ORIGINAL ARTICLE

SUITABILITY OF DRIVING SIMULATORS AS A TOOL TO STUDY DRIVING FATIGUE DUE TO VIBRATION AND ENVIRONMENT: A REVIEW

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ABSTRACT

Fatigue due to driving is an important aspect in maintaining drivers' performance and safety. There are many studies linking fatigue to reduction in performance and increase in accident risk. There are also some signs linking road and vehicle vibrations to fatigue, but this not been thoroughly investigated. Experiments have been made to detect and quantify levels of driving fatigue in human, usually involving driving over long distance of highway or normal roads. However, these methods are quite time consuming, high cost, hard to control and also potentially high risk. With the development of better display, computing power and motion technologies, driving simulators are becoming more and more realistic each year. With this insight, it is proposed that these driving simulators can be used as a tool to study human fatigue, where they can counter the above shortcomings significantly. This paper will review different methods conducted in past published works to investigate the viability and validity of using driving simulators as a tool for studying vibration matters and its effects on human fatigue. In this paper, there were twenty past studies have been reviewed in term of its simulator design and its study design. The selection is based on these keywords; simulator, fatigue, vibration, human and driver and all papers were filtered from 1990s to current year.

***Keywords**: Simulator, fatigue, vibration, human, driver*

INTRODUCTION

Fatigue can be characterized as both psychological and physiological effects on the human mind and body[1]. While many discussions have been made to how much the extent of former to the latter, the effect of fatigue while driving can cause serious issues in terms of decreasing performance and increasing risk of accidents.

One are that has not been thoroughly explored is the effect of vibration to driving fatigue. Vibration occurs when a vibrating object transmit vibration energy to a person's body. Drivers and passengers of cars are subjected to vibrations that are directly related to the characteristics of the vehicle and of the road surface. These vibrations are transmitted to the buttocks and back of the occupant along the vertebral axis via the base and back of the seat. In addition, the pedals and steering wheel transmit additional vibrations to the feet and hands of the driver. These vibrations, in combination with a seated posture, can produce a noticeable level of discomfort for both driver and passengers, especially during long journeys. In dynamic conditions, the vibrations from multiple sources are transferred to the driver through the seat. From the literature, Harrison et al.[2] concluded that the largest amplitude that affects the spine is at 4.75 Hz and the other two are the resonance frequency at 9.5 Hz and 12.7 Hz.

To this date, it is a time consuming affairs to do a measurement study on a real car on actual roadways, not to mention uncontrollable factors such as traffic and weather that will lead to repeatability issues. Furthermore, careful planning must be made to reduce all risks such as traffic accidents and vehicle failures while driving. Therefore, it is proposed that the present state of driving simulator technology makes it possible to manage or eliminate the negative factors, while at the same time, increase the repeatability and accuracy of the data gathered.

This paper will review different methods conducted in past published works to investigate the viability and validity of using driving simulators as a tool for studying vibration matters and its effects on human fatigue. In this paper, studies related to vibration and driving simulators will be gathered, then the findings will be presented to show the capabilities of modern driving simulator to be an economical in both time and resources, safe and repeatable tool to be used to study fatigue and vibration on drivers.

METHODS

A list of English articles was compiled from Science Direct and Google Scholar. Simulator, fatigue, vibration, human and driver were the main keyword search terms for this paper. In addition, a secondary search was performed by using bibliography of retrieved articles in order to support the first retrieved paper.

The literatures were filtered from 1990s to current year only. In this paper, there were twenty past studies have been reviewed in term of its simulator design and study design (subject, duration, and methods). Reason for selecting these papers is because there are many issues that can be compiled and gathered in the driving simulator studies related to fatigue and vibration on drivers. Furthermore, each study provide different aspects of simulator features and purpose, therefore, it can be references and basic guidelines for the researchers to develop their own simulator in their studies. In addition, the main objective of this paper to investigate the viability and validity of using driving simulators as a tool for studying vibration matters and its effects on human fatigue.

RESULTS AND DISCUSSIONS

There has been substantial research carried out by using simulator in the fatigue studies. All these studies resulted in the subjects feeling the simulator as being close to driving a real vehicle and are able to reproduce vehicle speeds closer to the real world. The main contributor to these results are the amount of Front Of View (FOV), which is in degrees, the force feedback on main vehicle controls (steering, pedals and gear lever), high optic flow of the scenarios, and the vibration data of the vehicle.

While the sixDegree of Freedom (DOF) motion base certainly will enhance the realism of the drive, it is felt that for the study of driving fatigue and vibration induced fatigue is not essential. This is due to the fact that most fatigue inducing driving scenario consist of continuous highway with little traffic and corners, which translate into little sideways movement and small acceleration and deceleration magnitudes[3]. However, for vibration related fatigue studies, the simulator should be equipped with additional hardware to vibrate the cabin so that road and engine vibration can be reproduced, and the critical low frequency vibration of 4.75 Hz, 9.5 Hz and 12.7 Hz can be investigated. It can be referred as a simulated shaker.

The present state of driving simulator technology makes it possible to implement the prediction of actual driving conditions towards human factors. Table 1 (from Table 1a to Table 1c) shows all the fatigue studies conducted on a driving simulator of varying setup and complexity. Based on Table 1, majority of the past studies had measured driver's performance in the entire of driving condition. It is due to the fact that driving performance can be captured easily by using simulator, by calculating steering wheel variability.

As mentioned by Svensson[17], steering wheel variability increases with the amount of drowsiness. The steering movements become larger and occur less often as the driver gets drowsier. On the other hand, if using the actual car on the actual road condition, an additional equipment such as electrooculography (EOG), and electroencephalography (EEG)need to be setup and take quite a long time to install and analyse it.

In addition, it is an advantage when using simulator or do a field works in the laboratory due to the researcher can control the environment and it is less hazardous[4]. By using a driving simulator, all the seasonal timing, day/night cycles and weather conditions can be recreated easily.

The road models and traffic behaviors can be modified according to the desired study parameters. Vehicle dynamics and road vibration can be programmed into the scenario. All the hazards and accidental risks associated with driving on an open road and highways can be eliminated. In a fatigue study, where long and continuous driving experiments are expected, all these positive attributes can be attained by using a driving simulator. All in all, a driving simulator, set up properly and validated, can be an indispensable tool in studying human fatigue to driving and vibration, due to its ability to lower time, resource, unpredictability and risk in a compared to actual road experiments.

CONCLUSION

With all the advancement in display, motion and processing technology, modern driving simulator are capable of recreating realistic driving experience. Subjective questionnaire, validation methods and experts review have resulted in subjects feeling “equal to real vehicle” while using these driving simulators. Based on these results, human responses data obtained from the usage of motion simulators are approaching closer and closer to the data from actual road driving. This is especially useful in human fatigue studies due to vibration, where long driving hours are needed to set the fatigue symptoms.

By using a driving simulator for studying drivers fatigue and vibration related fatigue, time and resources can be optimized, where the need to schedule for a drive session for the suitable weather and time of the day can be eliminated. Hazards and accident risks can be eliminated. Repeatability in experiments can be achieved. In short, driving simulator can be an indispensable and validated tool to study human fatigue and vibration related fatigue while driving. It can produce some scene similar to the actual road condition under controlled environment. It is very useful to investigate driver's behavior for variety of driving condition[16].

Table 1a: Fatigue studies using driving simulator

Ref	Simulator design/scenario	Study design
Jagannath& Balasubramanian[5]	The static driving simulator comprises of steering wheel with force feedback, gear shift lever, foot pedals and a projection of the driving environment for visual feedback.	Subjects: 20 Duration: 1 hour Methods: EMG, EEG, HR, seat interface pressure, blood pressure and oxygen saturation level
Shiomi et al.[6]	Ten hour railway operation simulator test for three days. All subjects were required to perform 12 minutes train driving exercised carried out over two days.	Subjects: 12 Duration: 10 hours Methods: others (spoken voice)
Trutschel et al.[7]	Overnight experiments in the real car driving simulation lab in the University.	Subjects: Not available Duration: 40 minutes driving Methods: EEG, EOG, performance, eye, subjective method (KSS)
Antonson et al.[8]	Using real car body Volvo 850. The landscape is projected on three large film screens and in three rear-view mirrors, and there is a simulation of road surface contact noise and vibration. Inside the car, several video cameras monitor the driver.	Subjects: 18 Duration: 10 km (training) and 35 km (experiment) Methods: performance, subjective method
Arora & Grenier[9]	WBV simulator (with car race game setup by using desktop computer, installed in-front of the simulator)	Subjects:10 Duration: 45 minutes Methods: EMG
Dixit et al.[10]	Driving simulator (with 180° view using a three-channel plasma screen with an immersive driving environment)	Subjects: 132 Duration: 90 minutes Methods: performance
Merat& Jamson[11]	The simulator consists of a Jaguar S-type cab, associated control loading (steering, brake and accelerator), a nine-channel 300° field-of-view projection system, a 4 m diameter simulation dome (rigid glass-fibre construction) and a large amplitude eight degree-of-freedom motion.	Subjects:33 Duration: Not available Methods: eye detection, performance, questionnaire
Ronen & Yair[12]	A Systems Technology Incorporated-Simulator (STI-SIM) fixed-based driving simulator was integrated into a full-size passenger car, providing the driver with the look and feel of driving a real car. The visual display of the road was projected on a 3m x 3m screen at a distance of 3m from the driver's eyes, providing a true horizontal field of 40^0 on a scale of 1:1. In the simulator car, on the right side of dashboard, a 12 in. touch screen was placed in order to record the driver's subjective level of adaptation.	Subjects:45 Duration: 30-40 minutes Methods: EOG, HR, subjective method

Table 1b: Fatigue studies using driving simulator

Ref	Simulator design/scenario	Study design
Auberlet et al.[13]	The study was conducted using the National Institute for Transport and Safety Research Simulator (INRETS-MSIS SIM2) driving simulator, which is an interactive fixed-base driving simulator with a complete PSA-Citroen Xantia car (height: 1380 mm, width: 1755 mm). The driving simulator was positioned in front of three angled projection surfaces. The entire projection image produced a 150° (horizontal) × 45° (vertical) forward view of the simulated road- way from the driver's position, at resolutions of 1024 × 768 pixels (SIM2). The control devices were the steering wheel, manual gearbox and pedals (brake, accelerator and clutch) of the complete car. The dynamic vehicle model used in the driving simulator is based on the ARHMM (Advanced Road Handling Multi-body Model). The driving simulator provided haptic feedback from the steering wheel. Speakers around the car created Doppler effects to simulate the noise of on-coming traffic on both the driving simulators. Auditory feedback was provided when the simulated vehicle's wheels crossed the rumble strips on both sides of the centreline or the sealed shoulder.	Subjects: 42 Duration: Not available Methods: performance, questionnaire
Davenne et al.[14]	The fixed-base INRETS-MSIS SIM2 driving simulator was composed of a computer and a video-game steering wheel with no force feedback applied. The participant's head was placed at 60 cm in front of the screen. The resolution of the visual scene was 1024 × 768 pixels and the update rate was 60 Hz. The simulator presented a highway driving scene on a 19-in. screen.	Subjects:34 Duration: three types of driving duration; 2 hours short driving session (3-5 AM), a 4 hours intermediate driving session (1-5 AM) and an 8 hours long driving session (9 PM-5 AM) Methods: performance
Nilsson et al.[15]	An AETNA driving trainer was modified for monitoring ability to maintain accelerator pedal position so as to maintain an indicated speed of 60 km per hour. A small red light mounted in the middle of the dash stayed on when pedal pressure was kept within prescribed limits. A 40" x 48" curved video projection screen in front of the simulator provided a view of a road ahead that filled 20' of the driver's visual field. A 2.5 hour video tape showed the view seen while driving a scenic, paved, mountain highway with few intersecting roads and scarcely any buildings.	Subjects: 80 Duration: based on subjects feeling Methods: subjective methods (Fatigue Checklist)
Kawamura et al.[16]	Kitami Institute of Technology Driving Simulator (KITDS) driving simulator consists of 6-axis motion base with 138° FOV, 3D stereo sound. Actual road profile, vehicle motion and visual image from a vehicle is used and reproduced in the simulator.	Subjects: 50 (47 males, 11 females) Duration: 10 minutes practice, then complete the circuit. Methods: Questionnaire and measurement between actual and reproduced vehicle motion.
Svensson[17]	EOG data, recorded from 20 drivers in the Swedish National Road and Transport Research Institute (VTI) driving simulator.	Subjects; 20 Duration: Not available Methods: EEG, EOG, eye/face detection, KSS, OSS

Table 1c: Fatigue studies using driving simulator

Ref	Simulator design/scenario	Study design
Otmani et al.[18]	Poste d'Analyse de la Vigilance enConduite Automobile Simulee (PAVCAS) driving simulator consist of a front cabin car and linked to three interactive display units (sampling frequency 60 Hz, delay in generation of picture 40 ms). The road image was placed 2.50 m away from the driver and covered 108° of horizontal (3 screens of 36°) and 24° of vertical visual field.	Subjects; 20 Duration: Not available Methods: EEG, performance, others
Sung et al.[19]	The driving simulator used 3D graphics. The method involved projecting images possessing field-of-view of 30(H) x 25(V) at 30 frames/s onto an 80-inch real projection screen. The motion is comprised of 3-axes oil pressure	Subjects; 10 Duration: 2 hours Methods: performance, oxygen saturation
Wilson & Russell[20]	Simulator flights	Subjects; 9 Duration: Not available Methods: EEG, eye/face detection, performance, others
Biggs et al.[21]	A 1-h practice session was given on the driving simulator 1 week prior to the study. Driving trials were counterbalanced to control for order effects. Thirty-minute sessions were chosen to eliminate confounding effects of boredom in the control condition.	Subjects: 12 Duration: 30 minutes Methods: performance, others
Kee et al.[22]	A custom made driving simulator system with modified vehicle instruments and controls. A video screen was installed and projected with a 32 inch LCD screen television located about 1 meter from the driver. The display unit reproduced town area, trunk road and motorway scenery with computer-generated pictures simulating daytime and night time driving condition. A total of 5 laps driving journey (each lap = 50 km) was simulated with different scenarios.	Subjects: 25 Duration: 3 hours Methods: EEG
Gastaldi et al.[23]	Experiments were conducted with the fixed-base driving simulator of the University of Padova. The simulation system includes a realistic cockpit equipped with a Dolby Surround® sound system, three networked computers, and five high-definition screens. This configuration can produce realistic virtual views of the road network and the surrounding environment.	Subjects:10 Duration: 40 minutes Methods: performance, others
Hallvig et al.[24]	The car body consisted of the front part of a Volvo 850 with a manual 5-shift gearbox. Noise, infrasound and vibration levels inside the cabin corresponded to those of a contemporary car. There were three channels of forward view of 120°× 30° from the subject's position in the simulator. A road stretch of 9 km had been sampled from the road that was used for the real driving experiment and this was looped in the simulator experiment.	Subjects: 10 Duration: 60 and 90 minutes Methods: EEG, performance, others

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