Evaluation of the Relationship between Comfortable Arousal and Driving Performance using Physiological Data

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Abstract: Driver's comfort and arousal states are related to driving. Drowsiness due to decreased arousal may lead to an inability to perform the cognition, prediction, judgment, and operation necessary for driving. On the other hand, drivers with negative emotional states such as anger are reported to have reduced driving performance. Therefore, monitoring the driver's comfort and arousal states is necessary for safe driving. Many studies have evaluated driver's comfort and arousal using physiological data. However, the comfort and arousal by physiological indexes correlated to driving performance have not yet been evaluated. This study aims to evaluate driver's comfort and arousal using electroencephalograph (EEG) and heart rate variability (HRV) indexes and to investigate their relationship with driving performance. We used a driving simulator to conduct experiments comparing between the conditions with and without music as stimuli on a monotonous driving course. Driving performance was evaluated using driving situation awareness and lane deviation. The results show that drivers responded more quickly to the warning signs and had reduced lane deviation when using music to evoke comfort and arousal.

Keywords: comfort, arousal, driving performance

1. Introduction

Many surveys, studies, and reports suggest that drowsiness is one of the major human factors that cause traffic accidents [1]. Drowsiness impairs driving performance, such as vehicle control, which results in a crash and fatalities. Powell et al. suggest that sleepiness can impair driving performance much or more than alcohol [2]. Thus, it is necessary to monitor the driver's arousal state, wake up when the driver becomes drowsy, and maintain the arousal level to be high enough to satisfy the driving.

However, increasing and maintaining arousal levels can cause discomfort and negative emotions to drivers. Driver's emotional state affects driving performance. Several studies indicate that negative emotional states such as anger and sadness affect driving safety [3-4]. H. Cai et al. compared driving performance with three emotional states (angry, excited, and neutral) [3], and reported that drivers had poorer lane control ability in the angry and excited states. Zimasa et al. examined the influence of sad, neutral, and happy moods on driving safety using hazard perception videos and an eye tracker [4], and suggested that a sad mood affected drivers the most, with the longest hazard response times, and the effects of a happy mood were less clear. Based on Russell's research, emotions are distributed in a two-dimensional circumplex space; valence and arousal [5]. Arousal ranges from calming to exciting, whereas valence ranges from positive to negative. In this study, we define valence as a comfort level. Different comfort levels lead to different emotional states. Therefore, it is important to consider comfort while improving the driver's arousal level for safe driving.

Several studies focus on increasing the driver's arousal from drowsiness to high or maintaining high arousal. However, few studies focused on both comfort and arousal in driving [6]. Moreover, it is unclear how positive emotion affects driving performance [4]. Therefore, this study focuses on the driver's high arousal and comfort state and define this state as a comfortable arousal state. Since physiological indexes can use to estimate arousal and comfort state, we employ them to investigate the effect comfortable arousal state on driving performance using physiological indexes.

2. Experiment

2.1 Experimental setup

This experiment aimed to investigate how comfort and arousal affect driving performance. The experiment was conducted in a low-complexity traffic environment and on a monotonous road which evokes drowsiness. Participants were asked to drive with music and no music stimuli that evoke comfort and arousal. Participants choose music stimuli before the experiment to evoke both comfort and arousal based on a driving simulator (Logitech G29 Driving Force Steering Wheel & Pedals and UC-win/Road by FORUM8) was used in this experiment (Fig. 1(a)). The UC-Win/Road simulation software was used to build the simulation models which is a straight two-lane divided highway (Fig. 1(b)). The scenario includes a typical driving environment on the highway. Each participant was asked to follow speed limits of 125 km/hour and comply with traffic laws throughout the experiment. During driving, a warning sign will randomly display on the road within 60 to 90 seconds.

(a) (b)

Fig. 1 (a) driving simulator, (b) driving scene

2.2 Data collection

Heart rate variability (HRV) data were collected and used to

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calculate HRV indexes for estimating mental comfort. We employed pNNx, RMSSD, CVNN, and SDNN as comfort indexes. The pNNx indexes are the proportion of successive NN (R-R) intervals that differ by more than x ms (where x is 10, 20, 30, 40, 50). The higher pNNx, RMSSD, CVNN, and SDNN indicates the higher comfort level.

EEG signal is classified into several bands based on the frequency, including δ, θ, α, β, and γ. θ is related to drowsiness, α represents relaxation, and β corresponds to alertness. Generally, θ, α, and β are used as indexes to estimate arousal levels. We employed β/α, θ, α, and β wave appearance rates as arousal indexes [6]. The higher β/α and β wave appearance rate indicates the higher arousal level.

We used driving situation awareness and lane deviation to evaluate driving performance. Lane deviation represents lateral wobble. Driving performance data were automatically logged in the driving simulator. These data includes (1) offset from lane center (offset from the center of the vehicle to the center of the road in meters) and (2) situation awareness using response time (response time for a warning sign).

2.3 Participants and experiment procedure

Seven students participated in the experiment. They have very little (less than two months) or no driving experience. Before the experiment, the participants listened to an explanation and answered a questionnaire about their favorite music that can evoke comfort and arousal. Then, the participants wear the sensors. We used an EEG sensor (NeuroSky Mindwave Mobile 2) and a pulse sensor (World Famous Electronics llc.) to measure EEG and heart rate variability. After that, participants practiced driving until they became familiar with the operation of the driving simulator. Then, the experiment procedure is as follows: (1) Participants rest for 1 minute. (2) They started driving according to a driving scenario. After taking 3-minute rest, participants repeated steps (1)-(2) with the condition of listening to the pre-selected music while driving.

2.4 Experimental Results

A paired samples t-test was performed to compare the physiological indexes between music and no music condition. As a result of the comfort indexes, there was a significant difference in CVNN for music (M=0.07, SD=0.03) and no music condition (M=0.06, SD=0.02); t(6)=-3.34, p=0.015 and a significant difference in SDNN for music (M=53.26, SD=18.56) and no music condition (M=43.90, SD=12.14); t (6)=-2.98, p=0.025. As a result of the arousal indexes, there was no significant difference in any EEG indexes. However, some indexes have higher values during music than no music conditions. For example, θ wave appearance rate has no significant difference for music (M=0.48, SD=0.06) and no music condition (M=0.43, SD=0.06); t(6)=-2.375, p=0.055. These results suggest that music affects driver comfort. Moreover, comfort indexes (CVNN, SDNN) and arousal indexes (θ wave appearance rate) have a higher average value in music conditions. Therefore, with the music condition, drivers feel more comfort and arousal than no music conditions.

The results for situation awareness are shown in Fig. 2. The results suggest that the reaction time for warning signs was slower in no music conditions than in music conditions. These results indicate that comfort and arousal from music conditions positively affected driving situation recognition.

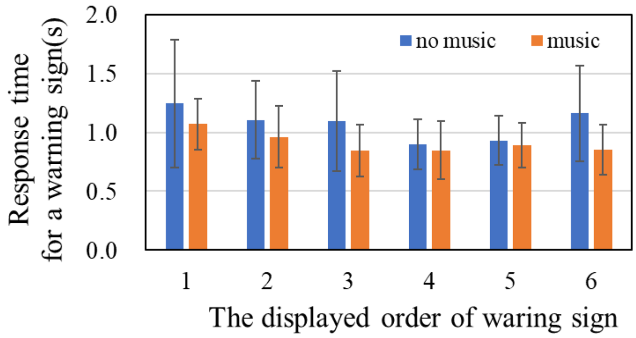

Fig. 2 Response time for a warning sign

In addition, the results for lane deviation are also shown in Fig. 3. The results suggest that no music conditions had greater lane deviation than music conditions. Thus, the comfort and arousal conditions with music also positively affected lane controls.

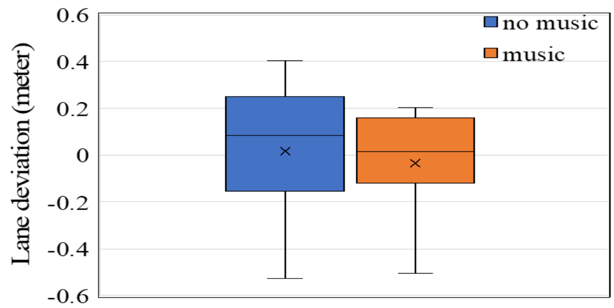

Fig. 3 Lane deviation (meter)

3. Conclusion

This study examines the effect of comfort and arousal on driving performance using physiological indexes. The physiological indexes results show that the music stimulus chosen by the participant can evoke a comfortable arousal state. A comfortable arousal state positively affected situation awareness by reducing response time for a warning sign. It also positively affected lane control ability by reducing lane deviation.

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