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Experimental Study to Investigate the Effect of Whole-body Vibration Using Steering Entropy as a Function of Drowsiness

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Abstract

Although there are many researches available on the characterization of the effects of whole-body vibration on seated occupants' comfort, however, drowsiness induced by vibration has received less attention to date. There are also less validated measurement methods available to quantify whole body vibration-induced drowsiness in vehicle occupants. Here, twenty male volunteers were recruited for this experiment. Experiment procedures comprised of two 10-minutes simulated driving sessions under no-vibration conditions and under vibration that were randomly organized. Gaussian random vibration, with 1-15 Hz frequency bandwidth at 0.2 ms2 r.m.s. for 30-minutes was used. As mentioned in the previous section, the selection of vibration amplitude of 0.2 ms2 r.m.s is to ensure that the amplitude level is away from the discomfort acceleration value, which is 0.315 ms2 r.m.s. During the driving session, volunteers were required to obey the speed limit of 100 kph and maintain a steady position in the left-hand lane. A deviation in steering angle was recorded and analyzed. Significant evidence of driving impairment following 30-minutes of exposure to vibration was found in all volunteers ($p < 0.01$) that was also linked to drowsiness. faced by tax authorities in improving the tax compliance level.

***Keywords**: Whole-body vibration, Drowsiness, Steering angle*

Drowsiness is one of the leading causes of accidents on motorways and major roadways, accounting for approximately 20% of road accidents worldwide. Drowsiness, which refers to sleepiness, is a multifactorial state that may lead to inappropriate driving behavior such as lack of awareness, poor judgment and slowed reaction times. In addition, drowsiness as a result of alcohol intake or monotonous driving conditions or night driving is known to significantly influence driving performance, compromising transportation safety. Although the performance of vehicle drivers has been well investigated under various conditions, vibration-induced drowsiness is not well-characterized. Relationships between amplitude and frequency of vibration and drowsiness levels have been assumed without sufficient quantitative data.

According to ISO 2631-1 (1997) International Standards [1], the transmitted vibration to the seated human body has a significant influence on human perception and ride comfort [2-3]. Exposure to vibration also has been found to correlate with a range of physiological reactions of the human body such as lower back pain and reduction in heart rate variability [4-5]. Although many studies have contributed much to the understanding and prediction of the subjective human body response to vibration [2] [6], few studies have considered the effect of vibration specifically on drowsiness levels for seated occupants in the vehicle. Therefore, there is considerable scope for defining the exact effects of vehicle and particularly seat vibration on driver drowsiness levels. According to several published reports on drowsiness and vehicle control, there is a close relationship between drowsiness and vehicle lateral control (standard deviation of lateral position-

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SDLP, steering angle variability) as well as longitudinal control (speed deviation) [7]. Steering angle variability is calculated as a deviation from the center of steering angle. Zero deviation means the center of the vehicle coincides or is parallel to the center of the lane position. Speed adjustment from the posted speed limit will result in speed deviation. A broader perspective has been adopted by Boer et al. to measure and predict the behavior of the driver while a driving a vehicle. A method developed by Boer et al. [8], called steering entropy was introduced to quantify the randomness of steering correction behavior. High entropy index will indicate the unpredictability of steering correction that might result from reduced or diverted attention. Therefore, the primary dependent variables for this investigation were volunteers' SDLP measured from the simulated driving vehicle, steering angle variability, speed deviation, and steering entropy.

Recruitment and Screening

Twenty young male (n = 20) participated in this investigation with a mean age (± SD) 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. Their demographic were recorded at enrolment. They were (mean ± SD) 168.2 ± 4.0 cm and weighed (mean ± SD) 64.2 ± 12.2 kg. The average BMI of participants was (mean ± SD) 22.6 ± 2.54 kg/m². All volunteers were screened using the Pittsburgh Sleep Quality Index (PSQI) to measure the sleep quality [9]. Volunteers who showed poor sleep quality index (PSQI > 5) were excluded from the investigation.

Experiment Setup

The experiment setup for drowsiness assessment is illustrated in Figure 1. The vehicle seat with adjustable headrest was mounted on a vibration table. The vibration table was mounted on four air cushions. The vehicle seat's inclination angle was set at 15° to the vertical direction. Experiment set-up has been developed with a single vertical hydraulic actuator to replicate the vibration perceived by the seated occupant in a moving vehicle. Although, the input vibration was not independent on each axis. However, the input vibration generated from the hydraulic vertical actuator is located below the table away from the center of the table. The off-center excitation provides the multi-axial (x, y, z-axis) input vibration.

This vibration setup also was built to be somewhat similar to the vibration that is transferred from the vehicle floor to the seat. Prior to drowsiness measurement, measurement of total transmitted vibration for each volunteer has been done in accordance with ISO 2631-1 (1997) International Standards [1]. The total transmitted vibration was measured both from the vehicle's seatback and seat pan. The measurement was carried out to adjust the required hydraulic input force for every volunteer to become 0.2 ms^2 r.m.s.

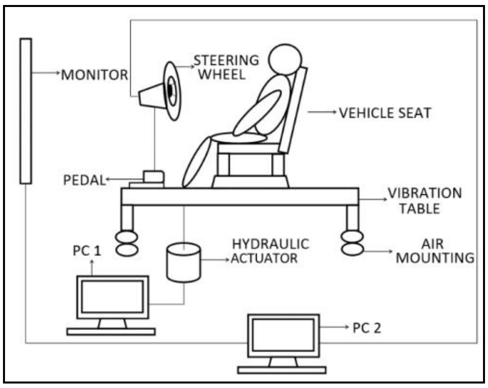

Figure 1. Schematic drawing of the experiment setup. An actual vehicle's seat was mounted on a vibration table. A hydraulic actuator located at the corner of the table will provide multi-axial input to the volunteer. A simulator also consists of a personal computer, a monitor and peripheral steering wheel, accelerator, and brake accessories.

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Experiment Procedures

The experiment was carried out in a controlled laboratory. Volunteers arrived at the laboratory at 0800 h. The experiment began at 0830 h. Prior to the experiment, all volunteers were screened using the Epworth Sleepiness Scale (ESS) to detect any abnormalities in sleep. Those with scores above ten, which indicated excessive daytime sleepiness, were excluded from the experiment.

Volunteers performed two separate test conditions [baseline (no-vibration condition) and with-vibration condition] in a randomized cross-over design, one week apart. The orders of two conditions were randomly ordered to avoid order-related influences. To standardize the learning effect, volunteers underwent a 10-minutes 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 the 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 with their eyes open. Volunteers were exposed to Gaussian random vibration, with 1-15 Hz frequency bandwidth. Total transmitted acceleration to the human body measured from seat pan and backrest was kept constant at 0.2 ms-2 r.m.s. 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.

Results

There were no significant differences in alertness level measured by the Epworth Sleepiness Scale (ESS) at baseline measurement between the no-vibration condition and with-vibration conditions. Comparison of driving performance indexes (SDLP, speed deviation, and steering angle variability) and subjective sleepiness scale (KSS) between no-vibration and with-vibration condition are presented here.

The outcome index measured in this study was steering angle variability. Steering angle variability is calculated as the deviation from the center of steering angle. Figure 2 shows the mean of steering angle variability measured for all twenty volunteers between the no-vibration condition and with-vibration condition. As Figure 2 shows, there is a significant increase of steering angle variability (mean ± SD: 0.67 ± 0.20 to 0.82 ± 0.20; $t(19) = 3.34$, $p < 0.01$) between before 30-minutes vibration and after 30 minutes exposure to vibration. Data for this table can be compared with the data in no-vibration condition. No significant differences were detected between before 30-minutes sitting and after 30-minutes sitting (mean ± SD: 0.69 ± 0.22 to 0.73 ± 0.28; $t(19) = 0.58$, $p > 0.05$).

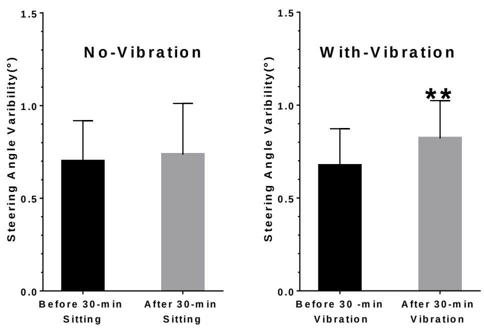

Figure 2. This bar graph represents the mean (± SD) of steering angle variability for twenty volunteers in no-vibration condition and with-vibration condition. The measurement was taken at 10-minutes driving before, and 10-minutes are driving after 30-minutes of sitting in no-vibration and 30-minutes sitting with-vibration. As can be seen in this figure, with-vibration condition reported significantly increase in steering angle variability than in no-vibration condition ($p < 0.01$).

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** $p < 0.01$

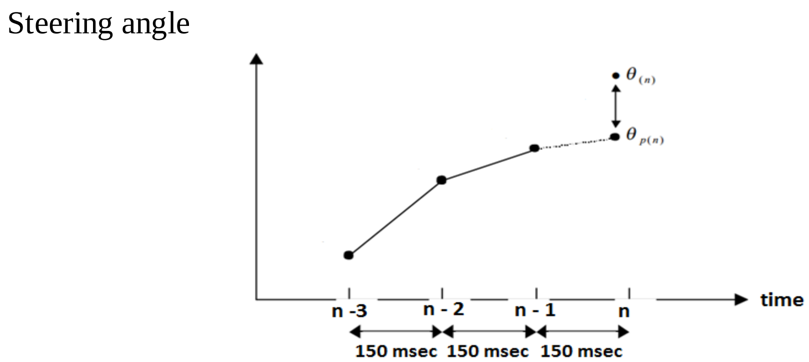
While driving a vehicle, driver continuously assesses the situation ahead by employing smooth and predictable steering correction. However, when getting distracted, the driver could not monitor the environment effectively and starting to employ a rough and unpredictable steering control. High entropy index will indicate the unpredictability of steering correction that might result from reduced or diverted attention. The predictability and the smoothness of steering correction were calculated by using steering entropy formula. Here, steering angles for the last three proceeding data points that were averaged over 150 ms periods were used to calculate the predicted steering angle θp (n) on the nth time point using a quadratic Taylor expansion in the center of (n−1). The predicted error e(n) is the difference between θp (n) and the steering angle θ(n) in real time at the nth time point [8]

Predicted angle $\theta_{p(n)}$ is calculated by

$$\theta_{p(n)} = \theta_{(n-1)} + (\theta_{(n-1)} - \theta_{(n-2)}) + \frac{1}{2}((\theta_{(n-1)} - \theta_{(n-1)}) - (\theta_{(n-2)} - \theta_{(n-3)}))$$

Which simplify to

$$\theta_{p(n)} = \frac{5}{2}\theta_{(n-1)} - 2\theta_{(n-2)} + \frac{1}{2}\theta_{(n-3)}$$



The difference between actual $\theta_{(n)}$ and predicted $\theta_{p(n)}$ is defined as the prediction error $e_{(n)}$.

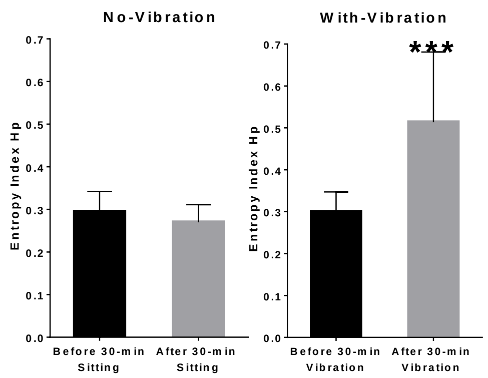


Figure 3: The bar graph represents the mean (± SD) of Entropy Index for twenty volunteers in no-vibration condition and with-vibration condition. A significant increase of entropy index

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was observed following 30-minutes exposure to vibration that indicates the unpredictability of steering behavior that can be linked to drowsiness.
* $p < .05$, ** $p < .01$, *** $p < .001$

Figure 3 shows a graphical representation of the mean of steering entropy over all volunteers. Lower HP index indicates the smoother the driver's steering behavior. The decreased in steering predictability caused by drowsiness resulted in increased of steering entropy.

As Figure 3 shows, there is a significant increase in steering entropy index following exposure to vibration ($p < 0.001$). The increase in steering entropy index indicated the randomness of steering correction behavior that caused by drowsiness-inducing vibration. No significant difference was observed in no-vibration condition ($p > 0.05$).

Conclusion

Another important finding was, there was a significant increase of steering entropy index (Hp 0.30 > Hp 0.52) for all the volunteers that indicate the unpredictability and randomness of steering correction frequency as a result of drowsiness caused by vibration. Predictable steering control was employed under alert condition. However, when a driver gets distracted, unpredictable steering control was employed as a result of reduced attention due to drowsiness.

Experiment design and procedures have 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 for human body ride comfort caused by vibration are reasonably well founded in ISO 2631-1 (1997) International Standard [1]. This study demonstrates a link between exposure to vibration and drowsiness, at least under these experimental conditions.

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