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Evaluation of reaction time performance and subjective drowsiness during whole-body vibration exposure

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Abstract. Despite the automotive industry's interest in how vibration affects the level of human comfort, there is little focus on the effect of vibration on drowsiness level. Thus, this study involves eighteen healthy male participants to study the effect of exposure to vibration on the drowsiness level. Prior to the experiment, the total transmitted vibration measured at interfaces between the seat pan and seat back to the human body for each participant was modified to become 0.2 ms^{-2} r.m.s and 0.4 ms^{-2} r.m.s. During the experiment, the participants were seated and exposed to 20-minutes of Gaussian random vibration with frequency band 1-15 Hz at two level of amplitude (low vibration amplitude and medium vibration amplitude) on separate days. The level of drowsiness was measured using a PVT test prior and after exposure to the vibration while participants rated their subjective drowsiness by using the Karolinska Sleepiness Scale (KSS). The significant increase in the number of lapse and reaction time because of the exposure to vibration in both conditions provide strong evidence of drowsiness. In this regard, the medium vibration amplitude shows a more prominent effect. All participants have shown a steady increase of drowsiness level in KSS. Meanwhile, there are no significant differences found between low vibration amplitude and medium vibration amplitude in the KSS. These findings suggest that human alertness level is greatly affected by the exposure to vibration and these effects are more pronounced at higher vibration amplitude. Both findings indicate that the presence of vibration promotes drowsiness, especially at higher vibration amplitude.

1. Introduction

Over the last decades, researchers have focused on early prediction and assessment on the drowsiness level of seated occupants' drowsiness in a range of transportation vehicles. There are many factors leading to drowsiness, including influences from substances like alcohol as well as sleep deprivation [1, 2]. In this regard, numerous national and international safety standards have been drafted which help describe the health risks of perceived vibration to the human body. These standards establish guidelines and thresholds, such as weighting filters, that can use to approximate the comfort of the human ride, however, how drowsiness is caused by the vibration of a vehicle is yet to investigated and understood. In this regard, drowsiness is a multifactorial aspect that influences not only the notions of quality perception (comfort) and judgment (safety) but also health as long-term exposure to vibration could lead to muscular-skeletal injuries [2]. Past studies had predicted and developed an understanding of how the human body subjectively responds to vibrations [3]. However, there is still limited quantitative study which investigated the influence of vibration on seated occupants' drowsiness level.

Studies had shown that drowsiness and prolonged sleep deprivation could lead to declining response speed (1/RT), increase in reaction time (RT) and the increase in the number of lapses (RT > 500 ms) [4, 5, 6], but the attempt to establish the relations between psychomotor deficit such as drowsiness through measuring the reaction time performances, has not yet been able to fully investigate the drowsiness caused by exposure to vehicle vibration. The experiment is based on the ISO2631-1, 'Evaluation of human exposure to whole-body vibration' weightings and test procedures [7] guidelines which stipulate that regardless of the frequency content, the fixed frequency weighted r.m.s value of vibration transmitted to the seated human occupants will show a constant subjective comfort rating, in order to conduct an objective and subjective measurement of human participants' drowsiness level based on human perceived vibration.

2. Methodology

2.1. Human participant
The study involved eighteen healthy, randomly selected male university students, with the mean age of 23.0 ± 1.3 years. The average height for the participants was 168.2 ± 4.0 cm, and their average weight was 69.3 ± 9.88 kg, with the average BMI of 22.6 (SD=2.54) kg/m². Prior to the experiment, the Epworth Sleepiness Scale (ESS) was used to detect any abnormalities in sleepiness among the participants [8]. A score of > 10 indicates excessive sleepiness, and participants with this score were exempted from the experiment [9]. The participants were instructed to have enough sleep a day prior, and based on the results, the participants' total ESS score ranged from 0 to 24. The scores below 7 are perceived as normal; 8 to 10 are considered as moderate while participants with scores of 11 to 15 are defined as elevated risks and finally, those with scores exceeding 16 illustrate severe excessive daytime sleepiness (EDS) [10], showing a high risk for them to fall asleep in a range of monotonous situations [11].

2.2. Objective Measure-Psychomotor Vigilance Test (PVT)
The PC-based Psychomotor Vigilance Test (PVT-192: Ambulatory Monitoring Inc., Ardsley, New York) was used to measure reaction time [12]. The test comprises of a 10–minutes visual reaction time task evaluating the sustained attention in two conditions; before vibration exposure and after vibration exposure. Participants were asked to click a mouse as fast as they can to respond to the appearance of a visual stimulus. The stimulus was in the form of a diode which emits a red light that displays time in milliseconds. A visual stimulus would appear in 2-10 seconds variable intervals of during each 10-minutes session. A software program was used to obtain three PVT performance metrics during each PVT condition; these metrics are mean reaction time, the number of lapses and median reaction time. A valid response would be > 100 ms and response less than 100 ms is considered as a false signal [5]. The participants were exposed to a Gaussian random vibration, with 1-15 Hz frequency bandwidth, for 20-minutes. During vibration condition, the participants were asked to sit comfortably while their feet as firmly fixed at the footrest, their back on the backrest and hands on their lap. They were also were asked to restrict any physical movement. The footrest was isolated from the vibration and is not connected to the vibration table and. The participants also endured the similar experimental procedures during the no-vibration condition. Here, after the first PVT test was completed, the participants were asked to sit for 20-minutes and the second PVT test will be carried out straight away after 20-minutes of sitting.

2.3. Subjective measure-Karolinska Sleepiness Scale (KSS)
The participants' subjective sleepiness was rated using Karolinska Sleepiness Scale (KSS). The scale was used prior to vibration exposure, every 5-minutes of vibration and after exposure to vibration. The test leader would initiate the rating by the uttering KSS. The scale had been used in many past studies. consists of the following indicators: 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 [13]. The participants and the test leader were not allowed to speak to each other, unless in the event of an emergency.

2.4. Experiment Procedures
An experimental setup was developed for the purpose of this study. The study had used an actual vehicle seat with adjustable headrest. The seat was affixed on a cast aluminum table, while the table was affixed on four air mountings. Air mountings were used to eliminate the table's rigid mass. The inclination angle of the seatback was set at 15° to the vertical direction. Meanwhile, the servo-controlled hydraulic actuator (5 kN) that was placed vertically at the corner of the table was used to determine the table's excitation input force prior to drowsiness measurement. The measurement of total transmitted vibration conducted on each participant has was based on ISO 2631-1 (1997) [7]. By using accelerometer pad, the measurement was conducted to modify the hydraulic input force required for every participant (Fig. 1). Each participant was instructed maintain a regular sleep pattern a week prior to the experiment and to avoid any caffeine intake. The experiment started at 9.00 AM, and prior to the experiment, participants were assessed by using Epworth Sleepiness Scale (ESS). Those with a score exceeding 10 will be exempted from the experiment [8]. A practice session was also given to all participants to minimize the learning effect. Participants were required to complete two randomly organized vibration conditions;

(a) Low amplitude vibration 0.2 ms^{-2} r.m.s.
(b) Medium amplitude vibration 0.4 ms^{-2} r.m.s.

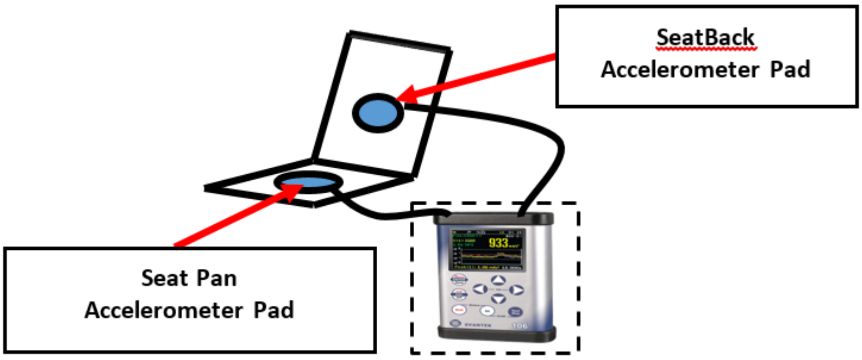

Figure 1. The vibration transmitted to the human body was measured by using two accelerometer pads that are connected to the seat back and seat pan

3. Results

3.1. Objective Measure
Table 1 presents the PVT results which measured the effects of vibration amplitude (ms^{-2} r.m.s) on the participants' drowsiness level. Three PVT metrics were assessed, which are (1) minor lapse, (2) mean RT and (3) median RT. The comparison between the PVT metrics prior and after exposure to vibration indicates the how a 20-minutes exposure to vibration could have significant ($p < 0.05$) influences on participant's RT in both conditions (low vibration amplitude - 0.2 ms^{-2} r.m.s and medium vibration amplitude - 0.4 ms^{-2} r.m.s). Furthermore, significant increases in the RT and number of lapses were observed in all eighteen participants.

The data in Table 1 shows that after a 20-minute exposure to vibration, all of the participants showed increase in the average number of PVT lapses (mean ± SEM) in both conditions participants from (1.67 ± 0.36 to 3.67 ± 0.58, p = 0.0018 in low vibration amplitude and from 1.71 ± 0.36 to 4.86 ± 0.46, p = 0.0002 in medium vibration amplitude which show a decrease in the level of alertness. When these two results were compared, there is a greater mean difference in medium vibration amplitude (0.4 ms-2 r.m.s) compared to low vibration amplitude (0.2 ms^{-2} r.m.s). Such apparent changes

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demonstrate that the effect of vibration amplitude show that the more pronounced lapse of attention in medium vibration amplitude (0.4 ms^{-2} r.m.s), and the result is significant ($p = 0.0024$).

The mean RT for eighteen participants in both vibration conditions show statistical significance, and there is an increase in the reaction time participants. Due to exposure to vibration, the participants mean RT for the participants had increased from (283.3 ± 6.24 to 320.2 ± 10.68, $p < 0.0001$ in low vibration amplitude and from 281.1 ± 6.56 to 360.6 ± 11.50, $p < 0.0001$ in medium vibration amplitude). In comparison, the mean difference of mean RT in medium vibration amplitude (0.4 ms^{-2}) is larger than low vibration amplitude (0.2 ms^{-2}). This shows that it is statistically significant ($p = 0.0027$) that exposure to medium vibration amplitude (0.4 ms^{-2}) will greatly influence the level human drowsiness level, as shown in the participants' mean RT. Table 1 also indicates the increase of PVT metrics based on the median RT as a result of the exposure to low and medium vibration amplitude. The participants' median RT had increased from 268.5 ± 7.21 to 301.3 ± 9.68, $p = 0.0020$ in low vibration amplitude and from 268.3 ± 7.89 to 329.1 ± 10.13, $p < 0.0001$ in medium vibration amplitude. The bigger difference in the mean for medium vibration amplitude (0.4 ms^{-2}) shows that higher vibration amplitude has a more apparent effect of drowsiness on a human. Meanwhile, the effect sizes for all PVT metrics were measured and shown in Table 2. In this light, the magnitude of the reaction time changes between prior and after the exposure to vibration in both conditions is indicated by the increase of effect sizes along with the increase in the magnitude of the difference between the participants and the decline of effect size as the variability of the differences increases. According to the definition above,

PVT metrics was arranged based on effect sizes and susceptibility to vibration. During the low vibration amplitude condition, the median RT indicated high effect size (ES = 0.838) of the difference between prior and after 20-minutes of exposure to vibration. This shows higher susceptibility to vibration followed by mean RT (ES = 0.796) and minor Lapse (ES = 0.632). The moderate statistical and the clinical difference between two variables are evident when the effect sizes exceed 0.5. Meanwhile, during the medium vibration amplitude condition, there was a high magnitude of the differences prior and after vibration exposure with the mean RT (ES = 0.848), followed by minor lapse (ES = 0.821) and median RT (ES = 0.784). Consequently, both results were compared and the result shows the significant difference between low vibration amplitude conditions and medium vibration amplitude conditions, and the effect is more significant in medium vibration amplitude which shows higher effect sizes. Further analysis indicates that the mean RT is a sensitive PVT metrics in both vibration amplitude conditions.

Table 1. Comparison of PVT metrics between low vibration amplitude and medium vibration amplitude is shown. A significant increase of reaction time and minor lapse (RT > 500 ms) can be observed following exposure to vibration. However, the effect is more pronounced in medium amplitude vibration.

	Low Vibration Amplitude 0.2 ms^{-2} r.m.s.	
	Before exposure	**After exposure**
Minor lapse (n)	1.67 ± 0.36	3.67 ± 0.58
Mean RT (ms)	283.1 ± 6.24	320.2 ± 10.68
Median RT (ms)	268.5 ± 7.21	301.3 ± 9.68

	Medium Vibration Amplitude 0.4 ms^{-2} r.m.s.	
	Before exposure	**After exposure**
Minor lapse (n)	1.71 ± 0.36	4.86 ± 0.46
Mean RT (ms)	281.1 ± 6.56	360.6 ± 11.50
Median RT (ms)	268.3 ± 7.89	329.1 ± 10.13

Table 2. The effect size of PVT metrics in both vibration conditions is shown. Higher effect size will indicate larger statistical and the clinical difference between two variables

Low Vibration Amplitude 0.2 ms^{-2} r.m.s.		
Rank	**PVT metrics**	**Effect size**
1	Median RT	0.838
2	Mean RT	0.796
3	Minor Lapse	0.632

Medium Vibration Amplitude 0.4 ms^{-2} r.m.s.		
Rank	**PVT metrics**	**Effect size**
1	Mean RT	0.848
2	Minor Lapse	0.821
3	Median RT	0.784

3.2. Subjective Measure

Fig. 2. presents the plot of Karolinska Sleepiness Scale (KSS) score for low and medium vibration amplitude against time. Based on the repeated measures-ANOVA test ($p < 0.0001$) of all eighteen participants in both conditions, it can be observed that there are significant increases in KSS score after every subsequent 5-minutes of exposure to vibration compared to prior to exposure. Fig. 2 illustrate a definite decrease in the level of as reflected by the continuous increase in subjective sleepiness score during exposure to vibration in both vibration amplitude conditions (0.2 ms^{-2} r.m.s. and 0.4 ms^{-2} r.m.s.). The figure indicates that the average KSS score (mean ± SEM) prior to vibration exposure for low and medium vibration amplitude was 2.56 ± 0.16 and 2.72 ± 0.19.

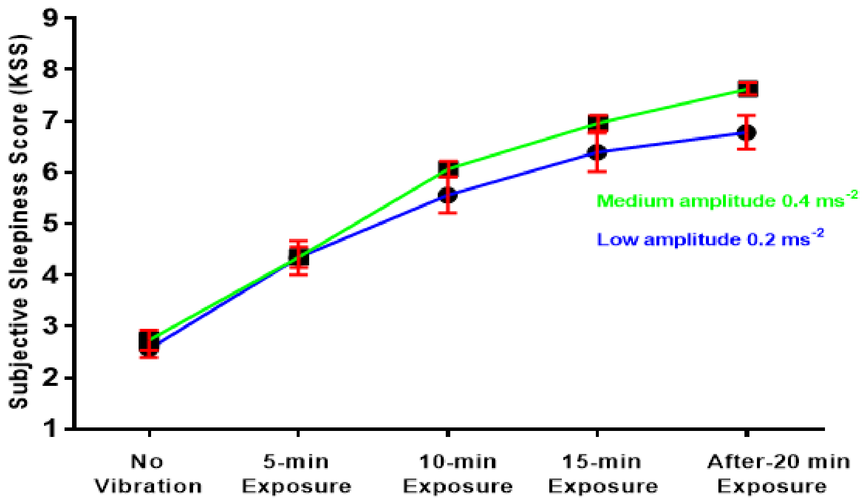

Figure 2. The mean of subjective sleepiness scores (KSS) for all the participants in two vibration conditions (low vibration amplitude and medium vibration amplitude)

However, there is significant statistical significance difference ($p > 0.05$) between low and medium vibration amplitude conditions prior to vibration exposure. Meanwhile, being exposed to vibration for 10-minutes, the average KSS score for all participants had consistently increased to 5.56 ± 0.35 (mean ± SEM) in low vibration amplitude and 6.06 ± 0.15 (mean ± SEM) in medium vibration amplitude. In this light, there is only a slight difference between values obtained for low and medium vibration amplitude. ($p > 0.05$). From the figure, it can be observed that there is a more pronounced drowsiness after the participants were exposed to the vibration for 20 minutes and the KSS values were 6.78 ±

0.33 (mean ± SEM) in low vibration amplitude and 7.61 ± 0.12 (mean ± SEM) in medium vibration amplitude. This clearly shows the depleting level of awareness in all participants after they were exposed to vibration for 20 minutes. One-way repeated measures-ANOVA was carried out to investigate the statistical significance, and the results show highly significant intra-individual and interindividual differences for all participants ($p < 0.0001$) for each vibration condition. Meanwhile, there are no significant differences between low vibration amplitude and medium vibration amplitude.

4. Discussion

This study hypothesized that when the participants are drowsy, they will not be able to provide a good judgment on their drowsiness level. The study has shown significant effects of vibration on human reaction time. Past studies have shown the impact of low vibration amplitude on the drowsiness of seated humans. [14]. These studies have shown a significant relationship between drowsiness level and vibration, as well as the significant increase in the reaction time after being exposed to vibration for 20 minutes [15, 16]. This study's finding is parallel to Azizan [14] which postulated that the increase in vibration amplitude could more significantly impair the level of human alertness. The present study had compared low vibration amplitude (0.2 ms^{-2} r.m.s) with medium vibration amplitude (0.4 ms^{-2} r.m.s) and indicated that the degree of drowsiness, as measured by PVT, was more significant when the vibration amplitude was double. In this regard, the increase in the transmitted vibration to the human body will make the drowsiness level more apparent. This finding shows that the link between exposure to vibration and the level of drowsiness. On the other hand, the study did not find any significant difference in the subjective measurement (KSS) in both vibration conditions. In this regard, this finding is consistent with the existing literature [17]. This study's finding provides a significant implication in the development a drowsiness contour which offers a comprehensive guideline on whole-body vibration area. On the hand, before the association between vibration exposure, and drowsiness level could be clearly understood, there is a need for more research on this topic^{-}

5. Conclusion

This present study is aimed to identify the impact of vibration on the reaction time and drowsiness level of seated occupants by conducting a comprehensive, objective measurement test (PVT) and subjective evaluation score (KSS). The finding supports the hypothesis that human drowsiness level could be considerably influenced by the presence of low-frequency vibration (between 1 -15 Hz). The results show that compared to low vibration amplitude (0.2 ms^{-2} r.m.s), medium vibration amplitude (0.4 ms^{-2} r.m.s) create a higher level of perceived drowsiness among the participants. On the other hand, the KSS result shows that there is no significant difference subjective drowsiness level found in both conditions of vibration while the PVT test shows a substantial increase in the reaction time and the number of lapses in both conditions, and medium vibration amplitude shows a higher degree of error. Thus, it is concluded that the increasing amount of vibration amplitude level would lead to the slower reaction time by the participants, indicating an elevated level of drowsiness.

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