Evaluation of a Motion Seat System for Reduction of a Driver's Passive Task-Related (TR) Fatigue

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A passive task-related (TR) fatigue that occurs monotonous driving environment can degrade driver's alertness and performance, thereby impairing driving safety. This study evaluated the driver's passive TR fatigue reduction effect of the motion seat system in terms of driving performance, physiological response, and subjective fatigue. 17 Korean drivers (6 females and 11 males) measured the driving performance (standard deviation of lane position, SDLP; break reaction time, BRT), percentage of eye closure (PERCLOS), and standard deviation of NN interval (SDNN) of the ECG during simulated driving for 90 minutes on a monotonous highway. The evaluation of the driving consisted of the first half (45 min) and the second half (45 min), while static seat condition in the first half and seat motion (bow, wave motion profile) condition in the second half. During static seat condition driving, SDLP, BRT, and PERCLOS were significantly higher ($\alpha = .05$) in the second half compared with first half by 6.0 cm, 92.8 msec and 1.3%, respectively. However, there was no significant difference between first half and second half under motion seat conditions. In addition, subjective passive mental fatigue was observed to be 1.2 times lower during motion seat conditions than static seat condition ($p < 0.01$). The results of this study indicated that motion seat system have some effect on the driver's passive TR fatigue reduction. Our findings may not extend to on road driving condition because we tested only simulation driving condition. Therefore, effect of motion seat system on driver's passive TR fatigue need to be evaluated in future studies under real road condition.

INTRODUCTION

Driver fatigue has been considered as one of the major cause of road accidents. According to statistics, driver fatigue is the largest contributor to the highway traffic accidents, which has been estimated to be involved in 2%–23% of all crashes (Li et al., 2010). In the USA in 2007, fatigue was implicated in at least 18% of fatal accidents and accounted for about 7% of all accidents (Smart Motorist, 2008). In England, up to 20% of serious road accidents is caused due to fatigue (The Royal Society of the Prevention of Accidents, 2001). Moreover, due to the difficulty of assessment of the exact number of fatigue-related collision, these numbers are still conservative estimation (Fu et al., 2016).

A passive task-related (TR) fatigue that occurs the monotonous driving environment can degrade driver's alertness and performance, thereby impairing driving safety. The exogenous factor that causes driver fatigue is driving task and driving environment. These factors include the road environment, the driver's familiarity with the driving environment, and the complexity of the driving task (Fletcher et al., 2005). Desmond and Hancock (2001) suggest that driver fatigue can be produced by active or passive task-related (TR) fatigue. Active TR fatigue is derived from continuous and obligatory high perceptual-motor demands. On the contrary, passive TR fatigue is produced when a driver is mainly monitoring the driving environment over an extended period of time when most or the entire actual driving task is automated.

Various techniques have been developed to detect and warn the driver's fatigue, but there is a limit to preventing fatigue. For example, a rumble strip designed by putting grooves on a road surface has the effect of awakening the driver by generating vibration and noise in the vehicle when the vehicle leaves the road. Also, various in-car technologies can detect driver fatigue using sensors and provide warnings when driver performance fall below certain thresholds. Examples include technologies based on monitoring drivers' eye movements, which then warn drivers of their fatigue if their eyes are closed for certain durations. However, the challenge that still remains with such systems is that they cannot prevent driver's fatigue. Therefore, a motion seat system to prevent passive TR fatigue by providing proper stimulation to the driver through seat movement has been developed as a countermeasure, but the fatigue reduction effect needs to be objectively evaluated.

The purpose of the present study was to assess an effect of passive TR fatigue reduction responses in a static seat condition compared to a motion seat condition. The driver's passive TR fatigue reduction effect of the motion seat was analyzed in terms of driving performance, mental fatigue, and subjective fatigue.

MATERIALS AND METHODS

Participants

17 Korean drivers (6 females and 11 males) volunteered to participate in the present study. All participants had valid driving licenses and those having a history of musculoskeletal injuries, surgery, or any current symptom of pain or injuries were excluded from the study. The present study was approved by the institutional review boards at Pohang

University of Science and Technology (PIRB-2016-E047). After a signed informed consent was obtained from a participant, age and height of the participant were acquired.

Apparatus

The driving was conducted in a fixed based driving simulator, which was integrated into a realistic car (EQ 900, Hyundai-Kia Motors, Korea) that provides the look and feel of driving in a car as seen in Figure 1. The simulation includes vehicle dynamics, visual and auditory displays, and a driving performance measurement system. A PC-based seat control system was developed in the present study and integrated with electronic control unit (ECU) to control seat configuration. UC-win/Road ver. 10 (Forum 8, Japan) driving simulation S/W was used to create a monotonous driving scenario to induce driver's passive TR fatigue. The simulated driving scenario in this study was a highway 142 km long with few curves and low traffic volume.

An eye tracker and an electrocardiograph (ECG) device were used to measure the physiology of the participants. An eye tracker (faceLAB 5, Seeing Machines Inc., USA) was installed at the top of the dashboard of the driving simulator to measure percentage of eye closure (PERCLOS). Heart rate variability (HRV) was measured by attaching a heart rate sensor (DTS BioMonitor XPTM, NORAXON Inc., USA) near the left clavicle, right clavicle, and stomach of the participant. Finally, a visual analogue scale (VAS) was used to evaluate the overall fatigue, physical fatigue, mental fatigue, active TR fatigue, and passive TR fatigue of the participants.

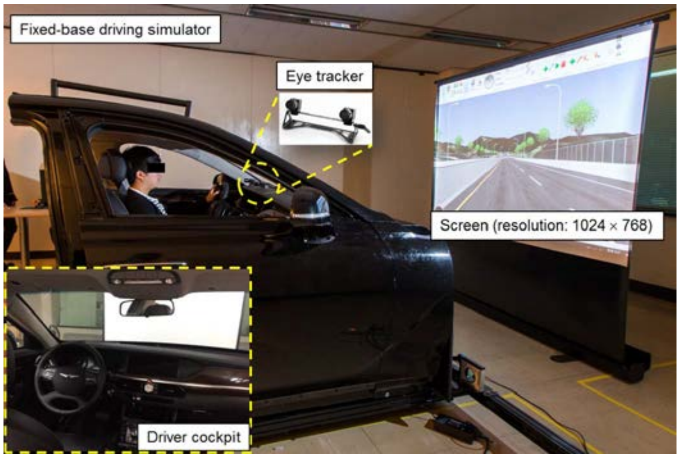

Figure 1. Fixed based driving simulator for evaluation of driver passive task-related fatigue

Seat Motion Profile

The present study developed seat motion profiles for preventing passive TR fatigue of driver. Our motion profile builds upon the dynamic models of stress and performance (Oron-Gilad et al., 2008) that the possibility of adding stimulus to the driver in order to allow the driver to maintain a comfortable stress level (Figure 2). Two types of motion profile (Bow and Wave) was developed by combining the seat back angle, seat pan angle, and lumbar support movement. The seat movements are in 1-minute intervals with changes in small (< 3°) motion. Initial seat positions are based on the driver's preferred seat configuration. Bow motion profile moves the seat in a similar manner to pulling a bow (the seat pan forward tilt with seat back recline). Wave motion profile moves the seat back and seat pan sequentially like waves (Figure 3).

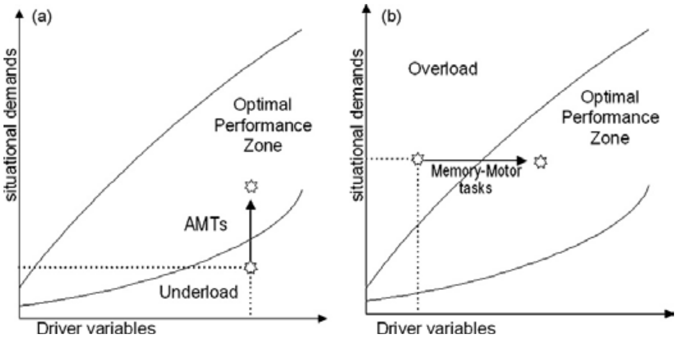

Figure 2. Countermeasures to fatigue in under load (left) and overload (right) situations (Oron-Gilad et al., 2008).

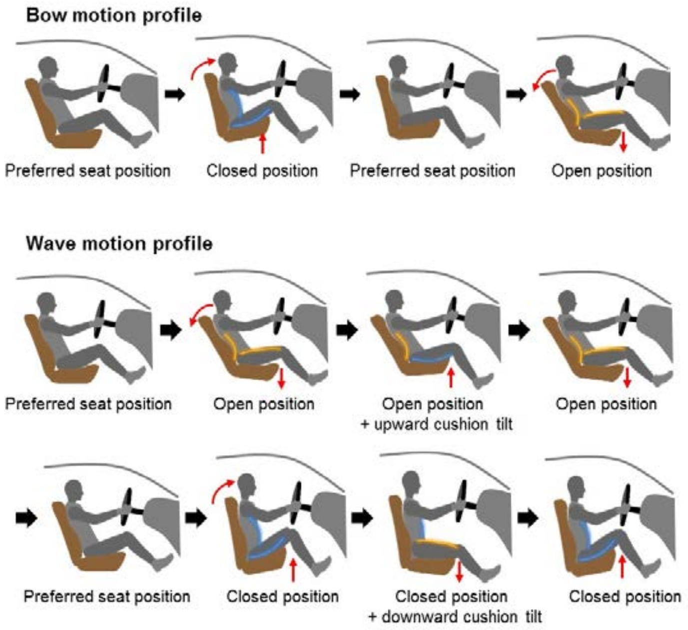

Figure 3. Bow and wave motion profile.

Experiment Procedure

Simulated driving experiment was conducted in two phases, preparation and main experiment phases. In the preparation phase, informed consents were obtained after explaining the purpose and procedure of the experiment. Subjects practiced driving in the simulator for approximately 10 min. While driving, subjects were instructed to maintain a driving lane and speed of 100 km/h.

In the main experiment phase, a driving experiment was conducted consisting of first half (fatigue induction session, 45 min) and second half (fatigue reduction effect evaluation session, 45 min). In the first half of experiment, the driving evaluation was performed without the seat motion, and the seat motion was provided in the second half (Figure 4). Brake reaction time (BRT) of the participant was measured in a total of 20 sudden situations during the driving. Subjective fatigue was measured before and after the driving. The evaluation was performed for static, bow, and wave for 3 days, respectively. The order of seat motion was randomized to eliminate the effects of the experiment sequence.

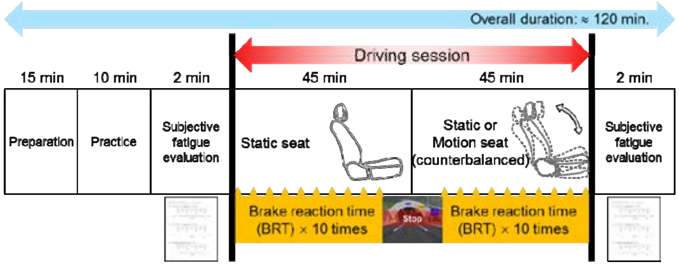

Figure 4. Experimental procedure

RESULTS

During static seat condition, driving performance measures were significantly increased in the second half compared with first half driving. SDLP was significantly increased by 6.0 cm under the static seat condition (F[1, 16] = 5.63, p = 0.03). In the motion seat conditions, SDLP was not found to be significantly different between first half and second half driving (p > 0.05; Figure 5). Similar to SDLP, the amount of BRT increment was significantly greater during static seat condition (92.8 msec) than motion seat conditions (Bow: 3.0 msec, wave: 16.6 msec). BRT was not significantly different between first half and second half driving under motion seat conditions (p > 0.05; Figure 6).

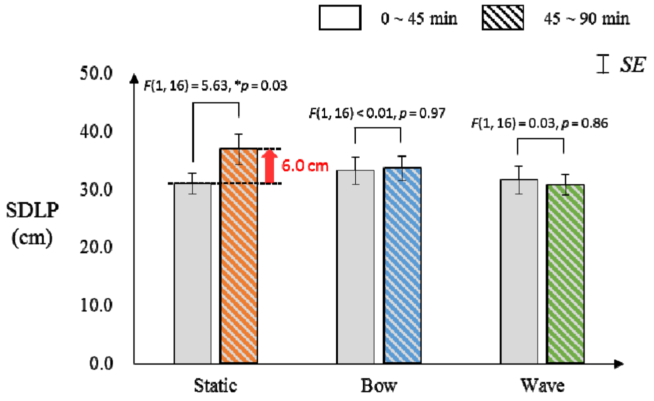

Figure 5. Standard deviation of lane position (SDLP)

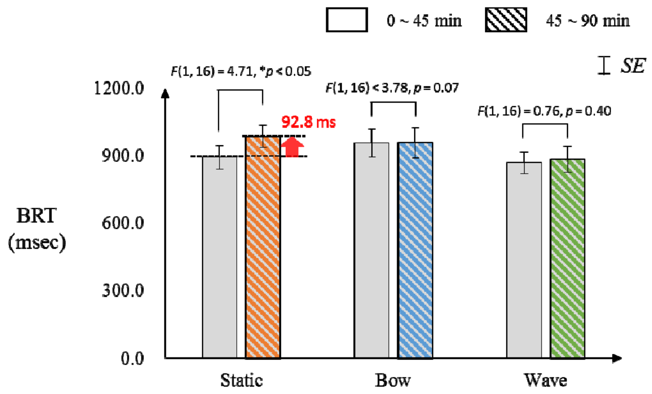

Figure 6. Brake reaction time (BRT)

PERCLOS was significantly increased by about 1.3% in the second half compared with first half under the static seat condition (F[1, 16] = 15.66, p < 0.03), but the bow and wave motion seat conditions had no significant difference (p > 0.05; Figure 7). SDNN showed no statistical difference between first half and second half in all seat motion conditions. Under the static seat condition, the observed SDNN increment was 24.4 msec, higher than that under the bow (4.8 times) and wave (7.6 times) motion seat conditions (Figure 8).

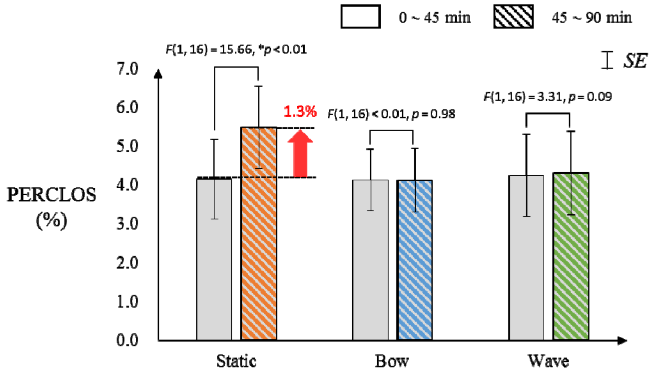

Figure 7. Percentage of eye closure (PERCLOS)

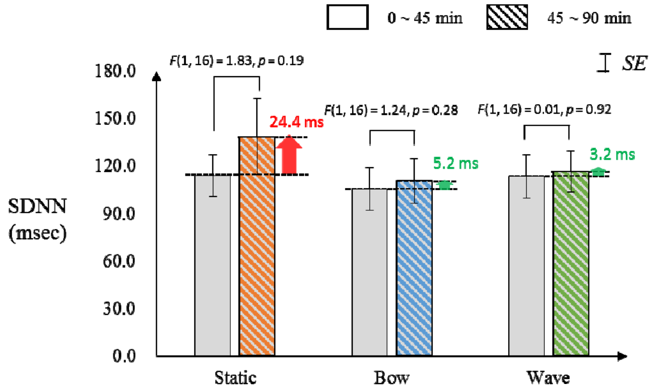

Figure 8. Standard deviation of the NN interval (SDNN)

After finishing driving, overall fatigue was increased to 152.9% in static seat, 133.5% in bow motion seat, and 87.3% in wave motion seat as compared with before driving. Furthermore, physical and mental fatigue were increased in all seat motion including static seat condition. Nevertheless, increase rate of physical and mental fatigue was not significantly different between seat motions. In the static seat condition, increase rate of passive mental fatigue was 1.2 times smaller than the motion seat conditions (*F*[2, 32] = 21.01, *p* < 0.01; Figure 9), while increase rate of active mental fatigue was not significantly different by seat motion (*F*[2, 32] = 1.35, *p* = 0.27; Figure 10).

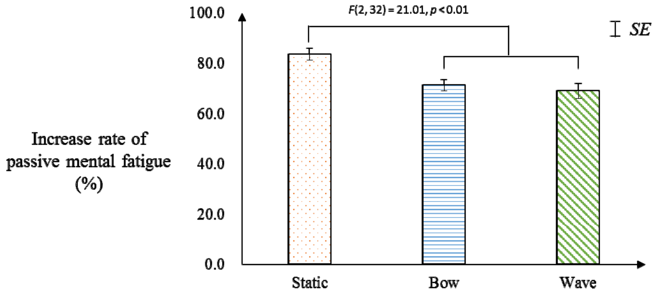

Figure 9. Increase rate of subjective passive mental fatigue

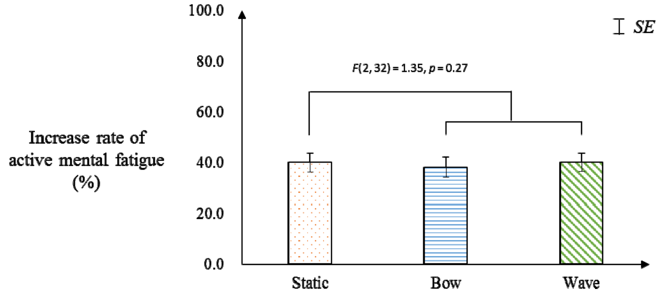

Figure 10. Increase rate of subjective active mental fatigue

DISCUSSION

In this study, the motion seats reduces the driver's passive TR fatigue in terms of driving performance, mental fatigue, and subjective fatigue. The motion seats has the effect of reducing BRT and SDLP by 9.3% and 20.1%, respectively, compared to the static seat in driving performance. BRT was maintained in the bow and wave motion seats but increased by about 92.8 ms in the static seat. Such an increase in the BRT implies that the risk of traffic accidents can be elevated in a sudden braking situation by increasing the braking distance about 3.0 m when driving at 100.0 km/h. In addition, 6.0 cm increase in SDLP under static seat condition indicated that stability of the vehicle was decreased. Similarly, Thiffault and Bergeron (2003) reported that frequency of over-correction of the steering wheel was increase about 20% under monotonous driving environment.

In the motion seat conditions, SDNN was increased about 12.6% compared to the static seat and this could increase the alertness of the driver. SDNN was increased about 24.4 ms in the static seat because the heart rate variability was increased about 4.7 ~ 7.6 times compared to the motion seats. In general, heart rate variability decreases as driver mental workload increases (Oron-Gilad et al., 2008; Ahsberg et al., 2000). Therefore, motion seats used in this study are presumed to maintain the appropriate level of stress by providing stimulation to the driver. PERCLOS is direct measure of the degree of eye closure and is used as an effective measure for fatigue evaluation and analysis (Dinges and Grace, 1998; Lal and Craig, 2001). In this study, PERCLOS was increased by about 1.3% in static seat, but there was no significant difference in PERCLOS between first half and second half driving under the motion seat conditions. Also, increase rate of passive mental fatigue of static seat condition was 1.2 times smaller than the motion seat conditions, while increase rate of active mental fatigue was not significantly different by seat motion. Therefore, driving fatigue has been caused by a driving environment rather than a driving task.

The motion seat system can be used to reduce the passive TR fatigue that can occur in partial autonomous driving. Partial autonomous driving may reduces the risk of traffic accidents by decreasing cognitive workload of driver. However, previous simulation studies revealed that an activation of partial autonomous driving cause about 60% of considerable increase in subjective fatigue (Saxby et al., 2008), thus increasing BRT about 350 msec by reducing the ability to cope with the sudden braking situation (Young and Stanton, 2007). Furthermore, Korber et al. (2015) reported that the driver's pupil diameter and blink frequency increased when SAE 3-level partial autonomous driving continued, which could mean that the driver’s passive TR fatigue was increased.

The limitation of this study is that we did not verify the effect of motion seat system on driver’s passive TR fatigue under real road condition. Although the fatigue reduction effect of the motion seat was evaluated by the simulation driving, there are various factors that cannot be expected in the simulation experiment when driving a real vehicle, such as the driving environment factors (road environment, nearby vehicles) and the driver factors (age, sex, distraction). Therefore, the effectiveness of a motion seat system needs to be quantitatively analyzed under real vehicle conditions.

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