Influence of Brightness and Traffic Flow on Driver's Eye-Fixation-Related Potentials

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Abstract. This paper investigates the influence of environmental factors and driver distraction on the eye-fixation-related potential (EFRP) of drivers. Brightness and traffic conditions were set up as environmental factors in experiments using a motion-based driving simulator, and several cognitive tasks were given simultaneously to the participants while they simulated driving. The results of this experiment show that brightness and traffic flow do not affect the EFRP. This shows that EFRP is a stable index of driver distraction.

Keywords: Electroencephalogram, Eye-fixation-related potentials, Distraction.

1 Introduction

In Japan, over 770,000 traffic accidents are reported per year [1]. About 31% of all traffic accidents are rear-end collisions. Driver-related factors in rear-end collisions include drivers taking their eyes off the road, drowsiness, inebriation, sudden illness, improper vision day dreaming, and speeding [2]. To decrease the number of car accidents, it is important to develop a safe-driving support system that can judge whether the driver is in a suitable state.

In this paper, we focus on driver distraction, which is a major factor in rear-end collisions. A distracted state is defined as a situation in which the driver's attention is focused on non-driving tasks such as conversations or thinking, and the driver is not paying sufficient attention for safe driving.

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Eye-fixation-related potentials (EFRPs) have been proposed as an index for levels of visual attention. An EFRP is a kind of electroencephalogram (EEG) potential that is elicited after the end of a saccadic eye movement. When an eye fixation begins, positive amplitude is observed for around 100 ms around the back of the head. This positive amplitude is called a lambda response, or P100. The amplitude of a lambda response increases according to the level of attention paid to an object [3], [4].

Some studies have reported the assessment of driver distraction levels based on EFRP. Nakada et al. [5] reported the influence of driver distraction and road situations (intersections and straight roads) on EFRP. During a complex driving situation, there is a difference in peak amplitude of the lambda response between the driver's attention levels. Yagi et al. [6] reported that illuminations increase the amplitude and delay the latency of the lambda response in dark conditions. However, the influence of road brightness, such as during day and nighttime, as well as traffic flow, is not clear.

The purpose of this study is to clarify the influence of brightness and traffic flow on EFRP. A series of experiments using a driving simulator (DS) were conducted, and the results showed the stability of EFRP as an index of distraction.

2 Methods

2.1 Main Task and Subtask

A dual-task paradigm is used for examining states of distraction while driving. A main task and subtask are given to the participants concurrently. The main task is driving, and the subtask is a cognitive activity.

Driving Task. An urban driving course was prepared, and the driver was allowed to accelerate freely within the speed limit. The driving course was made to simulate an existing city (Yokohama, Japan). The conditions of the course (congestion, number of turns, etc.) were set equally for each condition. Participants had to drive along the route using a car navigation system. Since the route was displayed only on the screen of the car navigation system without audio guidance, the participant had to check the screen periodically.

Cognitive Task. To distract the participants, question-and-answer tasks were given to the participants as cognitive tasks. The questions were designed for two difficulty levels. The more difficult questions were regarding declarative knowledge of geography, such as names of the prefectures in Japan, or names of countries beginning with the letter "A." This condition was set as a distracted state and required significant attention for thinking and memory recall. The easier questions were regarding personal information, such as the driver's name and age. This condition was set as a concentrate state as the participants could answer such questions without being distracted from their driving.

The recorded questions were presented by the experimenter. The participants were required to answer orally as soon as possible. Once the participant answered, or the experimenter judged that the question was too difficult to answer, the next question was presented.

2.2 Environmental Factors

Brightness. Two conditions, bright and dark, were prepared as the brightness factors. Luminance at the driver's eye position was measured using a photocell light meter.

Luminance under a bright condition was 40.0 lx, and 2.2 lx under a dark condition. Figures 1 and 2 show examples of the driver's view point.

Traffic Flow. Crowded and sparse conditions were prepared as traffic flow factors. Under a crowded condition, about eight moving objects, including cars, pedestrians and bicycles, were placed for 50 meters. Under sparse conditions, there were only two or fewer moving objects per 50 meters. Figures 3 and 4 show examples of the driver's view point.

Fig. 1. Bright condition

Fig. 2. Dark condition

Fig. 3. Crowded condition

Fig. 4. Sparse condition

2.3 Experimental Conditions

Table 1 shows the different experimental conditions. Six experimental conditions were set up based on a combination of cognitive task, brightness, and traffic flow conditions.

Table 1. Experimental conditions

		Cognitive task	
		Easy questions	Difficult questions
Environmental factors	Bright/ Crowded	Easy/Bright/Crowded	Difficult/Bright/Crowded
	Bright/ Sparse	Easy/Bright/Sparse	Difficult/Bright/Sparse
	Dark/ Sparse	Easy/Dark/Sparse	Difficult/Dark/Sparse

2.4 Measurements

Electrophysiological Recording. Electrophysiological data was recorded using a Polymate AP-216 (TEAC).

Electroencephalograms (EEGs). Electrodes were placed at six scalp locations (Fz, Cz, Pz, Oz, A1, and A2) according to the extended 10-20 system using sintered active electrodes. A2 was used as the initial reference for the recording, and the data were re-referenced to mathematically linked earlobes offline. A ground lead was placed at Fpz.

Electrooculograms (EOGs). A pair of electrodes was placed at the outer canthi of the eyes for a horizontal EOG. Another pair of electrodes was placed at the infra- and supra-orbital of the left eye for a vertical EOG.

Filters. EEGs and EOGs were recorded using a 0.05 Hz high-pass filter (for a constant time of 3 s) and digitized at 500 Hz.

Subjective Measures. Multiple subjective measures such as a simulator sickness questionnaire (SSQ) [7], NASA task load index (NASA-TLX) [8], and a questionnaire regarding the level of driving concentrations were used. The NASA-TLX measures the level of mental workload by using a questionnaire with seven options (min: 1 - max: 9). SSQ measures the level of motion sickness in the driving simulator through the questionnaire. A questionnaire on the level of driving concentration was also taken as a subjective index (min: 1 - max: 7). The participants were asked to fill out a NASA-TLX and concentration questionnaire after each experiment, and an SSQ after only the first and last experiments.

Behavioral Measures. Driving logs, such as speed and position, were recorded from the DS. The standard deviation of distance from the center line was used as an index of driving stability. The value is defined as the distance from the center line to the center of the car, and calculated only on a straightaway.

2.5 Participants

Twenty-two male university students who gave their written informed consent participated in the experiment (average age: 22.2 ± 1.5 years old). Each participant has a driver's license and drives a car on a regular basis; however, this was their first time driving in the DS.

3 Results

Data from sixteen of the participants (average age: 22.4 ± 1.6 years old) were analyzed, and the remaining six participants were excluded from the analysis due to recording errors and motion sickness.

3.1 Behavioral Measures

Figure 5 shows the mean value of the standard deviation in the distance from the center line. The horizontal axis indicates the condition, while the vertical axis indicates the mean value (unit: meter).

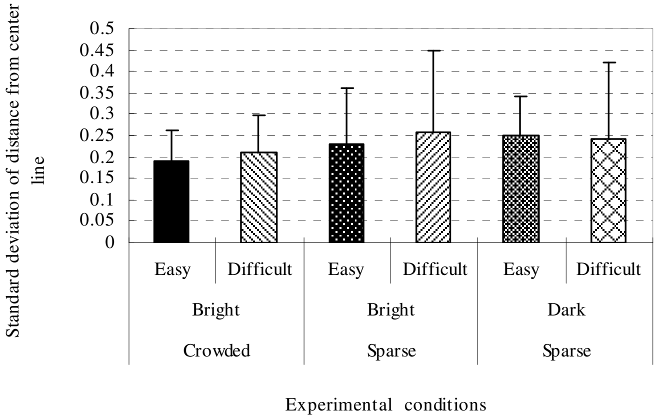


Fig. 5. Standard deviation in the distance from the center line

There was no significant difference among the conditions, as evaluated by Student's *t*-test. Driving behavior seemed to be fairly consistent. This suggests that driving behavior is not affected by cognitive tasks. The driver maintained more than the minimum attention level required to drive under each condition. This confirms that the driver's attention was well controlled during this experiment.

3.2 Subjective Measures

Level of Driving Concentration. Figure 6 shows the mean score of driving concentration. The horizontal axis indicates the conditions, and the vertical axis indicates the score at each level of driving concentration.

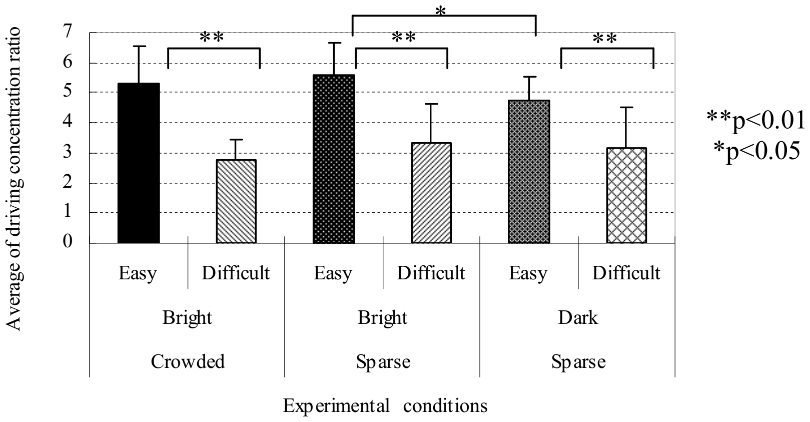


Fig. 6. Subjective scores for driving concentration

The scores were compared and analyzed for three differences using a T test: difficulty, brightness, and traffic flow. For differences in difficulty, the scores were high during easy conditions and low under difficult conditions. The scores were statistically different under easy conditions only. The scores were statistically different during each condition. These results indicate that driving concentration is affected by cognitive tasks, and that many participants cannot concentrate when driving under difficult conditions. For differences in brightness, the scores were higher under bright conditions, but the difference was slight during difficult conditions. The scores were statistically different during easy conditions only. For differences in traffic flow, the scores were low during crowded conditions. However the differences in score were slight between crowded and light traffic conditions. The scores showed no statistical difference.

NASA-TLX. Figure 7 shows a weighted workload (WWL), which is the score weighted by the NASA-TLX. The horizontal axis indicates the condition, while the vertical axis indicates the WWL score.

The WWL scores for the three differences listed above were also compared and analyzed using a T test. For differences in difficulty, the scores for easy conditions were lower than for difficult conditions. The scores were statistically different under each condition. These results indicate that driving concentration is affected by mental workload. For differences in brightness, the scores during dark conditions were a little higher than under bright conditions. The scores were statistically different during easy conditions only. For differences in traffic flow, the scores during crowded conditions were a little higher than during sparse conditions. The scores showed no statistical difference.

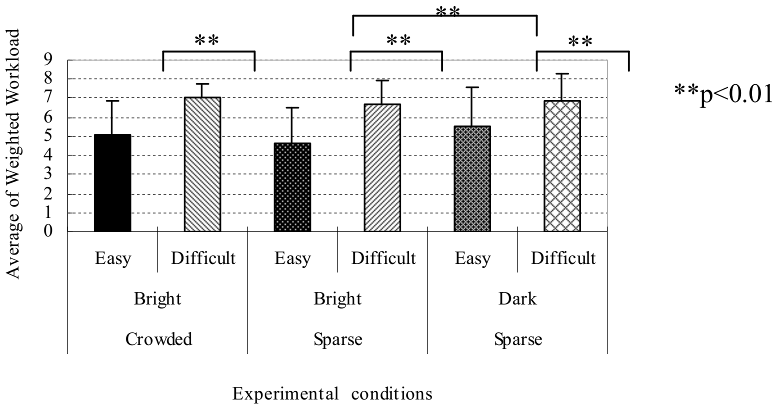


Fig. 7. WWL of NASA-TLX for each experimental condition

The results of these subjective measures show that driver attention is affected not by environmental factors but by driving difficulty.

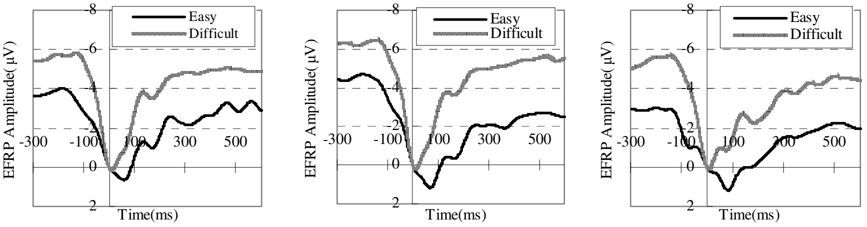
3.3 EFRP

An EOG that continues moving for 20–500 ms at over 3 mV/s is detected as a saccadic eye movement. The EFRPs were obtained by averaging the EEGs whose offsets were determined after the end of saccadic eye movements. The EFRPs were extracted from 300 ms before to 600 ms after the onset of a saccade end.

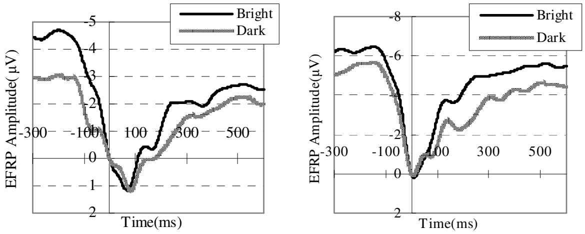
By evaluating the grand mean wave, we could exclude noises and artifacts (e.g., excessive eye blinking and muscle potentials). The EEG data at Oz were re-referenced mathematically by averaging A1 and A2 offline. A digital 1-15 Hz band-pass filter was also applied.

Because the participants could move their eyes freely during the experiments, the size and frequency of their saccadic eye movements were not equal. The baseline of the EFRP was aligned to the saccade offset amplitude at 0 ms to exclude the effects of eye movement.

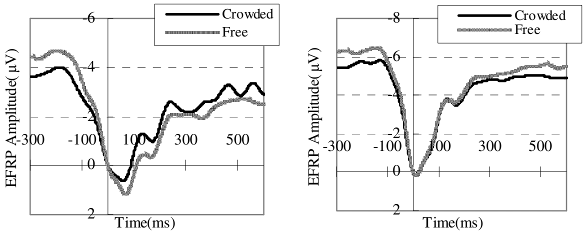
Figure 8 shows the grand mean wave of the EFRP for each condition. The horizontal axis indicates the time from the end of a saccadic eye movement, while the vertical axis indicates the amplitude of the lambda response from the obtained EFRP.



(a) Bright and crowded (b) Bright and sparse (c) Dark and sparse



(d) Easy and sparse (e) Difficult and sparse



(f) Easy and bright (g) Difficult and bright

Fig. 8. Grand mean waveforms of the EFRP under each condition

EFRPs were compared and analyzed using a T test for the three differences, difficulty, brightness, and traffic flow. Differences in difficulty are compared in Figures 8(a), 8(b), and 8(c). Brightness is compared in Figures 8(d) and 8(e), while traffic flow is compared between Figures 8(f) and 8(g). For differences in difficulty, the lambda response increases when the cognitive task is easy, and decreases when the cognitive task is difficult. The amplitude of the lambda response is statistically different under each condition ($p<0.05$, $p<0.01$, $p<0.05$). For differences in brightness, there is no significant difference in the lambda responses between bright and dark conditions. The amplitude of the lambda response shows no statistical difference. For differences in traffic flow, the lambda response under light conditions is larger than during heavy traffic flow during easy conditions. However, during difficult conditions there is no difference in the lambda response. The amplitude of the lambda response also shows no statistical difference.

As a result, the EFRP is affected not by environmental factors in this study but by difficulty only. This result is consistent with the subjective measurement results. This shows that the EFRP has a relation to driver attention. These results suggest that the EFRP is a sensitive index for detecting driver distractions, and is effective even when behavioral differences are not observed.

4 Discussion

Difficulty. For the dual-task paradigm used in this experiment, we requested the participants to engage in driving and cognitive tasks simultaneously. Therefore, the drivers were distracted while conducting difficult subtasks.

The lambda response for easy conditions is larger than for difficult conditions. Nakada et al. [5] reported that the amplitude of the lambda response decreases during high mental workload tasks (2-back cognitive tasks). The results in our study are consistent with their findings. This suggests that cognitive tasks, such as conversations requiring thought and memory recall, cause distractions and reduce driver attention.

Brightness. The amplitude of the lambda response is not statistically different among conditions of brightness. Yagi et al. [6] reported that the amplitude of the lambda response changes based on the brightness conditions, ranging from bright (500 lx, 1300 lx) to dark (5 lx) conditions. The bright and dark conditions in our experiment are 40 lx and 2.2 lx, which were chosen based on the restrictions of the DS. These luminance values are relatively small, and the difference in luminance is also small compared with [6]. Therefore, the level of luminance used in the DS may not be enough to affect the lambda response.

The level of driving concentration and NASA-TLX are affected by brightness during easy conditions only. Under difficult conditions, the driver cannot concentrate on driving when subjected to distractive subtasks. Conversely, under easy conditions, only little attention is taken away by the easy subtask, remaining enough attention for driving. As a result, the driver may react more sensitively to brightness in concentrated state.

Traffic Flow. For all amplitudes of lambda response, questionnaires regarding driving concentration and NASA-TLX showed no statistical differences among traffic conditions. Therefore, traffic flow does not affect driver distractions in this experiment.

The crowded conditions used in our experiment contained eight moving objects per 50 meters, which are usual conditions on urban roads. Additional experiments under more difficult traffic situations, such as unexpected vehicle movement or rushing pedestrians, are necessary to discuss the effects of traffic flow on EFRPs.

5 Conclusion

In this study, we examined how EFRPs are influenced by distractions, brightness levels, and traffic flow. We confirmed that the lambda response decreases when drivers lose concentration caused by thought and memory recall. We also showed that variations in luminance and traffic flow did not affect the EFRPs in this experiment. This shows the stability of the EFRP as an index for driver distraction, and how an EFRP may be used without considering environmental changes such as brightness and traffic levels.

As future work, we need to examine the effects of distractive environmental changes in further detail. Experiments under sunlight or harder traffic conditions should be conducted. We are also aiming toward a feasibility study by extending the attributes that may cause the driver distraction. For example, the separation of arousal and distraction is important for safe driving support.

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