Evaluation of Drowsiness by EEG analysis

- Basic Study on ITS Development for the Prevention of Drowsy Driving -

Atsuo MURATA and Kazuyuki NISHIJIMA
Dept. of Intelligent Mechanical Systems, Division of Industrial Innovation Sciences,
Graduate School of Natural Science and Technology, Okayama University
Dept. of Intelligent Mechanical Systems, Division of Industrial Innovation Sciences, Graduate School of Natural Science and Technology, Okayama University
3-1-1, Tsushimanaka, Okayama, 700-8530 Japan
TEL:81-086-251-8055 FAX:81-086-251-8056
E-mail:murata@iims.sys.okayama-u.ac.jp

Abstract—
The aim of this study was to identify a useful measure to estimate an arousal level of drivers, to apply the result to develop ITS (Intelligent Transportation System) that can warn drivers of their low arousal state and to prevent driving under low arousal level from occurring and contribute to the reduction of traffic accidents. The EEG(electroencephalography) during a monotonous task was measured, and it was investigated how these measures change under the low arousal (drowsy) state. The time series of mean power frequency of EEG was plotted on X-bar control chart. Under the low arousal state (drowsy state), the mean power frequency tended to be lower than central line (CL) and range between CL and lower control limit (LCL). Under the worst case, the mean power frequency was lower than LCL. The ratio of such intervals to total measurement period tended to increase under drowsy state. The mean power frequency was found to be effective for evaluating drowsiness of drivers.
Keyword: ITS, drowsiness, EEG, control chart, blink.

I. 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(electrocardiogram). 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 (Electrooculogram) 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 eta l.[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. Eventually, a 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,
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 develop ITS (Intelligent Transportation System) that can warn drivers of their low arousal state. It is expected that such a system can prevent driving under low arousal level from occurring and contribute to the reduction of traffic accidents.

II. METHOD

・**Participants**

Five male graduate or undergraduates (from 21 to 26 years old) participated in the experiment. They were all healthy and had no orthopaedic or neurological diseases.

・**Apparatus**

The outline of experimental (measurement) system is summarized in Figure 1. EEG and 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 1kHz.

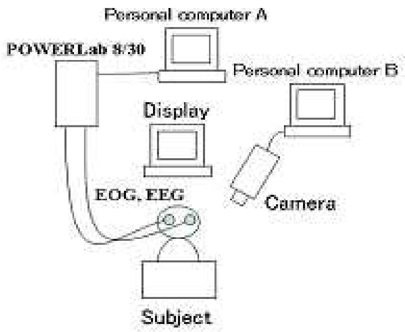

Figure 1. Outline of measurement system.

III. 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). 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 was calculated. This was plotted as a X-bar control chart as shown in Figure 2. Using a X-bar control chart, the judgment of drowsiness of participants was carried out. As for the EOG data, the blink was counted as a peak of waveform.

IV. RESULTS

・**EEG analysis**

The evaluation value was obtained as follows. FFT was carried out on EEG data consisting of 1024 measurements. MPF (mean power frequency) can be calculated as follows.

$$MPF = \frac{f_i \, pow_i}{\sum pow_i} \qquad (1)$$

Where f_i and pow_i are frequency and corresponding power, respectively. Lower MPF is lower arousal level is.

・**X-bar control chart**

The X-bar control chart of mean MPF obtained from FFT analysis of EEG is shown in Figure 2. Figure 2 corresponds to data under low arousal state. The interval of mean power frequency x was divided into three categories as follows:

(a) $x > CL-\sigma$
(b)$LCL< x < CL-\sigma$
(c) $x < LCL$

Where CL and σ represents the mean and the standard deviation of MPF under the high arousal state. LCL is given by CL-2σ. In Figure 3, the ratio of intervals (a)-(c) to total measurement interval is plotted as a function of measurement time interval. In Figure 4, the number of blinks for the same measurement interval with Figure 3 is plotted.

In Figures 5 and 6, a similar plot to Figures 2 and 3 is depicted. Figures 5 and 6 corresponds to data under high arousal state.

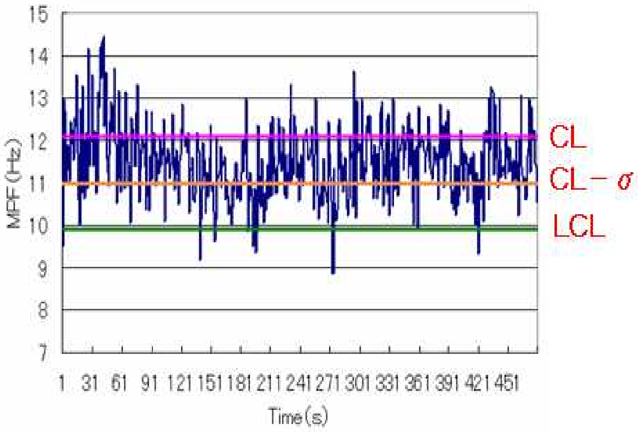

Figure 2. X-bar control chart of mean power frequency(MPF) (low arousal state).

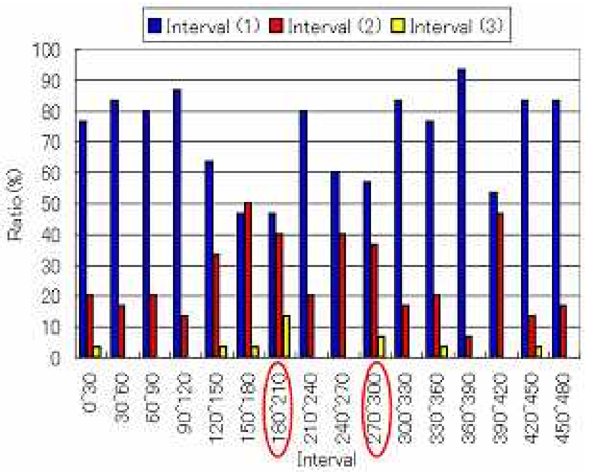

Figure 3.Ratio of intervals (a)-(c) to total measurement interval as a function of measurement time interval (low arousal state).

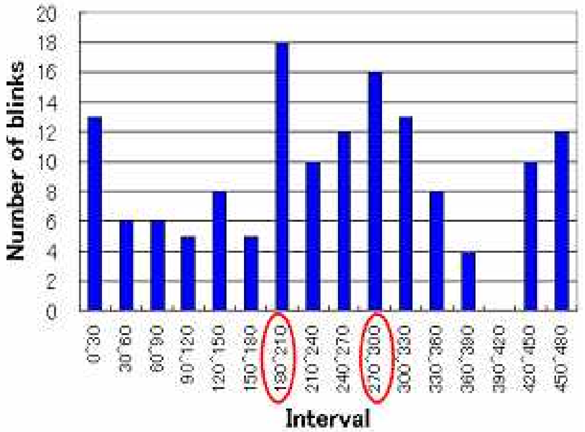

Figure 4. Number of blinks for the same measurement interval with Figure 3

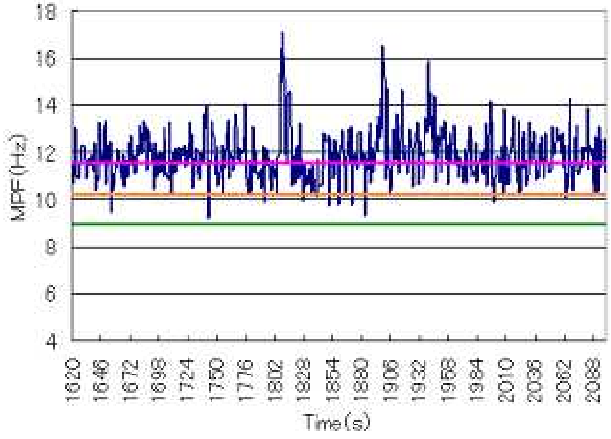

Figure 5. X-bar control chart of mean power frequency(MPF) (high arousal state).

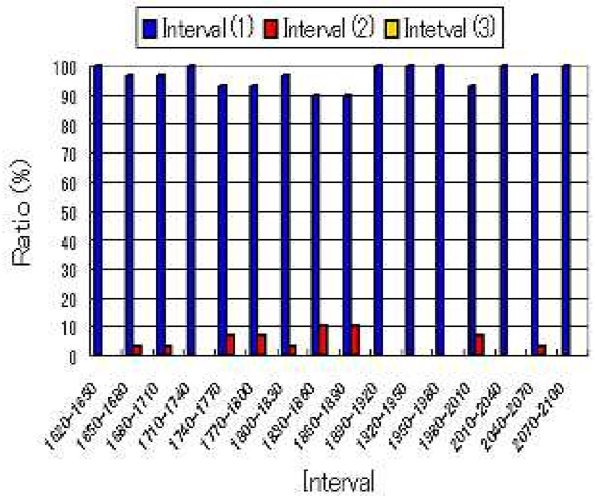

Figure 6.Ratio of intervals (a)-(c) to total measurement interval as a function of measurement time interval (high arousal state).

V. Discussion

As shown in Figure 4, we can predict that drowsiness is induced at the interval 180-210 s and the interval 270-300 s. This can also be confirmed in Figure 2, because at these intervals the MPF of EEG power spectrum became lower than LCL or ranged between LCL and CL-σ.

Under the high arousal state, as shown in Figure 5, such tendencies were not observed at all. Comparing Figures 3 and 6, it is clear that the ratio of interval (b) to total measurement interval under the low arousal state is larger than that under the high arousal state. In such a way, plotting MPF data every 1.024 s as a X-bar control chart and classifying the interval as (a), (b), and (c) was found to be effective to assess drowsiness.

In this study, it was shown that the mean power frequency of EEG decreased under drowsy states. The most important 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 values of EEG. Parameters. Future research should propose a method to estimate and predict arousal level reliably and stably on the basis of EEG parameters at present by using Bayesian network [14].

References

[1] Brookhuis, K.A. and Waard, D. 1993. The use of psychophysiology to assess driver status, Ergonomics, 36, 1099-1110.

[2] Kecklund, G. and Akersted, T. 1993. Sleepiness in long distance truck driving: An ambulatory EEG study of night driving, Ergonomics, 36, 1007-1017.

[3] Galley, N. 1993. The evaluation of the electrooculogram as a psychophysiological measuring instrument in the driver study of driver behavior, Ergonomics, 36, 1063-1070.

[4] Wright, N. and McGown, A. 2001. Vigilance on the civil flight deck: incidence of sleepiness and sleep during long-haul flights and associated changes in physiological parameters, Ergonomics, 44, 82-106.

[5] Skipper, J.H. and Wierwillie, W. 1986. Drowsy driver detection using discrimination analysis, Human Factors, 28, 527-540.

[6] McGregor, D.K. and Stern, J.A. 1996. Time on task and blink effects on saccade duration, Ergonomics, 39, 649-660.

[7] Fukui, T. and Morioka, T. 1971. The blink method as an assessment of fatigue, Ergonomics, 14, 23-30.

[8] Piccoli, B., D'orso, M., Zambelli.P.L., Troiano, P., and Assint, R. 2001. Observation distance and blinking rate measurement during on-site investigation: new electronic equipment, Ergonomics, 44, 668-676.

[9] Sharma, S. 2006. Linear temporal characteristics of heart interbeat interval as an index of the pilot's perceived risk, Ergonomics, 49, 874-884.

[10] Tejero, P. and Choliz, M. 2002. Driving on the motorway: the effect of alternating speed on driver's activation level and mental effort, Ergonomics, 45, 605-618.

[11] Milosevic, S. 1978. Vigilance performance and amplitude of EEG activity, Ergonomics, 21, 887-894.

[12] Fumio, Y. 1998. Frontal midline theta rhythm and eyeblinking activity during a VDT task and a video game; useful tools for psychophysiology in ergonomics, Ergonomics, 41, 678-688.

[13] Landstrom, U., Englund, K., Nordstrom, B., and Astrom, A. 1999. Sound exposure as a measure against driver drowsiness, Ergonomics, 42, 927-937.

[14] Hershman, R.L. (1971). A rule for the Integration of Bayesian Options, Human Factors,13, 255-259**.**