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Research paper

Lane keeping performances subjected to whole-body vibrations

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Abstract

Despite the fact that many research have been carried out on the characterization of the effects of whole-body vibration on seated occupants' comfort, there is still very little scientific knowledge regarding drowsiness caused by the vibrations. Furthermore, there are less verified measurement methods available to quantify the whole body vibration-induced drowsiness of the vehicle occupants. This study is therefore set out to evaluate the effect of vibrations on drowsiness. 20 male volunteers have been recruited for this experiment. The data for this study is gathered from 10-minute simulated driving sessions under both no-vibration conditions and with a vibration that is randomly organized. Gaussian random vibration, with 1-15 Hz frequency bandwidth at 0.2 ms^{-2} r.m.s. for 30 minutes, is applied. During the driving session, the volunteers are required to obey the speed limit of a 100 kph and keep a consistent position in the left-hand lane. The deviation in the lateral position are recorded and analyzed. Additionally, the volunteers are also asked to rate their subjective drowsiness level by means of Karolinska Sleepiness Scale (KSS) scores for every five minutes. Based on the results, the role of vibration in promoting drowsiness can be observed from the driving impairment following 30-mins exposure to vibration.

Keywords: *Whole-body vibration; drowsiness; lane performance; karolinska sleepiness scale; driving impairment*

1. Introduction

One of the most prominent causes for accidents on main roads and highways has been drowsy driving and it is reported that one out of five traffic-related injuries is caused by drowsy driving [1]. In response, the European Union (EU) has introduced a new regulation on sleepiness during driving, specifically among drivers suffering from sleep apnoea. According to this new regulation, the candidates for driving license and drivers who suffer from moderate to severe obstructive sleep apnoea will be required to have the recommendations from medical practitioners prior to applying or renewing their driving license [2]. This shows that the authority is considering the severity of drowsy/sleepy driving and equates it to drunk driving. Meanwhile, there is still a limited investigation of the drowsiness caused by vehicular vibration although there have been some studies that show probable relationship between exposure to vibration and reduction in level of wakefulness [3-5]. As a result, there is still no requirement imposed on automative industry to limit the vibration-induced drowsiness.

Past studies have indicated that drowsiness can significantly affect the driver's concentration and his/her overall driving performance, which compromises the road safety [6-8]. Such drowsiness could be caused by several reasons, including monotonous driving, night time driving or influences of drugs or alcohol. However, there is still a limited description on the components of drowsiness that is caused by exposure to vibrations.

There are only a few studies that have tested the assumption of a possible link between exposed vibration amplitude and frequency to the vehicle occupants and their drowsiness. One of the reasons for this is because there is little quantitative information on drowsiness as it is a multifactorial phenomenon. In the meantime, there are studies that have shown the correlation between vibrations and the different physiological reactions of the human body, including coronary heart rate and lower back pain [9-10]. Vibration can act as a stressor and affect the muscles and neurological features [11-12]. In the context of the automotive industry, vibrations can occur on a car seat structure due to various reasons such as road surface and vehicle power train. For a seat structure in a vehicle, the vibration modes transmitted to it (comprising of correspondence mode shapes and resonant frequency) occur at a frequency below 60 Hz [13] whereas for the human frame, the basic resonance occurs at a frequency less than 15 Hz [14].

It is widely known that the transmitted vibration affects the human perception and ride comfort [14-16]. ISO 2631-1 (1997) international standard has been used efficaciously to assess human exposure to whole-body vibration. The "Equivalent Comfort Contour," international standard is developed to assess the human body discomfort. On the other hand, the "Equivalent Drowsiness Contour" has still not yet developed [17].

As a result, there is a wide scope to outline how a driver's drowsiness level is affected by the vehicle, particularly the seat vibration. There is no particular work that has ranked the significance of the factors that cause the co-driving force drowsiness. This study will only focus on the drowsiness that is caused by vibrations. According to the past studies, sleepiness or drowsiness refers to the state between being awake and asleep [18]. Many studies have claimed that one's ability to drive effectively could be affected by drowsy driving [19]. In line with previous examinations on car control and drowsiness, there exists a close link between lane position variability and drowsiness. The standard deviation of lateral position (SDLP) is considered as the common lateral role standard deviation since it reflects on how many times a vehicle weaves and the increase in lane variability could cause lane crossing into the next traffic lane.

To date, there is no simulated driving experiment that is conducted to test the drowsiness caused by vehicle vibrations despite various

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studies have indicated the links between driving performance and drowsiness. In this regard, it is imperative to analyze the possibility of applying simulated driving to detect the drowsiness caused by vibrations. Consequently, the main objective of this study is to examine the effects of vibration on human drowsiness level using both objective (simulated driving test) and subjective (Karolinska Sleepiness Scale) measurement methods.

2. Experiment setup

2.1. Volunteers

This study involves twenty young males (n = 20) as voluntary test subjects and their mean age is 23.0 ± 1.3 years. The volunteers are selected randomly among the students of a university college and they need to have a regular or corrected-to-everyday vision and no history of low back pain (LBP). Their demographic information are recorded during the enrolment. Their height is 168.2 ± 4.0 cm and weight is 64.2 ± 12.2 kg with an average BMI of 22.6 ± 2.54 kg/m². The Pittsburgh Sleep Quality Index (PSQI) has been used to screen the volunteers based on their sleep excellence and those with poor sleep pleasant index (PSQI > 5) are excluded from this study.

2.2. Ethical considerations

The volunteers are given both verbal and written explanations on the contents and aims of the experiment before starting. The volunteers have also been told that they have the right to choose not to participate and their inputs during the experiment will remain confidential. In this regard, right after they are briefed on the experimental procedure and the laboratory facilities have been introduced to them, each volunteer is required to fill the informed written consent form.

The experimental protocol used in this study is sent to the RMIT College Human Research Ethics Committee for their official review and accreditation. It is approved with the Approval number: EC 00237.

2.3. Test setup

The experimental setup for drowsiness assessment is developed in this study. A mid-sized sedan car seat with an adjustable headrest is used for the experiments. The seat is located on a cast aluminum table (2 m x 1.2 m x 1.2 m), which is set up on four air mountings (regulated to 20 psi). The angle of seat's inclination is set at 15° to the vertical axis. A servo-managed hydraulic actuator (5 kN) has been fixed vertically on the corner of the desk and it provides the input force for the table's excitation. The off-center excitation will provide the multi-axial input power in specific orientations as well as create some vibrations similar to those generated by the vehicle seat mountings. The vibration table is designed to be dynamically rigid at frequencies below 100 Hz to prevent any interaction with the automobile seat structural dynamics. In this case, total transmitted vibration to each volunteer is made based on the ISO 2631-1 (1997) before the drowsiness is measured [17].

The measurement is done to modify each volunteer's desired hydraulic input force to be 0.2 ms^{-2} r.m.s. Two tri-axial accelerometer pads (SVANTEK SV-38V version) are applied to measure the vibration transmitted to the body of the human volunteer from the seat cushion and seatback [20]. On the other hand, in order to get the complete frequency weighted transmitted vibration to the seated human body, SV 106 Human Vibration exposure (HVE) meter (analyser) is used, which is connected to the accelerometer pads. In the meantime, the total frequency-weighted transmitted vibration to the seated human frame that is calculated through the HVE analyser uses weighting factors (ωk, ωd, ωc) and also multiplication factors.

2.4. Objective measurement

York driving simulator software (York PC technology, Kingston, Ontario, Canada) is utilized to examine the volunteers. A previous study has determined that this stimulator as an ecologically valid study tool to measure psychomotor performance [21]. The simulator is consisted of a personal computer, a 40-inch screen and peripheral guidance wheel, accelerator and brake accessories. During the experiment, the volunteers are shown a customised advanced driving scenario from the front view of the driver's seat. The driving simulation contains a cross-country motorway, with two lanes in each path. The volunteers are told to maintain a steady position in the left traffic lane at some point of the test and a steady constant velocity of 100 km/hour. The outcome variables measured by using the simulator will be applied to derive the standard deviation from the centre of lane (SDLP). The varying results will indicate whether the volunteers have been able to conduct the test accurately based on the instructions given.

2.5. Subjective measurement

The Karolinska Sleepiness Scale (KSS) is used to assess the subjective drowsiness level [22]. At each 5-minute interval during the simulated driving mission, the volunteers are prompted to use the word "KSS" to provide a subjective score based on the scales that are visible to them beside the reveal screen. It should be noted that the volunteers have been given a practice session to use the scale prior to the experiment. In short, the scale comprises of the following ratings: 1 = extremely alert, 2 = very alert, 3 = alert, 4 = instead alert, 5 = neither alert nor sleepy, 6 = some signs of sleepiness, 7 = sleepy, however no effort to live wide awake, 8 = sleepy, some attempts to stay wide awake, 9 = very sleepy, splendid attempts to stay unsleeping [22].

2.6. Experiment conditions

The site of the experiment is a laboratory with temperature and light control (21°C - 23°C, < 70 lux) with a noise level below 60 dB. For the experiment, the volunteers have arrived at the laboratory at 0800 hrs. They have had a normal sleep the previous night and had eaten a light breakfast. It is imperative for the volunteers to not drink any caffeinated or alcoholic drinks. An initial screening session is conducted to assess the volunteers in order to determine whether they are fit to join the study. They are also screened using Epworth Sleepiness Scale (ESS) to detect any sleep abnormalities and those with a score > 10 are excluded as this suggests excessive daylight hours sleepiness.

The experiment is started at 0830 hrs. Overall, the experiments are conducted in two weeks, wherein each week, the volunteers will complete either one of the separate test conditions [baseline (no-vibration condition) and with-vibration condition] in a randomized cross-over design. Each test is conducted a week apart and to prevent order-related influences, the condition orders have been randomly ordered. Furthermore, to decrease the learning effects, each volunteer will go through 10-mins exercise session prior baseline and with-vibration situations to acquaint themselves with the simulator interface. The experiments are conducted on all volunteers at the similar time of the day. In the with-vibration condition, the volunteers are required to drive with no vibration for 10 minutes as well as sitting for 30 minutes with exposure to vibration. They are exposed to a Gaussian random vibration with the bandwidth frequency of 1-15 Hz. A steady total acceleration of 0.2 ms^{-2} r.m.s is transmitted to the volunteer's body. Subsequently, the subjective sleepiness of volunteers is rated using KSS prior to the vibration exposure, at each five-minute interval of vibration and after vibration exposure. The score is initiated through the "KSS" pronounced by the check chief. The volunteers will go through a 30-minute sitting with the same process and sitting arrangement as the with-vibration condition, although there is no vibration exposure this time around. Afterwards, the volunteers are required to

drive for 10 minutes right after a 30-minute sitting. All in all, the whole length of every condition (no-vibration and with-vibration) is 50 minutes.

3. Results

In total, 20 volunteers have completed the experiment. The Epworth Sleepiness Scale (ESS) between baseline (no-vibration situation) and with-vibration condition at start of the test has found no significant difference in alertness level. This section presents the assessment results using the objective performance index (SDLP) and the subjective sleepiness scale (KSS) between the no-vibration and with-vibration conditions.

Figure 1 shows the results of SDLP where each panel in the figure represents the SLDP average and standard error of the mean (SE) prior and after 30 minutes of exposure to vibration and sitting (no-vibration). The measurement has been obtained 10 minutes driving before and 10 minutes driving after the 30 minutes of sitting in no-vibration and 30 minutes of sitting with-vibration. There is a significant increase of lane position variability (SDLP) ($P< 0.05$) for the with-vibration condition. These differences, in relation to the legal limits for driving are +2.4 cm (BAC 0.05%) [23]. The changes highlight that, after being subjected to the vibration for 30 minutes, $*P < 0.05$, the volunteers are unable to maintain straight position.

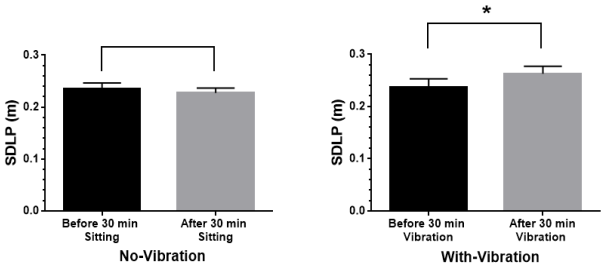


Fig. 1: The bar graph presents the mean (± SE) of SDLP for 20 volunteers in no-vibration condition and with-vibration condition

It can be observed that there is no significant difference in SDLP between before no-vibration condition and before with-vibration condition ($P > 0.05$). Meanwhile, compared to the baseline (no-vibration condition), the SDLP measure between before the exposure within the first 10 minutes of driving, as well as after the exposure to vibration indicates that being exposed to vibration for 30 minutes has notably affected the volunteers' lane maintaining performance. After being exposed to vibration for 30 minutes, there is an extensive acceleration of the lane variability or deviation from a lateral function (from mean ± SE: 23.6 ± 0.02 to mean ± SE: 26.2 ± 0.01; $P< 0.05$). In this regard, 2.6 cm increase in the variability indicates a poor lane control among volunteers. Based on the analysis of lane variability, volunteers have found it hard to maintain the vehicle in the middle of the left-hand lane when their alertness level is low in response to being exposed to vibrations. On the other hand, for the baseline (no-vibration condition) where lane position variability is decreased (mean ± SE: 23.5 ± 0.01 to mean ± SE: 22.8 ± 0.01; $P > 0.05$), there is insignificant difference. From repeated-measures evaluation of both conditions (no vibration and with-vibration), it can be observed that there is significant difference among the group variations ($P< 0.05$). This shows that vibration has a significant influence on drowsiness level as measured by SDLP.

In the meantime, Figure 2 shows a comparison between the means of subjective sleepiness scale (KSS) for the volunteers in both no-vibration and with-vibration situations. The differences are plotted in opposition to time. As shown, the initial KSS values for both conditions ($P > 0.05$), have no apparent differences. In this light, the KSS value is mean ± SE: 2.11 ± 0.13 for with-vibration condition and mean ± SE: 2.16 ± 0.19 for no-vibration circumstance at the start of the experiment. On the other hand, the values for subjective sleepiness scales for all volunteers have shown a substantial increase after exposure to vibration ($P < 0.05$). This implies that the level of alertness is reduced after vibration exposure.

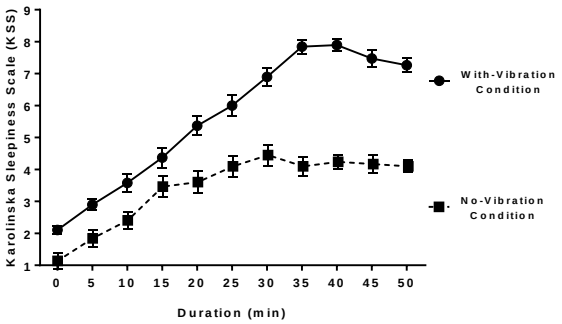


Fig. 2: The average score of subjective sleepiness scale (KSS) plotted against time for twenty volunteers in no-vibration condition and with-vibration condition

For the first 10 minutes, there is no significant distinction found in both conditions with KSS score (mean ± SE: 3.58 ± 0.29 in with-vibration condition and mean ± SE: 3.16 ± 0.19 in no-vibration circumstance). Figure 2 shows that there is an apparent decrease in degree of alertness as shown by the gradual increase in the rating of subjective sleepiness throughout the path of exposure to vibration. After being exposed to vibration for 15 minutes, the onset of the drowsiness is faster with KSS value of mean ± SE: 6.11 ± 0.32 while the most effective KSS value of mean ± SE: 4.84 ± 0.32 is shown in the no-vibration condition. The KSS value has accelerated significantly in the following 30 minutes for exposure to vibration than without vibration (mean ± SE: 7.26 ± 0.40 and mean ± SE: 5.16 ± 0.29, respectively; $P< 0.05$).

4. Conclusion

This study has characterized vibration as a critical source of driver's drowsiness. This study supports that the exposure to vibration can significantly influence the subjective sleepiness levels, as well as human psychomotor and lapse of attention. Based on this realization, the lane keeping performance of driver (SDLP) is affected by the exposure to vibration. According to the obtained results, the low excitation vibration at 0.2 ms^{-2} r.m.s increases SDLP by 11%. This is similar to the SDLP of drivers under the influence of alcohol (BAC .05%) [23]. Moreover, the KSS measures the formulation of drowsiness and it shows that the reduction in the alertness level as a result of vibration is more apparent in vibration situation compared to the no-vibration situation. Additionally, high correlation can be inferred between the KSS and SDLP. All in all, this research can facilitate the development of realistic and applicable guidelines to prevent vibration exposure in the automobile industry in order to decrease road injuries. This complements the present ISO 2631-1 to extend these recommendations for more detailed evaluation and establishment of thresholds and safe limits for drowsiness-inducing vibration.

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