# 特集 Drowsiness Detection Using Spectrum Analysis of Eye Movements and Effective Stimuli to Keep Drivers Awake*

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This paper presents a driving safety system based on a driving simulator. The system evaluates the driver's level of drowsiness by applying LF/HF analysis to the driver's eye movements. Drowsiness was detected by an increase of power in the low frequency band. When drowsiness was detected, stimuli were presented to raise the driver's level of awareness. Evaluation of stimuli has shown that stimuli involving active bodily motion, such as singing, chewing, and stretching muscles, are effective means of keeping drivers awake. Passive stimuli, such as listening to music, alarms, and lights produce a waking effect of shorter duration.

**Key words:** Drowsiness detection, Driving simulator, Eye movements, Lane deviation, Awakening stimulus, Awakening temporal duration, Physiological signals, Subjective drowsiness levels

## 1. INTRODUCTION

Driving with drowsiness is one of the main causes of car accidents. In order to prevent drivers from drowsy driving, there is a strong demand for safety driving systems. In this research, a safety driving system that detects driver's drowsiness before it leads to dangerous driving has been developed. This system consists of three parts; sensing, evaluation and stimulation (**Fig. 1**).

The sensing part monitors driver's physiological data and surroundings. The evaluation part determines whether the driver is drowsy or not. When the driver becomes drowsy, the stimulator is activated to awaken the driver. This system was combined with a driving simulator to evaluate drowsiness detection algorithm and effectiveness of the stimuli to keep the driver awake.

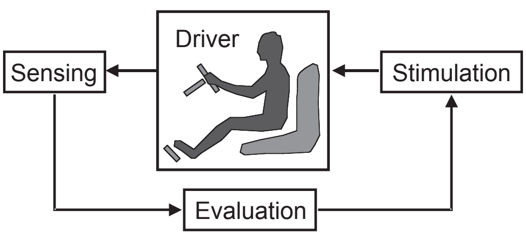


Fig. 1　Structure of the safety driving system

## 2. DRIVING SIMULATOR

A driving simulator was constructed with a complete set of a driving cockpit taken from a real car, including dashboard, steering wheel, seat, and pedals as shown in **Fig. 2**. A screen was placed in front of the driver's seat to show a computer-generated motion picture of a monotonous freeway driving (**Fig. 3**) that induces drowsiness to the driver.

## 3. SENSING AND EVALUATION

### 3.1 Drowsiness detection

Methods for detecting driver's drowsiness can be classified into two categories; a) analysis of drivers body motion such as head motion, and b) analysis of

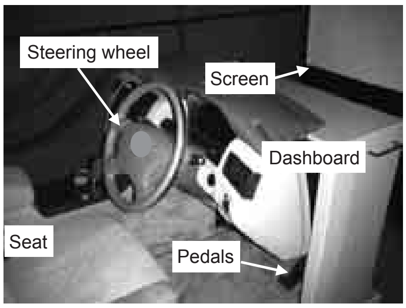


Fig. 2　Driving simulator

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Fig. 3　Monotonous freeway picture on screen

physiological data such as eye-blink rate and heart rate. When a driver becomes drowsy, the driver's head begins to sway or tilt and the car may drift off the course. These physical symptoms, however, become apparent only after the driver starts to doze off. On the other hand, physiological signals start to change in earlier stages of drowsiness. Therefore, physiological data is more suitable for drowsiness detection for prevention of dangerous driving.

Assuming that the lane deviation was a direct indication of drowsiness, we first measured correlations between lane deviation and the following physiological signals: pulse rate, ratio of low-frequency (LF) to high-frequency (HF) power from spectral analysis of R-R intervals of ECG, eye-movement measured by electro-oculography (EOG), body-surface temperature, skin resistance, and breath rate. The subject of this experiment drove the driving simulator for one hour.

We have chosen EOG for drowsiness detection because it showed the highest correlation with the lane deviation when LF/HF analysis was applied on EOG. The method of EOG is shown in **Fig. 4**. The permanent electric potential difference between the cornea and the retina generates

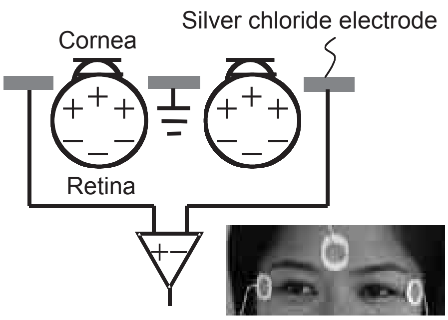
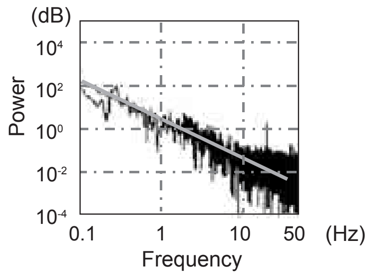



Fig. 4　The method of electro-oculography (EOG)

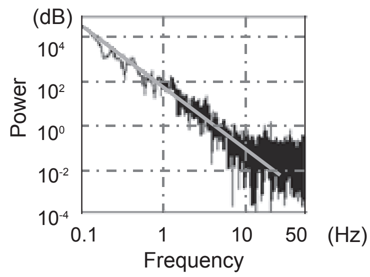
electrical field related to the orientation of the eyes in the surrounding tissues of the eyes. Horizontal eye movement was measured by placing a disposable silver chloride electrode on the outer corner of each eye, and the third electrode at the center of the forehead for reference. Electric potential difference between the two electrodes at the corners was amplified by an instrumentation differential amplifier. The analog output was digitized at sampling frequency of 100Hz. Power spectrum of the signal was obtained by 1024-point Fast Fourier Transform. LF/HF analysis is best known for its application on ECG. It is known that the power in low frequency spectrum increases when a human becomes drowsy[1] (**Fig. 5**).

### 3.2　Evaluation index

The next step was to find the optimum low frequency band for drowsiness detection using LF/HF analysis on EOG. Analysis of data obtained from 10 subjects has shown that the ratio between the power in 0 – 0.3 Hz band and the power in (0 – 0.3) + (3 – 10) Hz band had the highest correlation with the lane deviation (correlation coefficient: 0.81). Using this result, we have defined an alertness level indication $K_E$ by the following equation (1). The value of $K_E$ increases when the driver becomes drowsy.




(a) When driver is awake




(b) When driver is drowsy

Fig. 5　Power spectrum of eye movements

$$K_E = \frac{\text{Power }(0-0.3\text{ Hz})}{\text{Power }(0-0.3\text{ Hz}) + \text{Power }(0-10\text{ Hz})} \quad (1)$$

The evaluation module in the safety system uses this $K_E$ for drowsiness detection. If the drivers become drowsy, the value of $K_E$ becomes near 1 in our current evaluation system.

The correlation between lane deviation and the physiological signals shows in **Fig. 6**.

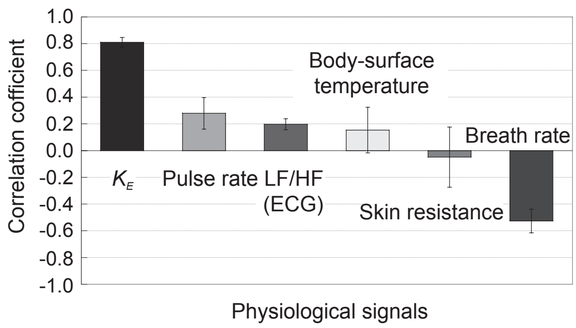



Fig. 6 Average value of correlation coefficient between physiological signals and lane deviation

## 4. EFFECTIVE STIMULI

### 4.1 Classification of stimuli

Stimuli were classified into active stimuli and passive stimuli, and the passive stimuli were further classified into chemical stimuli and external physical stimuli.

We have evaluated the following stimuli for awakening the driver. Chew a piece of gum (peppermint and/or caffeine), attach a caffeine sheet, take 50 ml of water, spray aroma oil (A: relaxer or B: refresher), turn on a 40W light bulb placed on the center of the dashboard, set off a alarm sound (approximately 70 dB), play driver's favorite songs, turn on an electric fan, give advice to do light exercises such as stretching shoulder and neck, play last and first word game with the examiner, sing driver's favorite songs to music (karaoke) (**Fig. 7**). Stimuli and their quantities and intensity of stimulation were selected according to commercial products for primary investigation. Effects of these stimuli were compared to find stimuli that kept the driver awake for 15 minutes, which is an average time to reach the next rest stop on freeways.

When the subject became drowsy, one of the stimuli was given to the subject, and duration of the awakening effect was measured.

### 4.2 Method

We asked two subjects in their twenty's, one male and one female, to make an oral report on their subjective drowsiness level every minute while driving in the

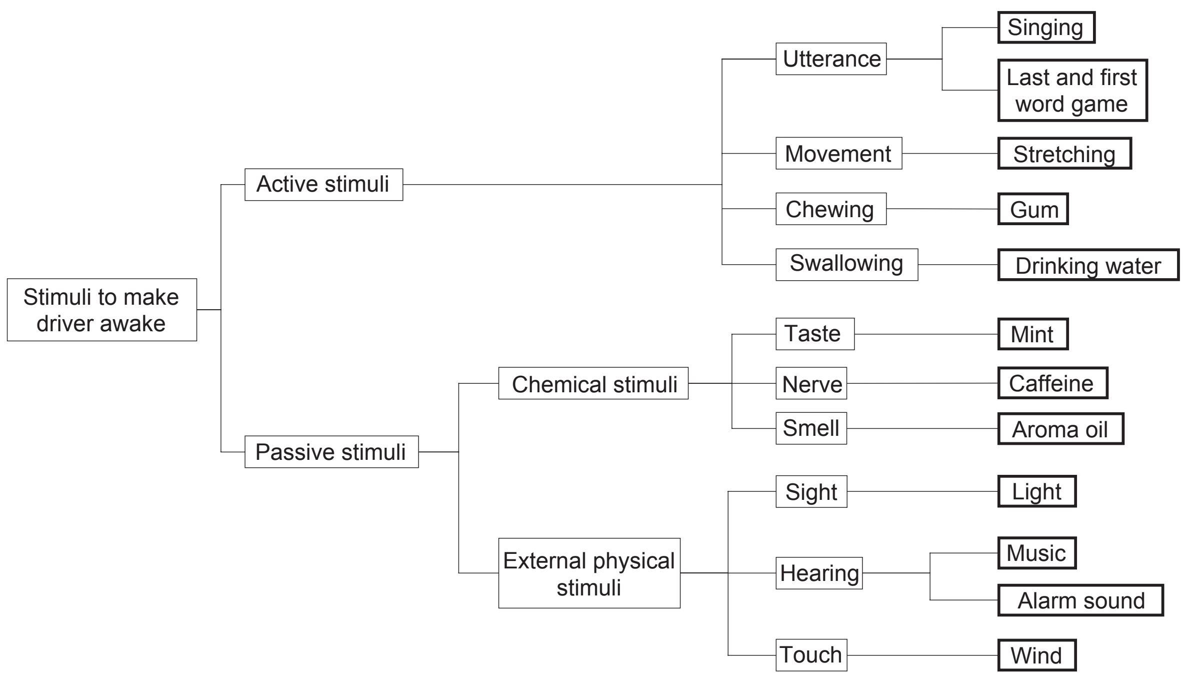



Fig. 7 Classification of stimuli to make driver awakeStimuli written in bold letters were experimented.

simulator. A notice was given by a sound every minute to report the drowsiness level. Drowsiness level was classified into five levels as given in **Table 1**.

### 4.3 Comparison of effective durations

One of the stimuli was activated when the driver's drowsiness level became 3, and the experiment was terminated when the drowsiness level reached 5. We compared the effectiveness of the stimuli by measuring the time it took from drowsiness level 3 to 5.

Without any stimuli, the drowsiness level reached 5 in only 6 minutes as shown in **Fig. 8**. Karaoke (**Fig. 9(a)**) and chewing a caffeine gum (**Fig. 9(b)**) could keep drivers awake for more than 30 minutes, which was more than two times longer of the targeted duration. Caffeine in the chewing gum has direct effect on the nervous system. The effectiveness of karaoke is due to the forced physical activity of singing. A similar stimulus such as speaking and playing last and first word game (**Fig. 9(c)**), which also involve forced active response, could only keep the subject awake for less than 20 minutes. Subjects have reported that playing a word game while driving became monotonous and that they quickly lost interest in it. Listening to the same music as karaoke without singing (**Fig. 9(d)**) could keep drivers awake less than 15 minutes.

Table 1　Driver's subjective drowsiness levels

| | |
|---|---|
| Level 1 | Awake |
| Level 2 | Slightly drowsy |
| Level 3 | Drowsy<br>(micro sleep occurs once a minute) |
| Level 4 | Very drowsy<br>(micro sleep occurs few times in a minute) |
| Level 5 | Unable to drive |

(Micro sleep is a brief sleep lasting up to a few seconds.)

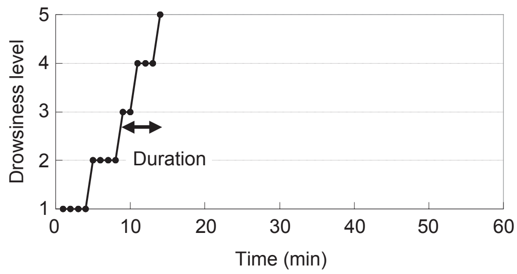



Fig. 8　Drowsiness level transition patterns without stimuli

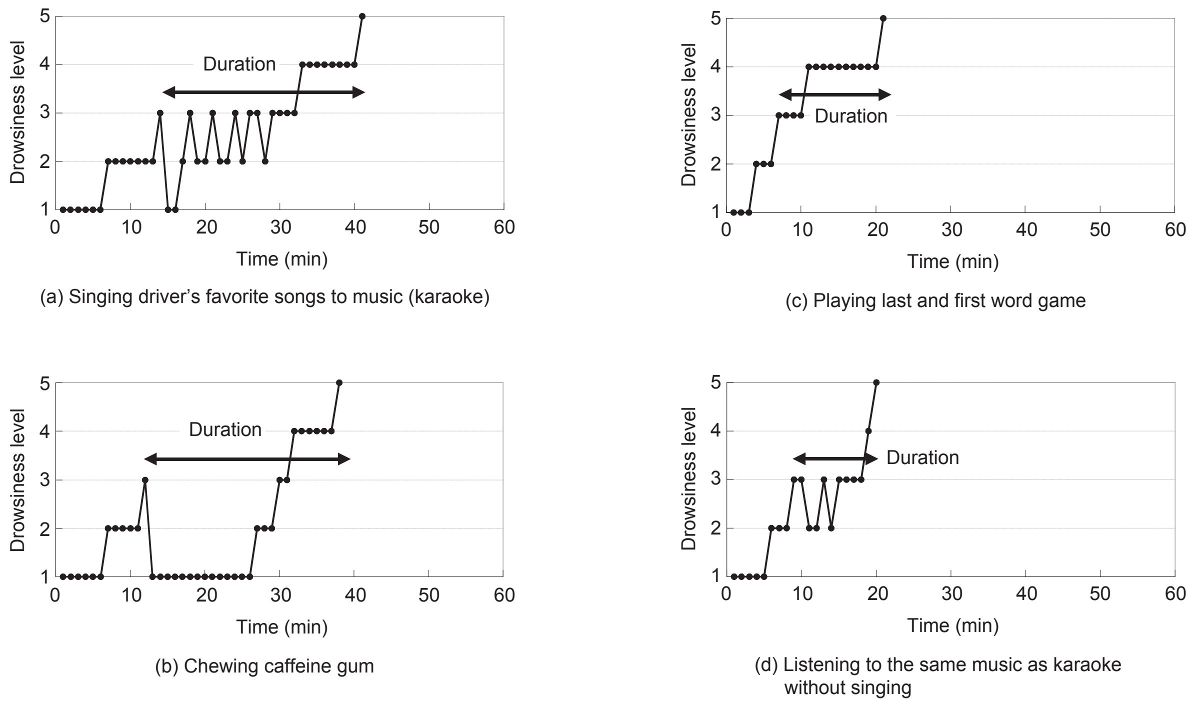



Fig. 9　Drowsiness level transition patterns of different stimuli

A sound alarm could keep the drivers awake for mere 10 minutes. These results suggest that effects of passive stimuli are temporary, while stimuli that force the driver to actively do something have longer awakening effect (**Fig. 10**). Although active stimuli are more effective, they are not effective unless the driver recognize the warning and follow the suggestions. Passive stimuli, although less effective, are more practical and reliable.

### 4.4 Influence of stimuli on measurement of eye movement

Those stimuli, which cause muscle movements and vibration, have influences for EOG and $K_E$. If the data from EOG are inaccurate, it is hard to evaluate driver's drowsiness level with $K_E$. Therefore, the correlation between $K_E$ and the lane deviation during drivers' drowsiness level from 3 to 5 was compared. **Figure 11** indicates average values of correlation coefficient. **Figure 12** shows some specific examples. Singing songs made the worst noise for $K_E$ (**Fig. 12 (b)**). It was possible to be one of the reasons that the vibration of subjects' vocal cords and muscles around mouth. On the other hand, chewing a piece of gum (**Fig. 12(c)**) did not affect EOG and also $K_E$. One of the reasons might be that chewing caused constant vibration; therefore the frequency of chewing was cut off. In addition, with long period chewing, the gum would be tasteless. Therefore, the subjects might stop chewing and that would cause the high value of correlation coefficient. While playing last and first word game (**Fig. 12(d)**), subjects frequently made humming sound with thinking. This sound might be a noise for sensing eye movement with EOG. Listening to the same music as karaoke without singing did not highly correlate with lane deviation. Listening to music might have a possibility to make humming noise unconsciously or cause the contraction of muscles near vocal cords (**Fig. 12(e)**). One of the results of light is indicated in **Fig. 12(f)**, but the other one's correlation coefficient was 0.10. According to the subject's face image during experiment taken by CCD camera, this subject squinted eyes because of bright light. This action might induce muscles tension.

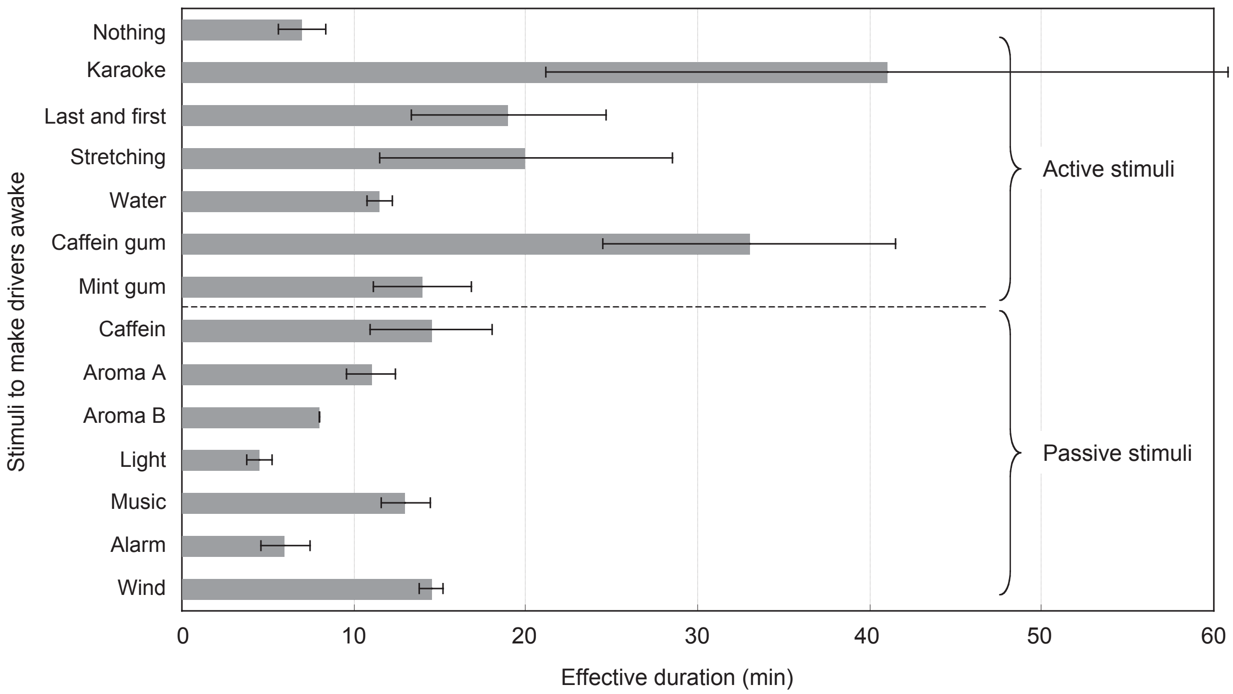



Fig. 10 Effective duration of stimuli

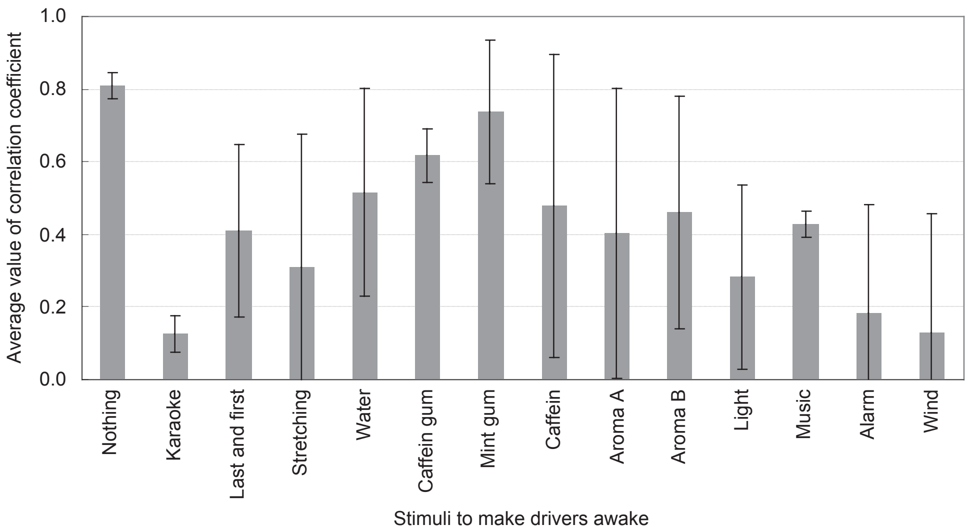



Fig. 11　Average values of correlation coefficient between lane deviation and stimuli

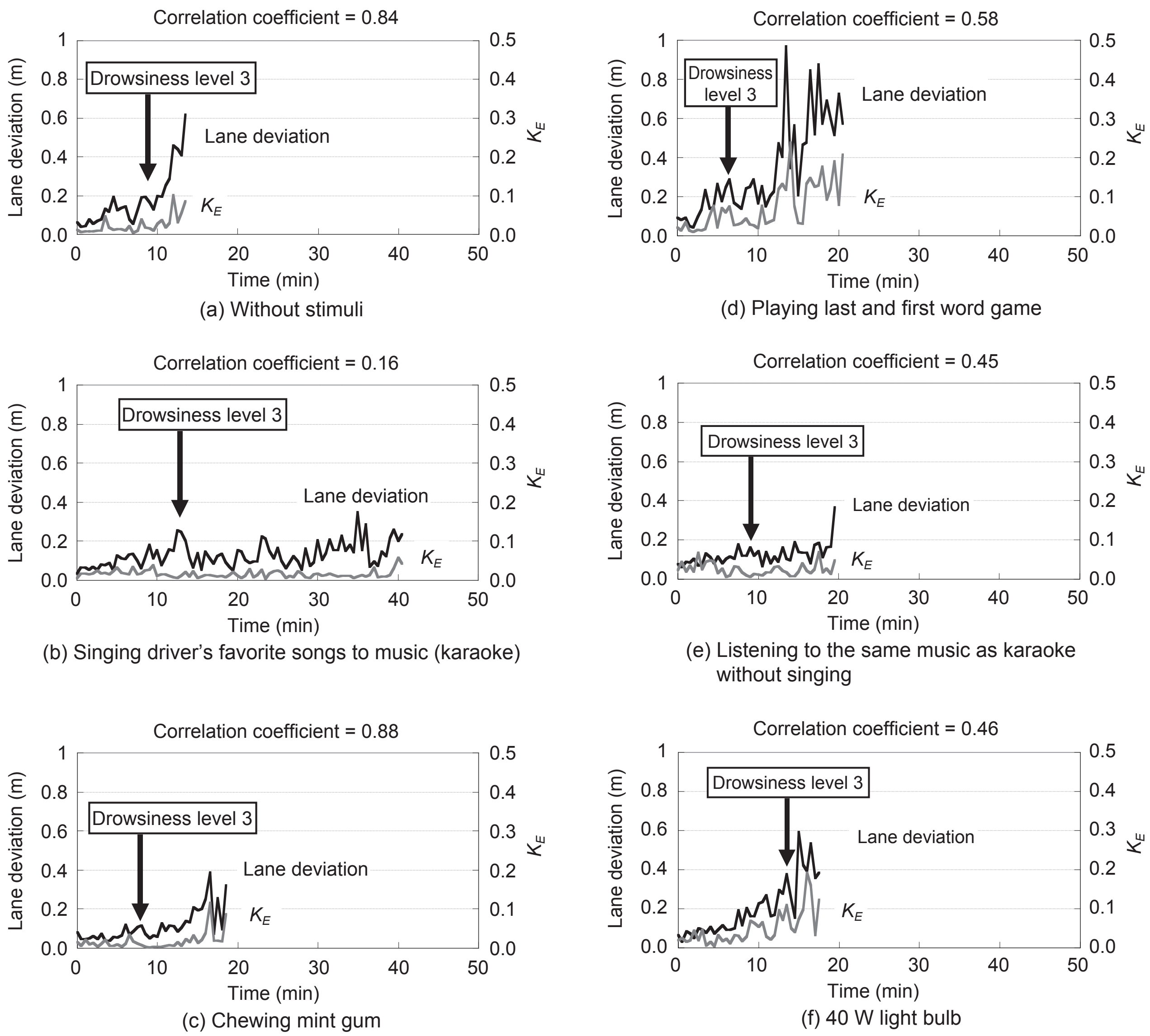



Fig. 12　Correlation coefficient between lane deviation and $K_E$

## 5．CONCLUSION

An evaluation of safety driving system consisting of drowsiness detection and awakening stimulation has shown that the system could keep the driver at lower drowsiness level for 10 to 30 minutes. Drowsiness was detected by increase of power in the lower frequency spectrum of driver's eye movements. Stimuli involving driver's active motion were more effective than passive stimuli. Our future works include development of eye movement sensor based on image processing, refinement of LF/HF analysis of eye movement, and evaluation of other stimuli for awakening the driver.

In the near future, the system consisting of non-contact drowsiness sensor and automatic awakening stimulation will provide us with safer and more comfortable driving cockpit.

## REFERENCES

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