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Effects of vibration on occupant driving performance under simulated driving conditions

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ABSTRACT

Although much research has been devoted to the characterization of the effects of whole-body vibration on seated occupants' comfort, drowsiness induced by vibration has received less attention to date. There are also little validated measurement methods available to quantify whole body vibration-induced drowsiness. Here, the effects of vibration on drowsiness were investigated. Twenty male volunteers were recruited for this experiment. Drowsiness was measured in a driving simulator, before and after 30-min exposure to vibration. Gaussian random vibration, with 1–15 Hz frequency bandwidth was used for excitation. During the driving session, volunteers were required to obey the speed limit of 100 kph and maintain a steady position on the left-hand lane. A deviation in lane position, steering angle variability, and speed deviation were recorded and analysed. Alternatively, volunteers rated their subjective drowsiness by Karolinska Sleepiness Scale (KSS) scores every 5-min. Following 30-min of exposure to vibration, a significant increase of lane deviation, steering angle variability, and KSS scores were observed in all volunteers suggesting the adverse effects of vibration on human alertness level.

1. Introduction

Drowsiness is one of the leading causes of accidents on motorways and major roadways, accounting for approximately 20% of road accidents worldwide (Horne and Reyner, 1995). Drowsiness, which refers to sleepiness, is a multifactorial state that may lead to inappropriate driving behaviour such as lack of awareness, poor judgement and slowed reaction times (Anderson and Horne, 2013). 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 (Larue, 2010; Kamdar et al., 2004; Akerstedt et al., 2005; Fairclough and Graham, 1999). Although the performance of vehicle drivers has been well investigated under various conditions, vibration-induced drowsiness is not well-characterised. 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 (1997), the transmitted vibration to the seated human body has a significant influence on human perception and ride comfort (Griffin, 1990; Baik, 2004; Factors et al., 1997). 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 (Vicente et al., 2011; Callaghan and McGill, 2001). Although many studies have contributed much to the understanding and prediction of the subjective human body response to vibration (Mansfield and Maeda, 2011; Maeda et al., 2008; Tewari and Prasad, 2000; Kjellberg and Wikström, 1985), 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-SDLP, steering angle variability) as well as longitudinal control (speed deviation) (Wierwille and Kirn, 1994; Thiffault and Bergeron, 2003). SDLP is calculated as a standard deviation of the average lateral position and corresponds to the amount of weaving in the car and increases in SDLP may ultimately result in the lane

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crossing into the road shoulder and adjacent traffic lane. 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 lane position. Speed adjustment from the posted speed limit will result in speed deviation. Therefore, the primary dependent variables for this investigation were volunteers' SDLP measured from simulated driving vehicle, steering angle variability and speed deviation.

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. Methods

2.1. 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/m^2. One week prior to a laboratory experiment, volunteers were required to maintain their normal amount of sleep (between 7 and 9 h) and keep a normal sleep schedule. Therefore, they were asked to keep a sleep diary of when they go to sleep at night and wake up each day. All volunteers were screened before the day of experiment using Pittsburgh Sleep Quality Index (PSQI) to measure the sleep quality (Buysse et al., 1989). Volunteers who showed poor sleep quality index (PSQI > 5) were excluded from the investigation.

2.2. Ethical considerations

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 Fig. 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 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. 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 for each volunteer has been done in accordance with ISO 2631-1 (1997) International Standards (1997). The total transmitted vibration was measured both from the vehicle's seat-back 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.

Two tri-axial accelerometer pads (SVANTEK SV-38V model) were used to measure the total transmitted vibration to the human body located at the seat cushion and the seatback (Fard et al., 2014). 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 (W_k, W_d, W_c) and multiplication factors (Table 1) to calculate the total frequency-weighted transmitted vibration. The weighting curves (W_k, W_d, W_c) given in Table 1 were from ISO 2631-1 (1997) International Standards (1997). 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 (Griffin, 1990). The multiplication factors (Table 1) were used to weight the effects of seatback and seat cushion vibrations (Griffin, 1990; M. Amzar and Fard, 2013; Fard et al., 2014).

2.4. Drowsiness measurement

2.4.1. Objective measure (Simulated Driving Test)

Volunteers were tested on the York driving simulator software (York Computer Technologies, Kingston, Ontario, Canada) as shown in Fig. 2. The simulator has been determined to be an ecologically valid research tool to measure psychomotor performance related to driving (Arnedt et al., 2005; Chung et al., 2005). 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 primary instruction for volunteers are:

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

Outcome variables measured by the simulator included (a) standard deviation of lateral position (SDLP) (b) speed deviation and (c) steering angle variability. The variation in these three outcome measures shows how well the volunteers able to conduct the test according to this instruction.

2.4.2. Subjective measure (Karolinska Sleepiness Scale-KSS)

Subjective drowsiness level was assessed using Karolinska Sleepiness Scale (KSS). KSS is a self-reported and subjective assessment of sleepiness that measures changes in sleepiness level at the time (Gillberg et al., 1994). It is a 9-point Likert scale varied from 1 = extremely alert, 2 = very alert, 3 = alert, 4 = rather alert, 5 = neither alert nor 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. KSS has been widely