25, 1.60, 2.00, 2.50, 3.15, 4.00, 5.00, 6.30, 8.00, 10.00 Hz) were determined for each of the three translational axes (*x*-, *y*-, and *z*-axis) of whole-body vibration. Performance was evaluated by three measures: (a) the total number of data entries in 30 s, (b) the number of typing errors, and (c) a subjective estimate of typing difficulty. The results are presented in tabular and graphical form.

Subjective estimates of typing difficulty varied with the magnitude, frequency, and direction of the vibration. Lateral vibration, especially in the range 1.6 to 6.3 Hz, created the greatest difficulty. Vertical vibration caused least difficulty. There were no statistically significant effects of vibration on typing speed or typing accuracy, probably because extra effort was used to counteract the vibration disturbance.

Contents

1. Introduction

1.1. Background and motivation

Studies of discomfort caused by whole-body vibration are mainly concerned with the sensations produced by the vibration and often ignore any inconvenience associated with the vibration (Griffin, 1990). Conversely, studies of the effects of vibration on activities have often measured the performance of a task without considering the 'discomfort' arising from the inconvenience.

Studies of the effects of vibration on activities have often focused on military personnel, with investigations of the effects of vibration on the vision or manual control of pilots and tank crew. There has been relatively little attention to the tasks performed by the general public as passengers. Exceptions are studies of the effects of vibration on drinking (e.g., Whitham, and Griffin, 1978; Corbridge and Griffin, 1991), effects of vibration on writing (e.g., Corbridge and Griffin, 1991) and effects on reading (e.g., Griffin and Hayward, 1994). There are no known comprehensive studies of the effects of vibration on typing that make it possible to predict the magnitudes, frequencies, and directions of vibration that will cause greatest problems.

In a survey of train passengers, Sundström (2006) found that reading was the most common activity undertaken during long journeys, followed by eating or drinking, looking out the window, and writing by hand. Writing or working with a computer was reported by 14% of the participants. The findings are similar to those of Westberg (2000).

Typing performance has been measured variously as words typed per minute, number of characters entered, number of correctly entered words, number of correctly entered characters, or character error rate (Matias *et al*. 1996; Sears and Zha, 2003). The nature of the task can affect performance and different performance patterns have been observed when subjects entered paragraphs rather than short sentences. When typing, it is possible to compromise speed to achieve accuracy, and vice versa, and both speed and accuracy may depend on effort and motivation. It is desirable that speed, accuracy, and effort are controlled or monitored when determining typing performance.

The objective of the study reported here was to investigate by experiment how typing performance depends on vibration direction (in the three translational axes of seat vibration: fore-and-aft (x-axis), lateral (y-axis), and vertical (z-axis)), vibration frequency, and vibration magnitude. Typing performance was measured by the total number of keyboard entries in 30 seconds, the number of errors, and subject estimates of typing difficulty.

It was hypothesised that vibration magnitude, vibration frequency, and vibration direction would affect typing performance and that this would also be reflected in the typing speed, typing errors, and subject estimates of typing difficulty. The greatest effect was expected to occur between 1.25 Hz and 6.3 Hz during horizontal vibration and between 4 and 8 Hz during vertical vibration. Since lateral vibration has the greatest effect on the postural stability of seated people, it was also expected that the greatest effect on typing would be observed during lateral vibration.

2. Apparatus and Procedure

2.1. Generation and measurement of vibration

The experiment was conducted on two hydraulic vibrators: one for horizontal oscillation and the other for vertical oscillation. The two vibrators were capable of producing displacements of up to 1 metre.

A full-bridge piezo-resistive accelerometer (Entran EGCSY-240D-10) was mounted at the centres of the vibrator platforms to measure acceleration in the direction of excitation.

2.2. Seating Arrangements

The same seat and table were used for all three directions of excitation. The seat and table were assembled to match recommendations for the height of a typing desk 670 ±10 mm (BS

5940, 1980) with a corresponding seat height of 457 ±78 mm (Pheasant, 1999). A footrest is recommended to achieve these heights if needed.

A rigid flat wooden seat was used with a thin layer of high stiffness, high friction rubber glued to the surfaces to reduce relative movement between subjects and the seat due to sliding. The table height was 762 mm, the seat height was 660 mm, and the footrest height was 102 mm. This arrangement resulted in the surface of the table 660 mm above the footrest and with the seat 458 mm above the footrest.

The backrest of the seat was rigid, flat, and vertical and extended to 554 mm above the seat surface. Neither the seat, nor the backrest, nor the table had any resonances within the frequency range studied (up to 10 Hz) in any of the three axes. A loose lap strap was worn by subjects for safety purposes.

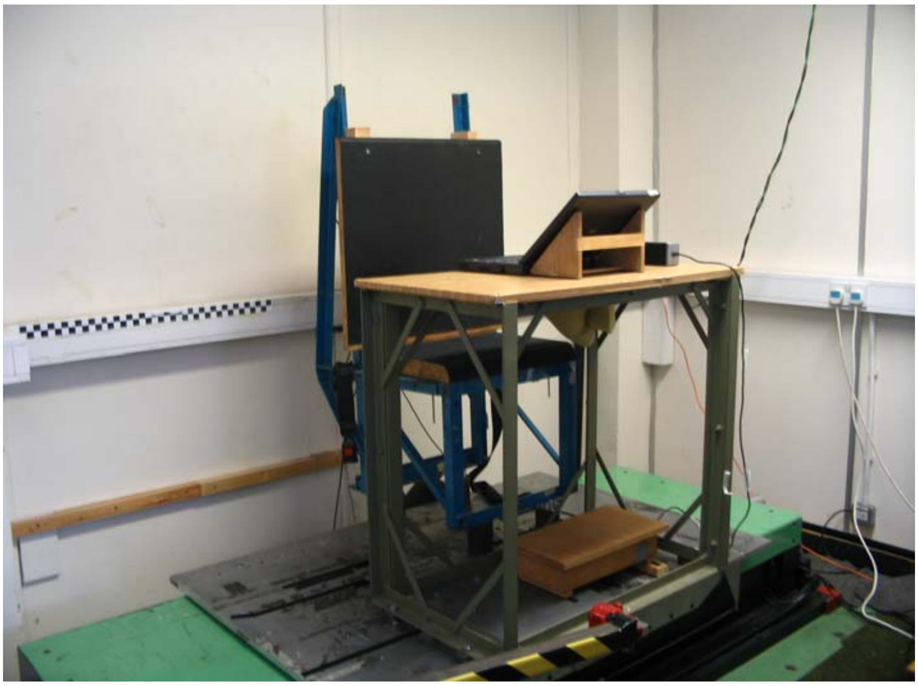

Figure 1 Experimental apparatus for lateral excitation.

2.3. Vibration production

An *HVLab* system (version 3.81) was used to generate and monitor all the vibration stimuli. The drive signals were processed through a digital-to-analogue converter at 100 samples per second. A low pass filter was then applied at 30 Hz. Analogue-to-digital conversation took place at 100 samples per second via a low pass filter at 20 Hz.

2.4. Vibration stimuli

Sixty conditions of sinusoidal oscillation were studied in each of the three directions: five magnitudes (0.63, 0.80, 1.00, 1.25, and 1.6 ms^{-2} r.m.s.) at each of 12 frequencies (at one-third octave intervals in the range 0.5 Hz to 10 Hz). .

An additional twelve conditions with one-third octave bands of random vibration at 1.00 ms^{-2} r.m.s were also studied.

The study was conducted in three separate experiments – one for each direction of excitation. Within each experiment, six blocks (each consisting of twelve different frequencies presented in a random order) were presented to subjects in a randomised order. In addition, static conditions were presented before and after each block.

2.5. The task

The task required subjects to enter a letter on the keyboard of a portable computer when the letter appeared on the screen.

When a subject entered a letter, a new letter was presented, irrespective of whether they typed the correct or incorrect letter. Subjects were asked to enter letters as fast as possible without compromising accuracy. They were instructed to rest their wrists on the surface in front of the keyboard (this reduces the relative movement between the hands and the keys and is helpful with some types of vibration).

Figure 2 shows the image on the screen as seen by a subject. The letters were in uppercase but subjects typed in lower case. The number at the top left of Figure 2 indicates the number of seconds the software had been running, the capital letter is the letter presented to the subject, and the lower case letter is the letter entered by the subject. The capital letter was 50 mm in height on a screen approximately 300 mm from the eyes. The typing task lasted 30 seconds.

The experimenter was able to observe subjects at all times.

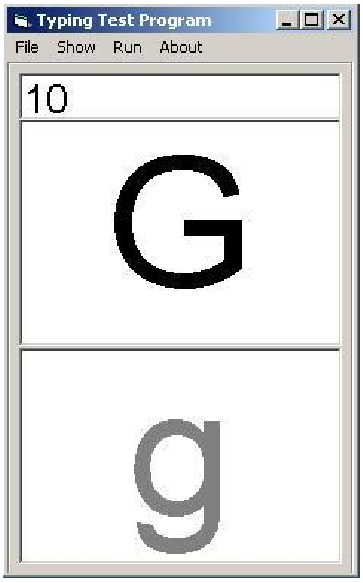

Figure 2: Task as seen by subjects

2.6. Subjects

Twelve subjects participated in three separate experiments corresponding to the three directions of vibration. They were drawn from a pool of 26 male subjects aged 19 to 25 years. The subjects were staff or students of the University of Southampton with statures ranging from 159 to 178 cm and weights from 59 to 86 kg. The experiment was approved by the Human Experimentation, Safety and Ethics Committee of the Institute of Sound and Vibration Research at the University of Southampton.

2.7. Procedure

Subjects completed a consent form confirming their fitness for the experiment and were instructed in the test procedure and given a practice. During the practice, their performance was monitored and training was deemed to be completed when, after 30 seconds of training, 100% accuracy was maintained for 5 seconds. The twelve frequencies were presented in a balanced order across subjects so as to minimise order effects.

2.8. Typing performance measurements

Three measures of typing performance were measured: the total number of keyboard entries (the total number of letters entered during the 30-s run with each vibration condition), the number of errors per 30-s run, and the subject estimate of typing difficulty obtained from their response to the following question: "*If you were to type in the same environment again, how many errors would you expect? Please give your answer in percentage.*"

2.9. Analysis

Non-parametric statistical tests were performed on each of the three measures of typing performance. The Friedman test for *k*-related samples and the Wilcoxon matched-pairs signed ranks test for two-related samples were employed to investigate effects of vibration magnitude and vibration frequency. The effect of vibration direction was investigated using the Mann-Whitney U-test for independent samples.

3. Results

The median number of keyboard entries in 30 seconds, the median number of errors, and the median subjective estimates of typing difficulty are summarised in Figures 3 to 12. The results of the statistical tests are summarised in Tables 1 to 6.

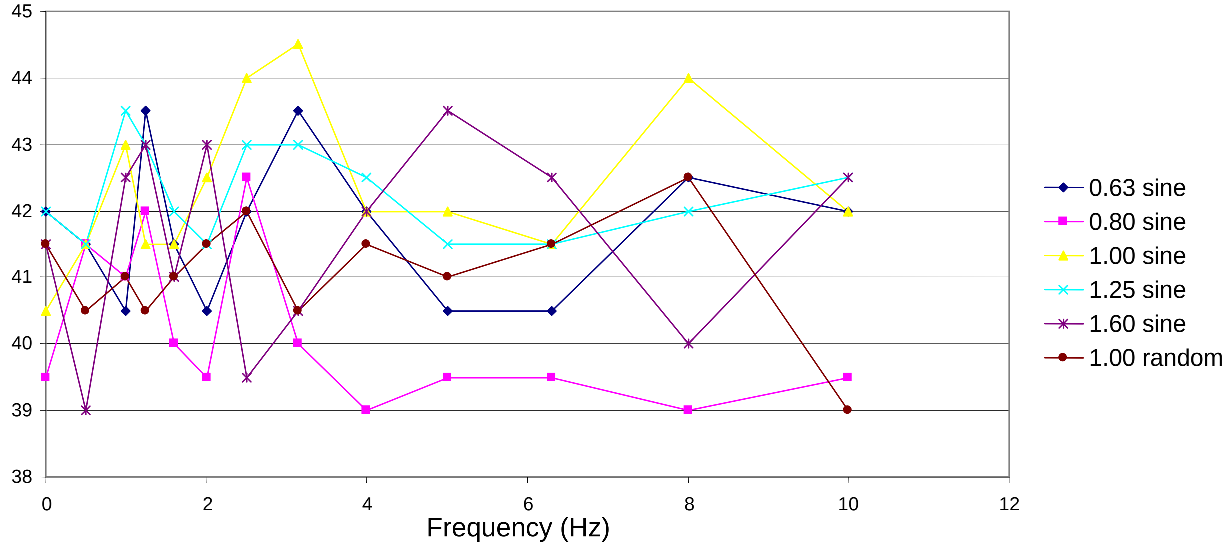

Figure 3 Median number of keyboard entries, fore-and-aft (*x*-axis) vibration.

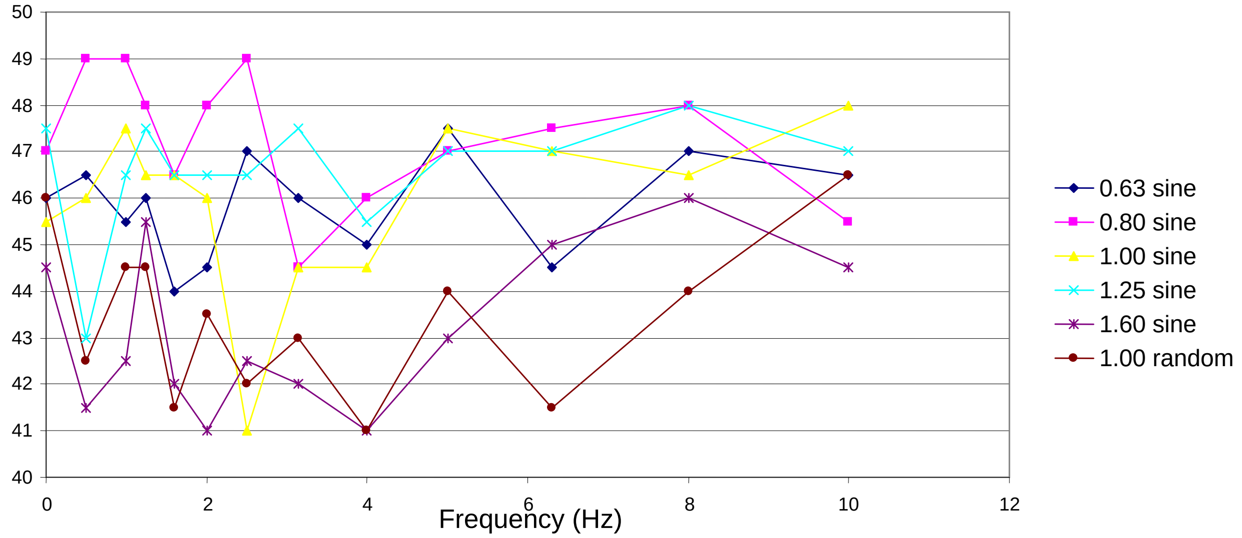

Figure 4 Median number of keyboard entries, lateral (*y*-axis) vibration.

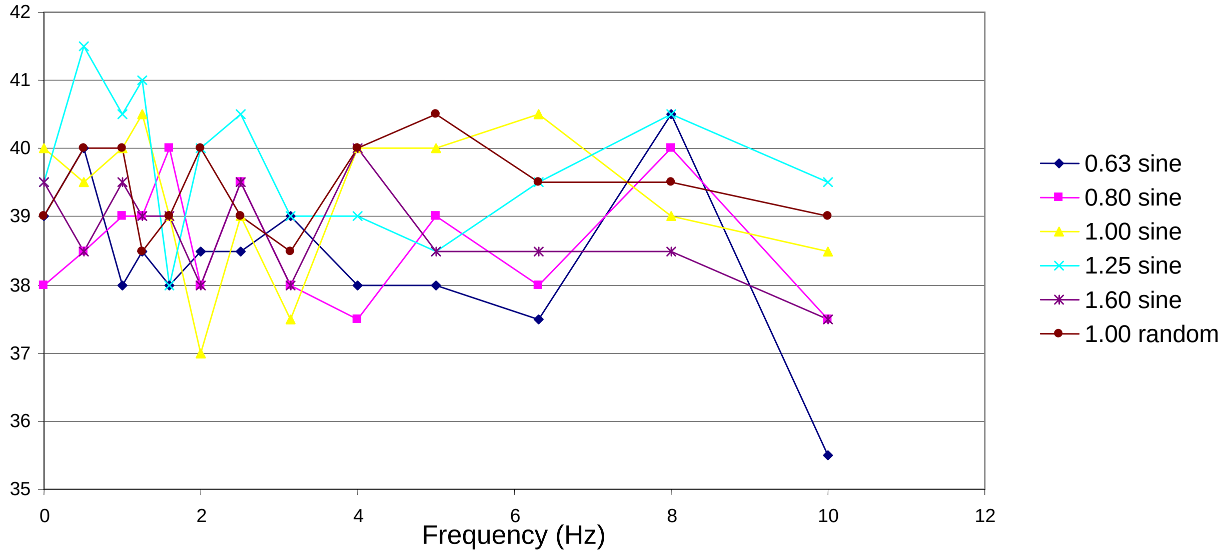

Figure 5 Median number of keyboard entries, vertical (*z*-axis) vibration.

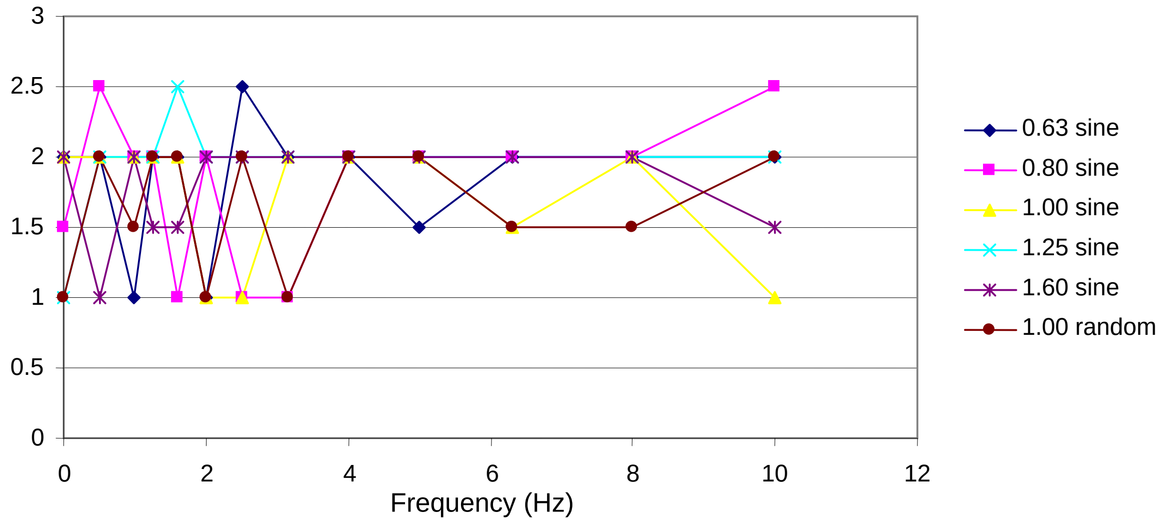

Figure 6 Median number of keyboard entry errors, fore-and-aft (*x*-axis) vibration.

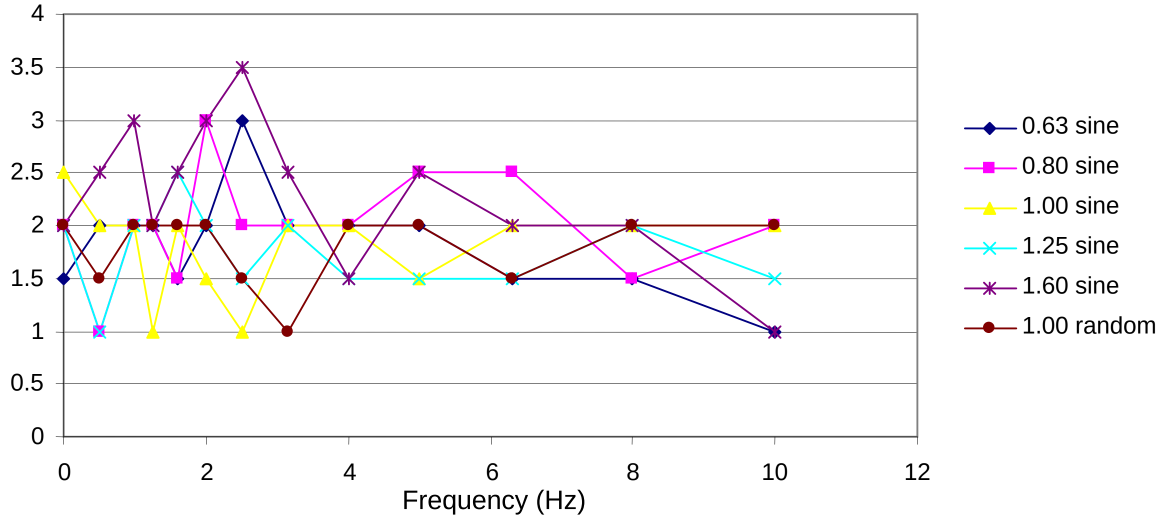

Figure 7 Median number of keyboard entry errors, lateral (*y*-axis) vibration.

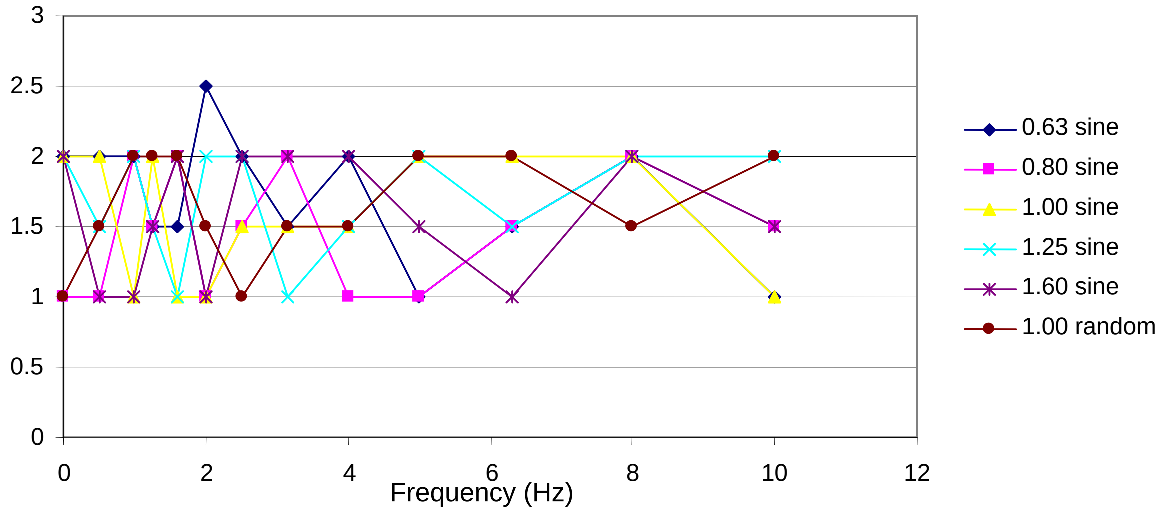

Figure 8 Median number of keyboard entry errors, vertical (*z*-axis) vibration.

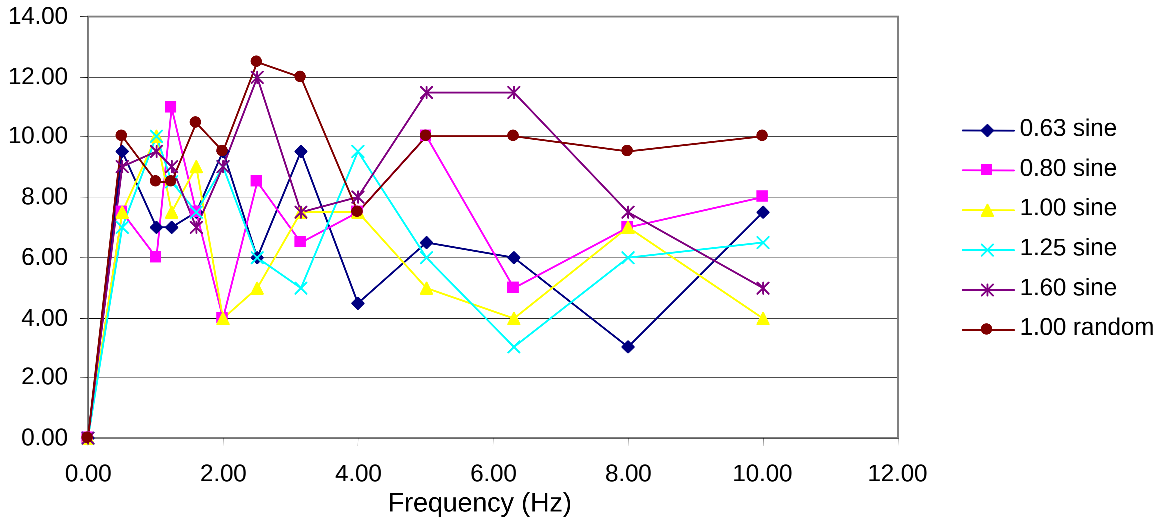

Figure 9 Median subjective estimates of typing difficulty, fore-and-aft (*x*-axis) vibration.

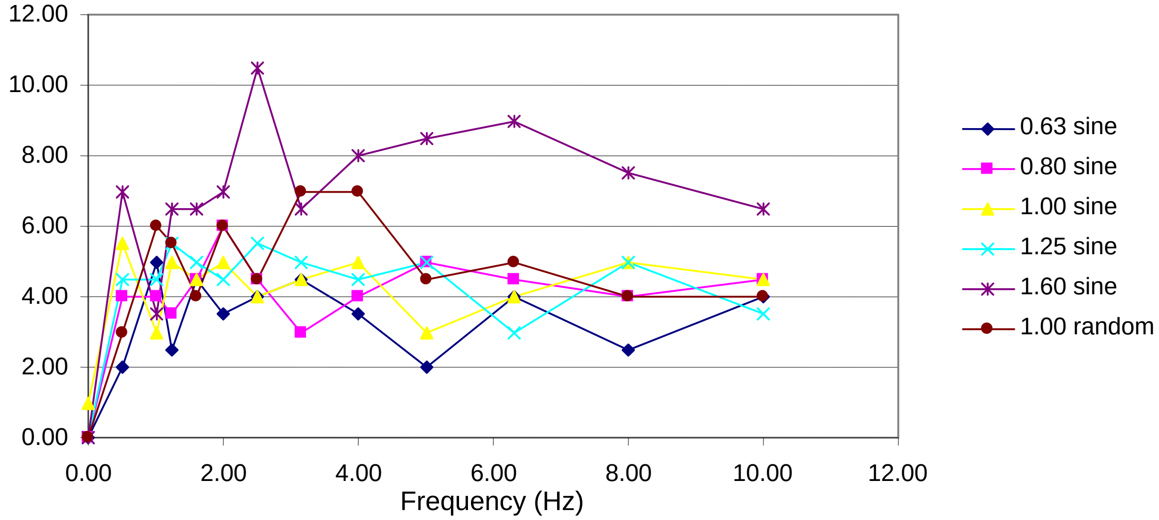

Figure 10 Median subjective estimates of typing difficulty, lateral (*y*-axis) vibration.

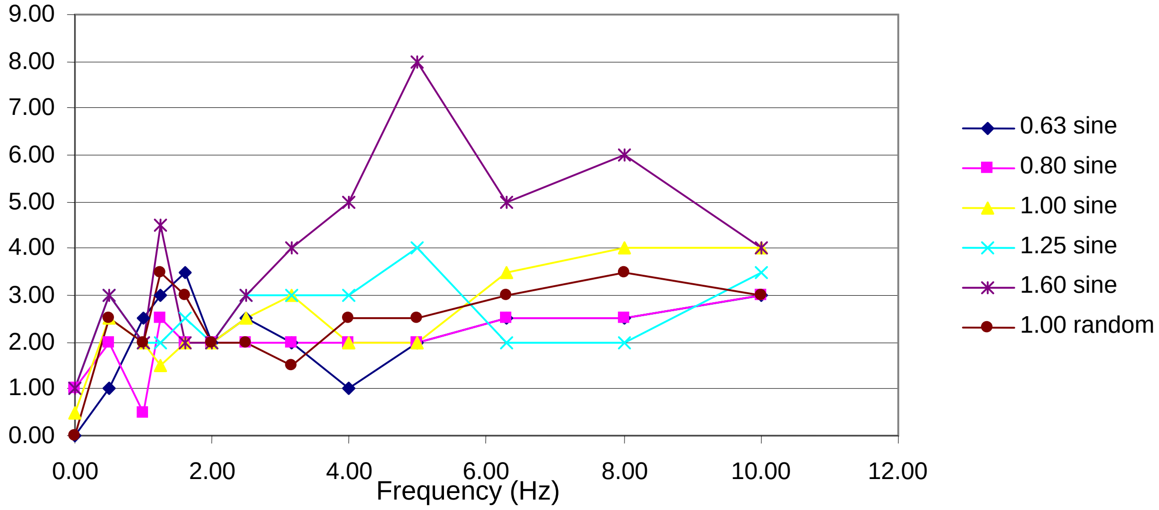

Figure 11 Median subjective estimates of typing difficulty, vertical (z-axis) vibration.

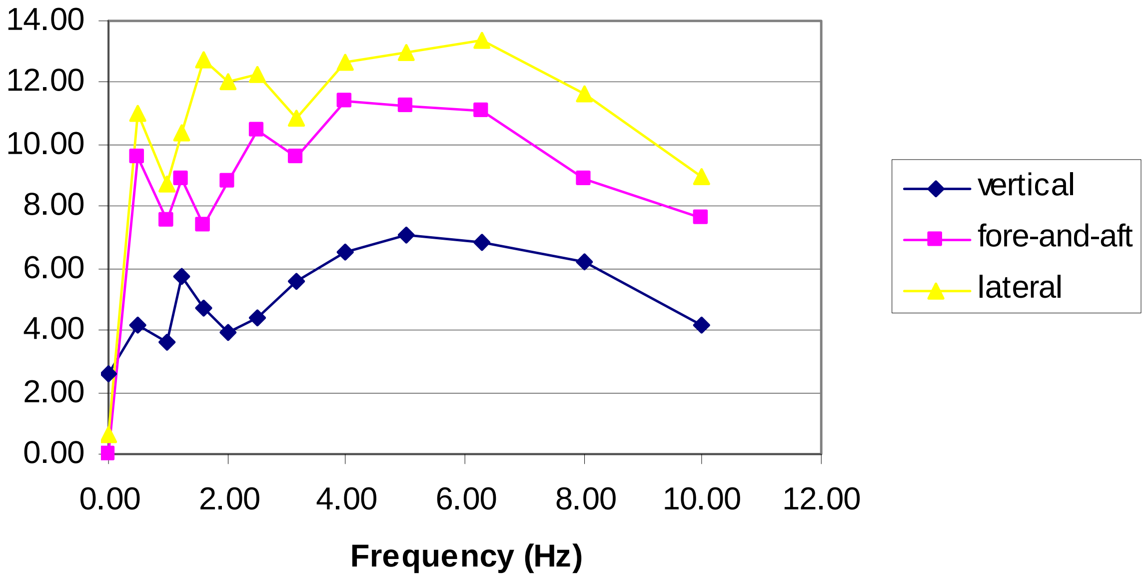

Figure 12 Mean subjective estimates of typing difficulty during 1.60 ms^{-2} r.m.s. vibration in the three different directions of excitation.

Table 1 Number of keyboard entries: statistical significance of effect of frequency (*p*-value; Friedman).

Mag Axis	0.63 sine	0.80 sine	1.00 sine	1.25 sine	1.60 sine	1.00 random
Vert	0.542	0.802	0.004	0.048	0.421	0.001
Fore-Aft	0.297	0.075	0.048	0.698	0.362	0.269
Lateral	0.433	0.286	0.047	0.000	0.000	0.032

Table 2 Number of keyboard entries: statistical significance of effect of magnitude (*p*-value; Friedman)

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.069	0.996	0.608	0.211	0.237	0.864	0.812	0.935	0.239	0.117	0.645	0.799
Fore-Aft	0.477	0.083	0.781	0.297	0.000	0.119	0.000	0.657	0.225	0.352	0.454	0.682
Lateral	0.000	0.010	0.355	0.368	0.000	0.006	0.246	0.000	0.300	0.860	0.213	0.578

Table 3 Number of errors: statistical significance of effect of frequency (*p*-value; Friedman).

Mag Axis	0.63 sine	0.80 sine	1.00 sine	1.25 sine	1.60 sine	1.00 random
Vert	0.705	0.377	0.004	0.712	0.997	0.007
Fore-Aft	0.720	0.537	0.830	0.849	0.692	0.053
Lateral	0.106	0.325	0.101	0.736	0.059	0.061

Table 4 Number of errors: statistical significance of effect of magnitude (*p*-value; Friedman).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.195	0.370	0.970	0.575	0.108	0.255	0.923	0.257	0.073	0.129	0.458	0.376
Fore-Aft	0.341	0.289	0.399	0.281	0.707	0.188	0.282	0.687	0.704	0.789	0.984	0.636
Lateral	0.497	0.279	0.096	0.653	0.101	0.002	0.721	0.709	0.399	0.131	0.825	0.269

Table 5 Subjective estimate: statistical significance of effect of frequency (*p*-value; Friedman).

Mag Axis	0.63 sine	0.80 sine	1.00 sine	1.25 sine	1.60 sine	1.00 random
Vert	0.008	0.006	0.002	0.028	0.002	0.003
Fore-Aft	0.000	0.000	0.000	0.000	0.000	0.000
Lateral	0.000	0.000	0.000	0.000	0.000	0.000

Table 6 Subjective estimate: statistical significance of effect of magnitude (*p*-value; Friedman).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.132	0.193	0.239	0.435	0.673	0.424	0.225	0.016	0.048	0.199	0.825	0.808
Fore-Aft	0.377	0.376	0.691	0.147	0.242	0.107	0.103	0.090	0.012	0.001	0.255	0.398
Lateral	0.006	0.013	0.001	0.027	0.021	0.011	0.182	0.036	0.000	0.001	0.002	0.259

Table 7 Number of keyboard entries: statistical significance of effect of direction (*p*-value; Friedman).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
0.63 sine	0.161	0.035	0.060	0.126	0.258	0.063	0.205	0.031	0.186	0.502	0.161	0.107
0.80 sine	0.127	0.656	0.264	0.587	0.439	0.258	0.264	0.274	0.205	0.472	0.144	0.337
1.00 sine	0.297	0.114	0.393	0.186	0.457	0.627	0.172	0.116	0.323	0.144	0.290	0.041
1.25 sine	0.656	0.315	0.297	0.174	0.107	0.517	0.401	0.273	0.457	0.132	0.138	0.337
1.60 sine	0.856	0.856	0.315	0.770	0.640	0.197	0.938	0.517	0.667	0.233	0.067	0.233
1.00 rand	0.662	0.144	0.297	0.258	0.754	0.393	0.915	0.620	0.183	0.249	0.297	0.138

Table 8 Number of errors: statistical significance of effect of direction (*p*-value; Friedman).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
0.63 sine	0.932	0.671	0.410	0.266	0.378	0.266	0.799	0.671	0.713	0.799	0.887	0.143
0.80 sine	0.198	0.932	0.319	0.799	0.478	0.160	0.713	0.887	0.887	0.178	0.378	0.143
1.00 sine	0.799	0.378	0.478	0.887	0.887	0.713	0.977	0.887	0.887	0.478	0.843	0.347
1.25 sine	0.799	0.799	0.755	0.887	0.843	0.671	0.755	0.590	0.443	0.671	0.590	0.291
1.60 sine	0.291	0.291	0.319	0.143	0.378	0.143	0.242	0.713	0.347	0.443	0.713	0.630
1.00 rand	0.843	0.242	0.291	0.478	0.410	0.843	0.932	0.551	0.932	0.843	0.671	0.630

Table 9 Subjective estimate: statistical significance of effect of direction (*p*-value; Friedman).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
0.63 sine	0.291	1.000	0.671	0.713	0.671	0.932	0.551	0.843	0.514	0.887	0.887	0.713
0.80 sine	0.713	0.713	0.713	0.887	0.266	0.671	0.887	0.932	0.630	0.843	0.843	0.514
1.00 sine	0.590	0.551	0.977	0.671	0.478	0.755	0.887	0.977	0.799	0.799	0.755	0.977
1.25 sine	0.977	0.887	0.976	0.713	0.755	0.671	0.755	0.887	0.671	0.843	0.671	0.630
1.60 sine	0.799	0.671	0.843	0.143	0.887	0.843	0.755	0.843	0.630	0.799	0.387	0.671
1.00 rand	0.799	0.478	0.671	0.978	0.143	0.799	0.932	0.887	0.478	1.000	0.843	0.799

Table 10 Number of keyboard entries: statistical significance of effect of random versus sine (*p*-value; Wilcoxon).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.227	0.687	0.180	0.125	0.774	1.000	1.000	0.508	0.549	0.344	0.508	0.508
Fore-Aft	0.289	0.508	0.727	1.000	1.000	0.227	1.000	0.774	1.000	1.000	0.754	0.754
Lateral	0.774	0.109	1.000	1.000	1.000	0.227	1.000	0.289	1.000	1.000	0.227	1.000

Table 11 Number of errors: statistical significance of effect of random versus sine (*p*-value; Wilcoxon).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.289	0.453	1.000	0.289	1.000	0.219	0.453	0.289	1.000	0.727	0.508	0.063
Fore-Aft	0.289	0.289	0.508	0.727	0.688	0.688	0.289	1.000	0.727	0.688	1.000	0.688
Lateral	0.688	1.000	0.031	1.000	0.125	0.219	0.688	0.453	0.289	1.000	0.344	1.000

Table 12 Subjective estimate: statistical significance of effect of random versus sine (*p*-value; Wilcoxon).

Freq Mag	0.50	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0
Vert	0.453	0.508	0.065	0.070	1.000	1.000	0.180	0.727	0.549	0.549	0.289	1.000
Fore-Aft	0.549	1.000	1.000	1.000	1.000	0.109	1.000	0.754	0.065	0.227	0.388	0.727
Lateral	0.344	0.021	0.727	0.754	1.000	0.180	0.289	0.508	0.002	0.016	0.453	0.219

3.1. Fore-and-aft vibration

Figure 3 and Tables 1 and 2 show that during exposure to fore-and-aft vibration the number of keyboard entries was not significantly affected by the vibration frequency ($p > 0.05$) or the vibration magnitude ($p > 0.05$). Similarly, Figure 6 and Tables 3 and 4 show that the number of typing errors were not significantly affected by the vibration frequency or the vibration magnitude. However, Figure 9 shows a general trend for subjective estimates of typing difficulty to increase as the vibration magnitude increased. Table 5 shows that estimates of typing difficulty were highly dependent on vibration frequency at each magnitude of sinusoidal vibration and with the one-third octave bands of random vibration ($p < 0.001$).

3.2. Lateral vibration

Figure 4 and Tables 1 and 2 show that during lateral vibration there was a trend towards fewer keyboard entries during higher magnitudes of lateral vibration, although the effect was not statistically significant. Figure 7 and Tables 3 and 4 show that the number of typing errors was not significantly affected by changes in the frequency or magnitude of lateral vibration. However, Figure 10 shows a clear trend for subjective estimates of typing difficulty to increase as the vibration magnitude increased. Table 5 shows that estimates of typing difficulty were highly dependent on vibration frequency at each vibration magnitude of sinusoidal vibration and with the one-third octave bands of random vibration ($p<0.001$).

3.3. Vertical vibration

Figure 5 and Tables 1 and 2 show that during vertical vibration the number of keyboard entries was not significantly affected by changes in vibration frequency ($p>0.05$) or vibration magnitude ($p>0.05$). Similarly, Figure 8 and Tables 3 and 4 also show that the number of typing errors was not significantly affected by the vibration frequency or vibration magnitude. However, Figure 11 shows a general trend for increasing subjective estimates of typing difficulty as the vibration magnitude increased. Table 5 shows that the effects of vibration frequency on estimates of typing difficulty were statistically significant at each magnitude of sinusoidal vibration and with the one-third octave bands of random vibration.

3.4. Comparison of fore-and-aft, lateral, and vertical vibration

Figure 12 compares subjective estimates of typing difficulty with each direction of vibration. Although not statistically significant ($p>0.05$, see Tables 7 to 9), there is a trend for a distinction between the three directions, with greatest difficulty during lateral vibration and least difficulty during vertical vibration.

3.5. Comparison of sinusoidal and random vibration

Figures 3 to 11 show that typing performance during exposure to 1.00 ms^{-2} r.m.s random vibration was generally worse than during 1.00 ms^{-2} r.m.s. sinusoidal vibration. However, the trend was not statistically significant other than in the subjective estimates of typing difficulty with 5.0 and 6.30 Hz lateral vibration,

4. Discussion

In this experiment, the magnitude, frequency, and direction of vibration had no statistically significant effect on typing speed or typing accuracy. However, with vibration in each of the three directions, the subjective estimates of typing difficulty were dependent on vibration frequency and tended to increase with increased vibration magnitude. The results suggest that although the task was often accomplished without statistically significant degradations in performance, extra effort was required to counteract the vibration disturbance.

Typing appears to have been more difficult during lateral vibration than during exposure to fore-and-aft and vertical vibration. The adverse effects of the lateral vibration may have arisen from increased upper-body movement resulting in more mechanical disruption of finger movement and, perhaps, more interference with vision. In the conditions of the experiment the subjects were in contact with a flat rigid backrest that partially controlled the movement of the upper-body. When sitting on a train seat and leaning forward to operate the keyboard of a portable computer resting on a table there may be less restraint to the upper-body and, perhaps, a greater effect of vibration on typing performance.

The experiment was conducted with the hands resting on the computer and with the computer resting on a rigid table in what may be considered a good ergonomic position. Different results may be expected if the hands are unsupported or if the table is not rigid, or if the computer is resting in the lap. By resting their hands on the computer the subjects were able to control the relative movement between their fingers and the keyboard that would otherwise be caused by the vibration. The conditions investigated were probably those in which the vibration would have least effects on typing performance.

5. Conclusions

In this study with moderate levels of whole-body vibration, the magnitude, frequency, and direction of vibration had little effect on typing speed or typing accuracy. However, the vibration did influence subjective estimates of typing difficulty, especially during lateral vibration. Typing speed and typing accuracy were little affected, probably because the posture adopted (especially support for the wrists) minimised disturbance and because the effort from the subjects was sufficient to counteract the disturbance caused by the vibration. The greater disturbance during lateral vibration may have been caused by swaying of the upper-body that may vary according to the back support available.

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