The Influence of Vibrations on Vehicle Occupant Fatigue

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ABSTRACT

The attempts to summarize the knowledge about the human body's response to vibration, merely by introducing a physical or empirical model do not reflect a modern understanding of the effects of vibration on body comfort or fatigue. Several studies have demonstrated that fatigue leads to impairment of the ability to perform tasks. Although the performance of vehicle drivers under fatigue conditions has been investigated in many types of environments, there is insufficient research about the effects of vibration on levels of mental alertness in seated drivers. The formulation of drowsiness caused by vibration in the vehicle is complex due to several confounding factors such as vehicle interior noise and traffic control. However, understanding the effects of only vibration on drowsiness can provide significant knowledge to predict and prevent the vehicle occupant (driver) drowsiness. Hence, we investigated the relationship between whole body vibration and human drowsiness. A human vibration test setup was designed for this study. Three conditions were selected for these studies which are no-vibration condition, low frequency sinusoidal vibration and low frequency random vibration. For vibration condition, volunteers were exposed to multi-axial vibration at a frequency between 1- 15 Hz with the transmitted vibration at 0.3 m/s^2 rms for 20 minutes. Changes in drowsiness level during vibration exposure were measured by recording brainwave activities along the scalp. Two brainwave spectrums (Beta wave and Theta wave) were considered for analysis. Exposure to vibration was found to be correlated with a reduction in alertness. Combined decrease in beta wave and increase in theta wave activity caused by vibrations were found to be statistically significant in sinusoidal and random vibration ($p < 0.05$). However, the effect of sinusoidal vibration is more pronounced compared to random vibration.

1. INTRODUCTION

Driver fatigue is a significant cause of accidents on motorways or major roadways. Studies illustrate that around one-quarter of serious motorway accidents are attributable to sleepy drivers in need of a rest, meaning that drowsiness causes more road accidents than drunk driving. The fatigue caused by extended hours of driving has considerable influences on driver alertness and performance, therefore, can compromise transportation safety. However, fatigue caused by vibration is not well investigated or reported in the available literature. The relationship between vibration magnitude and vibration frequency of vehicle occupant and fatigue has been established without sufficient research. This is because fatigue is a complex phenomenon, and there is little quantitative data exist. Whole body vibration has been found to correlate with a range of physiological reactions of the human body such as lower back pain and heart rate variability (HRV) [7, 13]. Disturbance of vision and balance have also been reported to occur during low-frequency exposure [6]. Vibration may also affect muscle and neurological functions, by acting as a stressor [2, 14].

In Automotive industry, vehicle’s seat structure is exposed to vibration from various sources such as vehicle powertrain and road surface. Fundamental vibration modes (resonant frequency and correspondence mode shapes) of automotive body which can transmit vibration to the seat structure occur at frequency below 60 Hz [16]. However, the fundamental resonance of the human body occurs at frequency below 15 Hz [6]. Vibration transmitted to the seated human body contributes significantly towards human perception and ride comfort quality [1, 3, 5, 8, 9]. Following that, ISO 2631-1 International Standard for evaluation of human exposure to whole-body vibration has been developed. Although this International Standard (ISO 2631) has been developed for the assessment of human discomfort which is called ‘Equivalent Comfort Contour, however, there is little quantitative knowledge on how vibration causes fatigue. In the past, fatigue research was directed at what was deemed to be the most relevant factor influencing driver fatigue namely the length of driving hours. For example, Australian legislated driving hours for truck drivers are partly based upon the assumption that driving in excess of 12 hours may lead to fatigue-related crashes. Regulations in other countries are generally based on the same assumption [11, 12].

Hence, there is considerable scope for defining the exact effects of vehicle, and particularly seat vibration on driver fatigue. In addition, no particular attempt has yet been made specifically to rank the contributors to driver fatigue in their order of importance. Therefore, the study will focus on drowsiness as one of the main criteria of fatigue. Drowsiness or sleepiness is a transitory period between awake and sleep. Various studies have suggested that drowsy driving affects the ability to drive safely. According to the literature, drowsiness or a state of near-sleep can be quantified in many ways. One of the most and reliable methods is by measuring brainwave activity as detected by electroencephalography (EEG) signals [15]. EEG is widely accepted as a valid indicator of drowsiness detection. EEG measures the potential difference of brainwave activity in the microvolt range by using electrodes placed on the scalp. The brainwave activities are classified according to their rhythm and frequency range, which are Beta (14 – 20 Hz), Alpha (8 – 13), Theta (4 – 7) and Delta (0.5 – 4 Hz) [4]. Beta wave is associated with the state of alertness and wakefulness whereas theta wave is associated with the state of drowsiness [15]. Moreover, Alpha wave is associated with the relaxed condition but conscious, and Delta wave is associated with deep sleep condition [4]. The experiment setup is purposely designed to investigate the relationship between the whole body vibration and seated human drowsiness level. The outcome from this investigation is believed to provide quantitative data with implications for the effort to improve overall driving performance.

2. METHODS

2.1 Subjects

Ten male university students with a mean age 23.0 ± 1.3 years participated as volunteer subjects. They were 168.2 ± 4.0 cm and weighed 64.2 ± 12.2 kg. They had normal hearing and normal or corrected-to-normal vision. Each participant must meet all the pre-screening criteria: no medical or history of back pain condition or neck injury, and not using any medications or drugs. All participants were refrained from taking any medicine or caffeine before the experiment. They were also instructed to have sufficient sleep the day before the experiment

2.2 Ethical Consideration

The subjects were provided with verbal and written explanations on the purpose and contents of the experiment. They were also informed that they have right to refuse participation in the experiment, and the results of the experiment would remain confidential. Following this, informed written consent form was obtained from all the participants after the procedure of the experiment was explained, and the laboratory facilities were introduced to them. The vibration exposure was set at a level that did not affect the health according to ISO 2631-1 standard [19]. The procedures used were approved by the RMIT University Human Research Ethics Committee (Approval Number: EC 00237).

2.3 Apparatus

Motion-based vibration simulator was developed for this experiment. The seat used for the experiments is a mid-sized sedan car seat. The seat is mounted on a table, and the table is mounted on four-air mountings. The vibration table was designed to be dynamically rigid at frequency below 200 Hz. This is to ensure that there is no interaction with seat structural dynamics. The excitation input for the table was provided by the hydraulic actuator that was placed at the corner of the table. The off-centre excitation provides the input power in different orientations to capture all available seat vibration modes and corresponding resonant frequencies. It also generates typical vibrations that are usually generated on the vehicle seat mountings (Fig.1).

Figure 1 – This Motion-based vibration simulator was developed for the human drowsiness assessment. Actual vehicle seat was mounted on a vibration table. The hydraulic actuator was located off-centre of the table to provide multi-axial input

2.4 Experimental Procedures

The experiment was conducted between 9.00 am to 12.00 pm, the period of the day associated with the peak in circadian-based sleepiness. The experiment was divided into three conditions (no-vibration condition, random vibration condition and sinusoidal vibration condition) and performed in separate days. The room temperature and noise level were kept at a level that was comfortable for the subject. Informed consent was obtained prior to subject participation. The experiment lasted roughly 30 minutes with 20 minutes of vibration exposure. Subject was asked to take a seat and assume a comfortable position. They were asked to sit comfortably with their back on the backrest and hands on their lap. A cross sign was placed on the wall in front of the volunteer at eye level. Subject was also instructed to limit any physical movement. Two vibration inputs (Gaussian random and Sweep sine) with the frequency range of 1 – 15 Hz were used for the experiment. Vibration acceleration to the human body was kept constant at 0.3 m/s^2 rms. EEG electrodes were carefully placed onto subjects scalp. Satisfactory contact between electrodes and the scalp was indicated by the green light (Fig.2).

2.5 EEG Recording

Emotive EPOC 14-channel wireless Neuro-headset (Emotive Systems, Inc., San Francisco) was selected for EEG recording. The electrode placement was arranged according to the international 10–20 system and referenced to the common mode sense (CMS-left mastoid) driven right leg (DRL-right mastoid) ground (Fig.2). The recorded signals were digitized using the embedded 16-bit ADC with 128 Hz sampling frequency per channel and sent to the computer through wireless technology. To ensure a satisfactory contact between sensors and scalp, all felt pads on top of the sensors have to be moistened with a saline solution. Impedance of contact was kept below 5 KΩ. EEG signals were recorded two minutes before vibration, 20 minutes during vibration and two minutes after vibration.

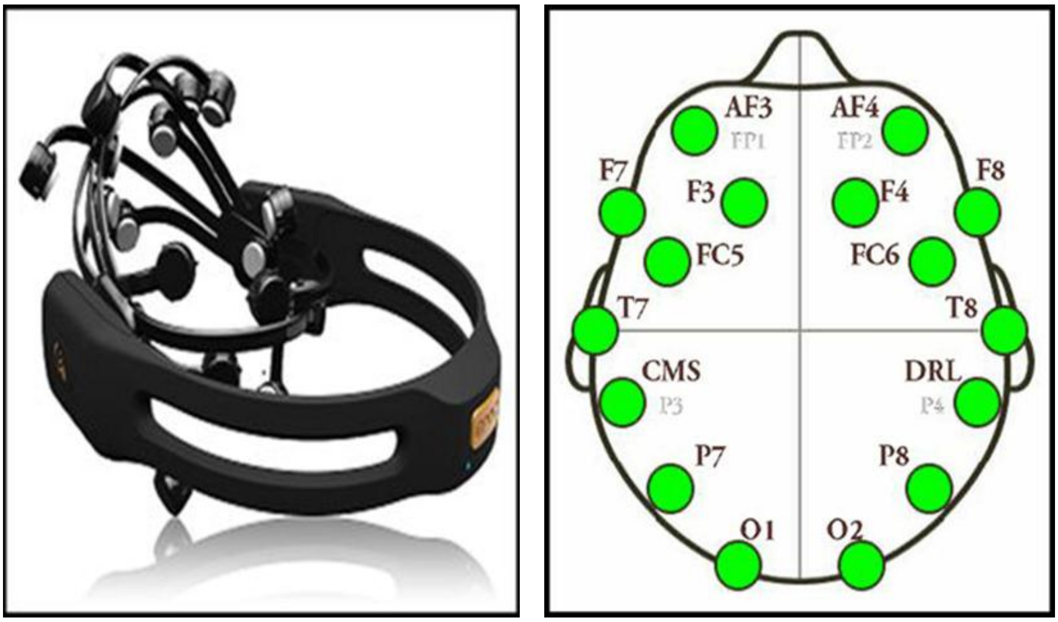
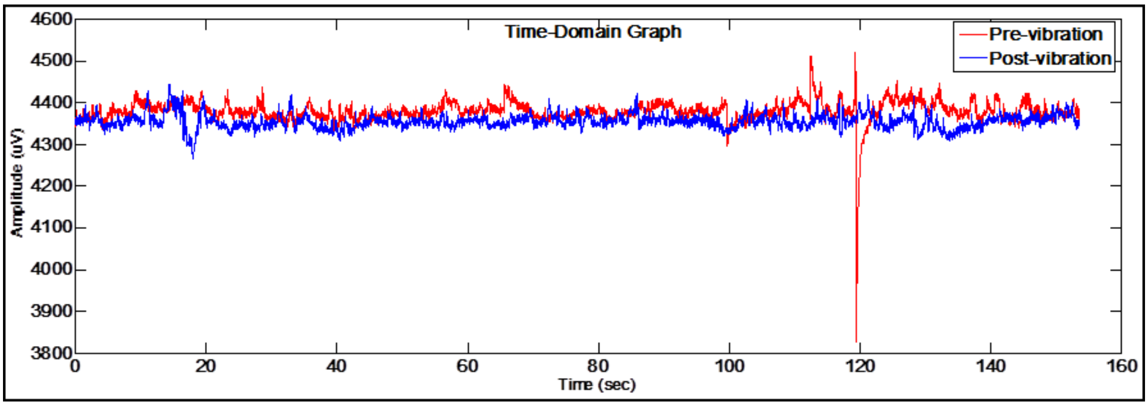


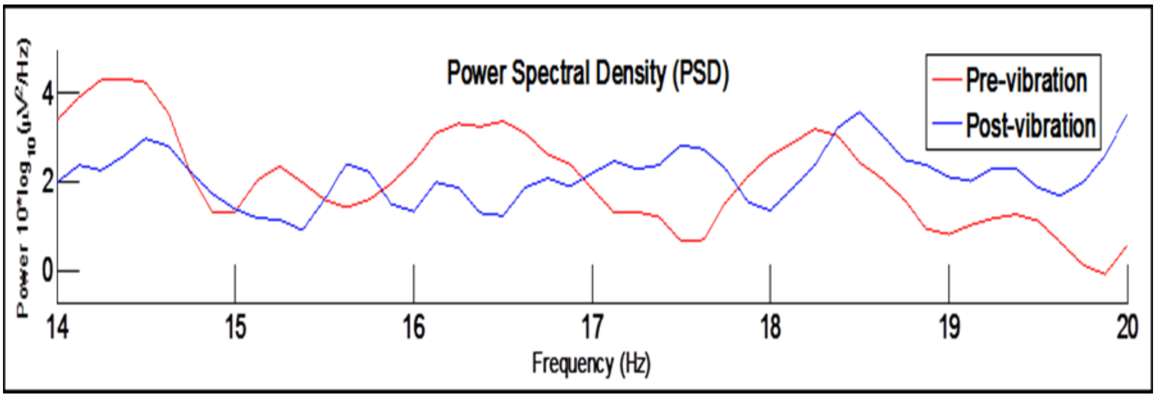
Figure 2 – This EEG headset and different electrode placement on the scalp were shown in this figure. The location is divided into four segments which are frontal, temporal, parietal and occipital. Satisfactory contact between skin and electrode was indicated by green colour

2.6 EEG Analysis

To investigate the influence of vibration on human drowsiness, EEG analysis was performed offline in the EEGLAB software (version 9.B). Raw EEG data was band-pass filtered between 0.5 to 30 Hz. The band pass filter was a type 1 Chebyshev filter with order 2. For 50-Hz noise removal, notch filter was used. In this investigation, the EEG signals were segmented into ten seconds epoch and subject to visual inspection for noise removal. Contamination of EEG activity by the eye blinking, muscle activity and pulse is a serious problem for EEG interpretation. Therefore, neural logarithmic called Independent Component Analysis (ICA) was introduced to remove the unwanted artefacts. Finally, artefacts-free signals were subjected to beta and theta wave frequencies for further analysis. The frequency domain analysis was performed using the Fast Fourier Transform (FFT) algorithm to calculate the absolute ($\mu V^2/Hz$) power density, relative (%) power density and mean frequency (Hz) within each of the sub-bands. Absolute power was log transformed in order to normalise the distribution of data (Fig.3). All statistical analysis were performed using the SPSS version 20.0 (SPSS Inc., Chicago, IL). The obtained results were considered as significant at the level of $p < 0.05$.



(a)



(b)

Figure 3 – Measured EEG signals were shown in this figure. Fig.3 (a) shows the measured brainwave signals at F3 location before and after vibration condition. Fig.3 (b) shows the frequency domain analysis in beta rhythm frequency for F3 location.

2.7 Signal Processing

The Fourier spectra of the measured signals can be derived from the time-domain data by the use of Fast Fourier Transform method (FFT). Since, the measured time-domain signals have contaminating noise, the Fourier spectra of the signals may also be corrupted by noise. The measured signals in the frequency domain can be written as

$$X_m(\omega_K) = X(\omega_K) + M(\omega_K) \tag{1}$$

$$Y_m(\omega_K) = Y(\omega_K) + N(\omega_K) \tag{2}$$

Where $X_m(\omega_K)$ and $Y_m(\omega_K)$ are the measured Fourier spectra of the input and output signal at selected angular frequency (k = 1,., F), respectively. The terms X (ω_K) and Y (ω_K) are the true values of the input and output spectra, and M (ω_K) and N (ω_K) are the noise on the spectra of the input and output signal, respectively. It is proven in [17] that the noise on the FFT coefficients tends to be uncorrelated and normally distributed with zero mean value when the number of time samples increases. The frequency response function (nonparametric form of the transfer function) of the system H (ω_K), at angular frequencies, can be derived from experimental data, by using the cross-spectral density function method [18].

$$H(\omega_K) = \frac{G_{x_m y_m}(\omega_K)}{G_{x_m x_m}(\omega_K)} \tag{3}$$

Where $G_{x_m y_m}(\omega_K)$ is cross spectrum of the measured input and the output at angular frequencies (ω_K), and $G_{x_m x_m}(\omega_K)$ is auto spectrum of the measured input.

3. RESULTS

3.1 Beta Activity

The results are illustrated in Fig.4. The relative wavelet energy or event-related spectral power for the Beta brainwave activity (14 – 20 Hz) was calculated from the F3 and F4 location. Beta wave is associated with the wakeful state of alertness, active and anxiety. A Decrease in beta activity indicates reduction in wakefulness. The value given in Fig.4 represents mean values of three conditions (no vibration, exposure to random vibration, exposure to sinusoidal vibration) after 20-minutes. The input vibration levels for both random and sinusoidal conditions were adjusted to be equal. The value of 100 was scaled to indicate the drowsiness baseline. In other words, the obtained mean value lower than 100 indicates a decrease in alertness.

As shown in Fig.4, the exposure to random and sinusoidal vibration was correlated with a decrease in beta activity. The decrease was statistically significant ($p < 0.05$). The effect of exposure to sinusoidal vibration is larger compared to the exposure to random vibration. Harmonic characteristic of sinusoidal vibration was found to have substantial influence on drowsiness level. However, in no vibration condition, the mean value shows an increase in beta activity. It demonstrates that the subject was in the state of alertness even after 20-minutes of sitting without any input of vibration. These provide evidence that the reduction in beta wave activity was correlated with vibration specifically in sinusoidal vibration. Figure 6 shows an example of brain topography indicates the beta activity of the subjects before and after vibration exposure. Higher activity is indicated by red-shaded areas whereas low activity is indicated by blue-shaded areas. A decrease in beta wave activity in the frontal area was observed in random and sinusoidal vibration. However, a larger decrease in activity was seen in sinusoidal vibration.

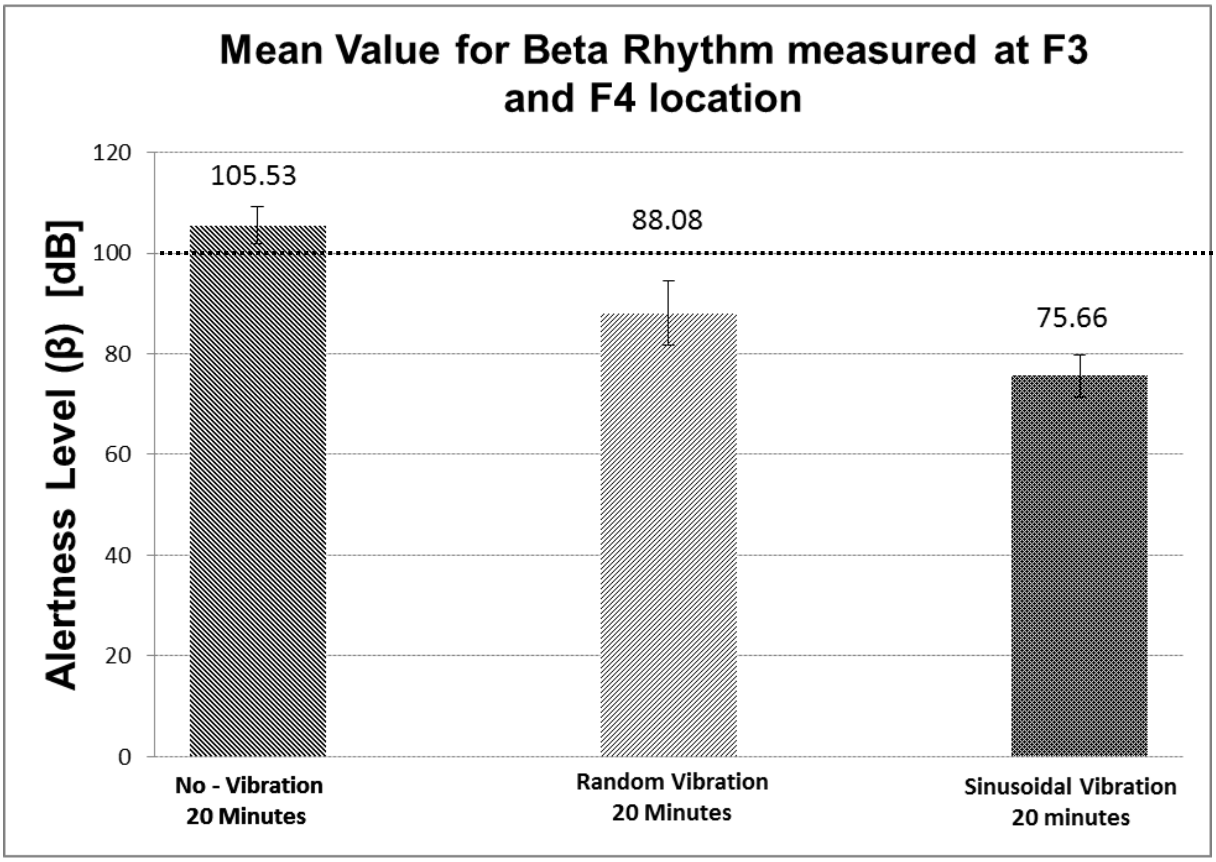


Figure 4 – Average values of Beta Rhythm brainwave Power Spectrum for "No-Vibration condition," "Random Vibration condition", and "Sinusoidal Vibration condition" measured at F3 and F4 locations of the scalp. The "No-Vibration condition" represents the measurement taken after 20 Minutes of sitting on the seat without any input vibration. The "Random Vibration" condition represents the measurement taken after 20 minutes of exposure to a random vibration. The "Sinusoidal

Vibration" condition represents the measurement taken after 20 minutes of exposure to a sinusoidal vibration. The input vibration levels for both random and sinusoidal conditions were adjusted to be equal. Level of 100 indicates alertness level baseline before 20 minutes.

3.2 Theta Activity

The results for theta wave activity are illustrated in Fig.5. The average value for theta brainwave activity (4 -7 Hz) was also calculated from AF3 and AF4 location for three different conditions (no vibration, exposure to random vibration, exposure to sinusoidal vibration) after 20-minutes. The input vibration levels for both random and sinusoidal conditions were adjusted to be equal. A baseline of 100 was scaled to indicate the level of drowsiness. Recent studies demonstrated that an increase in theta activity can be linked to drowsiness. It can be clearly observed from the figure that the exposure to random and sinusoidal vibration have a substantial increase of drowsiness level as compared to no vibration condition. However, in no vibration condition, the average value calculated was close to the score of 100. This result demonstrates that, there is no substantial difference in level of alertness before and after 20 minutes of sitting was observed.

The increase in theta activity was found to be statistically significant ($p < 0.05$). The P-value is given in Table 1. The average value for theta activity in sinusoidal vibration was found to have higher value compared to random vibration. The corresponding value obtained shows that the sinusoidal vibration has a larger influence on human drowsiness level. The brain topography image of theta activity in both sinusoidal and random vibration is shown in Fig.6. It can be concluded that reduction in wakefulness level is indicated by combined decrease in beta activity and increase in theta activity, and the effect is less pronounced in random vibration as compared to sinusoidal vibration.

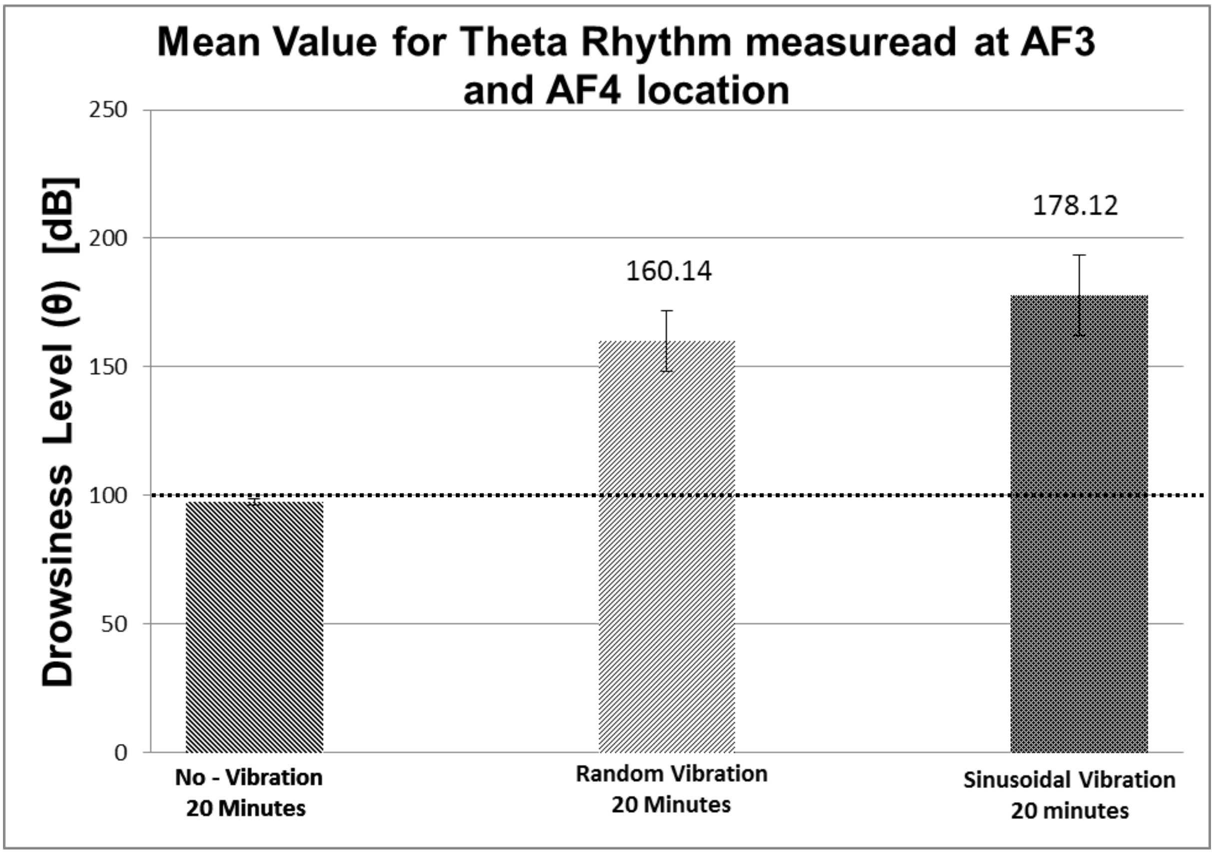


Figure 5 – Average values of Theta Rhythm brainwave Power Spectrum for "No-Vibration condition," "Random Vibration condition", and "Sinusoidal Vibration condition" measured at AF3 and AF4 locations of the scalp. The "No-Vibration condition" represents the measurement taken after 20 Minutes of sitting on the seat without any input vibration. The "Random Vibration" condition represents the measurement taken after 20 minutes of exposure to a random vibration. The "Sinusoidal

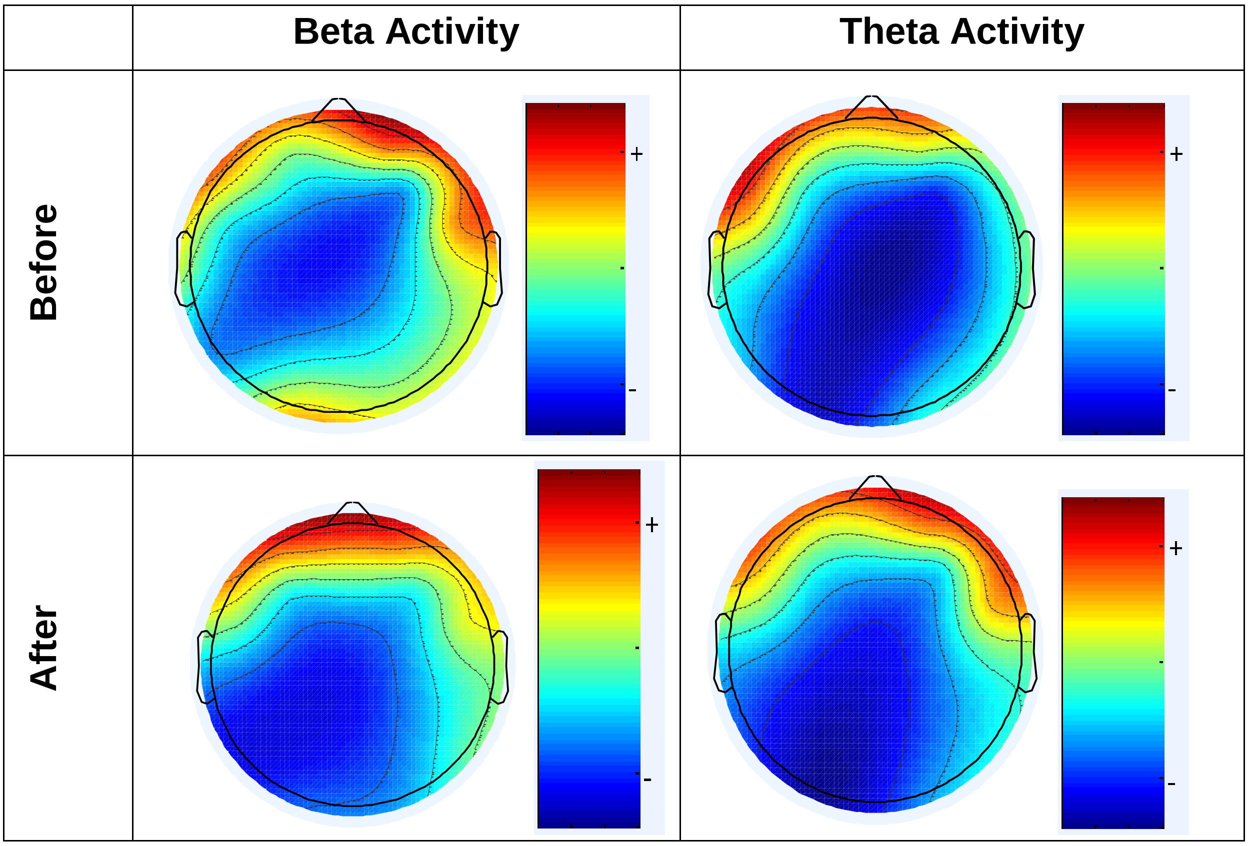
Vibration" condition represents the measurement taken after 20 minutes of exposure to a sinusoidal vibration. The input vibration levels for both random and sinusoidal conditions were adjusted to be equal. Level of 100 indicates drowsiness level baseline before 20 minutes.

Table 1 – Physical Statistical analysis was carried out. P-Value for vibrations condition were found to be statistically significant. ($P < 0.05$). It indicates vibration causes drowsiness. Moreover, in no vibration condition P-value was 0.045 for theta activity and 0.203 for beta activity.

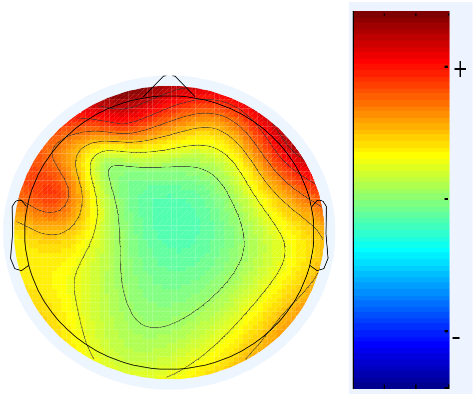
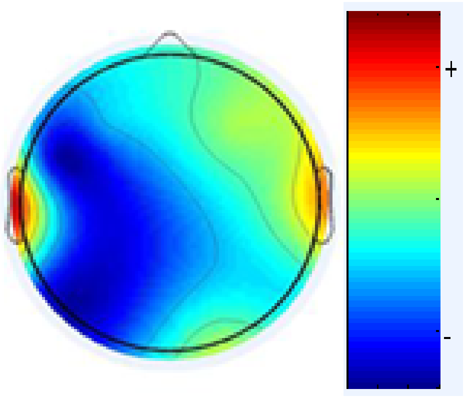
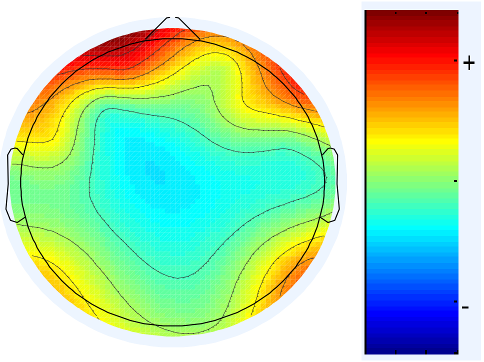
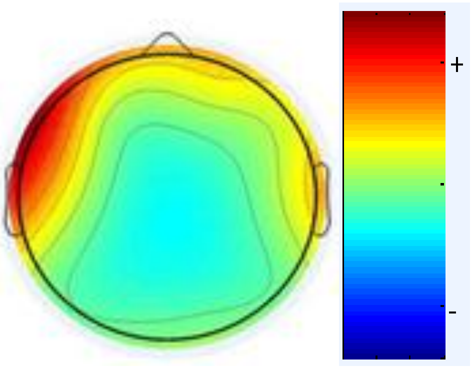
	Without Vibration After 20 minutes	With Vibration After 20 minutes	
		Random	Sinusoidal
Beta (β)	0.203	0.011*	0.008*
Theta (θ)	0.045*	0.004*	0.011*

Significance level *$P < 0.05$

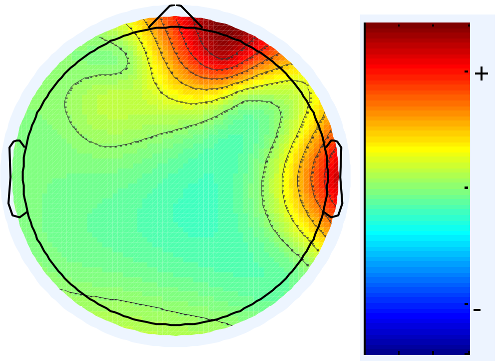
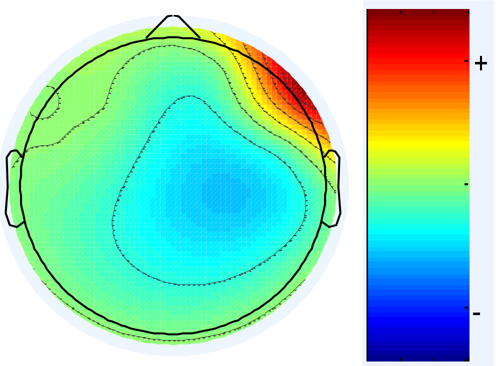
(A) No-Vibration Condition

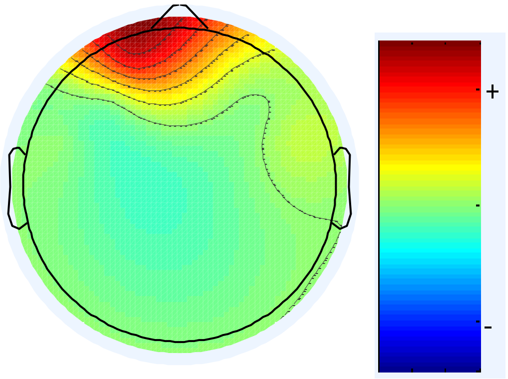
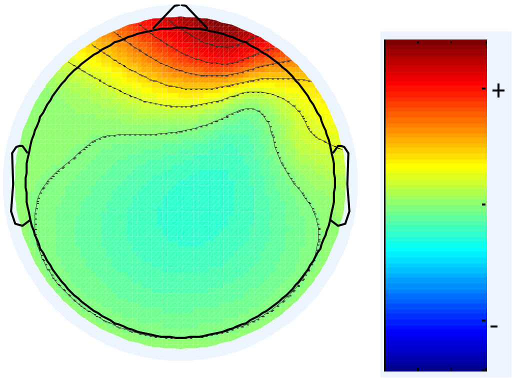


(B) Sinusoidal Vibration Condition

	Beta Activity	Theta Activity
Before Vibration		
After Vibration		

(C) Random Vibration Condition

	Beta Activity	Theta Activity
Before Vibration		

After Vibration		

4. DISCUSSION

Impaired alertness, as a result of driver drowsiness has been one of the primary causes of road accidents. However, drowsiness caused by vibration is not well investigated or understood. The present study attempts to fill the gap in the literature on human drowsiness and whole body vibration, as defining drowsiness caused by vibration is essential for decreasing fatigue-related accidents. The results obtained support the hypothesis that the low-frequency vibration may induce drowsiness and caused reduction in alertness. Comparison between random excitation and sinusoidal excitation has shown that the drowsiness effect being less pronounced during random excitation condition. This indicates that the sinusoidal excitation has greater influence on seated human drowsiness level. It should be noted that, the exposure to vibration stimuli can activate the large number of sensory receptors of the human body. The sensory receptors will convert the vibration sensation into electrical impulses and send to the brain for information processing. The brain then will determine the subjective response to the stimuli and conducts impulses back to the other part of the body. More activation of brain occurs in the case of varying stimuli to the different receptors of the human body e.g. during random vibration. However, less sensory stimulation will occur during harmonics characteristic and monotonous stimulation such as exposure to sinusoidal vibration. Therefore, a decrease in wakefulness level in sinusoidal vibration is more prominent. The finding is consistent with the previous study conducted by Landstrom (1985) [10].

Human sensitivity and response to external vibration are difficult to quantify. The sensation of the human body to a different form of vibration is described in terms of discomfort or unpleasantness. However, different individuals perceive vibration differently. Therefore, quantification of brainwave activity is believed to be a reliable indicator to predict seated human fatigue and drowsiness. The effects of vibration on the levels of alertness on the seated human were able to be detected by our proposed EEG methods. The results show a reduction in beta brainwave activity and increase in theta brainwave activity after as little as 20 minutes of vibration exposure.

5. CONCLUSIONS

Influences of vibrations to the seated human drowsiness have not been well discussed in ISO 2631-1 International Standard. This is because drowsiness caused by vibration is a complex phenomenon. The results of this research demonstrate that the vibration has significance influences on seated human alertness level. The effects of vibration on drowsiness are measured using EEG method. For all ten subjects, the power spectrum at frontal cortex (F3, F4, AF3, and AF4) showed statistically significant differences before and after vibration ($p < 0.05$). It was found that measured beta brainwave activity which indicates alertness level decreased in both random and sinusoidal excitation. However, the drowsiness effect in sinusoidal vibration was more pronounced compared to random vibration condition. Measurement results of the theta brainwave activity which indicates drowsiness level also showed similar results. The increase of theta wave activity shows the reduction in wakefulness level and the effect is less pronounced in random vibration. The results of this study will help to predict and characterize the seated human drowsiness level in response to vibration.

REFERENCES

[1] Baik S., Lee J., Suh J. (2003), A study on the characteristics of Vibration in Seat System." SAE Paper 2003-01-1603

[2] Berthoz A., Wisner (1972), A Striated and smooth-muscle activity during low-frequency vibration in Human Response to Vibration Conference, University of Sheffield, 1972

[3] Donati P., Grosjean A., Mistrot P., Roure L. (1983), The subjective equivalence of sinusoidal and random whole-body vibration in the sitting position (an experimental study using the 'floating reference vibration' method), Ergonomics, 26, 251–273

[4] Dussault C., Jouanin J-C., Guezennec C-Y. (2004), EEG and ECG changes during selected flight sequences. Aviation, space, and environmental medicine, 75(10):889–97

[5] Griffin M.J. (1976), Subjective equivalence of sinusoidal and random whole-body vibration, J. Acoust. Soc. Amer., 60, 1140– 1145

[6] Griffin M.J. (1990), Handbook of human vibration. London: Academic Press

[7] Helmkamp J.C., Talbott E.O., Marsh G.M. (1984), Whole Body Vibration-a critical review. Amer. Ind. Hyg. Ass J., 45:162–167

[8] Kim K.S., Kim J., Kim K.J., Dynamic modelling of seated human body based on measurements of apparent inertia matrix for fore-and-aft/vertical/pitch motion. Journal of Sound and Vibration, 330, 5716–5735

[9] Kitazaki S., Griffin M.J. (1997), A modal analysis of whole-body vertical vibration, using a finite element model of the human body. Journal of Sound and Vibration, 200, 83–103

[10] Landstrom, U., and Lundstrom, R. (1985). Changes in wakefulness during exposure to whole-body vibration. Electroencephalogry Clin Neurophysiol 61, 411-415.

[11] Lisper H.O., Laurell H., Van Loon (1986), Relation between time to falling asleep behind the wheel on closed track and changes in subsidiary reaction time during prolonged driving on a motorway.Ergonomics,29(3): 445-45

[12] Mackie R.R., Miller J.C. (1978), Effects of hours of service, regularity of schedules and cargo loading on truck and bus driver fatigue. US Department of Transport Report HS 803 799

[13] Tanaka M., Shigihara Y., Ishii A., et al. (2012), Effect of mental fatigue on the central nervous system: an electroencephalography study. Behavioural and brain functions. BBF., 8:48

[14] Wilder D.G., Woodworth B.B., Frymoyer J.W., Pope M.H. (1982), 60 Vibration and human spine. Spine, 7:243–254

[15] Zhao C., Zhao M., Liu J., Zheng C. (2012), Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator. Accident; analysis and prevention; 45:83-90

[16] Lo L., Fard M., Subic A., Jazar R. (2012), Structural dynamic characterization of a vehicle seat coupled with human occupant. Journal of Sound and Vibration, 1–12

[17] Schoukens J., Renneboog J. (1986), Modelling the noise influence on the Fourier coefficients after a discrete Fourier transform, IEEE Transactions on Instrumentation and Measurement, 35(3):278–286

[18] Bendat J.S., Piersol A.G. (1980), Engineering applications of correlation and spectral analysis, Johan Wiley & Son

[19] International Organization for Standardization, (1997), Mechanical vibration and shock – evaluation of human exposure – to whole-body vibration. Part 1: general requirements. International Standard, ISO 2631-1, Second edition 1997-05-01