Prediction of Drowsy Driving Using Behavioral Measures of Drivers – Change of Neck Bending Angle and Sitting Pressure Distribution

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Abstract. Recently, in Japan, the percentage of the death toll in traffic accidents due to drowsy driving is the most dominant in all death tolls in traffic accidents. Therefore, it is essential for automotive manufacturers to develop a warning system of drowsy driving. A lot of studies are conducted to prevent traffic accident due to drowsy driving, and make an attempt to assess drowsiness by physiological measures such as EEG. However, it is difficult to use such equipment for predicting drowsiness, because it is difficult to equip an automotive cockpit with such equipment due to expensiveness and measurement noise. As more convenient measure used to predict drowsiness, it was examined whether the neck bending angle and the sitting pressure distribution could be used to discriminate the arousal level. The effectiveness of these convenient measures was experimentally assessed. In order to prevent traffic accidents due to drowsy driving, an attempt was made to predict drowsiness (low arousal state) using the change of neck bending angle and sitting pressure distribution. As a result, these measures were found to be useful for evaluating arousal level and predicting arousal level in advance.

Keywords: ITS, prediction of drowsiness, neck bending angle, sitting pressure distribution, COP (Center of Pressure).

1 Introduction

Monitoring drowsiness during driving has been paid more and more attention. The development of 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, effective measures for warning drivers of the risk of causing a traffic accident have not been established.

Many studies used psychophysiological measures such as blink, EEG, saccade, and heart rate to assess fatigue. Brookhuis et al. [1] carried out an on-road experiment to assess driver status using measures such as Electroencephalography (EEG) and Electrocardiography (ECG). They found that changes in EEG and ECG reflected changes in driver status. 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

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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. Skipper et. Al. [3] 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. No measures alone can be used reliably to assess drowsiness, because each has advantages and disadvantages.

Murata et al. [4] and Murata et al. [5] made such an attempt to objectively evaluate the drowsiness of drivers using EEG or HRV measures. They succeeded in clarifying the decrease of EEG-MPF or the increase of RRV3 when the participant's arousal level is low. However, it was not possible to predict the drowsiness on the basis of the time series of EEG-MPF or RRV3. Moreover, such equipments to measure an arousal level is too expensive to put these into practical use in automotives. The drowsiness prediction system that should be used in automotive must be less expensive and more convenient. As a more convenient measure for predicting the arousal level, we paid attention to the vertical and horizontal neck bending angle and the change of sitting pressure distribution.

Although detecting the arousal level of a driver automatically by ITS and warn drivers of the drowsy state is an ultimate goal in such studies, it is impossible to develop such a system unless such studies [4,5] are further enhanced and the prediction method on the basis of some useful methodology is established. Few studies made an attempt to predict the arousal level systematically on the basis of physiological measures. Murata et al.[6,7] made an attempt to predict the arousal level using Bayesian theorem or multivariate analysis, and succeeded in the prediction with the accuracy of more than 85%. If a drowsiness prediction system is to put into practical use, more convenient measures which can be easily installed to the automotive cockpit.

As more convenient measure used to predict drowsiness, the neck bending angle and the sitting pressure distribution were used and examined whether these measures can be used to evaluate arousal level like EEH-MPF or RRV3 that had been proven to be effective for evaluating arousal level and succeeded to some extent in predicting the timing where the drowsy state is induced. The effectiveness of these convenient measures was experimentally assessed. In order to prevent traffic accidents due to drowsy driving, an attempt was made to predict drowsiness (low arousal state) using the change of neck bending angle and sitting pressure distribution. First, the time series of these measures were compared between low and high arousal states. The mean values were also compared between the two states. Moreover, the arousal level was predicted using a logistic regression model, and the discrimination percentage was compared among participants, and between low and high arousal states.

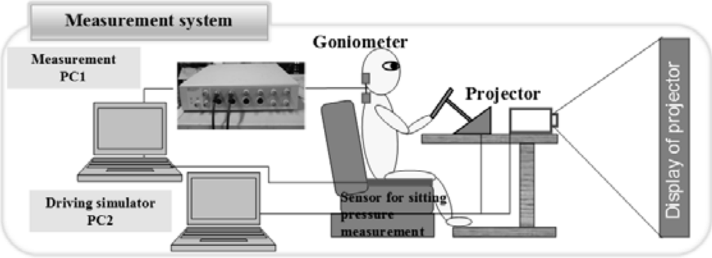

Fig. 1. Outline of measurement apparatus in the experiment

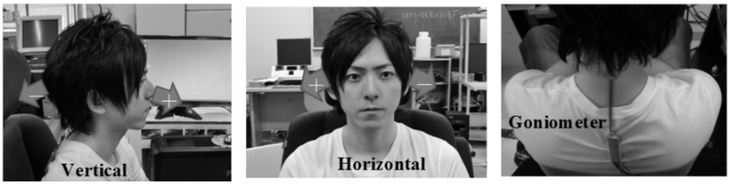

Fig. 2. Placement of goniometer

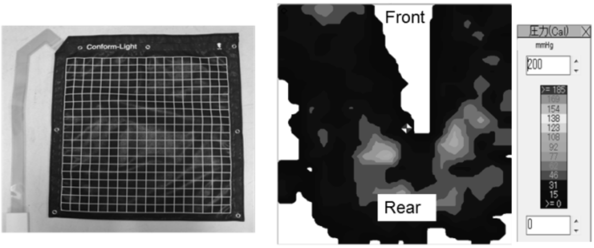

Fig. 3. Measurement system and example of sitting pressure

2 Method

2.1 Participant

Thirteen participants aged from 21 to 22 years old took part in the experiment. The visual acuity of the participants in both young and older groups was matched and more than 20/20. They had no orthopedic or neurological diseases. All provide the experimenter with informed consent on the participation to the experiment.

2.2 Apparatus

The outline of apparatus used in the experiment is shown in Fig.1. Goniometers (DKH) for vertical and horizontal neck bending angle measurement was attached to the back of neck to measure the bend angle of neck as depicted in Fig.2. A measurement system of sitting pressure distribution (Nitta, Conform-Light, See Fig.3) was placed on a driver's seat. Fig.3 also demonstrates the sitting pressure distribution.

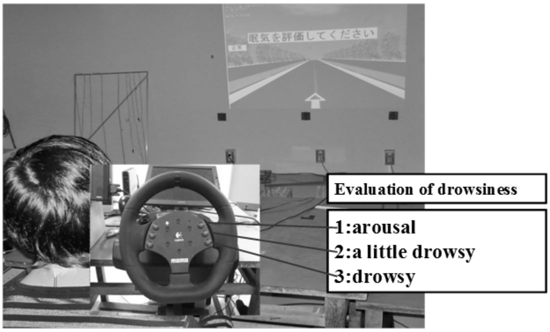

Fig. 4. Experimental setting

2.3 Task, Design and Procedure

While the participant was carrying out a simulated driving task (tracking) task, the bending angle of neck and the sitting pressure distribution were measured. The participant was required to report his or her subjective rating of drowsiness every 1 min. The experiment was continued until the participants fell asleep. The experimental setting is shown in Fig.4. The participant was required to press one of three switched attached on the right side of the steering wheel. The evaluation categories included 1. arousal, 2. a little drowsy, and 3.drowsy.

The participants were required to stay up all night and visit the laboratory. While the participant carried out a one-hour driving simulator task (See Fig.4), the vertical and horizontal bending angle of the neck was measured continuously. In the one-hour driving simulator task, the participants were required to keep the deviation from the moving line as small as possible and to keep the center of the road using a steering wheel. As the participants evaluated their arousal level 60 times during a one-hour experiment, the arousal was classified according to their rating value.

3 Results

The mean change of bending angle every 1 min and the frequency of larger change of center of sitting pressure (COP) were compared between the low and high arousal states. In Fig.5, an example of 420 s-time series of vertical and horizontal bending angle of the neck is depicted. In Fig.6, the horizontal bending angle is compared between the arousal and the drowsy states for eight participants A-M. The corresponding vertical bending angle of the neck is compared between the arousal and the drowsy states in Fig.7. The horizontal bending angle of neck is compared between arousal and drowsy states in Fig.8. The vertical bending angle of neck is compared between arousal and drowsy states in Fig.9.

The change Δ of COP was defined as follows. The coordinate (x_i, y_i) of COP is calculated every 0.02 s (sampling frequency of 50Hz).

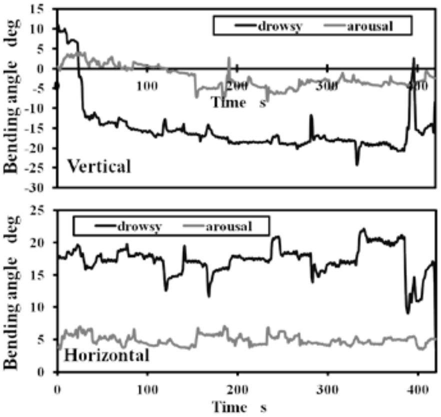

Fig. 5. Example of change of vertical and horizontal bending angle with time

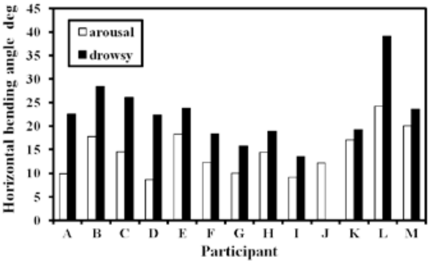

Fig. 6. Comparison of horizontal bending angle between arousal and drowsy states

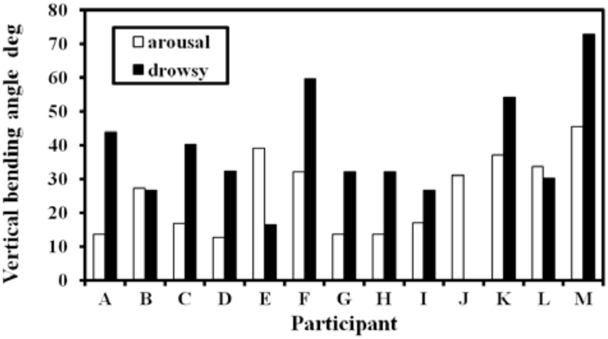

Fig. 7. Comparison of vertical bending angle between arousal and drowsy states

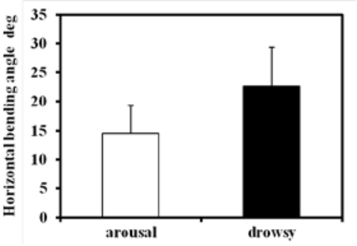

Fig. 8. Horizontal bending angle of neck compared between arousal and drowsy states

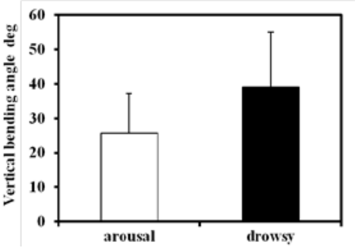

Fig. 9. Vertical bending angle of neck compared between arousal and drowsy states

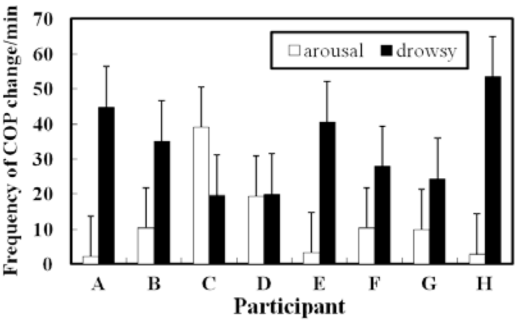

Fig. 10. Comparison of frequency of COP change between arousal and drowsy states from Murata et al.[8]

$$\Delta = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \tag{1}$$

where (x_i, y_i) and (x_{i-1}, y_{i-1}) represent the coordinate of COP at time i and i-1. After the frequency distribution of the change Δ was obtained for each participant, the number of Δ that is more than 99 % (upper 1%) was counted as change of posture (COP change). The frequency of COP change compared between the arousal and the drowsy states, which was cited from Murata et al.[8], is shown in Fig.10.

The frequency of COP change compared between the arousal and the drowsy states obtained in this experiment is shown in Fig.11. Participants were classified into (i) low drowsy and (ii) high drowsy groups. Five participants A-E and eight participants F-M belonged to (i) and (ii), respectively. In Fig.12, the frequency of COP change for (i) low drowsy group is compared between arousal and drowsy states. The frequency of COP change for (ii) high drowsy group is compared between arousal and drowsy states in Fig.13.

In Fig.14, the total movement of COP/min is compared between arousal and drowsy states. The total movements of COP/min for (i) low drowsy group and (ii) high drowsy group are compared between arousal and drowsy states in Fig.15 and Fig.16, respectively.

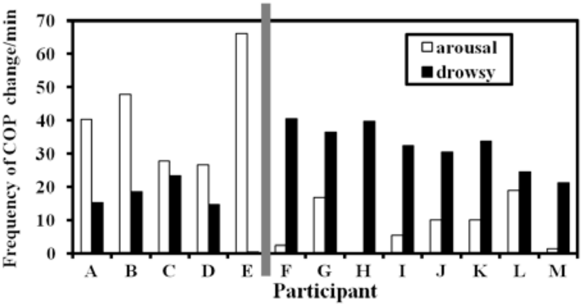

Fig. 11. Comparison of frequency of COP change between arousal and drowsy states

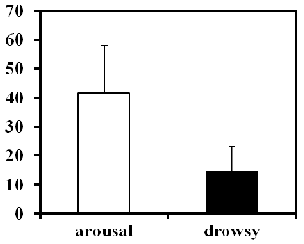

Fig. 12. Frequency of COP change/min compared between arousal and drowsy states for participants A-E (low level of drowsiness)

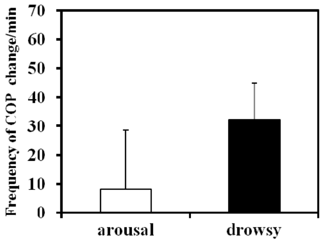

Fig. 13. Frequency of COP change/min compared between arousal and drowsy states for participants F-M (high level of drowsiness)

The results of logistic regression analysis using the rating of arousal level and one of the four measures (1)COP change/min, (2)bending angle of neck (horizontal), (3)bending angle of neck (vertical) , and (4)total movement of COP/min as dependent and independent variables, respectively, are shown in Fig.17 ((i)low arousal group) and Fig.18 ((ii) high arousal group). For both (i) low arousal and (ii) high arousal groups, the prediction accuracy of (2)bending angle of neck (horizontal) tended to be higher (about 0.8).

4 Discussion

Under the low arousal (drowsy) state, we confirmed that the vertical bending angle, the horizontal bending angle, and the COP change took significantly higher values. As demonstrated in Fig.5, both vertical and horizontal bending angles were different between arousal and drowsy states. Fig.6 and Fig.7 confirmed this tendency. In Fig.8 and Fig.9, the difference between the arousal and drowsy states is depicted. Under the drowsy states, the vertical and the horizontal bending angle got larger. These can be easily guessed to occur under the drowsy state. Although such equipment or a system.

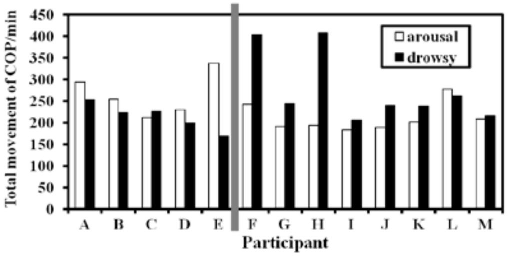

Fig. 14. Comparison of total movement of COP/min between arousal and drowsy states

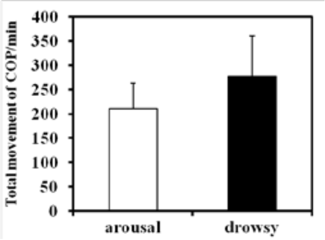

Fig. 15. Comparison of total movement of COP/min between arousal and drowsy states for (i) high drowsy group (participants F-M)

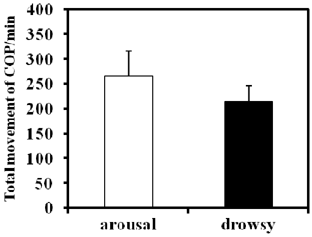

Fig. 16. Comparison of total movement of COP/min between arousal and drowsy states for (i) low drowsy group (participants A-E)

has already been on the market, these are not effective enough to predict the timing of low arousal state. The most important thing is to explore whether we can use these measure not to evaluate the arousal level but to predict the timing of low arousal state to occur in future.

As shown in Fig.11, there were individual differences among thirteen participants. The relaxing such individual differences might lead to higher prediction accuracy. While the result of the frequency of COP change for the participants A-E showed the tendency that the value is larger when the participants are arousal than when the participants were drowsy, this tended to be higher under the drowsy state than under the arousal state for participants F-M. As for the COP change, Murata et al.[8] showed a consistent tendency that the COP change is higher under the drowsy state than under the arousal state (see Fig.10). Synthetically judged, it seems reasonable to think that there exist two patterns in COP change: those for (i) low arousal group and for (ii) high arousal group. Different from neck bending angle (see Figs.7-9) and physiological measures such as EEG, EOG, and ECG, the behavioral pattern observed from the sitting pressure seems to be more influenced by individual differences. As shown in Fig.11, we found two patterns in COP change according to the severity of arousal degradation. The following two patterns were identified. In one pattern ((i) low arousal group in Fig.12), the frequency of COP change is smaller under the drowsy state

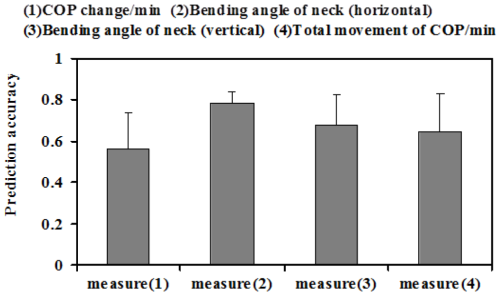

Fig. 17. Comparison of prediction accuracy among predictions using each of four measures (1)-(4) for (i) low arousal group (participants A-E)

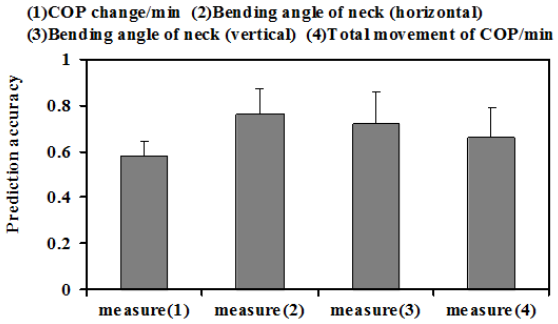

Fig. 18. Comparison of prediction accuracy among predictions using each of four measures (1)-(4) for (ii) high arousal group (participants F-M)

than under the arousal state. Other pattern ((ii) high arousal group in Fig.13) showed a tendency that the COP change is larger under the drowsy state than under the arousal state. Thus, such a finding of the two patterns might help relax individual differences and contribute to higher prediction accuracy.

As shown in Fig.14, Fig.15, and Fig.16, a similar tendency to the frequency of COP change was also observed for the total movement of COP. There existed two patterns of total movement of COP as in Fig.14: ((i) low arousal group in Fig.15) and ((ii) high arousal group in Fig.16). In (i) low arousal group (see Fig.14), the total movement of COP is smaller under the drowsy state than under the arousal state. In (ii) high arousal group (see Fig.16), the total movement of COP tended to be larger under the drowsy state than under the arousal state. In conclusion, these results suggest that the sitting pressure-based evaluation measures must be cautiously used and interpreted by taking the detailed drowsy state into account.

A logistic regression analysis, in which the subjective rating of drowsiness and the biological information corresponded to a dependent variable and an independent variable, respectively, was used to predict the drowsiness. The result is summarized separately for (i) low drowsy and (ii) high drowsy groups in Fig.17 and Fig.18. Although the prediction accuracy of (2) bending angle of neck (horizontal) tended to be higher (about 0.8) for both groups (i) and (ii), predicting the rating score of drowsiness by means of logistic regression analysis that entered a single evaluation measure could not attain high accuracy for other three measures (1) COP change/min, (3)bending angle of neck (vertical), and (4)total movement of COP/min. As mentioned above, individual differences in (1) COP change/min and (4)total movement of COP/min were to some extent relaxed and eliminated by the successful classification of (i) low drowsy and (ii) high drowsy groups. In spite of this, higher prediction accuracy was not obtained with a single evaluation measure. This seems to be the limitation of using behavioral measures such as the bending angle of the COP change for the prediction of drowsy sate. Therefore, future work should add to the more objective measurement technique of drowsiness such as EEG and observe the arousal level of participant more accurately, investigate the correspondence between EEG and the measures used in this study, and make an attempt to enhance the prediction accuracy.

On the basis of the experimental result, it had been suggested that the change of bending angle, the frequency of COP change, and the total movement of COP might be promising for predicting the drowsy state. It must be noted that the two measures derived on the basis of sitting pressure showed different patterns between (i) low arousal (participants A-E) and (ii) high arousal (participants F-M) groups. Future work should use the horizontal and vertical bending angles of the neck together the frequency of COP change and the total movement of COP so that higher discrimination accuracy can be obtained. The use of other convenient measures such as the eye blink together with the measures used in this study might further enhance the prediction accuracy of drowsiness.

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