Characterization of Hurried Driving Based on Collision Risk and Attentional Allocation

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***Abstract*— This paper proposes a method to characterize hurried driving from the viewpoint of attention allocation. When overtaking another car, drivers need to manage the collision risk by allocating their attention appropriately, thus increasing their mental workload. However, drivers' hurrying mental status likely arises in such situations, even though it is risky. Therefore, this study investigates the relationship between the risk of collision with surrounding vehicles and attention allocation when overtaking other vehicles. We will show that hurried driving can be characterized by outliers from the modeled distribution of normal driving in terms of the relationship between collision risk with the lead vehicle and continuous gaze time to the rear vehicle. Furthermore, a potential method to detect hurried driving is proposed by applying the results.**

I. Introduction

DRIVER assistance systems based on detection of the driver's human error are expected to reduce crashes. We focus on the fact that a driver's mental status is closely related to human error. For example, a hurrying mental status can induce risk-taking behavior [1], such as following too closely [2], and cause crashes. Thus, the purpose of this paper is to clarify the effect of the hurrying mental status on a driver's cognition, judgment, and behavior. It is expected that such research will lead to a driver-assistance system based on detection of abnormal driving, especially hurried driving.

Few studies focus on countermeasures for hurried driving, although it is widely understood as risky behavior. However, several studies have focused on detection of hurried driving, based on vehicle behavior or driver operation (e.g., roughness). Recently, Raksincharoensak et al. [3] proposed a method to detect hurried driving based on variance from the driver's normal pedal operation model.

On the other hand, it is thought that the hurrying mental status induces a decline of cognitive performance in complex traffic situations. Thus, it is expected that unsafe driving by a hurried driver can be detected earlier by change in cognitive performance than by vehicle motion and driver operation. Here, it is assumed that management of attentional allocation to hazards is greatly affected by the hurrying mental status. Thus, this study attempts to characterize hurried driving behavior based on drivers' attentional allocation, considering collision risk, and applies the results to a potential method to detect hurried driving.

First, experiments using a driving simulator are conducted with and without hurried driving. In particular, the effect of hurried driving on attentional allocation in preparation for overtaking is investigated. Overtaking is a complex task, and advanced attentional allocation performance is required. The hurrying mental status is expected to appear during overtaking. In this study, gaze positions (e.g., front and rear) are used to quantify attentional allocation. Second, hurried driving is characterized based on the attentional allocation of gaze behavior for a given collision risk toward a preceding car as a hazard in overtaking. Finally, a potential method to detect hurried driving is proposed, using hurried driving characteristics.

II. Experimental Method

A. Experimental Apparatus

A fixed-base driving simulator, DS-2000 (Mitsubishi Precision Co., Ltd.), that has a 37deg field of view is used for the experiments(Fig.1). Images of side mirrors and a rear-view mirror are imposed on the main screen. An eye-mark recorder, EMR-8B (NAC Image Technology, Inc.), is used to measure the gaze position of the driver's right eye. The sampling rates of the data recording of the driving simulator and eye-mark recorder are 60Hz.

Fig. 2. Experimental scenario.

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had a driving license. The experiments were conducted after the participants gave informed consent.

B. *Experimental Scenario*

The test track is a straight 6km-long road with two lanes in each direction. Participants are asked to drive at 80km/h in the left lanes, as they would drive in Japan. Driving the test track at this speed takes 270s. The driver encounters two vehicle groups to be overtaken in a trial (Fig. 2). The participant must overtake the lead vehicle in the same lane while avoiding collision with the vehicles in the other lanes. The two mean velocities of the lead vehicle are 40 and 60km/h. The four mean velocities of the vehicles in the side lane are 90, 110, 120km/h, and no vehicle. These mean velocities are fixed through each trial. Consequently, there are a total of eight scenario conditions (2 x 4).

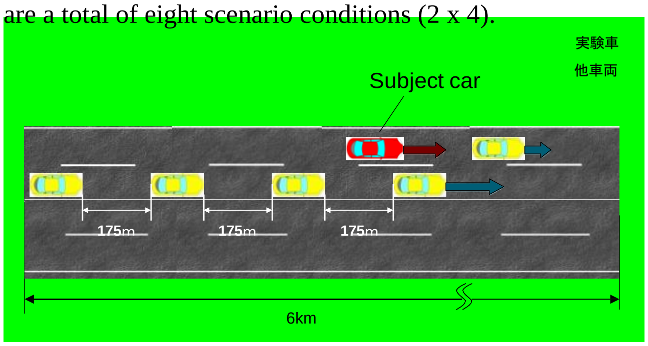


Fig. 2. Experimental scenario.

C. *Procedure*

Participants became accustomed to driving the simulator with 15min trials before executing the experiments. Twelve trials of the experiments in normal conditions (i.e., without hurrying) were conducted, followed by 12 trials with hurried driving tasks for each participant. One trial included two overtaking chances, for a total of 24 overtaking chances with normal and hurrying conditions. These overtaking events corresponded to three trials for each condition of eight scenarios. The scenario conditions appeared randomly.

The participants were instructed to drive the test track safely and to overtake the lead vehicle after confirming their safety, to use the turn signal and pass only if they felt that the preceding vehicle was slow, and to return to the original lane after passing. In the normal trial, the participants were instructed to reach the goal without any time pressure. In the hurried trial, the target time for the goal was assigned by subtracting 45s from the time in the normal condition. The examiner then announced the time every 30s from the start in order to give the participants time pressure in the hurrying condition. The subtracted time of 45s was determined by trial and error from another experiment in which around 80% of the drivers were able to reach the goal within the target time. No penalty was given even if the participants were not able to reach the goal in the target time.

The participants were nine healthy male students aged 21 to 24 who were not involved in this research. All participants had a driving license. The experiments were conducted after the participants gave informed consent.

D. *Analysis Method*

Collisionriskfortheprecedingvehicle

The relative motion of the two vehicles in a car-following situation can be expressed by the velocity of the subject vehicle V_o, the velocity of the preceding vehicle V_p, and the gap between the two vehicles *D*. We use these variables to determine how to evaluate the collision risk between two vehicles. There are several indices (e.g., Time-To-Collision (TTC)) to determine collision risk. Kitajima et al.[4] summarized the several indices for the collision risk. The index ϕ, which is based on the driver's visual information, is used to quantify the collision risk to the preceding vehicle (eq. (1)) [5].

$$\phi(V_r, V_p, D) = 10\log_{10}\left(\left|4\times10^{7}\times\frac{V_r - aV_p}{D^3}\right|\right) - b\log_{10} D - c \qquad (1)$$

where, relative velocity V_r is defined as eq.(2).

$$V_r = V_p - V_o = \frac{dD}{dt} \qquad (2)$$

It is shown that the expert drivers' last-second braking timing is modeled as the index $\phi = 0$, and it is applied to the design of an automatic braking system [5]. According to experimental results with expert drivers, coefficients in the index ϕ are given as $a = 0.2$, $b = -22.66$, and $c = 74.71$. A large ϕ indicates higher risk conditions.

Analysismethodofgazeposition

Fig.3 illustrates the analysis method of the gaze position. The driver's gaze position, measured by an eye-mark recorder, is classified into two categories, front and rear, by off-line processing manually. The gaze position is classified as rear when it is located in the rear-view mirror or the side mirrors from the data of the eye-mark recorder. Otherwise, it is classified as front. The data during eye blink is eliminated.

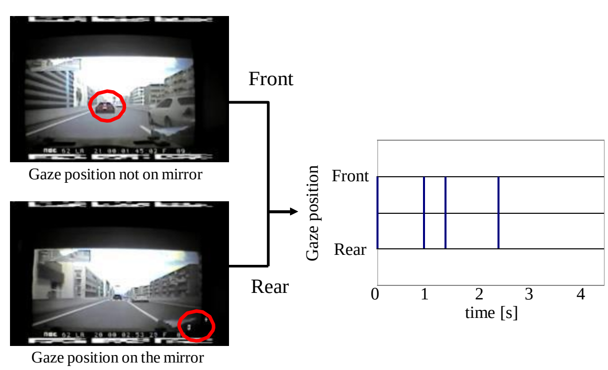
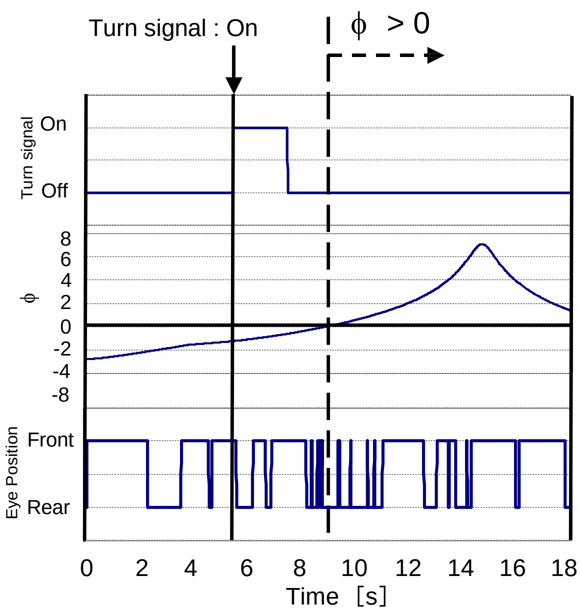


Fig. 3. Classification of visual behavior.

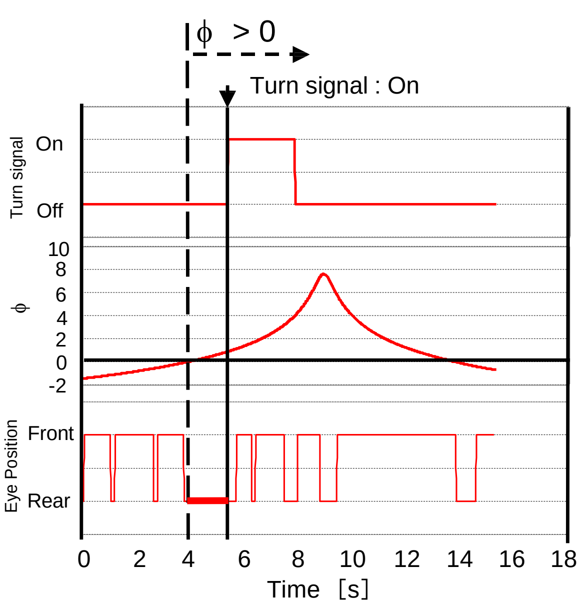
III. EXPERIMENTAL RESULTS

A. Comparison between normal and hurried driving behavior

Fig.4 shows an example of the experimental results when the participant's car is approaching a preceding vehicle and a car is in the next lane. For most of the trials in the normal condition, the turn signal is on before $\phi > 0$. In the hurried condition, the turn signal is sometimes on after $\phi > 0$. Furthermore, sometimes the participant demonstrates a long continuous gaze to the rear even in risky situations such as large ϕ in the hurried condition (Fig. 4(b)).



(a) Normal driving

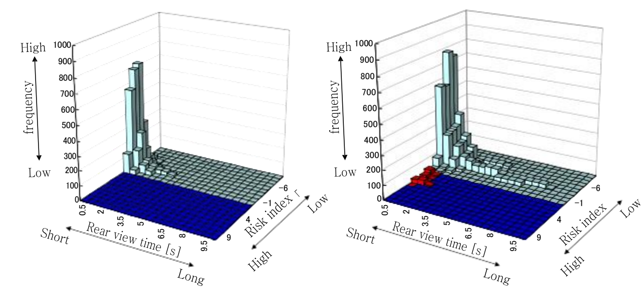


(b) Hurried driving

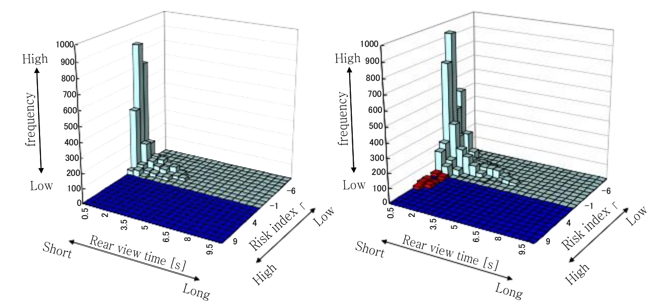
Fig.4 Example of overtaking behaviors

B. Relationship between collision risk and rear-view time

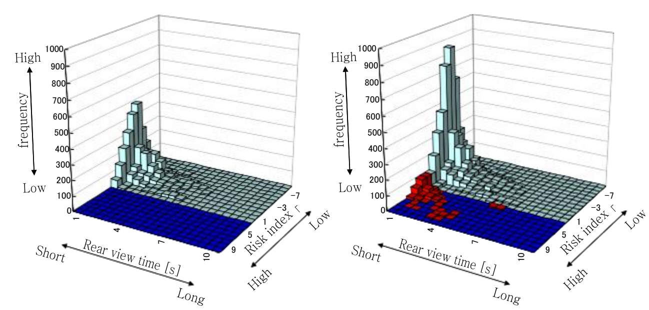
We assume that the relationship between collision risk for the preceding car ϕ and continuous rear-view time T reflects the results of the driver's attentional allocation toward a given collision risk. Fig.5 illustrates the distributions of ϕ and T of four participants. The dark areas denote situations with $\phi > 0$. It should be noted that data until the turn signal is on are analyzed to investigate distribution in the preparation phase for lane-changing.



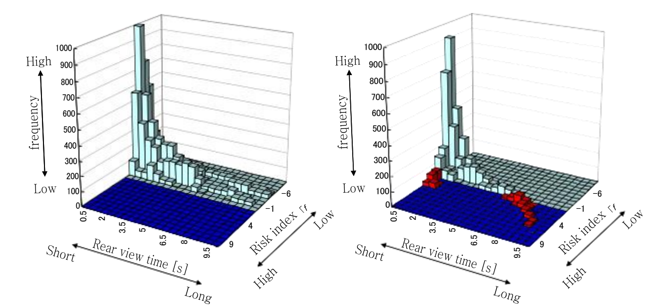
(a) Participant A



(b) Participant B



(c) Participant C



(d) Participant D

Fig. 5 Distribution of index ϕ and rear-view time
(Left figures: normal driving; Right figures: hurried driving)

Continuous rear-view time T has a peak in a certain area of the safer situations (i.e., negative ϕ). These phenomena indicate an increase in lane-changing intentions in certain risky conditions. With normal driving, no rear view was observed with $\phi > 0$. However, with hurried driving, rear-view behavior was observed even with $\phi > 0$. In addition, rear-view time T increased with hurried driving.

IV. CHARACTERIZATION OF HURRIED DRIVING

A. Modeling of the relationship between collision risk and rear-view time

We propose to characterize the distribution of index ϕ and rear-view time T observed in the previous section. We assume that the distribution in the normal condition can be modeled by a 2D normal distribution. The joint probability density function f of random variables $\boldsymbol{x} = [\phi, T]^{\mathrm{T}}$ is given by eq. (3).

$$f(\boldsymbol{x};\mu,\Sigma) = \frac{1}{2\pi|\Sigma|^{1/2}} \exp\left(\frac{1}{2}(\boldsymbol{x}-\mu)^{\mathrm{T}}\Sigma^{-1}(\boldsymbol{x}-\mu)\right), \quad (3)$$

where μ is the mean of $\boldsymbol{x}$ and Σ is its covariance matrix in the normal driving condition.

This study focuses on lane-changing preparation when the driver's intention to change lanes is high. Thus, we analyze all data collected during the experiments, except the data after turning on the turn signal until finishing lane-changing.

Figs. 6 and 7 depict participant B's distribution of ϕ and T in the normal driving and the hurried driving conditions with the probability ellipsoid of 90, 95, and 99% calculated by the data of normal driving. It is observed that many plots are out of the probability ellipsoid in the hurried driving condition as shown in Fig.7. In particular, high rear-view time T is observed even in the high risk index ϕ in this example.

B. Characterization of hurried driving

Based on the results of the previous section, we characterize hurried driving as the outlier from the modeled distribution of normal driving. For example, the outlier from the 95th percentile of the distribution of normal driving is treated as "hurried driving."

The Mahalanobis generalized distance d^2 of the variable $\boldsymbol{x}$ from the mean μ given by eq. (4) has a chi-squared (χ^2) distributed function.

$$d^2 = (\boldsymbol{x}-\boldsymbol{\mu})^{\mathrm{T}}\Sigma^{-1}(\boldsymbol{x}-\boldsymbol{\mu}), \quad (4)$$

where μ and Σ are calculated as the mean and covariance of state variable $\boldsymbol{x}$ in lane-changing preparation phase. Thus, variable $\boldsymbol{x}$ is considered as the outlier, or labeled as hurried driving when the following inequality is satisfied

$$d^2 > \chi^2(2, 0.05) = 5.99 \quad (5)$$

It should be noted that maximum likelihood estimation may be another possible method using the modeling distribution of hurried driving. It is, however, difficult to model hurried driving behavior appropriately in a distribution function. Thus, we treat hurried driving as the outlier from the distribution of normal driving.

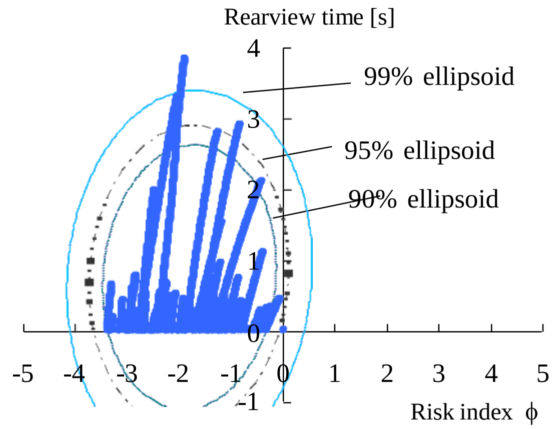


Fig.6 Index ϕ vs rear-view time with probability ellipsoid of the normal driving

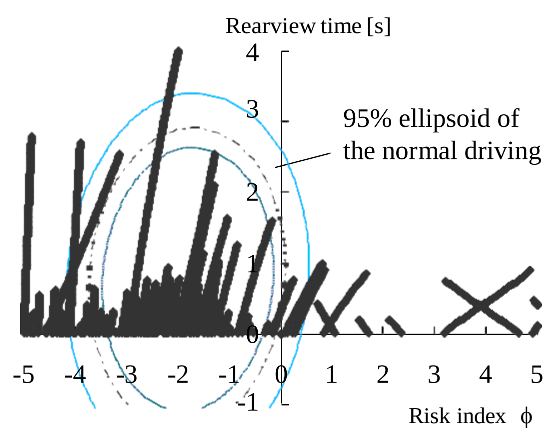


Fig.7 Index ϕ vs rear-view time with probability ellipsoid of the hurried driving

V. DETECTION METHOD OF HURRIED DRIVING

A. Algorithm of Detection Method

We propose a potential method to detect hurried driving as the outlier from the modeled distribution of normal driving based on the characterization in the previous section.

Fig.8 shows procedure of the proposed detection method. It is assumed that the gap to the preceding vehicle $D(t)$, relative velocity $V_r(t)$, and velocity of the preceding vehicle $V_p(t)$ are measured at each time t. These variables are utilized to calculate the risk index $\phi(t)$. On the other hand, the driver's gaze position is analyzed in real time to measure continous rear-view time $T(t)$. State variable vector $\boldsymbol{x}(t) = [\phi(t), T(t)]^{\mathrm{T}}$ is, then, obtained. State variable $\boldsymbol{x}(t)$ is stored in the memory, then μ , mean stored state variable $\boldsymbol{x}(t)$ and its covariance matrix Σ are updated in certain frequency. Mahalanobis generalized distance d^2 is calculated using the measured and stored variables. The state variable at each time $\boldsymbol{x}(t)$ is classified as "hurried driving" if inequality (5) is satisfied. Otherwise, the variable $\boldsymbol{x}(t)$ is labeled as normal driving. The classification is executed at each time.

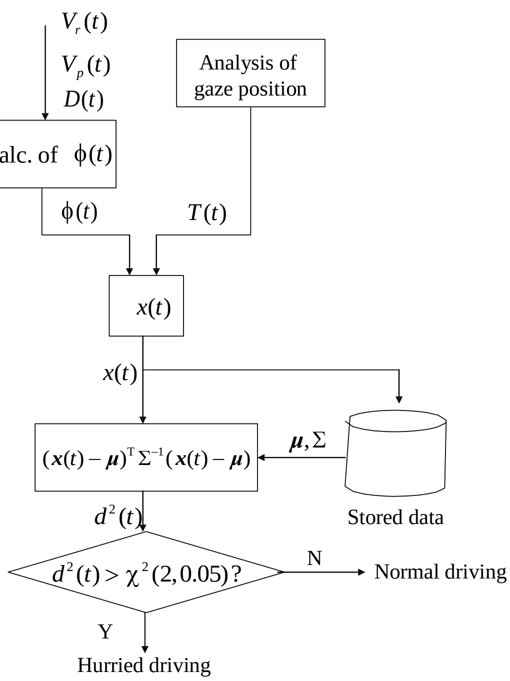


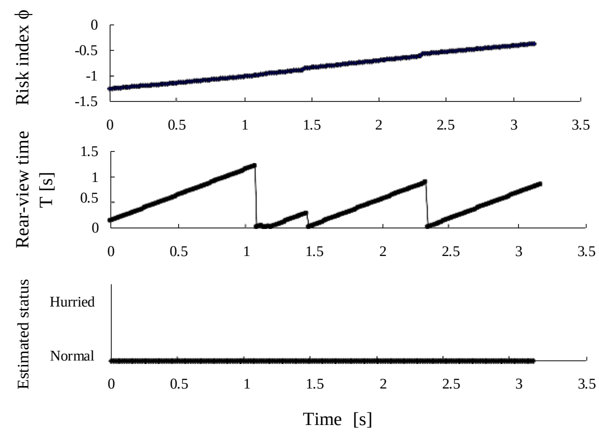
Fig.8 Algorithm of classification method

B. *Examples of Classifications of Driver Status*

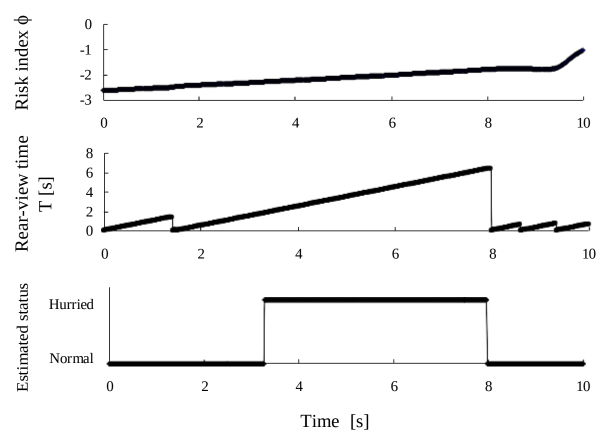
Fig.9 shows the typical examples of the classification results of driver's status by the proposed method. Fig.9-(a) illustrates an example of the participant A's driving behavior in normal condition. The frequent rear-views were observed with small rear-view time T while the risk index ϕ increases gradually by time due to approach of a lead vehicle. This frequent rear-view represents increase of lane-changing intention of the driver. The driver's status was classified as normal for all time of the figure.

Fig.9-(b) illustrates an example of participant A's driving behavior in hurried condition. A long rear-view was observed and it resulted in being classified as hurried driving from 3.2s. The driver's status was classified as normal driving by stopping the long rear-view and changed into short frequent rear-view.

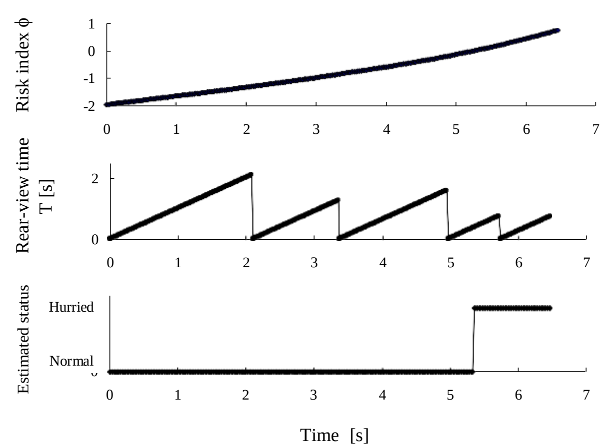
Fig.9-(c) illustrates an example of participant B's driving behavior in hurried condition. At the beginning, the driver status was classified as normal while relatively large rear-view was observed in the case of low risk index. Then the rear-view was switched into shorter one while the risk index gradually increased. This behavior keeps the classified status normal driving. Finally, the estimated status was classified as hurried driving while the rear-view time is not so large due to large risk index.



(a) Normal driving condition (participant A)



(b) Hurried driving condition (participant A)



(c) Hurried driving condition (participant B)

Fig.9 Estimated status by the proposed method.

C. Classification results of drivers status

Fig.10 shows the detected results of the proposed method. Detected rate shown in the vertical axis is defined as eq.(6).

$$(\text{Detected rate}) = \frac{(\text{Sum. of time classified as "hurried"})}{(\text{Total time of sampled data})} \quad (6)$$

In the results of the hurried driving condition, the detected rate is large. However, for participants H and I, the detected rate is small, possibly because these participants' rear-view time with normal driving is as large as that with hurried driving.

For comparison, hurried status is classified by another method that uses the inequality $\phi > 0$ (Fig.11). This detection method is based on overt risk for the preceding car. A few participants' detected rate is larger with hurried driving condition than with normal driving condition. However, the difference of the detected rate between the normal and hurried conditions is very small. Therefore, the proposed method has the ability to detect hurried status earlier with high detected rate.

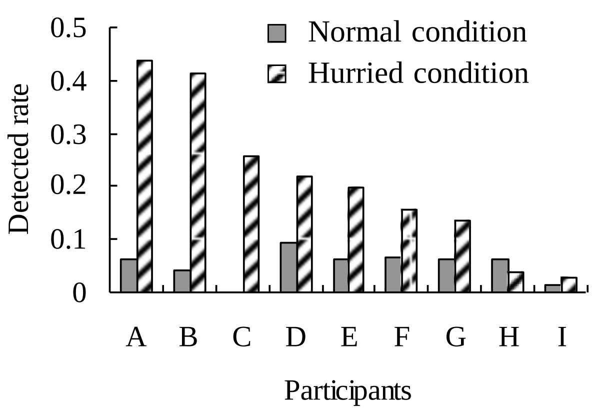


Fig.10 Detected rate of hurried driving status

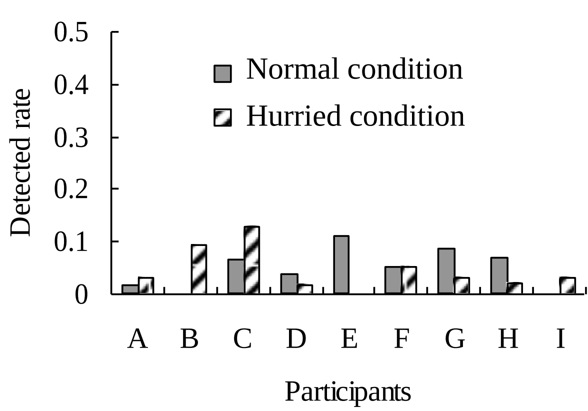


Fig.11 Detected rate by $\phi > 0$

VI. CONCLUSION

This study characterizes hurried driving based on the distribution of collision risk for the preceding vehicle and the continuous time gazing at the rear vehicle. It demonstrates that hurried driving can be characterized by the outlier from the modeled 2D normal distribution of normal driving in terms of the relationship between collision risk for the preceding vehicle and rear-view time. Furthermore, this characterization was applied to the potential detection method of hurried driving in preparation for lane-changing. This method can detect hurried driving with a higher rate of success in the hurried driving task than in the normal driving task. It was also shown that the method can detect hurried driving with a higher success rate than the other method that detects overt risky situation as large ϕ.

The proposed method can be used when lane-changing intention is high. Thus, we need to develop a method to detect lane-changing intention (e.g., Itoh and Inagaki [6]). In addition, this method may be applied to the detection of the other distractions, such as low arousal level and high mental workload.

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