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Prevention of drowsy driving by means of warning sound

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Abstract— **Traffic accidents occur due to inattentive driving such as drowsy driving. A variety of support systems that make an attempt to prevent inattentive driving are under development. The development of a system to prevent drowsy driving using auditory or tactile alarm system is undertaken. It is essential to detect the low arousal state and warn drivers of such a state so that drowsy can be prevented. EEG (Electroencephalography) was used to evaluate how an arousal level degraded with time for eight participants under a low arousal level. Mean power frequency (MPF) was calculated to evaluate an arousal level. The value of MPF was compared between high and low arousal levels. The difference of arousal effect among four warning sounds was examined. As a result, there was no significant difference of arousal effect among four alarm sounds. The alarm sound was found to temporarily heighten participants' arousal level.**

1. Introduction

Many studies have shown that night work such as driving a truck is associated with increased subjective sleepiness and increased EEG theta (4-7.9Hz) power density. In some cases, drivers actually fell asleep and induce critical and disastrous traffic accidents. Therefore, monitoring drowsiness during driving as an important risk factor for accidents in road transportation has been paid more and more attention. The development of ITS (Intelligent Transportation System) that can monitor drivers' arousal level and warn drivers of a risk of falling asleep and causing a traffic accident is essential for the assurance of safety during driving. However, we have not established effective measures for warning drivers of the risk of causing a traffic accident and preventing it from occurring. If such a monitoring function of drowsiness is built into ITS and we can warn drives of a risk of falling asleep in advance, this would contribute to the promotion of safety driving and eventually decreasing disastrous traffic accidents.

Brookhuis et al.[1] carried out an on-road experiment to assess driver status using psychophysiological measures such as EEG and ECG. They found that changes in psychological parameters such as EEG and ECG reflected changes in driver status and could predict driving impairment that might lead to a disastrous traffic accident. Kecklund et al. [2] recorded EEG continuously during a night or evening drive for eighteen truck drivers. They showed that during a night drive a significant intra-individual correlation was observed between subjective sleepiness and the EEG alpha burst activity. End-of the-drive subjective sleepiness and the EEG alpha burst activity were significantly correlated with total work hours. As a result of a regression analysis, total work hours and total break time predicted about 66% of the variance of EEG alpha burst activity during the end of drive. Galley[3] overcame a few disadvantages of EOG in the measurement of gaze behavior by using on-line computer identification of saccades and additional keyboard masking of relevant gazes by the experimenter. As EOG, especially saccades and blinks, is regarded as one of useful measures to evaluate drivers' drowsiness, such an improvement might be useful to detect the low arousal state of drivers. Wright et al.[4] investigated sleepiness in aircrew during long-haul flights, and showed that EEG and EOG are potentially promising measures on which to base an alarm system. Skipper[5] made an attempt to detect drowsiness of driver using discrimination analysis, and showed that the false alarm or miss would occur in such an attempt.

Many studies used psychophysiological measures such as blink, EEG, saccade, and heart rate to assess fatigue[6]-[12]. McGregor[6] suggested caution in interpreting saccade velocity change as an index of fatigue since most of the reduction in average saccade velocity might be secondary to increase in blink frequency. No measures alone can be used reliably to assess drowsiness, because each has advantages and disadvantages. The results of these studies must be integrated and effectively applied to the prevention of drowsy driving. To prevent drivers from driving under drowsy state and causing a disastrous traffic accident, not the gross tendency of reduced arousal level but more accurate identification of timing when the drowsy state occurs is necessary. It is not until such accurate measures to identify drowsiness and predict the timing of drowsy driving is established that we apply this to the development of ITS which can surely and reliably avoid unsafe and unintentional driving under drowsy and low arousal state.

Although the studies above made an attempt to evaluate drowsiness (or sleepiness) on the basis of psychophysiological measures, Landstrom et al.[13] examined the effectiveness of sound exposure as a measure against driver drowsiness. They used twelve lorry drivers in a total of 110 tests of a waking (alarm) sound system. The effectiveness of the waking sound system was verified through subjective ratings by lorry drivers. This system is used by a driver when he or she feels that their arousal level is becoming lower, and there is a risk of falling asleep.

The disadvantage of this system is that one must intentionally and spontaneously use the waking alarm system by monitoring their drowsiness by oneself. On the basis of the discussion above, objectively measuring and monitoring arousal level and providing warning sound with drivers is more necessary and have more social impact than the warning or alarm system by Landstrom et.al.[13]. An automobile in future is required to detect the arousal level of a driver automatically by ITS and warn drivers of the drowsy state by using some effective measures such as a waking sound system. In order to develop and realize such a system, we have been making an attempt using EEG or HRV measures.

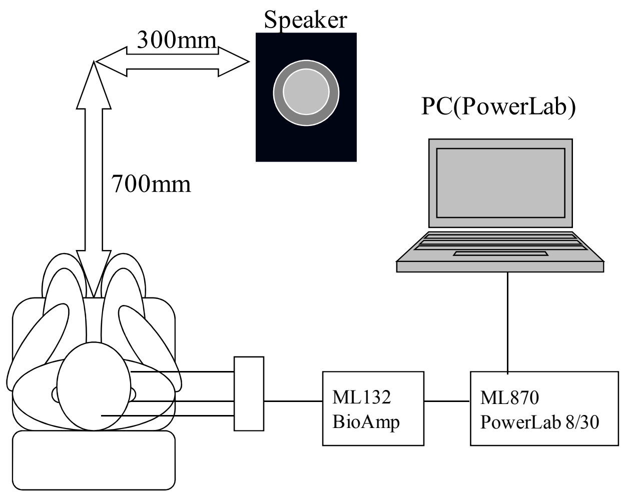

Fig.1 Outline of measurement system.

The aim of this study was to identify a useful measure to estimate an arousal level of drivers using EEG, to apply the result to warn drivers of drowsy state using a warning sound. It is expected that such a system can prevent driving under low arousal level from occurring and contribute to the reduction of traffic accidents. EEG (Electroencephalography) was used to evaluate how an arousal level degraded with time for eight participants under a low arousal level. Mean power frequency (MPF) was calculated to evaluate an arousal level. The value of MPF was compared before and after warning sound. The difference of arousal effect among four warning sounds was examined.

2. Method

2.1 Participants

Eight male graduate or undergraduates (from 21 to 26 years old) participated in the experiment. They were

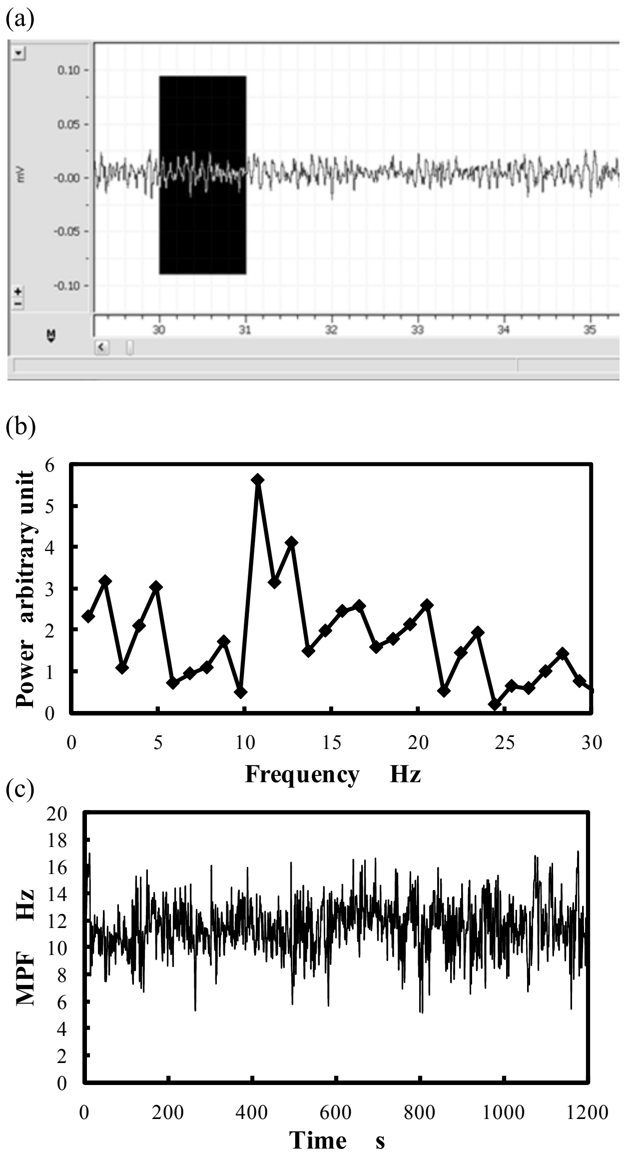

Fig.2 (a) Time series of EEG wave form, (b) An example of EEG power spectrum, (c) Time series of MPF.

all healthy and had no orthopedic or neurological diseases.

2.2. Apparatus

The outline of experimental (measurement) system is summarized in Figure 1. Electroencephalography (EEG) and Electrooculogram (EOG) activities were acquired with measurement equipment shown in Figure1. An A/D instrument PowerLab8/30 and bio-amplifier ML132 were used. Surface EEG was recorded using A/D instrument silver/silver chloride surface electrodes (MLAWBT9), and sampled with a sampling frequency of

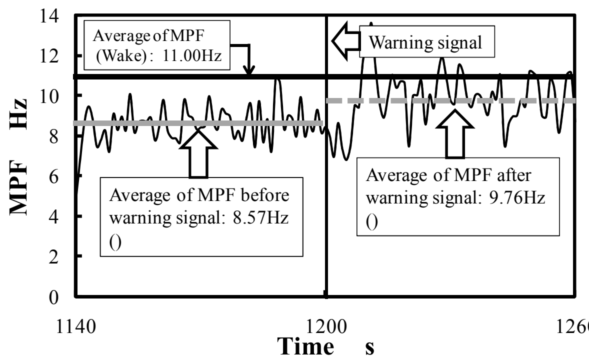

Fig.3 Comparison of MPF before and after the warning sounds.

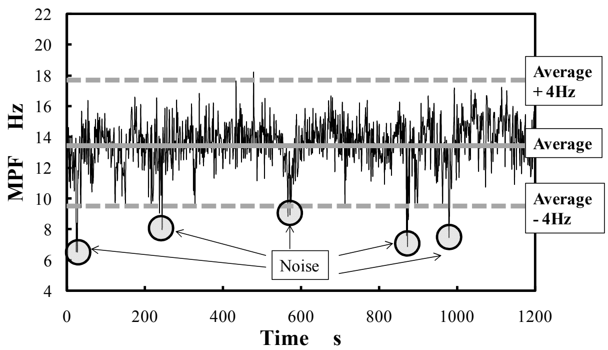

Fig.4 Removal of abnormal data.

1kHz.

2.3 Procedure

According to international 10-20 standard, EEGs were led from O1 and O2. The participants sat on an automobile seat, and were required to watch a driving scene recorded on a highway from the front side. The experimental duration was not predetermined, because the time until the participant became drowsy differed across the participants. Basically, the experiment was continued until the experimenter judged that the participant reached drowsy and low arousal state.

FFT was carried out every 1024 data (1.024 s) (See Fig.2(a) and (b)). Before the EEG data were entered into FFT program, the data were passed through a cosine taper window. Based on this, the mean power frequency (MPF) was calculated. This was plotted as a X-bar control chart as shown in Fig.2(c). Using a X-bar control chart, the judgment of drowsiness of participants was

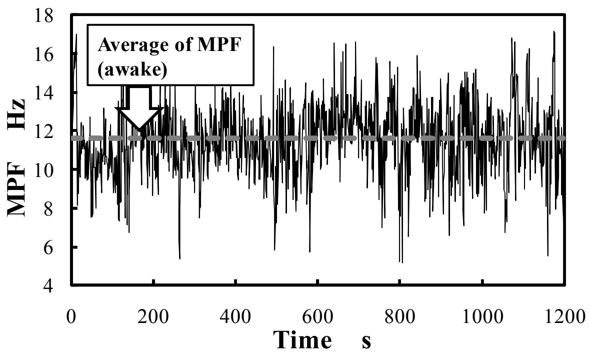

Fig.5 Times series of MPF during high arousal state (participant A).

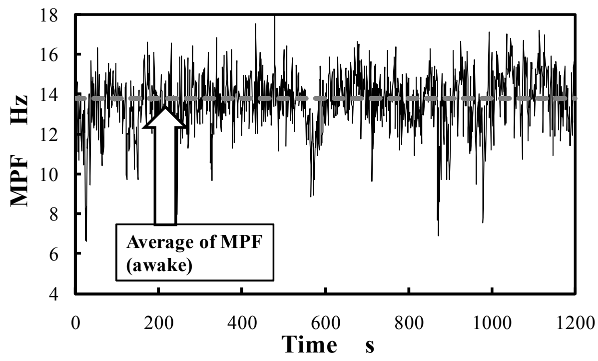

Fig.7 Times series of MPF during high arousal state (participant B).

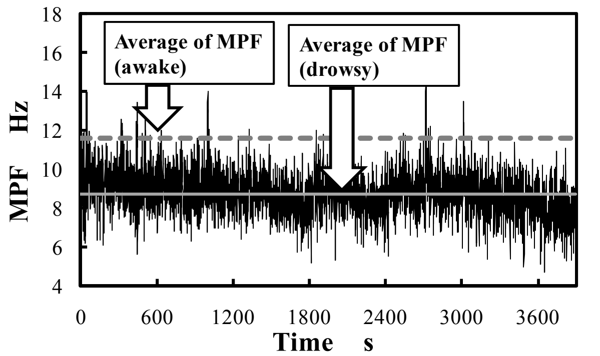

Fig.6 Times series of MPF during very low arousal state (participant A).

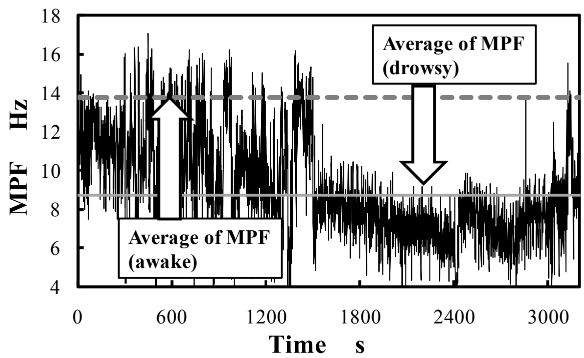

Fig.8 Times series of MPF during very low arousal state (participant B).

carried out.

The beep sound with various frequencies and human's voice were used. The cycle of beep sounds was 0.1 s. The speaker was installed 700mm vertically and 300mm horizontally away from the participant. The duration of the warning sound was fixed to 5 s. The warning sounds used in the experiment are summarized as follows. Beep sound of 1 kHz is most intimate and frequently used as a feedback to some operation. Beep sound of 4 kHz is regarded as most sensitive to humans. Beep sound of 10 kHz is regarded as difficult to hear especially for older adults whose perceptual ability declined.

(1) beep sound of 1 kHz
(2) beep sound of 4 kHz
(3) beep sound of 10 kHz
(4) Human's warning voice

The order of presentation of four types of warning sound was randomized across the participant.

The data analysis was carried out as follows (See Fig.3). The effect of warning sound on the enhancement of arousal level was evaluated using MPF before and after presentation of warning sound. The mean values of MPF before and after the presentation of warning sound were calculated as shown in Fig.3. The abnormal data were removed as shown in Fig.4. The data beyond the mean value + 3 x standard deviation or below the mean value - 3 x standard deviation were removed from the analysis.

3. Results

The X-bar control chart of mean power frequency (MPF) obtained from FFT analysis of EEG. The time series of MPF corresponds to data under high arousal and under very low arousal state is depicted in Fig.5 and

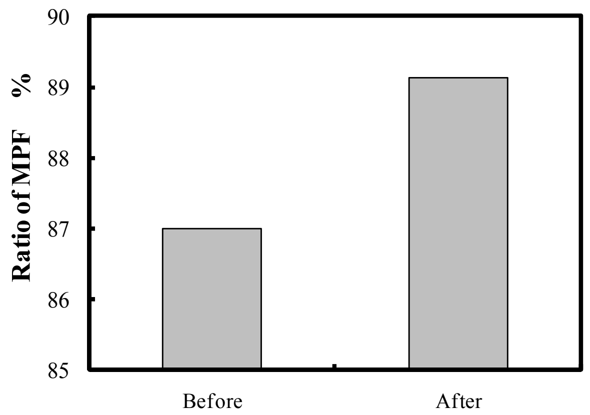

Fig.9 Ratio of MPF to mean MPF during high arousal state before and after warning sound.

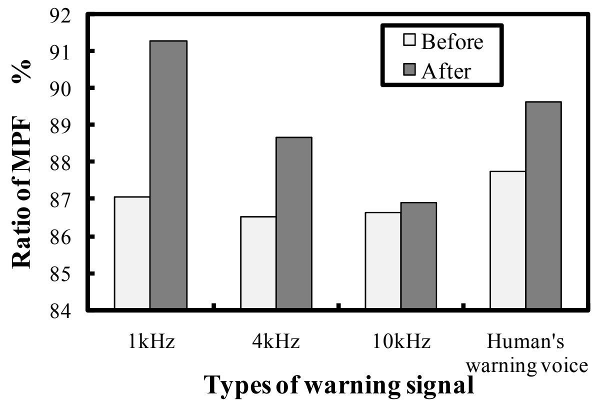

Fig.10 Ratio of MPF to mean MPF during high arousal state before and after warning sound (for each of four types of warning sounds).

Fig.6, respectively. Similar data for other participant is shown in Fig.7 and Fig.8.

According to Fig.3, effect of warning sound on the enhancement of arousal level was evaluated was evaluated. The results are summarized in Fig.9-Fig.10, and Fig.11. As for Fig.9, a t-test was carried out on the ratio of MPF to mean MPF during high arousal state. As a result, a significant (p<0.05) difference of the ratio before and after the warning sound was detected. A similar t-test was carried out for each type of sound shown in Fig.10. No significant difference of the ratio before and after the warning sound was detected before and after the presentation of each warning sound. A one-way (type of warning sound) ANOVA was carried

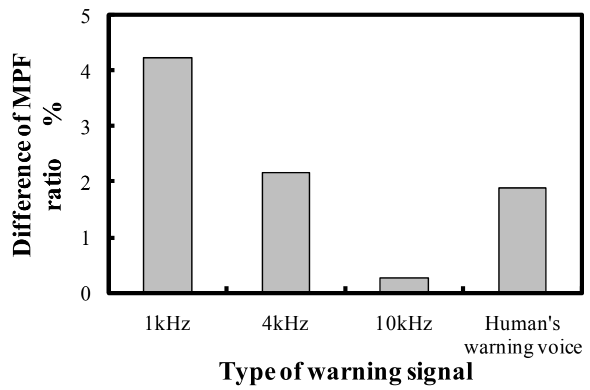

Fig.11 Difference of ratio of MPF to mean MPF during high arousal state before and after warning sound (for each of four types of warning sounds).

out on the difference of ratio of MPF to mean MPF during high arousal state (Fig.11) revealed no significant main effect.

4. Discussion

As shown in Fig.5-Fig.8, we can evaluate the arousal state of participant using Time series of MPF. This is in agreement with the results of Murata and Nishijima [14]. It has been confirmed further that the mean power frequency of EEG decrease under drowsy states.

As shown in Fig.9, it seems that the warning sound helps to change the state from low arousal level to somewhat high arousal level. However, the difference of alarm effect among four types of warning sound was not confirmed statistically, although the data shown in Fig.10 and Fig.11 in appearance seems to demonstrate the advantage of the beep sound of 1 kHz over other warning sounds.

Landstrom et al.[13] discussed the effectiveness of sound exposure as a means against driver drowsiness. The effectiveness of the waking sound system was verified through subjective ratings by lorry drivers. This system is used by a driver when he or she feels that their arousal level is becoming lower, and there is a risk of falling asleep. The disadvantage of Landstrom [13] is that one must intentionally and spontaneously use the waking alarm system by monitoring their drowsiness by oneself. Objectively measuring and monitoring arousal level and providing warning sound with drivers is more necessary and have more social contribution than the warning or alarm system by Landstrom et al.[13]. Therefore, in this study, monitoring the arousal level not subjectively but objectively using MPF, the effectiveness of alarm sound was explored. In this respect, this study must be more advantageous than Landstrom et al. [13]

The most important issue is to predict reliably the time when the driver becomes drowsy and potentially cause disastrous traffic accidents. However, at present, it is still not possible to predict the arousal level on the basis of the EEG values. Although the warning sound was found to increase arousal level, the different alarm effect among four types of warning sounds was not confirmed in the range of this experiment. More systematical experimental paradigm might be necessary to confirm the alarm effect among four types of warning sounds. For example, regarding type of sounds not as within-subject factor, but as between-subject factor might be an effective way for the verification, although such a method requires many time and participants.

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