# Effect Of Vibration On Occupant Driving Performances: Measured By Simulated Driving

Amzar Azizan, Ratchaphon Ittianuwat

**Abstract**: Although the performance of vehicle driver has been well investigated in many types of environments, however, drowsy driving caused by vibration has received far less attention. Experiment procedures comprised of two 10-minutes simulated driving sessions in no-vibration condition and with-vibration condition. In with-vibration condition, volunteers were exposed to a Gaussian random vibration, with 1-15 Hz frequency bandwidth at 0.2 $ms^{-2}$ r.m.s. for 30-minutes. A deviation in lane position and vehicle speed were recorded and analyzed. Volunteers have also rated their subjective drowsiness by giving score using Karolinska Sleepiness Scale (KSS) every 5-minutes interval. Strong evidence of driving impairment following 30-minutes exposure to vibration were found significant in all volunteers ($p < 0.05$).

**Index Terms**: human vibration, drowsiness, sleepiness, lane deviation, speed deviation

## 1 INTRODUCTION

THIS Drowsy driving is a significant cause of accidents on motorways or major roadways. Drowsy driving has been reported to account for approximately 20% of accidents worldwide [1]. In Australia, there were 251 fatalities (16.6% of total road deaths) caused explicitly by sleep-related accidents in 1998 alone [2]. In addition to that, a new EU regulation about sleepiness in driving with a focus on sleep apnoea patients has been issued. Drivers or driving license applicants with moderate and severe obstructive sleep apnoea shall be referred for further medical advice before a driving license is granted or renewed [3]. This suggests that the effect of drowsy/sleepy driving is comparable to drink driving. Although some research has demonstrated there is a possible link between short-term exposure to vibration and reduction of wakefulness level [4], [5], however, drowsiness caused by vibration is not well investigated and characterized in the available literature. Hence, automotive industry standards to limit vibration-induced drowsiness do not as yet exist. It is well established, the drowsiness caused by alcohol influenced, monotonous driving and night driving have considerable influences on driver alertness and performance, therefore, can compromise transportation safety [6]–[9]. However, the formulation of drowsiness caused by exposure to vibration is not well defined. The relationship between vibration amplitude and vibration frequency of vehicle occupant and drowsiness has been assumed without sufficient research. This is because drowsiness is a multifactorial phenomenon, and there is little quantitative data exist. 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 [10], [11]. Vibration may also affect muscle and neurological functions, by acting as a stressor [12], [13].


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In the Automotive industry, vehicle 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 the automotive body which can transmit vibration to the seat structure occur at a frequency below 60 Hz [14]. However, the fundamental resonance of the human body occurs at a frequency below 15 Hz [15]. It is well known that transmitted vibration to the seated human body has a significant influence on human perception and ride comfort [15]–[17]. ISO 2631-1 (1997) [18] International Standard for evaluation of human exposure to whole-body vibration has been used successfully for several years. Although this International Standard (ISO 2631-1) has been developed for the assessment of human body discomfort that is called "Equivalent Comfort Contour", however, there is no "Equivalent Drowsiness Contour" available. Hence, there is considerable scope for defining the exact effects of vehicle and particularly seat vibration on driver drowsiness levels. No particular attempt has yet been made to rank the factors that contribute to driver drowsiness in their order of importance. Therefore, we focused on drowsiness caused by vibration only. Drowsiness or sleepiness is an intermediate state between being awake and asleep [19]. Various studies have suggested that drowsy driving affects the ability to drive safely [20]. According to several prior investigations on drowsiness and vehicle control, there is a close relationship between drowsiness and lane position variability. Lane position variability is calculated as a standard deviation of the average lateral position. Lane position variability also corresponds to the amount of weaving in the car and increment of lane variability may ultimately result in the lane crossing into the road shoulder and adjacent traffic lane. Therefore, the primary dependent variables for this investigation were volunteers' lane position variability measured from simulated driving vehicle and speed variability (standard deviation of average vehicle speed). Although many studies have attempted to demonstrate the links between driving performance and drowsiness, drowsiness caused by vehicle vibration has not been experimentally assessed by simulated driving. Therefore, it was also important to investigate the feasibility and utility of simulated driving in the detection of drowsiness caused by vibration. Hence, it was the primary aim of this study to investigate the effects of vibration on human drowsiness level using both objective (Simulated Driving Test) and subjective (Karolinska Sleepiness Scale) measurement methods.

## 2 METHODOLOGY

### 2.1 Volunteer

Detailed volunteers demographic were recorded at enrolment. Twenty young male (n = 20) participated in this investigation with a mean age 23.0 ± 1.3. They were randomly selected from university students. They had no history of low back pain (LBP) and normal or corrected-to-normal vision. They were 168.2 ± 4.0 cm and weighed 64.2 ± 12.2 kg. The average BMI of participants was 22.6 ± 2.54 kg/m². All volunteers were screened using Pittsburgh Sleep Quality Index (PSQI) to measure the sleep quality [21]. Volunteers who showed poor sleep quality index (PSQI > 5) were excluded from the investigation.

### 2.2 Ethical Consideration

Before the investigation, volunteers were provided with verbal and written explanations of 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, the informed written consent form was obtained from all the volunteers after the procedure of the experiment was explained, and the laboratory facilities were introduced to them. The experimental protocol was reviewed and approved by the RMIT University Human Research Ethics Committee (Approval Number: EC 00237)

### 2.3 Experiment Setup

The experiment setup for drowsiness assessment is illustrated in Figure 1. The seat used for the experiments is a mid-sized sedan car seat with adjustable headrest. The seat was mounted on a cast aluminium table (2 m x 1.2 m x 1.2 m), and the table was mounted on four air mountings (regulated to 20 psi). The seat's inclination angle was set at 15° to the vertical direction. The excitation input force for the table was provided by the servo-controlled hydraulic actuator (5 kN) that was placed vertically at the corner of the table. The off-center excitation will provide multi-axial input power in different orientations. It also generates typical vibration that is usually generated on the vehicle seat mountings. The vibration table below the seat was designed to be dynamically rigid in frequencies below 100 Hz. This is to ensure that there is no interaction with vehicle seat structural dynamics. Prior to drowsiness measurement, measurement of total transmitted vibration to each volunteer has been done in accordance with ISO 2631-1 (1997). The measurement was carried out to adjust the required hydraulic input force for every volunteer to become 0.2 $ms^{-2}$ r.m.s. Two tri-axial accelerometer pads (SVANTEK SV-38V model) were used to measure the transmitted vibration to the human volunteer body at the seat cushion and the seatback [22]. The SV 106 Human Vibration Exposure (HVE) meter (analyser), which was connected to the accelerometer pads, was used to obtain the total frequency weighted transmitted vibration to the seated human body. The HVE analyser uses the weighting factors (Wk, Wd, Wc) and multiplication factors to calculate the total frequency-weighted transmitted vibration to the seated human body. The weighting curves (Wk, Wd, Wc) were from ISO 2631-1 (1997) [18]. The frequency weighting curves define the values by which the vibration magnitude at each specific frequency is to be multiplied in order to weight the measured vibration in accordance with the human body [15]. The multiplication factors were used to weight the effects of seatback and seat pan vibrations on the ride comfort assessment [15], [18], [22].

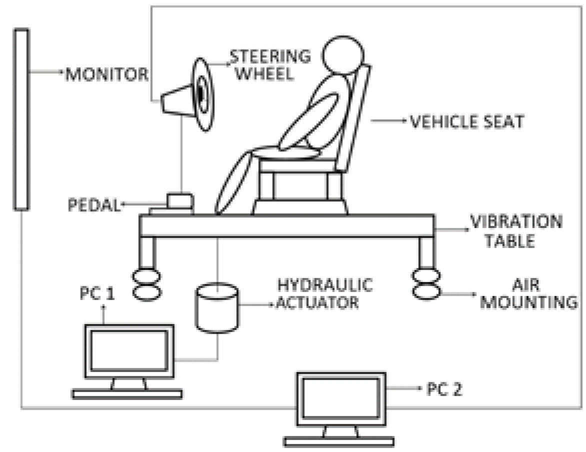


***Fig.1.*** *A driving simulator was designed for this study. An actual vehicle's seat was mounted on a vibration table. A hydraulic actuator located at the corner of the table will provide multi-axial input to the volunteer. A simulator also consists of personal computer, a 40-inch monitor and peripheral steering wheel, accelerator, and brake accessories.*

### 2.4 Objective Measure

Volunteers were tested on the York driving simulator software (York Computer Technologies, Kingston, Ontario, Canada) as shown in Figure I. The simulator has been determined to be an ecologically valid research tool to measure psychomotor performance related to driving [23], [24]. The simulator assembly consists of a personal computer, a 40-inch monitor and peripheral steering wheel, accelerator and brake accessories. A customized driving scenario was developed in which volunteers were presented with a forward view from the driver's seat. The driving simulation showed a cross-country highway, with two lanes in each direction. The two main instruction for volunteers are:

1. Maintain a steady position within the left traffic lane during the entire test.
2. Maintain a constant speed (usually 100 km/hour).

Outcome variables measured by the simulator included (a) deviation from the center of lane position (SDLP) and (b) deviation from the posted speed limit and the variation in these two outcome measures shows how well the volunteers able to conduct the test according to this instruction.

### 2.5 Subjective Measure

Subjective drowsiness level was assessed using Karolinska Sleepiness Scale (KSS). At every 5-minutes interval during the simulated driving task, volunteers were prompted by the word "KSS" by the investigator to provide subjective rating score according to scales visible at all times next to the monitor screen: The use of the scale had been practice beforehand, and consist of the following scores: 1 = extremely alert, 2 = very alert, 3 = alert, 4 = rather alert, 5 = neither alert or sleepy, 6 = some sign of sleepiness, 7 = sleepy, but no effort to stay awake, 8 = sleepy, some effort to stay awake, 9 = very sleepy, great effort to stay awake [25].

### 2.6 Experiment Procedures

Prior to the experiment, all volunteers were screened using Epworth Sleepiness Scale (ESS) to detect any abnormalities in sleep. Score > 10 will indicate excessive daytime sleepiness and were excluded from the experiment. Volunteers performed two separate test conditions [baseline (no-vibration) and with-vibration] in the controlled human vibration laboratory in a randomized cross-over design, one week apart. To minimize the learning effect, volunteers underwent a 10-minute practice session before baseline and with-vibration conditions to familiarize themselves with the simulator interface. All volunteers were assessed at approximately the same time of day. During with-vibration condition, volunteers were asked to drive for 10-minutes with no vibration followed by 30-minutes sitting with exposure to vibration. Volunteers were exposed to a Gaussian random vibration, with 1-15 Hz frequency bandwidth. Total transmitted acceleration to the human body was kept constant at 0.2 $ms^{-2}$ r.m.s. Volunteers rated their subjective sleepiness scale using KSS before vibration exposure, every 5-minutes of vibration and after vibration exposure [26]. The rating was initiated by the test leader saying “KSS”. Immediately after 30-minutes sitting, volunteers were required to drive for another 10-minutes. Similar procedures and sitting arrangement as in with-vibration condition with the only difference being no vibration exposure were applied for 30-minutes sitting. The total duration of each condition (no-vibration and with-vibration) is 50-minutes.

## 3 RESULTS

### 3.1 Objective Measures

A total of 20 volunteers completed the investigation. No volunteers reported simulator sickness. There was no significant difference in alertness level measured by Epworth Sleepiness Scale (ESS) between baseline (no-vibration) and with-vibration condition. Driving performance indexes and subjective sleepiness scale (KSS) in no-vibration and with-vibration condition are presented here. The following two driving performance indexes were assessed and included in the analyses: (1) standard deviation of lane position or lane variability (SDLP), (2) speed deviation from the posted speed limit. The following observations were made in conjunction with this analysis. Results of standard deviation of lane position (SDLP) are presented in Table 1. The repeated-measures procedures revealed a significant difference between group variations. As compared with the baseline condition (no-vibration) driving performance index between before exposure and after exposure to vibration showed that 30-minutes exposure to vibration had significant influences on volunteer lane keeping performance. We found that following 30-minutes exposure to vibration, the deviation from a lateral position or lane variability was significantly increased by 2.6 cm ($p < 0.01$) indicates poor lane control by all twenty volunteers. The analysis of lane position variability showed difficulties in maintaining the vehicle in the middle of the left-hand lane when alertness was lowest after exposure to vibration. Better lane control was observed in the baseline condition (no-vibration) where lane position variability was reduced by 0.7 cm. It indicates a little improvement of driving performance after 30-minutes sitting. A significant increase in standard deviation demonstrates the inability of the volunteers to maintain a steady position caused by drowsiness-inducing vibration. The secondary outcome index measured in this study was speed deviation. Speed deviation is calculated as the mean sum of the differences of the speed of the vehicle from the posted speed limit. Table I shows the average speed deviation measured for all volunteers in no-vibration and with-vibration condition. Although there was a slight increase of speed deviation following the exposure to 30-minutes vibration (6.28 ± 1.37 kph) and 30-minutes sitting (5.58 ± 0.85 kph), however, speed deviation failed to exhibit any statistically significant variation within and between groups ($p > 0.05$). Speed deviation did not show significant diurnal variation as compared to lane variability. As expected, speed deviation was considerably less sensitive outcome index that can reflex the low level of alertness caused by vibration.

***TABLE 1***

*THE SIGNIFICANT INCREASE OF LANE POSITION VARIABILITY (SDLP) (P < 0.05) WAS OBSERVED IN VIBRATION CONDITION. NO SIGNIFICANT CHANGES (P > 0.05) IN SPEED DEVIATION WERE OBSERVED IN BOTH CONDITIONS (BASELINE AND WITH VIBRATION) FOLLOWING 30-MINUTES EXPOSURE TO VIBRATION AND SITTING.*

| | Baseline | | With-Vibration | |
|---|---|---|---|---|
| Driving Index | Before | After | Before | After |
| SDLP (cm) | 23.5 | 22.8 | 23.6 | 26.2 |
| Speed Deviation (kph) | 4.68 | 5.58 | 5.30 | 6.28 |

### 3.2 Subjective Measures

Results of the subjective sleepiness (KSS) for all volunteers in both conditions (no-vibration and with-vibration) were recorded against time and were shown in Table 2. As illustrated here, initial KSS values did not differ between both conditions ($p > 0.05$). Significant increases in KSS score between before vibration exposure and every subsequent 5-minutes of exposure to vibration were detected using repeated measures-ANOVA test ($p < 0.01$) for all twenty volunteers. As can be seen in Table II, there is a clear decline in alertness level indicated by a progressive increase in subjective sleepiness score throughout the course of exposure to vibration. Before the experiment, the average KSS score was 2.11 ± 0.13 in with-vibration condition and 2.16 ± 0.19 in no-vibration condition. After 5-minutes of vibration exposure, KSS scores increased to 4.37 ± 0.31. Drowsiness was pronounced following 15-minutes exposure to vibration with KSS values of 6.11 ± 0.32 whereas KSS values of 4.84 ± 0.32 were observed in no-vibration condition. After 30-minutes, KSS score was significantly higher for all conditions and increased more significantly with exposure to vibration than without vibration ($p < 0.01$). To investigate the statistical significance, two-way repeated measures-ANOVA was carried out. It was found out that intra-individual and inter-individual differences in all twenty volunteers were highly significant ($p < 0.001$).

***TABLE 2***

*THE TABLE SHOWS AN AVERAGE SCORE OF SUBJECTIVE SLEEPINESS SCALE (KSS) FOR TWENTY VOLUNTEERS FOR SEVEN INTERVAL SESSION IN NO-VIBRATION COMPARED TO WITH-VIBRATION CONDITION. BEFORE THE EXPERIMENT, NO SIGNIFICANT CHANGES WERE OBSERVED FOR BOTH CONDITIONS (P > 0.05). HOWEVER, THE SUBJECTIVE SLEEPINESS SCALE FOR ALL VOLUNTEERS SHOWS A SIGNIFICANT INCREASE FOLLOWING EXPOSURE TO VIBRATION (P < 0.01). THIS INDICATES A REDUCTION IN ALERTNESS LEVEL DUE TO VIBRATION EXPOSURE. ALTHOUGH, THERE IS AN INCREASE OF SUBJECTIVE SCORE IN NO-VIBRATION CONDITION, HOWEVER, THE 30-MINUTES SITTING IS INSUFFICIENT TO INDUCE DROWSINESS.*

| (KSS) | Baseline (mean ± SE) | With-Vibration (mean ± SE) | P-Value |
|---|---|---|---|
| Before test-run | 2.16 ± 0.19 | 2.11 ± 0.13 | P > 0.05 |
| After 5-min | 3.94 ± 0.25 | 4.37 ± 0.31 | P < 0.05 |
| After 10-min | 4.53 ± 0.31 | 5.37 ± 0.30 | P < 0.05 |
| After 15-min | 4.84 ± 0.32 | 6.11 ± 0.32 | P < 0.05 |
| After 20-min | 5.00 ± 0.29 | 6.79 ± 0.37 | P < 0.05 |
| After 25-min | 5.10 ± 0.33 | 7.05 ± 0.43 | P < 0.05 |
| After 30-min | 5.16 ± 0.29 | 7.26 ± 0.41 | P < 0.05 |

## 4 DISCUSSION

Driver drowsiness has been one of the primary causes of road accidents [28]. However, drowsiness that is caused by vehicle vibration is not well understood or investigated. This study examined the relationship between human drowsiness levels and exposure to whole body vibration as can be experienced during driving. We demonstrated that the increase of human drowsiness level, measured by simulated driving software and Karolinska Sleepiness Scale (KSS) significantly correlated with exposure to vibration. These data support the hypothesis that exposure to vibration (random vibration with 1-15 Hz frequency band) even for as little as 30-minutes causes drowsiness and adversely affects psychomotor performance as measured by lane keeping performance, found in all twenty volunteers. The deficits in performance observed in this study are comparable to performance on the York Driving Simulator (YDS) under an alcohol intoxication of .05% blood alcohol concentration which corresponds to a severe performance deficit [29]. High effect sizes were observed for SDLP, which indicate large statistical and clinical differences between no-vibration and with-vibration condition. SDLP is related to the amount of drowsiness in the driver. SDLP greater as the driver becomes drowsier. As drowsiness increase, situational awareness decreases and the drivers ability to predict an upcoming event is lowered. This lead to over-compensation by the driver and the wheel tends to be moved frequently. The continuous variations of standard deviation of lane position (SDLP) show that the low level of alertness when volunteers were exposed to vibration and cause difficulties in maintaining the vehicle in the middle of the left-hand lane. It has also been reported that SDLP is the most common and persistent finding in sleep deprivation and drowsiness [30], [31]. Our results demonstrate, for the first time that exposure to whole-body vibration is a possible mechanism for psychomotor deficit under driving conditions. Together these changes in SDLP indicated that exposure to as little as 30-minutes of vibration reduced human alertness levels and induced significant drowsiness. Another important finding to emerge from this study is that speed deviation failed to exhibit any statistically significant variation between no-vibration condition and with-vibration condition. This finding is consistent with the literature that longitudinal measure such as speed deviation is not found capable of detecting drowsiness [29]. As expected, results from the subjective measurement (KSS) also shows a significant declination of alertness level for all the volunteers following 30-minutes exposure to vibration. The increase in subjective sleepiness scores provides important corroborating evidence that exposure to 30-minutes of vibration level can steadily reduce human alertness levels that are linked to drowsiness [32]. Various methods have been proposed in the past to assess human drowsiness and performance, such as measuring brainwave activity using electroencephalography (EEG) [19], [33]–[35]. EEG method has the ability to measure changes in brainwave power spectrum. However, the implementation of EEG in the real environment is still challenging. Brainwave activity signals measured by the electrode on the human scalp can be easily distorted by movement artefacts such as muscle activity and eye movements [36]. Placement of EEG electrodes may be uncomfortable and, therefore, impractical [10], [19], [37]. Experiment design has been developed to replicate the actual driving condition. Therefore, the vibration perceived by volunteers in this study is similar to the actual vibration felt in the typical vehicle. An actual vehicle seat was selected to ensure good vibration transmissibility to the human body. The assessment and guidelines of human body ride comfort caused by vibration are reasonably well founded in ISO 2631-1 (1997) International Standard [18]. Following that, the relevant weighting factor has been established to represent the human perception of vibration. Although the guidelines for health effect due to exposure to vibration are well documented, there is little quantitative research data available on the influences of vibration on seated human drowsiness. In many studies, the relationship between vibration and drowsiness has been assumed without supporting research [38]. This study demonstrates a link between exposure to vibration and drowsiness, at least under these experimental conditions. Therefore, it is imperative to further characterize this association under combined noise and vibration conditions that more closely resemble driving and to identify the component of noise and vibration that are most responsible for the decline in driver alertness.

## 5 CONCLUSIONS

The novel contribution of this study is characterization the role of vibration, which our findings have identified vibration as an important source of driver drowsiness. Our data clearly demonstrate that exposure to vibration has considerable influence on subjective sleepiness levels, and more importantly, human psychomotor and lapse of attention. Exposure to low frequency vibration between 1-15 Hz significantly impacts lane keeping the performance of the driver (SDLP). Finding shows a low amplitude vibration at 0.2 $ms^{-2}$ r.m.s. Increased SDLP by 11% which is comparable to SDLP under the influence of alcohol (BAC .05%). This line of research can then assist in the development of practical and relevant guidelines for limitation of vibration exposure in the automotive industry, in an effort to reduce the burden of disease of road accidents. This will also complement the existing ISO 2631-1 (effects of vibration on comfort) to extend these guidelines in assessment and establishment of thresholds and safe limits for drowsiness-inducing vibration.

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