

Australian Government

Australian Transport Safety Bureau

ATSB RESEARCH AND ANALYSIS REPORT Road Safety Research Grant 2007/01 Final Report

Instrumentation to acquire road profile data for use in whole body vibration apparatus

John Patterson Mark Schier Caroline Owen Julie Pallant

Swinburne University of Technology

April 2007



Australian Government

Australian Transport Safety Bureau

ATSB RESEARCH AND ANALYSIS REPORT ROAD SAFETYRESEARCH GRANT 2007/01

Instrumentation to acquire road profile data for use in whole body vibration apparatus

John Patterson Mark Schier Caroline Owen Julie Pallant

Faculty of Life & Social Sciences Swinburne University of Technology

April 2007

Published by:	Australian Transport Safety Bureau
Postal address:	PO Box 967, Civic Square ACT 2608
Office location:	15 Mort Street, Canberra City, Australian Capital Territory
Telephone:	1800 621 372; from overseas + 61 2 6274 6590
Facsimile:	02 6274 6474; from overseas + 61 2 6274 6474
E-mail:	atsbinfo@atsb.gov.au
Internet:	www.atsb.gov.au

© Swinburne University of Technology 2006

To encourage the dissemination of this publication, it may be copied, downloaded, displayed, printed, reproduced, and distributed in unaltered form (retaining this notice). Subject to the provisions of the Copyright Act 1968, no other use of the material in this publication may be made without the authorisation of Swinburne University of Technology.

DOCUMENT RETRIEVAL INFORMATION

Publication date

April 2007

No. of pages

ISBN 978-0-642-25546-4

Publication title

Instrumentation to acquire road profile data for use in whole body vibration apparatus

Authors

John Patterson, Mark Schier, Caroline Owen, Julie Pallant Faculty of Life & Social Sciences, Swinburne University of Technology

Performing Organisation

Swinburne University of Technology PO Box 218 Hawthorn Vic 3122

Sponsor [Available from]

Australian Transport Safety Bureau PO Box 967, Civic Square ACT 2608 Australia www.atsb.gov.au

Reference No.

Apr2007/DOTARS 50208

Acknowledgements

We wish to acknowledge the invaluable assistance of Professor Peter Cadusch, Swinburne University of Technology for his assistance in processing the acceleration data for the trial, as well as his filter software which streamlined the extraction of the heart rate data from the raw files. David Simpson's contribution in designing and refining the three electronic devices was another vital collaboration. Three important assistants were Martin Dubaj, Sarah Nelder and Cameron Czernicki whose efforts to overcome the vicissitudes imposed on us by major building works meant that the project finished on time: a sterling effort.

Abstract

Previous research demonstrated that vertical whole-body vibration can induce feelings reminiscent of fatigue and lassitude. These studies used 4 Hz as the driving frequency as this has been shown to be prominent in road-induced vibration in heavy vehicles. A series of tests of cognition, brain function, heart rate and questionnaires concerning subjective effects were previously validated using 10 minutes of vibration at 4 Hz. This report describes the use of these measures in a comparison between the effects caused by 4 Hz vibration and a vibration pattern recorded from a road in a small articulated truck. Twenty-two young healthy participants were each exposed in separate experiments to 10 minutes of each vibration pattern. The results indicated that a road profile used to create a pattern of vertical vibration was as effective as 4 Hz in most respects. There were minor differences from the previous study but these may have been due to the smaller numbers who participated in the current study. The equipment developed to obtain the road profile acceleration data proved to be very effective at obtaining a signal suitable for use in controlling the hydraulic actuator. The differences in subjective and physiological responses to the two vibration profiles were minor, suggesting that 4 Hz may be a suitable substitute to 'real' road profiles in studying the effects of vertical vibration on fatigue.

Keywords:

Vibration, fatigue, road profile, psychophysics

Notes

ATSB reports are disseminated in the interest of information exchange.
 The views expressed are those of the authors and do not necessarily represent those of the Australian Government.

Instrumentation to acquire road profile data for use in whole body vibration apparatus iv

CONTENTS

E	XECUT	IVE SUMMARYVI										
1	INTI	RODUCTION										
	1.1	Background1										
2	мет											
4												
	2.1	Location for road profiles										
	2.2	Recording of road profiles										
	2.3	Creation of the road profile signal 5										
	2.4	Participants										
	2.5	Recording arrangement										
	2.6	Procedure										
	2.7	Results analysis 10										
3	RES	ULTS										
	3.1	Questionnaire data										
	3.2	Physiological data										
	3.2.	1 N-back task										
	3.2.	2 Heart rate variability										
	3.2.	3 EEG activity										
4	DISC	CUSSION										
	4.1	Questionnaire data										
	4.2	N-Back Task data										
	4.3	Heart Rate data										
	4.4	EEG frequency data 30										
	4.5	Conclusion										
5	REF	ERENCES										
A 1	DDENIP											
A	FEND	1AE5										
A	PPEND	IX A: RAW DATA FROM QUESTIONNAIRES										
A]	PPEND	IX B: QUESTIONNAIRE 49										

EXECUTIVE SUMMARY

The objective of the project.

The major objective of this project was to develop, utilise and then evaluate instrumentation to record road profiles as acceleration values. These values were then to be used in a comparison of the influence of vertical road vibrations and a 4 Hz sine wave on the subjective and physiological responses of young participants. Several electronic devices were required to achieve this goal. The evaluation of the data obtained from the road was undertaken by using these acceleration values to drive a vertical hydraulic ram which was attached to a mounted seat. Volunteers were then exposed to two vibration patterns: 4 Hz sine-wave and the modified road profile. A series of physiological recordings were obtained from the participants during two non-vibration and one vibration period, and they attempted a single cognitive task during each period. The results were compared to determine if the road profile vibration pattern resulted in similar changes to those occurring when the 4 Hz sine-wave was used.

Recording and modifying the road profile.

The major objective of this project was to develop, utilise, and then evaluate, instrumentation to record road profiles as vertical acceleration values, using small accelerometers developed for the project and a purpose-built data acquisition system which could output a serial stream of data to a laptop for storage and subsequent analysis. These data were the vertical accelerations recorded from the driver's seat frame. Several trips were taken over a strip of public road known to be 'rough' and the data recorded. These numbers were then subjected to a process to characterise their frequency content, amplitudes and acceleration values. From the files, a representative set was chosen to be scaled and adjusted so that they could be used to drive the hydraulic actuator controller in the laboratory. Subjective tests on volunteers were used to determine if the vibration was within acceptable limits, but these do not form part of the recordings used in the study.

Recorded information from participants.

Twenty-two volunteers each undertook two 30-minute recording periods. Each recording period involved 10 minutes of control condition (no vibration), 10 minutes of vibration (either 4 Hz, or the road profile), and finally 10 minutes of no vibration. At least one day separated the two recording periods to allow for a wash-out of any effects.

Changes in mood and energy from questionnaire responses

A comparison of the questionnaire responses before and after the vibration sessions (i.e. before and after the 4 Hz session; and, before and after the road profile session) revealed a significant difference between the overall expression of tiredness before the 4 Hz and after the 4 Hz. This confirmed the previous study's results. Before and after the road profile vibration, the questionnaire measures of *energy* and *mood* showed very similar patterns. For almost all the questions associated with general tiredness or fatigue both the 4 Hz and road profile responses were significantly different from the baseline, or no-vibration, period. The majority of *energy* questions resulted in a significant change in response between the before and after vibration conditions. Only two measures – 'I feel half awake' and 'I feel carefree' did not differ significantly before and after vibration. Neither of these is thought to be related directly to a feeling of tiredness or fatigue. Two measures – 'I feel vigorous' and 'I feel peppy' – were significantly different between the before and

after vibration conditions for the road vibration condition, but there were no differences for the 4 Hz condition. For the *mood* measures, the questions were more direct and simple and these had fewer significant differences. Two measures ('lively' and 'exhausted') were significant in both 4 Hz and road profile conditions. Both these directly relate to commonly held views as to what tiredness and fatigue mean to non-specialist people. Another 11 measures were either significant in 4 Hz or the road profile vibration conditions, but not in both. In some of these, perhaps larger numbers of participants may have produced a convergence of outcome. As with our previous study, these significant differences are taken to confirm that the presence of vibration in the vertical direction is, regardless of the nature of the signal, resulting in consistent changes in personal perceptions commonly associated with tiredness and fatigue. The differences in outcome may be explained by the differences in the vibration signals. The 4 Hz component present in the road vibration profile was less intense than in the pure 4 Hz situation. The conclusion is that the test protocol and the presence of some vertical vibration, consistently causes perceptions to trend towards a feeling of tiredness. Further, the 4 Hz signal may be an adequate replacement for a more complex signal in producing this effect. Conversely, the study has confirmed these psychological changes seen with 4 Hz are not unique to this signal, but may be caused also by road profiles.

Heart rate changes

Increases in the mean heart rate were observed when participants were doing the *n*-back task. (This is a computer-based attention task where the participant watches letters appear one after each other on a computer screen, and they have to press a button to indicate, for each one, if it is the same as, or different to, the letter which was shown two steps previously in the sequence.). Further, the standard deviations were smaller compared with the non-task period preceding the task period. This is in keeping with the general opinion that heart rate variation is less when we are 'stressed'. Comparing the standard deviations observed during the two periods of vibration, there was a larger reduction for the 4 Hz protocol when the participants were not doing the cognitive task. For the road profile, the standard deviation. This could be interpreted to suggest that the 4 Hz vibration was more 'stressing' than the road profile; however, caution must be exercised in this conclusion as the 4 Hz signal may be mechanically adding a consistent value to the ECG through harmonics from the electrodes moving on the skin. In conclusion, though, it would appear that there are no major differences in physiological state between the 4 Hz and road profile form of vibration in heart rate terms. Trends in both vibration conditions were essentially the same.

Changes in cognitive processing and short term memory

The test used for the study relies on attention and short-term memory. The results from the study were slightly unexpected for the 4 Hz component, in that they were not consistent with previous observations using this frequency of vibration. In previous studies, there was an increase in reaction time for incorrect responses, but only during the vibration condition. In the current study there was only a linear decrease in reaction time over the succeeding recording periods (the last five minutes of each 10-minute block). The road profile results, however, had an additional decrease in reaction time after the vibration period was finished. This suggests that there was delayed response caused by the vibration. Again, the delay was only for incorrect responses. Reaction times to correct responses maintained the steady improvement over time which is associated with a practice effect. While this needs confirming with greater numbers of participants, it is an important observation if confirmed. The road profile vibration is possibly causing increased processing time when the answer is not immediately clear; that is, uncertainty exists.

Changes in electrical activity in the brain

Brain electrical activity (electroencephalogram: EEG) is a very complex parameter to measure and interpret. In our laboratory we simplify the analysis and interpretation of EEG data by concentrating on any changes in frequency of activity, rather than specific changes in signal amplitude over time. In previous studies there have been indications of 'tuning' of the brain to the driving frequency with an increase in proportion of the electrical frequency recorded from the scalp which matched the vibration frequency. This occurred again in the current study with the 4 Hz vibration resulting in a large proportion of 4 Hz in the overall signals recorded from the brain during the vibration component of the testing. The situation with the road profile was as expected. Being a range of frequencies, there was no guarantee of it being likely that only one frequency would increase as was the case with 4 Hz. Rather, it was expected that there would be a general shift in proportions of brain activity during vibration. This is what occurred. It is not possible to further examine this result because of the complexity of the brain's function; however, there may be more conclusions which could be drawn from a more detailed analysis of the signals. For example, it may be worthwhile to take signals from participants whose reactions were strong and compare their changes to those whose reactions were weaker to the vibration.

Conclusions

The hypothesis that vertical vibrations produced by road profile acceleration data and 4 Hz sinewave acceleration data would produce similar changes in subjectively reported and recorded effects on participants was, in general, supported. The differences between the two types of vibration may be due to variations in the sub-population of participants used for the current project compared to previous studies, or entirely caused by the different nature of the road profile vibration signal.

While it was never expected that the two vibration patterns would produce identical results, the level of overlap is most gratifying. It clearly shows that either vibration pattern is capable of causing trends towards a condition for which subjective ratings are suggestive of fatigue; or are believed by the participants to be fatigue-like. That there were differences in detail between the results of the study when 4 Hz was used and those obtained from road profile data, is also encouraging – it indicates that simple vibration does not cause effects coincidently, but that the frequency, and hence the acceleration, component is capable of altering the ratings to specific questionnaire questions, the brain electrical activity responses and the cognitive/short term memory responses.

1 INTRODUCTION

1.1 Background

Studies previously undertaken at Swinburne University of Technology (unpublished data) revealed that even short periods of low level sinusoidal vertical motion at 4 Hz can result in altered subjective mood/energy states, increases in reaction time to problem solving tasks, and changes in heart rate variability and brain electrical activity. The subjectively reported mood/energy changes were all in the direction of increased lethargy, tiredness and feelings of fatigue. Heart Rate Variability and electroencephalographic (brain electrical recordings) data showed that the 4 Hz vibrations were altering aspects of physiological arousal. While these data are useful in the understanding of basic processes occurring with an increase in fatigue when we are exposed to a pure sine-wave vertical displacement, they may not be relevant to the real-world situation where road vibrations are more complex. A logical next step beyond the previous experiments is to record and use real road profiles which, anecdotally, are considered to be causing fatigue, and to use these to repeat the previous experiments.

Vibration can be of concern in two particular ways. High level accelerations, particularly at frequencies above 8 Hz, are known to be capable of causing physical damage to tissues (Carlsöö, 1982). Low frequency, and consequently lower accelerations, are not considered to be likely to cause physical damage, but may cause problems of hand-eye coordination (McLeod and Griffin, 1988). High frequency, high acceleration vibrations are thought to modify neuromuscular control and to affect hormone levels, but these are usually applied for only short bursts (unpublished data).

The human body has high sensitivity to vertical (4 -10 Hz), lateral and longitudinal (0.5 - 2 Hz) vibrations, and physical problems associated with these have been recognised (ISO, 1997). Hassan and McManus (2001) studied the influence of Whole Body Vibration (WBV) induced by surface roughness on heavy vehicle drivers' perception and comfort and reported that drivers of heavy articulated vehicles mainly complain about vibrations in the frequency range 1.4 Hz - 5.6 Hz. The results of recent surveys of WBV exposure levels experienced by Australian heavy vehicle drivers indicate that the measured WBV exceed the comfort and perception thresholds (ISO, 1997) of 0.315 and 0.01 m/s² respectively (Sweatman and McFarlane, 2000). Hassan (2002) noted that the highest weighted RMS (root-mean-square) accelerations occurred in the vertical axis with a minimum value of 0.45 m/s² in the range 1 Hz - 4 Hz, which can easily exceed the above thresholds. A study of the characteristics of selected heavy trucks measured the highest vertical vibrations in the range 1 Hz - 4 Hz (Sweatman and McFarlane, 2000).

Of particular relevance is the observation that the human brain progressively has a greater percentage of lower frequency activity when we progress to sleep. Normally awake brain electrical activity (electroencephalogram or EEG) is dominated by frequencies above 8 Hz. When undertaking mental activity the frequencies which predominate are up in the range of 14 Hz – 20 Hz; motor (muscle) activity can push the envelope to include frequencies up to 40 Hz. When in a drowsy or sleep state, the frequencies which predominate are in the lower range of 0.5 - 7 Hz. This is arrived at by adding all the power across the full range of frequencies and determining the proportion of each frequency band as a percentage of the total.

As can be seen from above, the vibrations used in our laboratory studies are known to occur on the road, but the question we wish to answer is how closely does the simple 4 Hz stimulus mimic the complex road profile signals in inducing feelings of fatigue.

This question could only be answered in a small number of ways. One which had appeal was to use the exact same apparatus used for the 4 Hz situation, but use a real road profile. While less ideal than recording in a vehicle while it traversed a section of road, it has the benefit of allowing tight

controls on variables to simplify the analysis. It also allowed recordings to occur which were likely to be complicated (such as EEG) in a travelling vehicle, and also likely to interfere with the driver. A paradigm which allowed a direct comparison between a laboratory-based synthetic (4 Hz sinusoidal) frequency to drive the vertical vibration and a recorded road profile was considered an advantage, as it would validate the previous observations as well as indicate the validity of laboratory-based measurements.

2 METHOD

2.1 Location for road profiles

Using a small semi-trailer (Figure 1; Hino FD model prime mover and a custom-built enclosed trailer) recordings of the acceleration profile were made of a stretch of road near Melbourne which is known to be rough, and able to be travelled at 100 km/h. This stretch of road is at the entrance to the new multi-lane Calder Freeway, but is the remains of the old highway. Consequently, it has not had the newer preparation for a freeway, but is typical of single lane, older roads.

Figure 1 The small Hino FD prime mover and trailer used in the study.



The truck was run out and back around an approximate 20-minute loop with, and without, the trailer being attached, maintaining as close to the speed limit as possible. The limitation was truck power.

The vehicle was used as a publicity device with a purpose-built trailer which was not designed primarily for high speed driving at what was close to the limit of the prime-mover's capacity. This resulted in a top speed on the level, fully loaded, of a little over 80 km/h when the trailer was attached, which was less than we desired, but all that could be achieved.

Anecdotal comments by the driver – a University employee – and two of the researchers who were passengers, indicated that the chosen stretch of road and the vehicle resulted in a quite uncomfortable ride.

The loop of road included two stretches of smooth pavement, one stretch of very rough pavement (freeway entrance, old Calder Highway) and a stretch of freeway pavement. These regions were used to represent typical levels of vehicle vibration, but did not cover the sort of road known to have a predominance of 4 Hz: roads built on the expansive clay soil. These roads are typically in regional areas and a return trip to access them was beyond the scope of the current project. The goal of the experiments did not, however, require a specific road profile; rather that people's reactions to a 'typical' road profile would be compared to those from a 4 Hz vibration.

2.2 Recording of road profiles

Two purpose-built accelerometers (Figure 2) were constructed based on previous prototypes used successfully in laboratory trials. These were clamped to the floor mounting brackets on the driver's and passenger's seats with G-clamps and were orientated to record the vertical vibrations of the cabin floor.

Figure 2 The purpose-built accelerometer with the ADXL202 (Analog Devices Inc.) chip mounted on the printed circuit board.



Figure 3 The purpose designed and built data acquisition device used to record acceleration values and output a data stream to a laptop for storage.



Another specially built data acquisition device (Figure 3) was constructed to accept the signals from, and to provide power to, the accelerometer boxes. This microprocessor device was designed to be powered from the cigarette lighter socket in trucks and cars. This serial acquisition box was configured to deliver a continuous stream of values via a serial port to a laptop running a serial acquisition program. The data were then recorded onto the laptop's hard drive for future processing.

The illustration in Figure 3 shows the device with the cigarette lighter adapter attached. The 'output' port on the left side provided power for the accelerometer devices. Although only one channel was used in this study, the system can power two accelerometers and acquire two accelerometer channels.

The truck details are as follows:

- Prime mover wheelbase 3830 mm (front to rear axle)
- Semi-trailer wheelbase 9840 mm (kingpin to rear axle)
- Width of trailer 1260 mm
- Trailer weight approximately 8 tonnes.

2.3 Creation of the road profile signal

As recorded, the signals consisting of a set of numbers were not suitable to control the hydraulic controller used to drive a hydraulic ram to create the vertical motion. The recorded values were processed (see below) and the modified road profile signal was converted into a file which could then be used to drive the hydraulic system. This involved design and construction of another microprocessor controlled circuit which could read the data file from a computer and convert it into analogue voltages; these were scaled to drive the hydraulic controller at an appropriate level to simulate the displacement which occurred on the road to the truck seat frame.

Figure 4 The accelerometer clamped to the driver's seat frame in the truck.



The signals used to drive the vibrating chair are based on vertical acceleration data recorded on the frame of a seat in the cabin of the truck (Figure 4) driven on the Calder Highway in various conditions. In the most recent series, acceleration data for three driving conditions were recorded, (in the following these are referred to as: CalderLocal, CalderLocalTrailer and SUTLocal), and analysed off-line to identify basic signal parameters. The CalderLocal signal was chosen as the basis for the synthesised road vibration signal.

The following paragraphs describe the processing sequence, the characteristics of the individual recorded signals and the synthesis of the final drive signal.

1. Data Recovery.

Acceleration data were sampled at 6 ms intervals at 10 bit resolution (although the dynamic range of vibrations was limited to slightly less than 8 bits) and stored in ASCII form on the hard-drive of the lap-top computer used to control the acquisition system. The recorded data files were found to contain occasional errors, typically a single missing character. Non-conforming entries were detected and subsequently replaced by the median of their six neighbouring values. Visual inspection of the resulting arrays suggests that this procedure cleared essentially all of the errors.

2. Acceleration Spectra.

Spectral processing was based on the Welch periodogram method, using 5 second Hamming windows with 50% overlap. In practice the general form of the acceleration spectrum trend seems to be a roughly white signal filtered by a single pole system (probably due to the truck's suspension) with cut-off frequency in the vicinity of 4 Hz. In most cases the combination of the high frequency emphasis expected for an acceleration signal and the low-pass character of the suspension response leads to a peak in spectrum in the vicinity of 2 to 3 Hz. These values were then stored on a laptop and sent by the serial port to a dedicated converter (Figure 5) which reproduced the digital levels as analogue amplitudes suitable to drive the hydraulic controller.

Figure 5 Device to regenerate vibration signals from digitally stored acceleration values.



The illustrated device was designed and built to allow the regeneration of the analogue levels from the digitally stored acceleration values. The ribbon cable allowed the unit to receive a serial string from a laptop and output a value as an analogue voltage which was used to drive the hydraulic controller via the BNC lead as shown.

2.4 Participants

Young, healthy participants (n = 22, average age 22.85 years) volunteered for the study and most were students at Swinburne University of Technology. They were provided with an informed consent form which explained to them the procedures they were agreeing to. The consent form and all procedures involving volunteers were approved by the Swinburne Human Ethics Committee,

keeping within the parameters and procedures established by the Swinburne University of Technology's policies on Code of Conduct, Human Experimental Ethics Clearances and Intellectual Property.

2.5 Recording arrangement

A previously developed questionnaire was available for the participants to complete and it consisted of a section for determining mood-related issues (14 items), a section for energy-related issues (24 items) and other psychological measures of the participant's perceptions of the experience. Participants had to identify the level of subjective opinion about their 'state' at the time of the questionnaire. Additional personal experience items were also completed.

Figure 6 A view of the hydraulic ram located under the seat (KAB Seating, model 554B) showing the mounting frame for the system in the foreground.



Figure 7 A side view of the truck seat with the hydraulic controller in the back right of the illustration.



The apparatus (Figures 6 and 7) used to create the vertical vibrations consisted of a combined electronic/hydraulic interface (Instron, Norwood MA USA, computer/hydraulic controller), hydraulic controller (Zonic Master Controller, Milford Ohio USA), an hydraulic pump, cooling circuit, hydraulic ram (Zonic hydraulic exciter head), a frame for supporting the truck seat above the hydraulic ram, and a bracket for mounting the accelerometer was attached to the frame immediately below the seat frame. A separate pneumatic pump was used to provide the required air pressure for the seat dampers.

The procedure for the *n-back* cognitive task consisted of the participants holding a two-button response box while they remained seated on the vibration rig. A 17 inch LCD screen was placed on an adjustable stand at eye-level. The software presented large letters at approximately 3-second intervals with the letter visible for approximately 260 ms, with a black screen for the remainder of the inter-stimulus interval. As shown in Figure 9, the task was only presented for the last five minutes of each of the three 10-minute protocol blocks. For each 5-minute task period the participant was asked to press the 'Yes' button if the letter in front of them was the same as the one that appeared two places before, or the 'No' button if it was not the same (see Figure 11). For each of the 100 stimuli presented in the 5-minute block, 20 were valid targets. That is, they were two places after the same letter; for all the remaining 78, the correct response should have been to press the 'No' button. Because the first two letters cannot be preceded by any valid target letter, these two stimuli are ignored in the analysis. The nature of the analysis produces the following outputs: a correct response to the right letter; an incorrect response to the right letter; a correct response to the wrong letter; a response when no letter presented.

Figure 8 A schematic of the International 10-20 system for electrode placement on the scalp. The four electrode locations used in the current study are indicated by the coloured rings.



The physiological recording system was based on an 8-channel data acquisition system and software (PowerLab and Chart software; AD Instruments, Sydney). The physiological data were recorded using a purpose-built differential amplifier system. Two disposable electrodes were used with one on each wrist for recording of the electrocardiogram (ECG). Four silver-silver-chloride coated tin electrodes were attached to the scalp after abrasion and cleaning of the skin with normal electrophysiological techniques to provide an electrode impedance of less than 10 k Ω . The location of the electrodes on the scalp was determined using the International 10-20 system of electrode placement and the electrodes were in F3, F4, P3 and P4 (Figure 8). A forehead reference electrode and an earlobe ground were also attached.

Heart rate was obtained from the electrocardiogram recording and converted into inter-beat intervals by custom written software used to detect the QRS complex of the ECG (Figure 12).

A computer was used to view the acquired data (Figures 13, 14, 15) from the various sources as indicated below:

Channel 1: Driving signal for the hydraulic ram.

- Channel 2: Accelerometer output from the seat frame bracket above the hydraulic ram.
- Channel 3: Electrocardiogram
- Channel 4: F3 EEG signal
- Channel 5: F4 EEG signal.
- Channel 6: P3 EEG signal.
- Channel 7: P4 EEG signal.

Channel 8: Accelerometer attached to the participant's hips by an adjustable strap.

Channel 9: Computed heart rate from Channel 3.

2.6 Procedure

The following outlines the procedure for each participant (Figure 9).

- 1. Read and sign consent form.
- 2. Complete the questionnaire items on their current state.
- 3. Have the electrodes attached while they sit on the vibration rig seat.
- 4. They are given a brief familiarisation experience trying the *n*-back task.
- 5. Once all channels are recording properly, the test proper starts with a 10-minute baseline.
- 6. During the last five minutes of the first 10-minute period, the participant does the *n*-back task.
- 7. Without any break in proceedings the seat is set into motion (using either the 4 Hz sinewave signal, or the modified road profile) for the next 10-minute period; during the last 5 minutes the participant also completes a 5-minute *n*-back session while the vibration continues.
- 8. The vibration is then switched off and the last 10 minutes of recording occurs with another 5-minute *n*-back at the conclusion of this period.
- 9. The study interval concludes when the participant completes the last section of the questionnaire on their current feelings. During this period all electrodes are removed along with any electrode paste.

At the completion of the first experiment, each participant was asked to come on another day to undertake the second vibration experiment. The order of presentation of the 4 Hz and road vibrations in each vibration experiment was counterbalanced across participants.

All data were then saved and backed up.

Figure 9 The recording protocol: EEG and ECG were recorded during the 30minute recording session.



The electrode application and consent form aspects are not illustrated.

2.7 Results analysis

Data from the questionnaires were entered into an SPSS file and descriptive statistics were carried out on the various conditions (Figure 10):

- 4 Hz baseline against 4 Hz post-vibration.
- Road profile baseline against road profile post-vibration.
- Data from the heart rate, EEG and *n*-back task were exported from the data recording computer and after averaging they were separated into the following groups:
 - 4 Hz baseline against 4 Hz vibration.
 - 4 Hz vibration against 4 Hz post-vibration.
 - Road profile baseline against road profile vibration.
 - Road profile vibration against road profile post-vibration.

Figure 10 The location during the experiments where the comparisons were derived for the questionnaire data.

Questionnaire	No Vibration	Vibration	No Vibration	Questionnaire
Before condition: "energy" and "mood" questions	statistical	l comparison of	responses	After condition: "energy" and "mood" questions

4 Hz vibration Condition

Road vibration Condition

Questionnaire	No Vibration	Vibration	No Vibration	Questionnaire
Before condition: "energy" and "mood" questions	statistical	comparison of	responses	After condition: "energy" and "mood" questions

All of these data had descriptive statistics applied to them to seek out any significant differences between the 4 Hz and road profile conditions.

The cognitive task which is computerised automatically generates the various output data from participants' responses. Averages of reaction times and scores on correct responses are available as an output file. These are recorded relevant to the task. The four alternatives are: correct target response; correct non-target response; false response and correct stimulus response.



Figure 11 A schematic which illustrates the *n*-back task and the correct response.

Figure 12 A schematic of a standard ECG signal and how a threshold is applied to leave the peaks of the 'R' waves from which the R-R interval is obtained and the heart rate is computed.



Heart Rate = 1/R-R Interval

The letters, 'P', 'Q', 'R' and 'S', are standard designators used in cardiology to label the waveforms found in the standard 12-lead ECG. The complex indicated by 'QRS' is caused by the electrical activity in the ventricle of the heart which is related to the heart beat. The physiological data – heart rate and the four EEG channels – were extracted from the data acquisition program as text files with two channels: time and analogue value. For heart rate the R-R intervals were obtained by applying a threshold to the electrocardiogram channel to detect the QRS peaks (see Figure 12).

Once converted to inter-beat intervals, the values from the ECG were subjected to descriptive statistics. From these the mean values and standard deviations of the heart rates during all the conditions were obtained and plotted.

The electroencephalography data were processed using a routine Fast Fourier Transform process used in the laboratory for all the brain electrical activity studies. The total electrical activity was normalised across the various participants and the frequency bins were then quoted as percentages of the total electrical power across all frequencies.

3 **RESULTS**

3.1 Questionnaire data

The statistical analysis of the questionnaire data supported all of the previous study's observations in relation to the effects of 4 Hz vertical vibration on theses measures. This was an important internal control for the project as there were differences in some aspects of the location of the vibration rig and where the experiments were undertaken which were unavoidable.

The following tables indicate the questionnaire items and the significance of the differences between the baseline (no-vibration condition) and the responses after the vibration (actually 10 minutes after the vibration ceased).

•				-	
		Road Vi	ibration	4	Hz
	Items	t	Sig.	t	Sig.
Pair 1	I feel sleepy	-4.672	*000.	-4.500	.000*
Pair 2	I feel active	4.328	*000.	3.576	.002*
Pair 3	I feel half asleep	-2.468	.022*	-2.581	.017*
Pair 4	I feel lively	4.389	.000*	3.932	.001*
Pair 5	My eyes are heavy	-4.897	.000*	-2.492	.021*
Pair 6	Full of pep	5.452	*000.	2.981	.007*
Pair 7	Half awake	-1.790	.089	-1.000	.329
Pair 8	Energetic	4.297	*000.	3.039	.006*
Pair 9	Dead on my feet	-3.212	.004*	-3.016	.007*
Pair 10	Vigorous	2.193	.040*	1.254	.224
Pair 11	Bushed	-2.796	.011*	-3.521	.002*
Pair 12	Рерру	3.750	.001*	1.466	.158
Pair 13	Dozing off	-3.632	.002*	-4.039	.001*
Pair 14	Wide-awake	3.444	.002*	3.926	.001*
Pair 15	Carefree	-1.976	.061	1.301	.207
Pair 16	Groggy	-3.804	.001*	-4.018	.001*
Pair 17	Alert	5.210	.000*	3.038	.006*
Pair 18	Wakeful	4.638	.000*	3.250	.004*

Table 1 The t values and significance levels for the differences between the responses to each of the 'Energy' questions before and after the vibration (n = 22).

* Significant at the *p*<0.05 level.

The data in Table 1 are not meant to be considered as a statistical comparison of the differences between the two conditions, but rather, as a means of showing that there was a high degree of similarity between the two vibration forms. For these 'energy' measures, all but two showed a significant difference between the two conditions ('half awake' and 'carefree'). For two additional measures ('vigorous', and 'peppy'), the road vibration resulted in a significant difference between the non-vibration condition and the vibration, however, this difference was not seen with 4 Hz.

		Road Vibration		4	Hz
	Items	t	Sig.	t	Sig.
Pair 1	Panicky	.568	.576	1.312	.204
Pair 2	Lively	4.805	.000*	3.044	.006*
Pair 3	Confused	1.449	.162	.000	1.000
Pair 4	Worn out	-1.571	.131	-2.837	.010*
Pair 5	Depressed	2.017	.057	2.160	.042*
Pair 6	Downhearted	1.821	.083	2.027	.056
Pair 7	Annoyed	1.449	.162	.810	.427
Pair 8	Exhausted	-2.247	.036*	-3.873	.001*
Pair 9	Mixed-up	370	.715	-1.368	.186
Pair 10	Sleepy	-3.156	.005*	819	.422
Pair 12	Bitter	2.160	.042*	1.742	.096
Pair 13	Unhappy	2.347	.029*	1.449	.162
Pair 14	Anxious	.901	.378	3.600	.002*
Pair 15	Worried	3.578	.002*	.439	.665
Pair 16	Energetic	1.449	.162	370	.715
Pair 17	Miserable	568	.576	2.324	.030*
Pair 18	Muddled	1.742	.096	1.368	.186
Pair 19	Nervous	1.368	.186	3.813	.001*
Pair 20	Angry	3.846	.001*	-1.596	.125
Pair 21	Active	-3.645	.002*	1.000	.329
Pair 22	Tired	.000	1.000	2.453	.023*
Pair 23	Bad tempered	5.139	.000*	326	.747
Pair 24	Alert	.901	.378	1.449	.162

 Table 2 The t values and the significance values (p<0.05) for the questions dealing with 'Mood' issues (n = 22).</th>

* Significant at the p < 0.05 level.

<u>Note</u>: Pair 11 in Road Vibration condition cannot be analysed because (quote SPSS) 'The correlation and t cannot be computed because the standard error of the difference is 0'.

In Table 2, mood measures such as 'lively' and 'exhausted' were similarly affected by the presence of the vibration. With only road profile vibration was there a difference with 'sleep', 'bitter', 'unhappy', 'worried' and 'bad-tempered'. In contrast, 'worn out', 'depressed', 'anxious', 'miserable', 'nervous' and 'tired' were only significant if the vibration was 4 Hz. Measures where there was no difference of any significance in either vibration condition were: 'panicky', 'confused', 'downhearted', 'annoyed', 'mixed-up', 'energetic', 'muddled' and 'alert'.

Items were incorporated into the questionnaire to seek an estimate of the subjective levels of pretest 'energy'. The scale was 1 to 10, with 1 rating no level of the item, and 10, extreme levels of the item. When the means of these were compared with each other within a vibration condition, and with the same item in the other vibration condition, there were no marked differences (the maximum rating difference was 0.78 for the 'sleepiness' item). The pre-test rated levels of sleepiness, lethargy, lacking energy, tiredness and fatigue items were all slightly less than half way between 'Not at all' and 'Extremely'.

To determine if the vibration period was in anyway familiar with previous experiences in transport, ratings were included for a variety of transport modes. Again the rating scales were 1 ('not at all'), to 10 ('very similar'). The values recorded were very similar for both 4 Hz and the road profile conditions (maximum rating difference was 1.06 for the 'car' item). When each of the mean rating values were compared within vibration conditions, the following ranking of subjective ratings of similarity was obtained: Bus> Car> Train> Motor Bike> Amusement ride> Twin engine plane> Jet

aircraft> Bike> Boat. The ranking suggests that both vibration conditions were, overall, more like a bus and car, than a bicycle or boat.

As a means of accessing information about subjective feelings about, or induced by, the vibration experience, a series of items were listed and rated from 1, ('not at all') to 10, ('extremely'). There were no obvious or marked differences between the responses recorded for 4 Hz and road vibration conditions (maximum rating difference was 0.91 for the 'sleepiness' item). A comparison of the means revealed that the ratings were ranked in the following sequence: Boredom> Tiredness> Difficulty Concentrating> Sleepiness> Relaxation> Lethargy> Exhaustion> Physical Heaviness> Excitement> Anxiety> Confusion> Depression> Dizziness. The ranking suggested that overall, boredom was a stronger experience than dizziness.

To distinguish short term responses from an overall experience, there were additional responses sought for items where a rating of 1 was 'not at all' and 10 was 'extremely'. There were no differences when the mean rating responses from either vibration condition were compared (maximum rating difference between the road profile and the 4 Hz condition was only 0.46 for the 'boring' item). There were some different subjective ratings provided for the items, and these were of interest in their relationship to the issue of tiredness. The most extreme reported level was for the 'tiring' item (mean 6.50) and the next most extreme was 'boring' (at 5.91). The next two highest values reported, in descending order, were 'soothing' and 'relaxing'. The rest were much lower in rating and the whole sequence – from the highest rating value (closest to 10) to the lowest (closest to zero) – was: Tiring> Boring> Relaxing> Calming> Soothing> Enjoyable> Exciting> Disorienting> Unpleasant> Uncomfortable> Unsettling> Confusing> Painful. The mean value for the last item was 1.32 which is very close to 'not at all'. These data suggest that the experience was generally considered to be more enervating and relaxing than unpleasant or aggravating.

3.2 Physiological data

The nature of the recording of physiological data are shown in the following figures (Figures 13, 14, 15). The sequence of channels is numbered from the top down and the channel data are as indicated in the Methods (Section 2.5).

Figure 13 This is a screen shot of the data file where the physiological data are monitored while being acquired. This figure was obtained while the data were acquired during a 4 Hz stimulus period.



Figure 14 As for Figure 13, this is a screen shot of the data file where the physiological data were acquired when the driving frequency was from the road profile data.



Figure 15. This figure illustrates the recording of data throughout the 30-minute period with the 10 minutes of 4 Hz vibration shown in the top trace and the two baseline no-vibration periods on either side.



3.2.1 N-back task

The cognitive task (*n*-back) data (Figures 16, 17, 18, 19) show the expected practice effect with progressive improvement in reaction time during the 30-minute recording period and the three 5-minute sessions of carrying out the tasks. There were no differences in accuracy between any of the three periods in each vibration condition, nor between the two vibration conditions. As can be seen from Table 3 and Table 4, participants maintained nearly 100% accuracy. The average reaction time for the baseline conditions in both the 4 Hz and road profile trials (the first 5 minutes) was 700 ms for the three correct response types. By the third period, the reaction time was down to 600 ms for the same responses. The incorrect response type was consistently slower, up to 1 second. There was the expected practice improvement in the 4 Hz incorrect response reaction time so that it decreased to 800 ms by the last task period. With the road profile data, the last reaction time had increased to 900 ms and was the only one of the reaction times which did not follow the expected progressive improvement.





The upper values represent the number of valid key presses to any stimulus, with the performance approaching 100%. The lower values are the correct target responses, out of 20 possible. The three time periods are the three 5-minute intervals at the end of each 10-minute session when the task was undertaken. There is no evidence of an effect during or after the vibration (times 2 and 3).

Figure 17 Overall average accuracy results for the *n*-back task, for the road profile protocol.



The upper values in Figure 17 represent the number of valid key presses to any stimulus, with the performance approaching 100%. The lower values are the correct target responses, out of 20 possible. The three time periods are the three 5-minute intervals at the end of each 10-minute session when the task was undertaken. There is no evidence of an effect during or after the vibration (times 2 and 3).

Figure 18 Overall average reaction time results for the *n*-back task, for the 4 Hz protocol.



In Figure 18, the standard errors are shown as vertical bars. The upper line represents where a response was made that was incorrect (wrong button pressed). The other plots are for the correct responses. The three time periods are the three 5-minute intervals at the end of each 10-minute session when the task was undertaken. There is no evidence of an effect during or after the vibration (times 1 and 3).



Figure 19. Overall average reaction time results for the *n*-back task, for the road profile protocol.

In Figure 19, the standard errors are shown as vertical bars. The upper line represents where a response was made that was incorrect (wrong button pressed). The other plots are for the correct responses. The three time periods are the three 5-minute intervals at the end of each 10-minute session when the task was undertaken. There is evidence of an effect after the vibration (time period 3) for the false target result (light blue line).

Table 3Correct response values for the *n-back* task for the 4 Hz vibration
protocol (seen in Figure 16).

4 Hz Condition	Before		Dui	ring	After		
Task parameter	Mean	S.D.	Mean	S.D.	Mean	S.D.	
No. Correct Stim Responses	96.50	4.52	97.64	0.95	97.41	1.10	
No. False Stim Responses	0.05	0.21	0.23	0.53	0.45	1.10	
No. Correct Tgt Responses	18.09	1.85	17.91	1.69	17.82	2.26	
No. False Tgt Responses	2.68	4.31	1.45	1.79	1.00	1.45	

The mean number of correct responses and the standard deviations for the various response conditions are listed: correct responses to the presence of a valid task (out of 100), invalid responses to a valid task (out of 100), incorrect responses to a valid task (out of 20), and incorrect responses to a valid task (out of 100).

Table 4Correct response values for the *n-back* task for the road vibration
protocol (seen in Figure 17).

Road Profile Condition	Before		Du	ring	After		
Task parameter	Mean	S.D.	Mean	S.D.	Mean	S.D.	
No. Correct Stim Responses	97.50	1.14	97.50	1.19	97.50	0.96	
No. False Stim Responses	0.14	0.47	0.09	0.43	0.23	0.43	
No. Correct Tgt Responses	17.73	2.29	17.95	2.28	18.09	2.00	
No. False Tgt Responses	2.09	1.77	1.36	2.06	1.14	1.49	

The mean number of correct responses and the standard deviations for the various response conditions are listed: correct responses to the presence of a valid task (out of 100), invalid responses to a valid task (out of 100), incorrect responses to a valid task (out of 20), and incorrect responses to a valid task (out of 100).

3.2.2 Heart rate variability

The results for the heart rate and heart rate variability are detailed in the following graphs (Figures 20, 21, 22, 23).

Figure 20 A plot of the mean heart rates (HR) in beats per minute for all the stages of the 4 Hz vibration condition.



The stages – each of 5 minutes, are indicated along the x-axis of Figure 20, which is also a time measure with the total duration being 30 minutes. The increase in HR which occurs when the participants start the *n*-back task is readily observed for the first two tasks, but less evident between the no-task and task conditions in the last 10-minute period.

Figure 21 Data from Figure 20 were plotted as standard deviations with the mean value of these shown for each condition.



The 'step' nature of the reduction in variation with each cognitive task period is clearly shown in Figure 21. Unlike the situation obtained during the road-vibration protocol, the variation in heart rate during the task stage of the vibration period is marked and the mean value is no less than the other two periods of task performance.





The stages – each of 5 minutes, are indicated along the x-axis, with the total duration being 30 minutes. The increase in HR which occurs when the participants start the *n*-back task is readily observed for the first two tasks, but less evident between the no-task and task conditions in the last 10-minute period.

Figure 23 Data from Figure 22 were plotted as standard deviations with the mean value of these shown for each condition.



The 'step' nature of the reduction in variation with each cognitive task period is clearly shown. The least variation and the lowest mean deviation occurred in the task period during vibration.

3.2.3 EEG activity

The following graphs show some of the large amount of data and comparisons which can be obtained from the EEG recordings in the various conditions.

These are:

No vibration period before

5 minutes of no cognitive task

5 minutes of cognitive task

Vibration period

5 minutes of no cognitive task

5 minutes of cognitive task

No vibration period after

5 minutes of no cognitive task

5 minutes of cognitive task

Further there are the 4 electrode sites used as indicated in the Methods (see Section 2.5), two on each side in front of the head, and two on each side at the back of the head. Lastly we have the frequency domain for EEG which is normally taken to cover the range from nearly 0 Hz to 40 Hz. For reasons associated with the size of the signals, we have concentrated on the lower frequencies and pooled all the frequencies above 15 Hz. These were divided into 8 frequency bins: 1 to 3, 3 to 5, 5 to 7, 7 to 9, 9 to 11, 11 to 13, 13 to 15 and 15+.

The following figures (Figure 24, 25, 26) are examples of the various analyses.

In Figure 24 it is evident that across the various conditions and across the two vibration modes, the standard errors remain relatively consistent suggesting that there is no marked difference in the effects of the two different vibration conditions in the F3 location, even when the cognitive task is being undertaken.

Figure 24. This figure demonstrates the relative power of the spectrum in different frequency bands.



The data were obtained from the F3 (left frontal) electrode while the participants were doing the task (second 5-minutes of the three study periods). The bars are the means of both 4 Hz and road profile values. For each frequency band, the left-hand column shows the mean and standard error for the before vibration condition, the middle column is for the vibration period and the right-hand column is for the post-vibration interval.



Figure 25. This figure compares the road vibration and 4 Hz conditions when the participants were sitting with no task to carry out.

Data were obtained from the posterior electrode on the right side. There are only minor differences between the two vibration conditions. Importantly, there is evidence of an increase in the 03-05 band in the 4 Hz condition. In the equivalent road condition there are increases in the first three bins which include the frequencies inherent in the vibration pattern.



Figure 26. A similar graph of data obtained from the frontal electrode on the left side.

Note the increase in the power in the 03-05 Hz frequency bin for the 4 Hz panel. The road panel, by comparison, shows no great differences in any of the frequency bins which contrasts with the data from the P4 electrode in Figure 25.

The EEG frequency data confirm that 4 Hz induces – either by mechanical means (simply moving the electrode) or by somatosensory means (stimulating our vibration receptors) – a similar frequency power increase in the EEG signal which confirms the results from the previous study. Interestingly there was no comparable increase in any one frequency bin during the more complex road profile vibration period.

4 **DISCUSSION**

4.1 Questionnaire data

The goal of developing the questionnaire was to obtain subjective estimates of the sensations and perceptions of the participants to their initial state and after their period of vibration. The questionnaire specifically requests they report about the vibration 'experience' and so it is assumed that these comments were related to the vibration and not the no-vibration periods. The general close similarity – no mean value differed by more than one rating point – between the responses to all items for the road profile condition and the 4 Hz condition, suggests that the experiences were considered to induce similar feelings and sensations. The main purpose of the participant recording part of the study was to see if there were any marked differences in induced feelings and experiences between the road profile vibration and that produced by a 4 Hz stimulus. The lack of marked differences suggests that the two profiles were – overall – equally effective in inducing changes.

The questionnaire parameters which were most different after the vibration from before were 'tiredness' and 'sleepiness'. The 'after' ratings for these were nearly double the 'pre-test' values. While this is suggestive, it cannot be as reliable a measure of fatigue as more sophisticated tests using complex task paradigms. The reason these were not used in this study is simple: the time available to have the participants in the truck seat doing tests had to be short to avoid the problems of boredom and distraction. The important result from this study was the observed consistency in the ratings for these measures for the road profile vibration and the 4 Hz.

The initial questions were designed to determine, in a simple way, the baseline state of the participants in respect of tiredness, sleep characteristics, sleep satisfaction and proneness to motion sickness. Most of the ratings in response to these questions were between 'not at all' and 'extremely', with the standard deviation generally around 2 rating points. This suggests that the participants were generally similar in their sleep habits and sleep quality, by their estimation. The approach used in this questionnaire is not going to provide detailed information about sleep; that requires much more extensive questioning. The goal was to ensure that the participants represented a population of normal sleepers. While it can be argued that these were predominately young people – average between 21 and 23 years – and that this group is more cavalier in their approach to sleep, the fact that they are 'normal' cannot be ignored or trivialised. In fact, this group may be of more relevance given that they are more represented in the road toll. It would require a much larger study to get different age groups, and a longer time to ensure that all participants attended the test phase only when they had a specific night's sleep.

The questionnaire responses to items designed to probe for various commonly used expressions of energy levels and mood state followed the expected trend for 4 Hz. Almost all of the measures were in line with our previous results where a study on 40 people showed that the constant 4 Hz sine-wave vibration pattern produced significantly increased expressions generally associated with tiredness, but no significant changes to those items not expected to be related to tiredness or fatigue.

As can be seen from Table 1, items such as 'feeling sleepy', 'feeling lively', 'feeling alert' all showed significant differences between the no vibration and vibration conditions for both the road profile data and the 4 Hz data. The only items where there was a discrepancy between the levels of significance between road profile and 4 Hz responses were: 'I feel vigorous' and 'I feel peppy'. Informal observations of the participants suggested that the meanings of these questions were not immediately clear to some people. Except for these items, the questionnaire responses to the energy questions all showed the same trend for the two vibration conditions.

From Table 2, the analysis to responses to mood items also showed a similar trend for 4 Hz to the previous study. With these items there are more issues which might be postulated as being less connected or influenced by fatigue or tiredness. Participant responses to such mood issues as 'annoyed', 'miserable' and 'worried' were expected to be relatively unaffected by the vibration. The items where there were significant differences between pre- and post-vibration values were: 'lively', 'exhausted', 'energetic', 'active' and 'alert'. All of these are strongly connected with the concept of tiredness and fatigue. Examples of cases where the differences were not significant were: 'panicky', 'mixed up', 'annoyed' and 'worried'. Generally there were similar trends for the road profile vibration responses and the 4 Hz vibration responses. As with the energy measures there were some items where there were differences in significance between the two conditions. Three items, 'worn out', 'depressed' and 'nervous', were significantly different in response to 4 Hz but not road profile vibration protocols. By contrast, 'sleepy', 'tired' and 'uncertain' were significantly different for the road profile but not for the 4 Hz conditions. It is particularly interesting that 'sleepy' and 'tired', which are very similar in meaning, were both reported to differ more for the road profile condition. This suggests that the questionnaire is consistent in the nature of the responses and that these items at least are valid.

The results from the questionnaires suggest that the road profile vibration has the same effect on mood and energy as the continuous 4Hz vibration for nearly all the measures used in the study. The data appear internally consistent, except where understanding of the meaning of the question may have confounded the responses. Overall, both forms of vibration increased the reported value of those items which were intended to determine increased feelings of fatigue and tiredness. This part of the study, therefore, had a successful outcome. The major question and problem is the definition and use of the expression 'fatigue'. Whether all of us share an identical understanding of this concept is a key question and so the use of multiple descriptors in the questionnaire is designed to gather as much peripherally associated information as possible. Simply asking if the participant felt fatigued would run the risk of obtaining information with a semantic, or 'knowledge' bias. The observation in this study that items such as 'tiredness', 'difficulty concentrating' and 'boredom' were given higher rating levels than items such as 'confusion', 'anxiety' and 'dizziness' suggests that the consequences of the vibration of both forms are related to items more associated with fatigue and tiredness. It must be noted that the recording arrangement was limited to a sequence in which the vibration was the middle 10 minutes, but, because the questionnaire took some time to complete it prevented this occurring immediately after the vibration. Instead, filling in the questionnaire occurred at the end of the session some 10 minutes after the vibration had ceased. This means that the observations intended to be related to the vibration experience, and which specifically requested these responses, were perhaps affected by the 10 minutes of no-vibration which intervened.

4.2 N-Back Task data

The use of the *n*-back task has a significant confound when used in studies such as these. As a task which demands activity (pushing buttons) and displays a changing visual field., the concern arises from the possibility that the change in activity removes any induced fatigue or boredom and invigorates the participant. This is similar to the recommendation that tired drivers should get out of their car and walk around. If this suggestion is true, then the performance of the participants may be better than would be expected if there was a depression in attention caused by the vibration. Another concern with the task is that it is too easy and does not require elevated attention. If the performance of participants is such that 100% of responses are correct, then the task is likely to be too easy and not readily subject to performance decrement. A more difficult version, such as having three letters to remember, may have been a better approach; however, to maintain comparability with the previous study it was decided not to change this test.

Despite these concerns, there are two sets of results from the *n*-back that can be of value in assessing attention changes: error rate and reaction time. An increase in error rate occurring with the vibration would be suggestive of a decrease in attention. Another measure is that of the response time or reaction time of the participant to the stimulus presentation. There are several alternatives which can occur. A correct response occurs when the participant correctly identifies the current letter as the same as the target and presses the correct button. An incorrect response is recorded if the participant presses the 'yes' button when the current letter is not the same as the target letter, or, the participant presses the 'no' button when the current letter is the same as the target. Additional information is recorded if the participant presses either button too quickly (anticipation) with a reaction time which is too fast to be acceptable. For the purposes of this study the only aspect of significance was the loss of consistency in the pattern of results. The increase in reaction time – longer response time – after the road profile data requires additional investigation. While it is possible that the increased delay was caused by a delayed reaction to the road profile, the confounding effect of the nature of the type of task may have simply caused a wider variation in reaction times. This is supported by the increased variance in the values obtained for this particular condition, exceeding those from any other test point.

4.3 Heart Rate data

Heart rate (HR) is normally a stable physiological parameter which is subject to change as a result of increasing physical activity and, in some situations, emotional stress. It has been suggested that it is not the average heart rate which is of note in emotionally stressful situations. The parameter of interest is the variation in heart rate (HRV).

The results of the analysis of HR and HRV in this study with the two vibration conditions showed that there were no major differences whether it was road profile or 4 Hz. The HR during the notask part of each test period (the first five minutes) was always more variable than the period in which the *n*-back task was being undertaken. The fact that the mean HRV was lowest during the road profile task stage would be suggestive that this was the most 'stressful' condition. The drop in HRV occurring at the onset of each task period is also supportive of the 'added stress' of the task starting. The value of this measure is apparent when it is obvious that the HRV parameters do change, particularly for the last task in the set, when the mean heart rate shows no marked change at all. This suggests that there may be merit in examining the relationship between the difficulty of the task – that is not getting it 100% correct – and the HRV. The *n*-back task may be a good task for these conditions, but only if it is made more demanding, and combined with HRV measures.

The comparison between the 4 Hz and road profile HRV data suggests that there may be a slight difference during vibration between these patterns. While there is a trend, a more extensive analysis would be required to establish if the observed differences were significant. The larger variation about the mean value evident in the 4 Hz vibration condition compared with the more consistent pattern for the road profile may be an artefact of the shaking, but it may also be a physiological consequence of the movement of the chest and heart in a regular fashion altering venous return to the heart.

To conclude, it is clear that the two vibration conditions were not fundamentally different in their affect on HR or HRV, but there are differences. It is also clear that the HR and HRV are not constant as they can be modulated by the stress of doing the cognitive task. It is suggested that of the two profiles, the road profile pattern may have the most impact on underlying 'non-physical stress', although a much larger study on this would be necessary to obtain sufficient data for a relevant analysis to occur.

4.4 EEG frequency data

There was no evidence visible in the EEG frequency data to suggest that the changes in brain activity induced by the stimulus were fundamentally different whether the stimulus was a 4 Hz or road profile vibration. This outcome supports the conclusion that only small differences in responses were induced by the two patterns of vibration. Had one of the analyses of the EEG frequency data produced a totally different result from the other, then the question would have arisen as to the validity of the protocols. It is not expected that a major difference in activity in the brain would be caused by, essentially, the same general stimulus type. The greater part of the brain's activity is handling external and internal parameters and only a proportion would be involved in the response to vibration. Had the responses to each vibration been identical there would also be concern as to the validity of the experiment and the conclusions drawn. The results, however, were essentially the same with sufficient differences to suggest that the actual recordings were in fact directly influenced by the individual nature of the vibrations. It must be remembered that the road profile data included a component of 4 Hz. This would suggest, in turn, that the EEG signal recorded in road profile part of the experiments might be expected to include signals also found in the 4 Hz vibration study. This is the logic in assuming that the responses to the vibrations would contain some similarity in EEG response.

Further analysis of the EEG data, including analysis of the information in the time domain, rather than the frequency domain, is beyond the scope of this study. It is not known whether there may be additional indications of vibration response details beyond those found in the frequency domain. The advantage of the frequency domain is the benefit of treating the whole recording interval and averaging over this period. This ensures that any small responses are not missed. It has the disadvantage of then reducing the magnitude of any responses. Another disadvantage of the frequency domain is that there may be responses which vary progressively throughout the period of study. This may be as a result of the increasing influence of the vibration accumulating with time. Early in the vibration period the influence may be small but rise as the effect compounds. This is only one of many possible outcomes. There is an effective limit to how small a time interval can be used for frequency analysis and so very small time samples are not suitable for frequency domain interpretation. Time domain data – that is the voltage changes which occur continuously – can show rapidly occurring activity changes. Analysis of this is, however, a very time consuming process with no guarantee of success.

4.5 Conclusion

The experimental design and equipment constructed have resulted in an experiment producing data supporting the hypothesis that vibrations produced by road profile acceleration data and 4 Hz sine-wave acceleration data would produce similar reported and recorded effects on participants. The differences observed may be due to variations in the sub-population of participants used for the current project compared to previous studies, or entirely caused by the different nature of the road profile vibration signal.

While it was never expected that the two vibration patterns would result in identical results, the level of overlap is most gratifying. It clearly shows that either vibration pattern is capable of causing trends towards subjective fatigue. That there were differences in detail between the results of the study when 4 Hz was used and those obtained from road profile data, is also encouraging as it indicates that simple vibration does not cause effects coincidently, but that the frequency, and hence the acceleration, component is capable of altering the questionnaire responses, the brain electrical activity responses and the cognitive/short term memory responses in subtle ways.

5 **REFERENCES**

Carlsöö, S. (1982) The effect of vibration on the skeleton, joints and muscles: a review of the literature *Applied Ergonomics*, **13** (4), 251 - 258.

Hassan, R., (2002) Assessment of road roughness effects on heavy vehicles, PhD Thesis submitted in partial fulfilment of the requirements of the degree of Doctor of Philosophy in Civil Engineering, Swinburne University of Technology.

Hassan R. and McManus, K. (2001) Truck Ride Number- A New Management Tool, Proceedings of the 20th ARRB Conference on Managing your Transport Assets, 19-21 March, Melbourne, Australia.

ISO (1997) 'Mechanical vibration and shock Evaluation of human exposure to whole body vibration', Part 1 General requirements, 2nd edition, International Organization for Standardisation.

McLeod, R.W. and Griffin, M.J. (1988) Performance of a complex manual control task during exposure to vertical whole-body vibration between 0.5 and 5.0 Hz *Ergonomics* **31** (8), 1193 – 1203.

Sweatman, P. and McFarlane, S. (2000) Investigation into the Specification of Heavy Trucks and Consequent Effects on Truck Dynamics and Drivers: Final Report, Federal Office of Road Safety, Australia.

APPENDIXES

APPENDIX A: RAW DATA FROM QUESTIONNAIRES

Road Profile Condition

			Pai						
	Energy' Items				95% Co	nfidence			
				Std.	Interva	l of Diff			
Differer	ices between pre- and		Std.	Error					Sig. (2-
post-	vibration measures	Mean	Dev.	Mean	Lower	Upper	t	df	tailed)
Pair 1	I feel sleepy	-2.136	2.145	.457	-3.087	-1.185	-4.672	21	.000*
Pair 2	I feel active	1.500	1.626	.347	.779	2.221	4.328	21	.000*
Pair 3	I feel half asleep	-1.636	3.110	.663	-3.015	258	-2.468	21	.022*
Pair 4	I feel half lively	1.818	1.943	.414	.957	2.680	4.389	21	.000*
Pair 5	My eyes feel heavy	-2.591	2.482	.529	-3.691	-1.491	-4.897	21	.000*
Pair 6	I feel full of pep	1.727	1.486	.317	1.068	2.386	5.452	21	.000*
Pair 7	I feel half awake	952	2.439	.532	-2.062	.158	-1.790	20	.089
Pair 8	I feel energetic	1.682	1.836	.391	.868	2.496	4.297	21	.000*
Pair 9	I feel dead on my feet	-1.591	2.323	.495	-2.621	561	-3.212	21	.004*
Pair 10	I feel vigorous	1.045	2.236	.477	.054	2.037	2.193	21	.040*
Pair 11	I feel bushed	-1.409	2.364	.504	-2.457	361	-2.796	21	.011*
Pair 12	I feel peppy	1.364	1.706	.364	.607	2.120	3.750	21	.001*
Pair 13	I am dozing off	-2.409	3.112	.663	-3.789	-1.030	-3.632	21	.002*
Pair 14	I feel wide awake	2.045	2.786	.594	.810	3.281	3.444	21	.002*
Pair 15	I feel carefree	591	1.403	.299	-1.213	.031	-1.976	21	.061
Pair 16	I feel groggy	-2.409	2.971	.633	-3.726	-1.092	-3.804	21	.001*
Pair 17	I feel alert	2.364	2.128	.454	1.420	3.307	5.210	21	.000*
Pair 18	I feel wakeful	1.864	1.885	.402	1.028	2.699	4.638	21	.000*

* Significant at the p < 0.05 level.

	'Energy' Items				95% Co	nfidence			
			Std.	Std.	Interval of Dif				Sig.
Differe	nces between pre- and		Devia	Error					(2-
post-	vibration measures	Mean	tion	Mean	Lower	Upper	t	df	tailed)
Pair 1	I feel sleepy	-1.636	1.706	.364	-2.393	880	-4.500	21	.000*
Pair 2	I feel active	1.318	1.729	.369	.552	2.085	3.576	21	.002*
Pair 3	I feel half asleep	-1.273	2.313	.493	-2.298	247	-2.581	21	.017*
Pair 4	I feel half lively	1.409	1.681	.358	.664	2.154	3.932	21	.001*
Pair 5	My eyes feel heavy	-1.455	2.738	.584	-2.669	240	-2.492	21	.021*
Pair 6	I feel full of pep	1.000	1.574	.335	.302	1.698	2.981	21	.007*
Pair 7	I feel half awake	455	2.132	.455	-1.400	.491	-1.000	21	.329
Pair 8	I feel energetic	1.136	1.754	.374	.359	1.914	3.039	21	.006*
Pair 9	I feel dead on my feet	-1.524	2.316	.505	-2.578	470	-3.016	20	.007*
Pair 10	I feel vigorous	.545	2.041	.435	359	1.450	1.254	21	.224
Pair 11	I feel bushed	-1.273	1.695	.361	-2.024	521	-3.521	21	.002*
Pair 12	I feel peppy	.636	2.036	.434	267	1.539	1.466	21	.158
Pair 13	I feel I am dozing off	-2.545	2.956	.630	-3.856	-1.235	-4.039	21	.001*
Pair 14	I feel wide awake	1.682	2.009	.428	.791	2.573	3.926	21	.001*
Pair 15	I feel carefree	.591	2.130	.454	354	1.536	1.301	21	.207
Pair 16	I feel groggy	-2.136	2.494	.532	-3.242	-1.031	-4.018	21	.001*
Pair 17	I feel alert	1.364	2.105	.449	.430	2.297	3.038	21	.006*
Pair 18	I feel wakeful	1.227	1.771	.378	.442	2.012	3.250	21	.004*

* Significant at the p < 0.05 level.

			Pa	aired Diffe					
']	Mood' Items				95% Co	95% Confidence			
					Interva	Interval of Diff			
Differe	nces between pre-			Std.					
and	post-vibration		Std.	Error					Sig. (2-
	measures	Mean	Dev.	Mean	Lower	Upper	t	df	tailed)
Pair 1	Panicky	.045	.375	.080	121	.212	.568	21	.576
Pair 2	Lively	1.091	1.065	.227	.619	1.563	4.805	21	.000*
Pair 3	Confused	.182	.588	.125	079	.443	1.449	21	.162
Pair 4	Worn out	409	1.221	.260	951	.132	-1.571	21	.131
Pair 5	Depressed	.227	.528	.113	007	.462	2.017	21	.057
Pair 6	Downhearted	.136	.351	.075	019	.292	1.821	21	.083
Pair 7	Annoyed	.091	.294	.063	040	.221	1.449	21	.162
Pair 8	Exhausted	409	.854	.182	788	030	-2.247	21	.036*
Pair 9	Mixed-up	045	.575	.123	301	.210	370	21	.715
Pair 10	Sleepy	864	1.283	.274	-1.433	295	-3.156	21	.005*
Pair 12	Bitter	.182	.395	.084	.007	.357	2.160	21	.042*
Pair 13	Unhappy	.364	.727	.155	.041	.686	2.347	21	.029*
Pair 14	Anxious	.136	.710	.151	179	.451	.901	21	.378
Pair 15	Worried	.682	.894	.191	.286	1.078	3.578	21	.002*
Pair 16	Energetic	.091	.294	.063	040	.221	1.449	21	.162
Pair 17	Miserable	045	.375	.080	212	.121	568	21	.576
Pair 18	Muddled	.227	.612	.130	044	.499	1.742	21	.096
Pair 19	Angry	.136	.468	.100	071	.344	1.368	21	.186
Pair 20	Active	.909	1.109	.236	.417	1.401	3.846	21	.001*
Pair 21	Tired	818	1.053	.224	-1.285	351	-3.645	21	.002*
Pair 22	Bad tempered	.000	.309	.066	137	.137	.000	21	1.000
Pair 23	Alert	1.136	1.037	.221	.677	1.596	5.139	21	.000*
Pair 24	Uncertain	.136	.710	.151	179	.451	.901	21	.378

* Significant at the p < 0.05 level. <u>Note</u>: Pair 11 not analysed: (quote SPSS) 'The correlation and t cannot be computed because the standard error of the difference is 0'.

			ired Diffe						
	(Mood)				95% Confidence				
	MOOU			Std.	Interva	l of Diff			
Differ	ences between pre-		Std.	Error					Sig. (2-
and pos	t-vibration measures	Mean	Dev.	Mean	Lower	Upper	t	df	tailed)
Pair 1	Panicky	.227	.813	.173	133	.588	1.312	21	.204
Pair 2	Lively	.727	1.120	.239	.230	1.224	3.044	21	.006*
Pair 3	Confused	.000	.436	.093	194	.194	.000	21	1.000
Pair 4	Worn out	727	1.202	.256	-1.260	194	-2.837	21	.010*
Pair 5	Depressed	.182	.395	.084	.007	.357	2.160	21	.042*
Pair 6	Downhearted	.273	.631	.135	007	.553	2.027	21	.056
Pair 7	Annoyed	.091	.526	.112	142	.324	.810	21	.427
Pair 8	Exhausted	714	.845	.184	-1.099	330	-3.873	20	.001*
Pair 9	Mixed-up	136	.468	.100	344	.071	-1.368	21	.186
Pair 10	Sleepy	409	2.343	.500	-1.448	.630	819	21	.422
Pair 11	Bitter	.091	.294	.063	040	.221	1.449	21	.162
Pair 12	Unhappy	.227	.612	.130	044	.499	1.742	21	.096
Pair 13	Anxious	.182	.588	.125	079	.443	1.449	21	.162
Pair 14	Worried	.864	1.125	.240	.365	1.363	3.600	21	.002*
Pair 15	Energetic	.045	.486	.104	170	.261	.439	21	.665
Pair 16	Miserable	045	.575	.123	301	.210	370	21	.715
Pair 17	Muddled	.273	.550	.117	.029	.517	2.324	21	.030*
Pair 18	Angry	.136	.468	.100	071	.344	1.368	21	.186
Pair 19	Active	.682	.839	.179	.310	1.054	3.813	21	.001*
Pair 20	Tired	455	1.335	.285	-1.047	.138	-1.596	21	.125
Pair 21	Bad tempered	.045	.213	.045	049	.140	1.000	21	.329
Pair 22	Alert	.636	1.217	.259	.097	1.176	2.453	21	.023*
Pair 23	Uncertain	045	.653	.139	335	.244	326	21	.747
Pair 24	Panicky	.091	.294	.063	040	.221	1.449	21	.162

* Significant at the *p*<0.05

Road I Tollic Collution	1		1		1	1
Parameter	Ν	Range	Min.	Max.	Mean	Std. Dev.
Vibration Test Condition	22	0	1	1	1.00	.000
Time of Testing	19	14:20	3:45	18:05	12:24	3:40
Subject Gender	21	1	1	2	1.43	.507
Subject Age	21	27	18	45	22.86	7.398
Education Level	21	3	2	5	3.14	1.276
Is Subject Pregnant	21	0	2	2	2.00	.000
History of epileptic seizure	21	0	2	2	2.00	.000
Problems with balance	21	0	2	2	2.00	.000
Any major health problems	21	0	2	2	2.00	.000
Low blood pressure	21	1	1	2	1.95	.218
Feelings of dizziness or faintness	21	1	1	2	1.86	.359
Drivers licence	21	1	1	2	1.24	.436
Number of years driving	17	24.0	1.0	25.0	5.882	6.9788
Fallen asleep at the wheel	19	1	1	2	1.95	.229
Number times fallen asleep	1	0	1	1	1.00	
Truck licence	21	0	2	2	2.00	.000
Number of years truck licence	0					
Suffer from motion sickness	22	7	0	7	2.05	2.886
Enjoyment of amusement ride	22	8	2	10	7.73	2.028
Number of amusement rides	18	50	0	50	8.33	11.762
Sleep History	22	9	0	9	1.14	2.376
Sleep affected by shift work	22	1	1	2	1.86	.351
Avg hours sleep on work day	22	4.0	6.0	10.0	7.523	1.1178
Avg hours sleep on weekend	22	6.5	5.5	12.0	8.886	1.6614
General level of sleep satisfaction	22	9	1	10	6.55	2.345
Bed time for previous night (24 hr)	22	23:30	0:00	23:30	7:20	9:56
Time of getting up on current day (24	22	6:20	6:10	12:30	8:23	1:38
hr)						
Number of hours slept previous night	22	7.0	4.0	11.0	7.470	1.6061
Level of satisfaction with previous	22	7	3	10	6.14	2.336
night sleep						
Number of hours been awake	22	10.0	.5	10.5	4.977	3.0608
Pre test level of sleepiness	22	6	1	7	3.95	1.963
Pre test level of lethargy	22	6	1	7	3.23	1.798
Pre test level of lacking energy	22	7	1	8	3.86	2.007
Pre test level of tiredness	22	6	2	8	4.36	2.105
Pre test level of fatigue	22	7	1	8	3.36	2.013

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Pre-test Energy Level question 1	22	7	1	8	4.14	2.295
Pre-test Energy Level question 2	22	7	1	8	5.82	1.790
Pre-test Energy Level question 3	22	8	1	9	3.36	2.300
Pre-test Energy Level question 4	22	8	1	9	5.68	1.756
Pre-test Energy Level question 5	22	7	1	8	2.82	2.015
Pre-test Energy Level question 6	22	6	2	8	5.32	1.427
Pre-test Energy Level question 7	21	6	1	7	3.76	1.868
Pre-test Energy Level question 8	22	6	2	8	5.68	1.615
Pre-test Energy Level question 9	22	8	1	9	2.18	2.039
Pre-test Energy Level question 10	22	6	1	7	4.91	1.797
Pre-test Energy Level question 11	22	6	1	7	3.50	1.871
Pre-test Energy Level question 12	22	6	1	7	4.91	1.659
Pre-test Energy Level question 13	22	6	1	7	2.91	1.998
Pre-test Energy Level question 14	22	8	1	9	5.45	2.444
Pre-test Energy Level question 15	22	9	1	10	5.95	2.299
Pre-test Energy Level question 16	22	5	1	6	2.41	1.469
Pre-test Energy Level question 17	22	8	1	9	6.09	1.849
Pre-test Energy Level question 18	22	6	3	9	6.09	1.571

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Pre-test Mood Levels question 1	22	1	0	1	.14	.351
Pre-test Mood Levels question 2	22	4	0	4	2.23	1.193
Pre-test Mood Levels question 3	22	2	0	2	.27	.550
Pre-test Mood Levels question 4	22	3	0	3	1.09	1.065
Pre-test Mood Levels question 5	22	3	0	3	.45	.963
Pre-test Mood Levels question 6	22	3	0	3	.45	.800
Pre-test Mood Levels question 7	22	1	0	1	.18	.395
Pre-test Mood Levels question 8	22	3	0	3	.77	.922
Pre-test Mood Levels question 9	22	3	0	3	.23	.752
Pre-test Mood Levels question 10	22	3	0	3	1.23	.869
Pre-test Mood Levels question 11	22	2	0	2	.14	.468
Pre-test Mood Levels question 12	22	4	0	4	.45	.963
Pre-test Mood Levels question 13	22	3	0	3	.41	.734
Pre-test Mood Levels question 14	22	2	0	2	.27	.703
Pre-test Mood Levels question 15	22	3	0	3	1.73	1.032
Pre-test Mood Levels question 16	22	3	0	3	.27	.767
Pre-test Mood Levels question 17	22	2	0	2	.23	.528
Pre-test Mood Levels question 18	22	2	0	2	.32	.646
Pre-test Mood Levels question 19	22	2	0	2	.14	.468
Pre-test Mood Levels question 20	22	3	0	3	1.86	1.037
Pre-test Mood Levels question 21	22	3	0	3	1.27	.883
Pre-test Mood Levels question 22	22	1	0	1	.09	.294
Pre-test Mood Levels question 23	22	3	0	3	2.05	.844
Pre-test Mood Levels question 24	22	2	0	2	.41	.666

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Post-test Energy Level question 1	22	8	2	10	6.27	1.932
Post-test Energy Level question 2	22	7	1	8	4.32	1.862
Post-test Energy Level question 3	22	6	2	8	5.00	1.604
Post-test Energy Level question 4	22	6	1	7	3.86	1.583
Post-test Energy Level question 5	22	7	2	9	5.41	1.681
Post-test Energy Level question 6	22	5	1	6	3.59	1.563
Post-test Energy Level question 7	22	6	2	8	4.68	1.393
Post-test Energy Level question 8	22	6	1	7	4.00	1.512
Post-test Energy Level question 9	22	7	1	8	3.77	1.998
Post-test Energy Level question 10	22	7	1	8	3.86	1.699
Post-test Energy Level question 11	22	7	2	9	4.91	1.849
Post-test Energy Level question 12	22	5	1	6	3.55	1.654
Post-test Energy Level question 13	22	9	1	10	5.32	2.276
Post-test Energy Level question 14	22	7	1	8	3.41	1.894
Post-test Energy Level question 15	22	8	2	10	6.55	2.154
Post-test Energy Level question 16	22	6	2	8	4.82	2.196
Post-test Energy Level question 17	22	7	1	8	3.73	1.804
Post-test Energy Level question 18	22	6	1	7	4.23	1.850

T4	NT	D	M.	М	M	C4.1 D
Item	N	Range	Min.	Max.	Mean	Std. Dev.
Post-test Mood Levels question 1	22	1	0	1	.09	.294
Post-test Mood Levels question 2	22	3	0	3	1.14	.889
Post-test Mood Levels question 3	22	1	0	1	.09	.294
Post-test Mood Levels question 4	22	4	0	4	1.50	1.225
Post-test Mood Levels question 5	22	3	0	3	.23	.752
Post-test Mood Levels question 6	22	3	0	3	.32	.780
Post-test Mood Levels question 7	22	1	0	1	.09	.294
Post-test Mood Levels question 8	22	3	0	3	1.18	1.053
Post-test Mood Levels question 9	22	2	0	2	.27	.631
Post-test Mood Levels question 10	22	4	0	4	2.09	1.151
Post-test Mood Levels question 11	22	2	0	2	.14	.468
Post-test Mood Levels question 12	22	3	0	3	.27	.767
Post-test Mood Levels question 13	22	1	0	1	.05	.213
Post-test Mood Levels question 14	22	1	0	1	.14	.351
Post-test Mood Levels question 15	22	3	0	3	1.05	.899
Post-test Mood Levels question 16	22	3	0	3	.18	.664
Post-test Mood Levels question 17	22	2	0	2	.27	.631
Post-test Mood Levels question 18	22	1	0	1	.09	.294
Post-test Mood Levels question 19	22	0	0	0	.00	.000
Post-test Mood Levels question 20	22	3	0	3	.95	.899
Post-test Mood Levels question 21	22	4	0	4	2.09	1.109
Post-test Mood Levels question 22	22	2	0	2	.09	.426
Post-test Mood Levels question 23	22	2	0	2	.91	.684
Post-test Mood Levels question 24	22	2	0	2	.27	.550

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Experience a sensation of pressure	22	6	1	7	2.09	1.849
Experience a sensation of movement	21	8	1	9	5.14	2.613
Experience a sensation of bouncing	22	7	1	8	5.23	2.069
Experience a sensation of tipping forward	22	5	1	6	1.95	1.647
Experience a sensation of tipping backward	21	5	1	6	1.57	1.207
Experience a sensation of tipping left	21	7	1	8	1.76	1.729
Experience a sensation of tipping right	21	3	1	4	1.43	.978
Experience any effect on your balance sense	22	5	1	6	1.68	1.427
Experience change in sensations over time	22	3	1	4	2.32	.716
Experience feelings of Tiredness	22	7	3	10	6.77	2.159
Experience feelings of Anxiety	22	6	1	7	1.95	1.67
Experience feelings of Physical Heaviness	22	7	1	8	4.23	2.861
Experience feelings of Sleepiness	22	9	1	10	6.27	2.492
Experience feelings of Confusion	22	5	1	6	1.95	1.463
Experience feelings of Depression	22	8	1	9	1.59	1.790
Experience feelings of Difficulty	22	9	1	10	6.41	2.938
Concentrating						
Experience feelings of Lethargy	22	8	1	9	4.86	2.713
Experience feelings of Exhaustion	22	8	1	9	4.45	2.773
Experience feelings of Dizziness	22	6	1	7	1.50	1.336
Experience feelings of Boredom	21	9	1	10	6.42	2.529
Experience feelings of Excitement	22	6	1	7	2.23	1.798
Experience feelings of Relaxation	22	9	1	10	5.68	2.495
How similar the experience was to car	21	8	2	10	5.29	2.125
How similar the experience was to motor	20	9	1	10	3.90	2.553
bike						
How similar the experience was to bike	22	7	1	8	2.45	1.920
How similar the experience was to bus	22	9	1	10	6.50	2.283
How similar the experience was to train	22	7	1	8	4.77	2.308
How similar the experience was to boat	22	6	1	7	2.41	1.894
How similar the experience was to jet	21	6	1	7	2.95	2.376
aircraft						
How similar the experience was to twin	19	8	1	9	3.32	2.335
engine plane						
How similar the experience was to	22	7	1	8	3.41	2.343
amusement rides						
Was experience Tiring	22	8	2	10	6.64	2.258
Was experience Exciting	22	7	1	8	2.86	2.007
Was experience Unpleasant	22	6	1	7	2.18	1.680
Was experience Soothing	22	9	1	10	4.32	2.697
Was experience Uncomfortable	22	5	1	6	2.14	1.699
Was experience Enjoyable	22	8	1	9	3.18	2.281
Was experience Disorienting	22	8	1	9	2.55	2.425
Was experience Relaxing	22	9	1	10	4.86	2.850
Was experience Unsettling	22	4	1	5	1.77	1.152
Was experience Confusing	22	4	1	5	1.64	1.136
Was experience Boring	22	9	1	10	5.91	2.776
Was experience Calming	22	9	1	10	4.55	2.923
Was experience Painful	22	3	1	4	1.32	.716

4 Hz Condition	4 Hz Conditie	on
----------------	---------------	----

Parameter	Ν	Range	Min.	Max.	Mean	Std. Dev.
Vibration Test Condition	22	0	2	2	2.00	.000
Time of Testing	22	9:21	9:00	18:21	13:36	2:46
Subject Gender	22	1	1	2	1.41	.503
Subject Age	22	44	1	45	21.86	8.593
Education Level	22	6	2	8	3.36	1.649
Is Subject Pregnant	22	0	2	2	2.00	.000
History of epileptic seizure	22	0	2	2	2.00	.000
Problems with balance	22	0	2	2	2.00	.000
Any major health problems	22	0	2	2	2.00	.000
Low blood pressure	22	1	1	2	1.95	.213
Feelings of dizziness or faintness	22	1	1	2	1.82	.395
Drivers licence	22	10	1	11	1.68	2.124
Number of years driving	17	24.0	1.0	25.0	5.294	6.7432
Fallen asleep at the wheel	19	1	1	2	1.95	.229
Number times fallen asleep	1	0	1	1	1.00	
Truck licence	22	0	2	2	2.00	.000
Number of years truck licence	0					
Suffer from motion sickness	22	7	0	7	1.77	2.776
Enjoyment of amusement ride	21	9	1	10	7.76	2.256
Number of amusement rides	19	50	0	50	10.95	14.650
Sleep History	22	9	0	9	1.77	3.131
Sleep affected by shift work	21	1	1	2	1.81	.402
Avg hours sleep on work day	22	4.5	5.5	10.0	7.250	1.2607
Avg hours sleep on weekend	22	6.5	5.5	12.0	8.773	1.6310
General level of sleep satisfaction	21	6	2	8	6.33	1.906
Bed time for previous night (24 hr)	22	24:00	0:00	24:00	7:43	9:49
Time of getting up on current day (24	22	5:20	6:25	11:45	8:26	1:36
hr)						
Number of hours slept previous night	22	5.0	4.0	9.0	6.920	1.3303
Level of satisfaction with previous	22	8	2	10	6.07	2.20
night sleep						
Number of hours been awake	22	10.0	1.0	11.0	5.318	3.0911
Pre-test level of sleepiness	22	9	1	10	4.73	2.208
Pre-test level of lethargy	22	7	1	8	3.86	2.031
Pre-test level of lacking energy	22	8	1	9	4.82	2.218
Pre-test level of tiredness	22	8	1	9	4.95	2.171
Pre-test level of fatigue	22	7	1	8	4.00	2.070

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Pre-test Energy Level question 1	22	8	1	9	4.91	2.505
Pre-test Energy Level question 2	22	7	2	9	5.09	1.659
Pre-test Energy Level question 3	22	7	1	8	4.09	2.617
Pre-test Energy Level question 4	22	8	1	9	4.82	2.015
Pre-test Energy Level question 5	22	7	1	8	3.68	2.191
Pre-test Energy Level question 6	22	8	1	9	4.55	2.241
Pre-test Energy Level question 7	22	6	1	7	4.05	1.914
Pre-test Energy Level question 8	22	7	2	9	4.68	2.079
Pre-test Energy Level question 9	21	6	1	7	2.67	2.008
Pre-test Energy Level question 10	22	8	1	9	4.14	2.031
Pre-test Energy Level question 11	22	6	1	7	3.64	1.840
Pre-test Energy Level question 12	22	7	2	9	4.41	2.016
Pre-test Energy Level question 13	22	7	1	8	3.27	2.208
Pre-test Energy Level question 14	22	7	2	9	4.86	2.376
Pre-test Energy Level question 15	22	8	2	10	6.18	2.302
Pre-test Energy Level question 16	22	7	1	8	3.14	2.100
Pre-test Energy Level question 17	22	9	0	9	5.32	2.338
Pre-test Energy Level question 18	22	8	1	9	5.23	2.329

4	Hz	Condition
---	----	-----------

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Pre-test Mood Levels question 1	22	2	0	2	.36	.658
Pre-test Mood Levels question 2	22	3	0	3	1.68	1.086
Pre-test Mood Levels question 3	22	2	0	2	.18	.501
Pre-test Mood Levels question 4	22	3	0	3	1.09	1.109
Pre-test Mood Levels question 5	22	3	0	3	.41	.908
Pre-test Mood Levels question 6	22	3	0	3	.59	.959
Pre-test Mood Levels question 7	22	2	0	2	.23	.528
Pre-test Mood Levels question 8	21	3	0	3	.81	.981
Pre-test Mood Levels question 9	22	3	0	3	.18	.664
Pre-test Mood Levels question 10	22	10	0	10	1.95	2.035
Pre-test Mood Levels question 11	22	2	0	2	.14	.468
Pre-test Mood Levels question 12	22	2	0	2	.32	.646
Pre-test Mood Levels question 13	22	2	0	2	.27	.550
Pre-test Mood Levels question 14	22	2	0	2	.23	.528
Pre-test Mood Levels question 15	22	3	0	3	1.50	1.102
Pre-test Mood Levels question 16	22	2	0	2	.27	.703
Pre-test Mood Levels question 17	22	3	0	3	.32	.716
Pre-test Mood Levels question 18	22	2	0	2	.32	.568
Pre-test Mood Levels question 19	22	2	0	2	.18	.501
Pre-test Mood Levels question 20	22	3	0	3	1.36	1.093
Pre-test Mood Levels question 21	22	4	0	4	1.64	.953
Pre-test Mood Levels question 22	22	1	0	1	.14	.351
Pre-test Mood Levels question 23	22	3	0	3	1.64	.953
Pre-test Mood Levels question 24	22	2	0	2	.32	.568

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Post-test Energy Level question 1	22	8	2	10	6.55	2.087
Post-test Energy Level question 2	22	7	1	8	3.77	1.850
Post-test Energy Level question 3	22	8	1	9	5.36	2.300
Post-test Energy Level question 4	22	6	1	7	3.41	1.501
Post-test Energy Level question 5	22	8	1	9	5.14	2.376
Post-test Energy Level question 6	22	6	1	7	3.55	1.792
Post-test Energy Level question 7	22	6	2	8	4.50	1.504
Post-test Energy Level question 8	22	7	1	8	3.55	1.819
Post-test Energy Level question 9	22	8	1	9	4.09	2.448
Post-test Energy Level question 10	22	7	1	8	3.59	1.563
Post-test Energy Level question 11	22	8	1	9	4.91	1.925
Post-test Energy Level question 12	22	7	1	8	3.77	1.771
Post-test Energy Level question 13	22	9	1	10	5.82	2.648
Post-test Energy Level question 14	22	6	1	7	3.18	1.532
Post-test Energy Level question 15	22	9	1	10	5.59	2.482
Post-test Energy Level question 16	22	8	1	9	5.27	2.272
Post-test Energy Level question 17	22	7	1	8	3.95	1.731
Post-test Energy Level question 18	22	7	1	8	4.00	1.718

Item	Ν	Range	Min.	Max.	Mean	Std. Dev.
Post-test Mood Levels question 1	22	2	0	2	.14	.468
Post-test Mood Levels question 2	22	3	0	3	.95	.844
Post-test Mood Levels question 3	22	1	0	1	.18	.395
Post-test Mood Levels question 4	22	4	0	4	1.82	1.181
Post-test Mood Levels question 5	22	3	0	3	.23	.752
Post-test Mood Levels question 6	22	2	0	2	.32	.646
Post-test Mood Levels question 7	22	1	0	1	.14	.351
Post-test Mood Levels question 8	22	4	0	4	1.50	1.144
Post-test Mood Levels question 9	22	2	0	2	.32	.568
Post-test Mood Levels question 10	22	3	1	4	2.36	1.002
Post-test Mood Levels question 11	22	1	0	1	.05	.213
Post-test Mood Levels question 12	22	2	0	2	.23	.612
Post-test Mood Levels question 13	22	1	0	1	.05	.213
Post-test Mood Levels question 14	22	1	0	1	.05	.213
Post-test Mood Levels question 15	22	3	0	3	.64	.953
Post-test Mood Levels question 16	22	3	0	3	.23	.752
Post-test Mood Levels question 17	22	1	0	1	.36	.492
Post-test Mood Levels question 18	22	1	0	1	.05	.213
Post-test Mood Levels question 19	22	1	0	1	.05	.213
Post-test Mood Levels question 20	22	2	0	2	.68	.780
Post-test Mood Levels question 21	22	4	0	4	2.09	1.151
Post-test Mood Levels question 22	22	1	0	1	.09	.294
Post-test Mood Levels question 23	22	3	0	3	1.00	.926
Post-test Mood Levels question 24	22	3	0	3	.36	.790

						Std.
Item	Ν	Range	Min.	Max.	Mean	Dev.
Experience a sensation of pressure	21	6	1	7	2.76	2.211
Experience a sensation of movement	22	8	1	9	4.95	2.716
Experience a sensation of bouncing	21	9	1	10	6.14	2.197
Experience a sensation of tipping forward	21	7	1	8	2.95	2.334
Experience a sensation of tipping backward	21	3	1	4	1.52	.814
Experience a sensation of tipping left	21	3	1	4	1.43	.811
Experience any change in your balance	21	6	1	7	1.86	1.797
sense						
Experience a sensation of tipping right	21	6	1	7	2.10	1.670
Experience change in sensations over time	21	2	1	3	2.14	.573
Experience feelings of Tiredness	22	8	2	10	7.05	2.081
Experience feelings of Anxiety	22	5	1	6	2.18	1.868
Experience feelings of Physical Heaviness	22	8	1	9	4.73	2.763
Experience feelings of Sleepiness	22	8	2	10	7.18	1.893
Experience feelings of Confusion	22	6	1	7	2.27	1.907
Experience feelings of Depression	22	7	1	8	1.50	1.504
Experience feelings of Difficulty	22	8	1	9	6.41	2.085
Concentrating						
Experience feelings of Lethargy	22	8	1	9	4.91	2.635
Experience feelings of Exhaustion	22	8	1	9	4.68	2.358
Experience feelings of Dizziness	22	6	1	7	1.82	1.651
Experience feelings of Boredom	22	9	1	10	6.50	2.632
Experience feelings of Excitement	22	6	1	7	2.23	1.688
Experience feelings of Relaxation	22	9	1	10	5.14	2.731
How similar the experience was to car	22	8	1	9	4.23	2.617
How similar the experience was to motor	21	9	1	10	3.52	2.750
bike						
How similar the experience was to bike	22	6	1	7	1.77	1.541
How similar the experience was to bus	22	9	1	10	5.77	2.159
How similar the experience was to train	22	9	1	10	4.95	2.554
How similar the experience was to boat	22	5	1	6	2.55	1.654
How similar the experience was to jet	21	6	1	7	2.81	1.990
aircraft						
How similar the experience was to twin	20	6	1	7	3.20	1.881
engine plane		-		-	2.1.0	
How similar the experience was to	21	8	I	9	3.10	2.364
amusement rides	22	0	1	10	6.50	2 405
Was experience Tiring	22	9	1	10	6.50	2.405
Was experience Exciting	22	- 7	1	8	2.73	1.882
Was experience Unpleasant	22	5	1	6	1.95	1.647
Was experience Soothing	22	9	1	10	4.36	2.953
Was experience Uncomfortable	22	6	1	1	2.14	1.754
Was experience Enjoyable	22	8	1	9	3.09	2.114
Was experience Disorienting	22	8	1	9	2.32	2.255
Was experience Relaxing	22	9		10	4.77	2.724
Was experience Unsettling	22	5		6	2.00	1.574
Was experience Confusing	22	3		4	1.86	1.037
Was experience Boring	22	9	1	10	5.45	2.790
Was experience Calming	22	9		10	4.73	2.831
Was experience Painful	22	5		6	1.36	1.136

APPENDIX B: QUESTIONNAIRE

The questionnaire used in the study is shown on the succeeding pages. This was specifically developed for research into the effects of vibration on fatigue by Dr. Julie Pallant.



Pre-exposure questionnaire

Today's date:	Current time:
Demographics	Highest education level achieved:
Gender: Male Female	 Some secondary school Completed secondary school
Age:	 Additional trade training Undergraduate University Postgraduate University

Exclusion criteria	
Are you pregnant (or is there a chance that you are pregnant)?	Have you ever been diagnosed with any major health problems (eg. cancer, heart disease, stroke)?
□ Yes □ No	🗆 Yes 🗖 No
Have you ever experienced an epileptic seizure?	Do you have low blood pressure?
🗆 Yes 🗖 No	□ Yes □ No
Do you currently have any problems with your sense of balance?	Do you ever feel dizzy or faint?
	□ Yes □ No
□ Yes □ No	

Driving experience

Instrumentation to acquire road profile data for use in whole body vibration apparatus 51

Do you have a driver's licence?	Do you have a truck driving licence?
□ Yes □ No	🗆 Yes 🗖 No
If yes:	If yes, how many years of truck driving experience have you had?
How many years of driving experience have you had?	
Have you ever fallen asleep while driving?	
□ Yes □ No If Yes, how many times	

Motion experience Do you suffer motion or travel sickness as a passenger in any of the following? (please tick any that apply)	Do you enjoy amusement park rides (eg. rollercoaster):
	not at all 1 2 3 4 5 6 7 8 9 10 very much
□ Car	
□ Motorbike	In the last 2 years how many amusement park rides have you been on?
□ Bus	
Plane	
Boat	
Amusement park rides	

Sleep History	
Do you suffer from any of the following sleep problems? (please tick any that apply):	Is your sleep adversely affected by shift work:
Difficulty getting to sleep	□ Yes □ No
Difficulty staying asleep	On an average work day how many hours
Restless sleep	sleep do you normally get:
Disturbed sleep (noisy environment)	
Loud snoring	On an average weekend or holiday how many hours sleep do you normally get:
Sleep apnea (stop breathing during sleep)	
Narcolepsy (sudden uncontrollable sleep)	
Other:	Overall how satisfied are you with the amount of sleep that you generally get?
<u> </u>	very 1 2 3 4 5 6 7 8 9 10 very dissatisfied satisfied

Current state What time did you go to sleep last night:	Please rate how you feel at the moment on the following scales:
What time did you wake up this morning:	Sleepy not at all 1 2 3 4 5 6 7 8 9 10 extremely
How many hours sleep did you get last night?	Lethargic not at all 1 2 3 4 5 6 7 8 9 10 extremely
Overall how satisfied are you with the amount of sleep that you had last night?	Lacking energy not at all 1 2 3 4 5 6 7 8 9 10 extremely
very 1 2 3 4 5 6 7 8 9 10 very dissatisfied satisfied	Tired not at all 1 2 3 4 5 6 7 8 9 10 extremely
How many hours have you been awake: 	Fatigued not at all 1 2 3 4 5 6 7 8 9 10 extremely

Current energy level

Please rate how you feel <u>now</u> by writing a number from 1 (not at all) to 10 (extremely) on the line next to each of the statements provided below.

not at all 1 2 3 4 5 6 7 8 9 10 extremely



Current Mood

Below is a list of words that describe feelings people have. Please read each one carefully. Then circle ONE answer which best describes how you feel right now.

Not at all o	A little	2	Moderately 2	<i>Quite a bit</i>	Extremely
	,		Z		7
1. Panicky	0 1 2 3 4	9. Mixed-up	0 1 2 3 4	17. Muddled	0 1 2 3 4
2. Lively	0 1 2 3 4	10. Sleepy	0 1 2 3 4	18. Nervous	0 1 2 3 4
3. Confused	0 1 2 3 4	11. Bitter	0 1 2 3 4	19. Angry	0 1 2 3 4
4. Worn out	01234	12. Unhappy	01234	20. Active	01234
5. Depressed	01234	13. Anxious	01234	21. Tired	01234
6. Downhearted	01234	14. Worried	01234	22. Bad tempered	01234
7. Annoyed	01234	15. Energetic	01234	23. Alert	01234
8. Exhausted	0 1 2 3 4	16. Miserable	0 1 2 3 4	24. Uncertain	01234

Post-exposure questionnaire

Instructions

While seated on the vibrating chair people experience different sensations. We are interested in finding out what it was like for you. Please answer the following questions concerning how you feel now and the sensations and perceptions you experienced while seated on the chair.

Current energy

Please rate how you feel <u>now</u> by writing a number from 1 (not at all) to 10 (extremely) on the line next to each of the statements provided below.

not at all 1 2 3 4 5 6 7 8 9 10 extremely



Current Mood

Below is a list of words that describe feelings people have. Please read each one carefully. Then circle ONE answer which best describes how you feel right now.

Not at all 0	A little 1)	Moderately 2	<i>Quite a</i> 3	bit	Extremely 4
1. Panicky	0 1 2 3 4	9. Mixed-up	0 1 2 3 4	17	7. Muddled	0 1 2 3 4
2. Lively	0 1 2 3 4	10. Sleepy	0 1 2 3 4	18	3. Nervous	0 1 2 3 4
3. Confused	0 1 2 3 4	11. Bitter	0 1 2 3 4	19	9. Angry	0 1 2 3 4
4. Worn out	0 1 2 3 4	12. Unhappy	0 1 2 3 4	20). Active	0 1 2 3 4
5. Depressed	0 1 2 3 4	13. Anxious	0 1 2 3 4	21	I. Tired	0 1 2 3 4
6. Downhearted	0 1 2 3 4	14. Worried	0 1 2 3 4	22	2. Bad tempered	0 1 2 3 4
7. Annoyed	0 1 2 3 4	15. Energetic	0 1 2 3 4	23	3. Alert	0 1 2 3 4
8. Exhausted	0 1 2 3 4	16. Miserable	0 1 2 3 4	24	1. Uncertain	0 1 2 3 4

Please describe your sensations and perceptions while on the vibrating chair:

Sensations													
While sitting on the chair did you experience a sensation of pressure? not at all 1 2 3 4 5 6 7 8 9 10 extremely													
If yes, where did you experience this feeling?													
Did you experience a feeling of movement? not at all 1 2 3 4 5 6 7 8 9 10 extremely													
If yes, please describe:													
Did you experience a consistion of bouncing? not at all 1 2 2 4 5 4 7 0 0 10 outcomely													
Did you experience a sensation of <u>bouncing</u>	1 : <i>not at an</i>	1	Z	5	4	5	0	/	0	7	10	слистнету	
Did you experience a sensation of <u>tipping</u> :	forward	not	at a	// 	1	2	3	4	5	6	78	9 10 ex	tremely
backward not at all 1 2 3 4 5 6 7 8 9 10 extremely											tremely		
	left	not	at a	// 	1	2	3	4	5	6	/ 8	9 10 ex	tremely
	right	not	at a	//	7	2	3	4	5	6	/ 8	9 10 ex	tremely
Did you experience any effect on your sens	e of balance	?	2	3	4	5	6	7	8	9	10	extremely	
During the time you were sitting on the chair did you experience:													
 An increase in sensation over time A decrease in sensation over time No change in sensation No sensation at all 													
		5 01	•			_		_		_			
Tiredness	not at all	1	2	3	4	5	6	7	8	9	10	extremely	
Anxiety	not at all	1	2	3	4	5	6	7	8	9	10	extremely	
Physical heaviness	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Sleepiness	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Confusion	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Depression	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Lethargy	not at all	1	2	3	4	5	6	/	8	9	10	exiremely	
Exnaustion	not at all	1	2	3	4	5	6	/	8	9	10	exiremely	
Dizziness	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Boredom	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Excitement	not at all	1	2	3	4	5	6	/	8	9	10	extremely	
Relaxation	not at all	1	2	3	4	5	6	7	8	9	10	extremely	

Comparison with past experiences

Please rate how similar the experience was to:													
Travelling in car	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
Riding on a motor bike	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
Riding a bike	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
Travelling in a bus	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
	not at all	1	2	3	4	5	6	7	8	9	10 very similar		
I ravelling in a boat	not at all	1	2	3	4	5	6	7	8	9	10 verv similar		
Large commercial jet aircraft	not at all	1	2	3	Δ	5	6	7	8	9	10 verv similar		
Small single or twin engine plane	not at all	1	2	2		5	4	, 7	0	, 0	10 vory similar		
Amusement park ride	nui di dii	1	Ζ	3	4	9	0	/	0	7	iu very siitiidi		

Evaluation of experience

Please rate your experience on the following dimensions:

Tiring	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Exciting	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Unpleasant	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Soothing	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Uncomfortable	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Enjoyable	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Disorienting	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Relaxing	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Unsettling	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Confusing	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Boring	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Calming	not at all	1	2	3	4	5	6	7	8	9	10 extremely
Painful	not at all	1	2	3	4	5	6	7	8	9	10 extremely

Location of sensation

On the diagram below please indicate (with small crosses) regions of your body where you experienced any physical sensation during the vibration.

