FEASIBILITY STUDY ON DETECTING DRUNK DRIVING BY DRIVING MANEUVER AND VEHICLE BEHAVIOR - DISCRIMINATING BETWEEN DRUNK DRIVING AND DROWSY DRIVING USING DATA FROM VAHICLE-BASED SENSORS -

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ABSTRACT

Drunk driving remains a major factor in fatal accidents around the world. Previous studies have suggested various approaches to prevent drunk driving. For example, sensors were developed to detect alcohol intoxication. Other significant studies has shown how alcohol intoxication affects driving maneuvers and the resulting vehicle behavior. Such approaches have high applicability because they do not require the installation special devices. In addition, alcohol is known to induce drowsiness. Drowsiness also affects driving maneuvers and vehicle behaviors. Therefore, to accurately detect alcohol intoxication, the effect of drowsiness must be separated from that of alcohol intoxication. However, the difference between these two types of impaired driving remains unclear. If the type of impaired driving can be identified, effective countermeasures may be applied. To address this issue, the present study distinguishes between drunk driving and drowsy driving based on driving maneuvers and the resulting vehicle behavior, which are determined using data from vehicle-based sensors. Data on driving maneuvers and vehicle behavior were collected using a driving simulator set to a simple driving scenario to induce drowsiness. The experiment consisted of five driving sessions. The first session was sober driving (i.e., before drinking). Following the first session, the participants took a meal with an arbitrary amount of alcoholic drink. From the second session to the fifth sessions were drunk driving. Breath alcohol concentration (BrAC) was measured and driver drowsiness was determined by using the Stanford Sleepiness Scale (SSS). The results which culculated by standardized partial regression coefficient suggest that the standard deviation of the steering angle is affected by alcohol, whereas the standard deviation of lateral vehicle position is affected by drowsiness. Discriminant analysis were used for discriminating between four states: “Sober and Awake”, “Sober and Drowsy”, “Drunk and Awake”, and “Drunk and Drowsy”. The “Sober and Awake” state is accurately detected at a rate of 96.8%; for “Drunk and Drowsy” the rate is 65.1%, and for “Drunk and Awake” the rate is 41.1%. We discuss how, in general, almost all vehicle behavior reflects the driver’s maneuvers. For example, alcohol intoxication led to a relatively large increase in the standard deviation of steering angle, although the standard deviation of lateral vehicle position increased only slightly. Conversely, drowsiness led to a relatively small increase in the standard deviation of steering angle but a relatively large increase in the standard deviation of lateral vehicle position. This mismatched relation may be caused by frequencies involved in steering: high-frequency steering results from alcohol intoxication, whereas low-frequency or intermittent steering results from drowsiness. This means that high-frequency steering is poorly reflected in vehicle behavior because of the integral characteristics of the vehicle steering mechanism. We conclude that alcohol intoxication mainly affects driving maneuvers whereas drowsiness mainly affects vehicle behavior. Moreover, the normal state “Sober and Awake” and the impaired state “Drunk and Drowsy” may be discriminated based on these evaluation indices. Future work should investigate the frequency of steering operations in each driving state. These findings should be integrated into advanced driver assistance systems to assist impaired drivers.

INTRODUCTION

Drunk driving remains one of the main factors in fatal accidents around the world, and the risk of traffic accidents is known to increase for drunk drivers [1]. Previous studies have suggested various approaches to prevent drunk driving. For example, sensors were developed to detect alcohol intoxication [2][3]. Other studies have investigated how alcohol affects driving maneuvers and vehicle behavior [4]–[6]. Such approaches have high applicability because they do not require the installation special devices. However, driving maneuvers and vehicle behavior are affected not only by drunk driving but also by drowsy driving. Drowsy driving is also extremely dangerous and may influence any driver [7]–[9]. The effect of drunk driving on driving maneuvers and vehicle behavior can be predicted, and this effect changes when drowsiness is included. Therefore, to accurately detect alcohol intoxication, the effect of drowsiness must be separated from that of alcohol intoxication. However, few studies have focused on differentiating between alcohol impairment and drowsiness based on driving maneuvers and vehicle behavior [13]–[15]. The present work addresses this shortcoming by studying the feasibility of differentiating between drunk driving and drowsy driving based on driving maneuvers and vehicle behavior as determined from data acquired by vehicle-based sensors. Moreover, we discuss the experimental results based on the driver's state, the driving maneuvers, and vehicle behavior.

METHOD

Objective

Driver ability is affected by factors such as alcohol intake and drowsiness. If these factors can be differentiated by some algorithm, it may be possible for the vehicle to provide appropriate support for the driver. For example, if some characteristics of drunk driving can be detected by an algorithm, the vehicle may emit an emergency alarm or be disabled altogether. If characteristics of drowsy driving are detected, a stimulus may be applied to wake the driver and encourage him or her to find a safe rest area. In this study, we divide the driver's state into four quadrants defined by alcohol states (sober or drunk) and arousal states (awake or drowsy) and verify the rate at which each quadrants may be identified based on data from driving maneuvers and vehicle behavior collected from a driving simulator (see Figure 1).

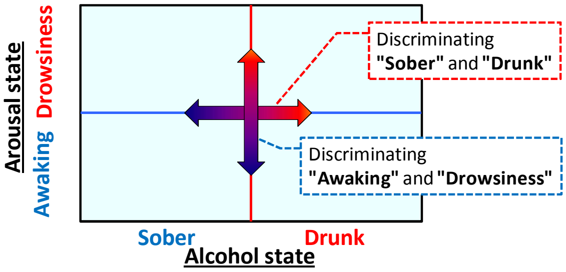

Figure 1. Quadrants for discriminating between alcohol and drowsiness.

Equipment and experiment settings

Driving maneuvers and vehicle behavior were collected by using a driving simulator at the Japan Automobile Research Institute. The driving simulator has a 360° screen and a six-axis-motion base. To induce drowsiness, it was used at a simple setting (i.e., a straight road at nighttime with no other vehicles or pedestrians; see Figure 2). The driving speed was 60 km/h, which the participants could adjust by operating the gas pedal.

Figure 2. Driving simulator and experiment setting.

Constitution

For each participant, the experiment consisted of five driving sessions. The first session was sober driving (i.e., before drinking). Following the first session, the participants took a one-hour meal with an arbitrary amount of alcoholic drink. Next came four sessions: the second session immediately after drinking, the third session one hour after drinking, the fourth session two hours after drinking, and the fifth and final session three hours after drinking (see Figure 3). Each driving session was divided into two driving periods, with a rest between driving periods. Each driving period lasted ten minutes and the rest period lasted approximately one minute (see Figure 4). The rests were taken to prevent excessive drowsiness. During the rest time, the room light was on and participants wiped their face with wet tissue and talked with the operator of the driving simulator.

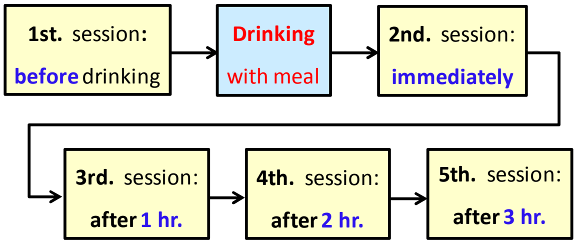

Figure 3. Flowchart of experiment procedure.

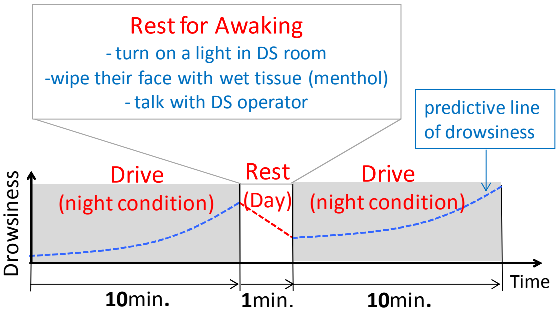

Figure 4. Driving session.

Measured parameters and definitions

The parameters measured included steering angle and gas pedal stroke, which were recorded for driving maneuvers, and speed, lane position, and yaw angle, which were recorded for vehicle behavior. Driver drowsiness was determined by using the Stanford Sleepiness Scale (SSS).

Each driving session was divided into four periods, from 1Q to 4Q (see Figure 5). Breath-alcohol concentration (BrAC) was measured in the waiting room before driving (A1, before 1Q) and after driving (A2, after 4Q). Participants assessed their drowsiness by SSS before driving (A1, before 1Q), before rest (B1, after 2Q), after rest (B2, before 3Q), and after driving (A2, after 4Q). These measurements were necessary to associate with BrAC and SSS at comparable times in each period. These values are defined for each period (See Table 1).

All measured parameters for driving maneuvers and vehicle behavior were calculated for each period (see Figure 6). Initially, all measured parameters were split into 32 s windows. Based on the 32 s window, 95% values were calculated in each period. To reduce the influence of personal driving characteristics for driving maneuvers, the value of the 95 percentile was normalized by the value obtained for sober and awake driving. This procedure yielded representative values for each evaluation index. Each participant provided 20 such representative values for each evaluation index.

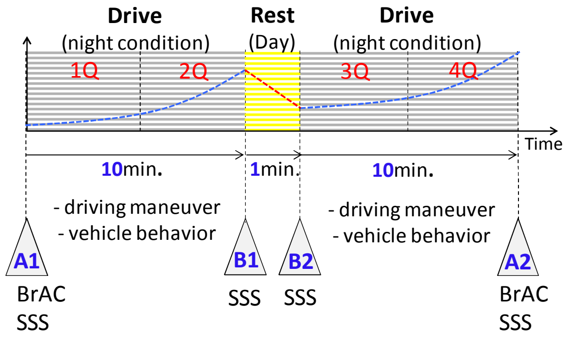

Figure 5. Timing of alcohol measurement and drowsiness scale.

Table 1.
Application of BrAC and SSS for each period.

Period	Alcohol (BrAC)	Drowsiness (SSS)
1Q	A1	A1
2Q	(A1 + A2)/2	B1
3Q	(A1 + A2)/2	B2
4Q	A2	A2

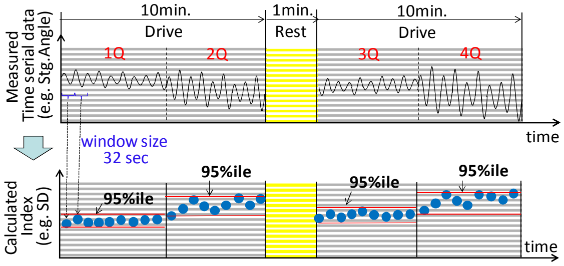

Figure 6. Graphical representation of representative values in each period.

Participants and instructions

Eight male drivers participated in this experiment. Each drove his own car approximately every day. All participants were instructed to keep their speed at approximately 60 km/h by using their gas pedal and to keep their vehicle centered in the lane to the extent possible.

RESULTS

Breath-alcohol concentration and Stanford Sleepiness Scale

Figure 7 shows BrAC transitions for each participant. Before drinking, the BrAC of all participants was 0 mg/L. Just after drinking, the BrAC levels ranged from approximately 0.27 to 0.61 mg/L. Over time, the BrAC levels decreased. Figure 8 shows the distribution in drowsiness (SSS) over the various driving states for all participants. These results are based on a total of 160 data, which ensured a sufficient sample size for all states: “sober and awake” (n = 31), “drunk and drowsy” (n = 43), and “drunk and awake” (n = 56).” However, only a single datum falls in the state “sober and drowsy..”

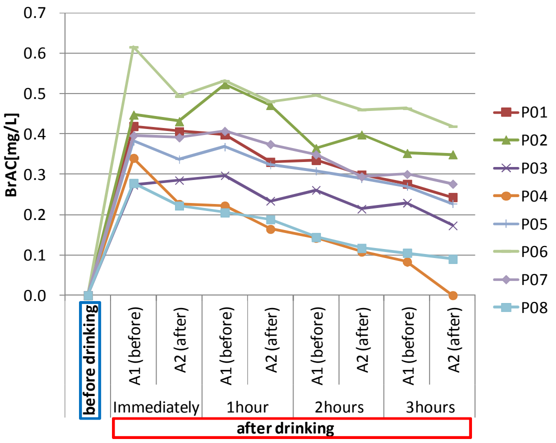

Figure 7. Result of breath-alcohol concentration for each participant.

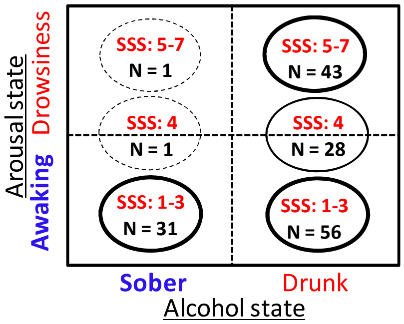

Figure 8. Sample number for each driving state.

Influence on evaluation indices

For all 160 data, we investigated the relation between BrAC levels and each evaluation index. Figure 9 shows the normalized standard deviation of steering angle as a function of BrAC. The results indicate that the standard deviation of steering angle increases with BrAC. Figure 10 shows the analogous plot for SSS, which indicates that the standard deviation of steering angle increases with SSS. Thus, BrAC levels and SSS indicate a similar effect on the standard deviation of steering angle.

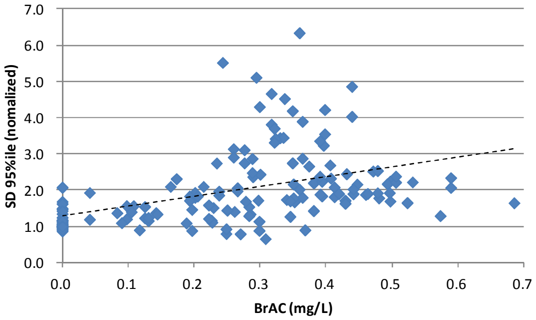

Figure 9. Normalized standard deviation of steering angle as a function of BrAC .

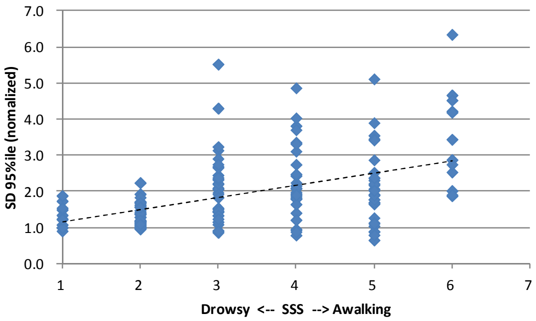

Figure 10. Normalized standard deviation of steering angle as a function of SSS.

These results indicate that there are interaction between alcohol effect and drowsiness effect because alcohol intake induces drowsiness, as is already known [13]. To clarify any relation between evaluation indices for alcohol intake and drowsiness, we calculated the standardized partial regression coefficient obtained by a multiple regression analysis. In the multiple regression analysis, the objective variable was set to each evaluation index in turn, and the explanatory variables were set to BrAC and SSS values (see Table 2). As the result, indices related to steering angle (and especially its standard deviation) might be affected by alcohol. In contrast, indices related to the lateral position of the vehicle (and especially its standard deviation) might be affected by drowsiness. These results indicate that alcohol tends to affect driving maneuvers and drowsiness tends to affect vehicle behavior.

Table 2.
Standardized partial regression coefficient calculated by multiple regression analysis (objective variables are each evaluation index, explanatory variables are BrAC and SSS).

Explanatory Variable	Driving Maneuver: Steering Angle				Vehicle behavior: Lateral Position			
	SD 95%ile	Left 95%ile	Right 95%ile	Range	SD 95%ile	Left 95%ile	Right 95%ile	Range
Alcohol (BrAC)	0.38	0.32	0.32	0.33	0.29	0.20	−0.14	0.34
Drowsiness (SSS)	0.19	0.25	0.29	0.27	0.42	0.04	0.18	0.34

Discriminating between drunk driving and drowsy driving

To discriminate between the intoxicated state and the drowsy state, we applied a discriminant analysis. This study uses two discriminant functions to differentiate between four states, “sober and awake,” “sober and drowsy,” “drunk and awake,” and “drunk and drowsy” (see Figure 11). In the analysis, the standard deviation of steering angle was chosen as an index to identify the intoxicated state, and the standard deviation of vehicle lateral position was chosen as an index to identify the drowsy state. Two discriminant functions were thus obtained to identify the intoxicated state (Equation 1) and the drowsy state (Equation 2). The scatter diagram in Figure 12 shows the distribution of each of the four states and the discriminant functions for the intoxicated and drowsy states. The x axis gives the standard deviation of steering angle and the y axis gives the standard deviation of vehicle lateral position. The red line separates the intoxicated state from the sober state, and the blue line separates the drowsy state from the awake state.” The blue circles represent the “sober and awake” state (n = 31) and are concentrated in a narrow area under the boundaries of both the intoxicated and drowsy states. The red squares indicate the “drunk and drowsy” state (n = 43) and are spread over a wide area, although many fall above the boundary for the intoxicated state. The pink triangles represent the “drunk and awake” state (n = 56) and are also spread over a wide area. To confirm the accuracy of the results, we counted the number of the points that fall into the correct state (see Figure 13).

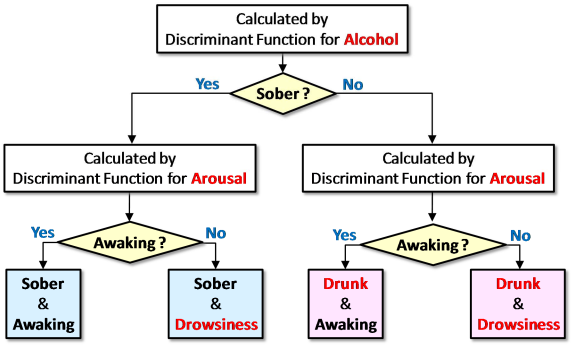

Figure 11. Flowchart for discriminating between intoxicated and drowsy states.

$$(\text{"Sober" or "Drunk}) = -1.12 * (\text{SD of steering angle}) - 1.16 * (\text{SD of lateral position}) + 3.19 \quad \cdot\cdot\cdot\cdot\cdot (\text{Equation 1})$$

$$(\text{"Awaking" or "Drowsiness"}) = -0.08 * (\text{SD of steering angle}) + 1.31 * (\text{SD of lateral position}) - 2.30 \quad \cdot\cdot\cdot\cdot\cdot (\text{Equation 2})$$

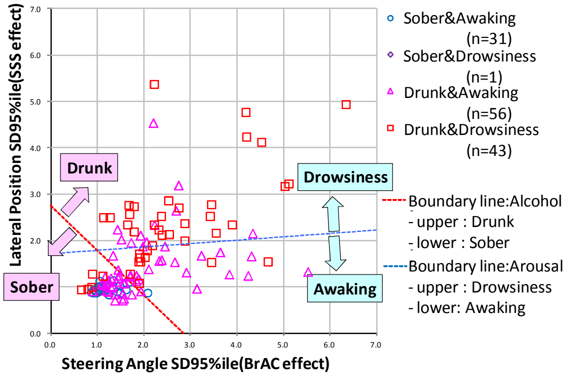

Figure 12. Feasibility of discriminating between intoxicated and sober states and between drowsy and awake states.

Based on the results, the “sober and awake” state is correctly identified at a rate of 96.8% (31 total “sober and awake” points, with 30 correct points). Only one point incorrectly identifies the “drunk and awake” state. The state “drunk and drowsy” is correctly identified at a rate of 65.1% (43 total points for “drunk and drowsy,” with 28 correct points). For the “drunk and awake” state, the accuracy is 41.1% (56 total points for “drunk and awake,” with 23 correct points).

Based on this analysis, the normal state (“sober and awake”) seems to discriminate with the highest probability, and the most dangerous state ("drunk and drowsy") is discriminated with satisfactory probability. However, the state "drunk and awake" is difficult to correctly identify.

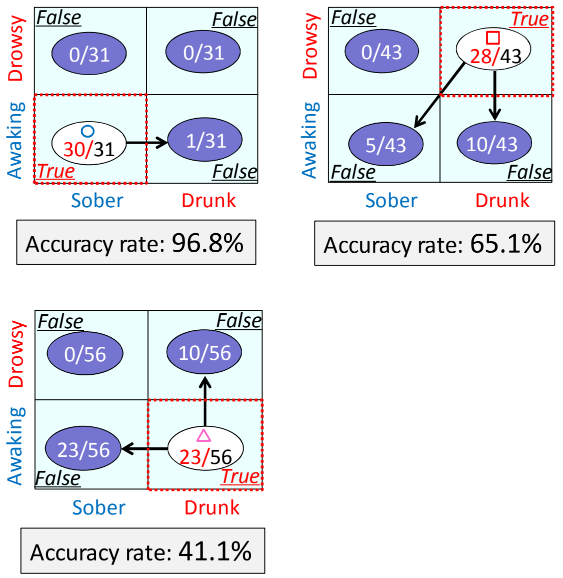

Figure 13. Accuracy of discriminating between quadrants.

DISCUSSION

This discussion focuses on the characteristics of indices for driving maneuvers and vehicle behavior. Almost all vehicle behavior occurs as a result of driving maneuvers. For horizontal motion, the displacement of the vehicle should be controlled by the steering wheel and the transmission functions of the vehicle steering mechanism. However, in this study, the effects of alcohol are strongly manifested in the standard deviation of steering angle. In contrast, the effects of drowsiness are strongly manifested in the standard deviation of the vehicle lateral position. This result seems to contradict the relation between driving maneuvers and vehicle behavior. However, we hypothesize that intoxication results in the steering angle being modified at a relatively high frequency, whereas drowsiness result in the steering angle being modified at a lower frequency. Conversely, if the steering angle is modified at a low frequency because of drowsiness, the effect on the lateral position of the vehicle becomes large. This means that high-frequency steering is poorly reflected in vehicle behavior because of the integral characteristics of the vehicle steering mechanism. This consideration might explain the results of this experiment and should be tested in each state.

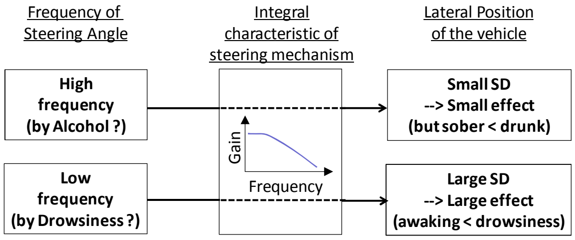

Figure 14. Hypothesized relation between frequency of modification of steering angle and of vehicle lateral position.

CONCLUSIONS

Based on experiments using a driving simulator, we conclude that intoxication mainly affects driving maneuvers whereas drowsiness mainly affects vehicle behavior. These evaluation indices can discriminate with high probability between the ordinary condition ("sober and awake") and the impaired condition ("drunk and drowsy"). Moreover, we hypothesize that the frequency with which steering angle is modified may explain these results, with a higher frequency corresponding to intoxication and a lower frequency corresponding to drowsiness. In future work, the frequency of steering modifications should be investigated under all conditions, and "sober and drowsy" data should be collected and investigated to clarify the effect of drowsiness. These results should contribute to the development of advanced driver assistance systems to assist impaired drivers.

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