Development of a Safe Driving Promotion System by Displaying Driving Scores and Rankings

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A critical factor in preventing vehicle accidents is a sufficient following distance. However, most drivers follow the car ahead too closely. A questionnaire survey examined the reasons for close-following distance, which included preventing cars from cutting in, being in hurry, feeling safe with a short following distance, and unaware of what a safe following distance is. It indicated that close-following is due to hastiness and unawareness of driving behavior. Then the results were used to develop and test a new safe driving promotion system, which displays a driver's driving score and his or her rank. Drivers should be encouraged by their driving scores and rankings which will directly rouse a competitive spirit and will induce self-consciousness. Furthermore, drivers' behaviors were browsed on the Web. This system should help drivers realize a safe following distance.

Keywords: *Reasons for close-following distance, Safe driving promotion system, Score and ranking display, Competitive spirit, Self-consciousness*

1. Introduction

Many countries prohibit following other cars too closely. In general, the greater the following distance, the more time drivers have to react to traffic situations around them and to avoid a hazard. Despite numerous safe driving campaigns or lectures advocating a safe following distance, most people drive their cars with a close following distance. Thus, how this problem is addressed needs to be reexamined.

It is difficult to say what an appropriate following distance is. However, the "two-second rule" or "three-second rule" has been suggested for safe driving in general traffic situations [1,2]. Using these rules, drivers should drive so that the time gap, which is the time required for the vehicle in front and the driver's vehicle to pass the same point, is two or three seconds.

Many researches have documented that the following distances of most drivers are too close, and the connection between close-following driving and traffic offenses [3-5]. Rajalin *et al*. has stopped drivers with a headway of less than a half of a second on the road and inquired about the reasons for their short headways [5]. The open answers were divided into five categories: (1) vehicle spacing 'adequate,' (2) overtaking intentions, (3) behavior of the other vehicle, (4) close-following is a habit, and (5) other reasons. The answers of close-following drivers may depend on the situations because Rajalin's research was conducted on the spot. Respondents, who were stopped by the police, may lie or give feasible excuses to interviewers. The common opinions for the reasons of close-following of ordinary road users are also needed for further road safety studies.

In this study, the reasons for close-following in general situations were examined via a questionnaire survey. Then we proposed a new safe driving promotion system, which displays driving scores and rankings. Drivers should be encouraged by their driving scores and rankings and compete with other drivers on safe driving. This system can be used as if it were a game because it does not force safe driving.

2. Questionnaire survey

2.1. Methods

2.1.1. Participants. Respondents to a questionnaire consisted of three groups. The first group consisted of young drivers under 24 years old with a mean age of 20.2 years old (SD=1.5) and included 98 males and 13 females. The second group, which was comprised of 42 males and 12 females, consisted of middle-age drivers from 25 to 64 years old with an average age of 49.1 years old (SD=10.2). The third group consisted of 44 male examiners at driving schools. Their average age was 42.9 years old (SD=7.2).

2.1.2. Questionnaire items. The questionnaire was anonymous and was administered in groups. Participants were given a list of reasons (Table 1) that might result in close-following, which was compiled by the authors. Participants were asked the main reasons for close-following of general road users.

For each item, participants answered on a seven-point scale, ranging from 1 = "That is definitely not the reason" to 7 = "That is the very reason" (2 = "That is mostly likely not the reason," 3 = "That is probably not the reason," 4 = "I do not know," 5 = "That is probably the reason," and 6 = "That is most likely the reason.")

2.2. Results and Discussion

The right columns of Table 1 show the average rating of each reason by group. The highest rated reason was to prevent "cutting in". This tendency was observed in all three groups. We have previously reported that most people have the common misunderstanding that a long following distance causes many interrupting car to cut in and delay their arrival [6]. This misconception seems to produce close-following behaviors.

Rajalin *et al*. did not find this reason. This difference might be due to distinct situations. Their respondents were actual drivers who drove within a 0.5 sec time gap, which may be too close of a following distance for preventing cutting in to be a valid reason. However, we asked drivers about other people's behavior. This inference suggests that Rajalin *et al*. investigated the reasons for the behaviors of very close-following drivers, while we examined general reasons for close-following.

The second high-rated reason was being in a hurry. Other reasons, No. 6, 9, and 11 in Table 1, are probably related to this. This reason was also the second most cited reason in the study of Rajalin *et al*. In addition, the third and fourth reasons show the people are unaware of their risky behavior.

With the exception of "No special reason (No. 10)," the top ten reasons, which are greater or equal to 4.0 points, can be classified into two groups, hastiness and unawareness. Items in the hasty group suggest that people want to drive fast (No. 2, 6, and 9) and want to prevent cutting-in because their arrival time may be delayed (No. 1). The unaware group implies that people do not know what an appropriate following distance is. They are overconfident to their driving skills (No. 3 and 4) or they imitate other driver's following distances (No. 4, 5, 7, and 8).

In this study, respondents were not asked about their own reasons for close-following distances, but were asked to infer the reasons of other people's behavior. However, their responses should reflect general reasons for close-following distances because the respondents answered based on their daily driving behaviors.

3. Safe driving promotion system

3.1. Outline of the system

We assumed that employing a psychological mechanism, which includes a sense of competition and self-consciousness about how one appears to others, could suppress the close-following distance behavior. Scores and rankings of driving behavior will directly rouse a competitive spirit and will induce self-consciousness. The browsing system, which provides detailed information on driving behaviors, should directly produce both.

We have developed a new system, which is based on our old one (ASSIST: Assistant System for Safe driving by Informative Supervision and Training [7,8]). The ASSIST wirelessly transfers information on risky driving behavior of a driver to a supervisor. Then the supervisor can warn the driver to drive safer when the driver's behavior is recognized as risky driving.

Figure 1 outlines the new system proposed in this paper. This new system is composed of a server system and client systems. The client systems, which are mounted on vehicles, acquire drivers' driving behaviors and then transmit the data to the server system. Then the server system receives the driving data, calculates scores and ranks these scores, and then transmits the scores and rankings back to the client systems. All the data is stored in a database on the server system. Supervisors can access the driving data and administrate their drivers using a system like the ASSIST. Furthermore, anyone with permission can also browse the data because the data is on the Internet. Thus, the driver will have the sense of being watched by somebody, which should make his or her driving behavior safer.

A similar project has been conducted in the Netherlands [9]. In the Netherlands project, driving behaviors were evaluated using following distance and speed, which were used to determine behavior points. These behavior points were then converted into reward points, and the driver was rewarded for good driving behavior. It has been reported that the project worked well, and drivers' behaviors became safer.

There are several differences between their project and ours. First, our proposal does not contain a reward. Instead, it uses a sense of competition and self-

Table 1. Reasons for close-following distance

No	Reasons	Young	Middle	Examiner	Average
1	They think a short following distance will prevent other vehicles from cutting in.	5.4	4.8	5.7	5.3
2	They feel rushed.	5.2	4.5	5.5	5.1
3	They think that an accident will not occur with their present close following distance.	5.0	4.4	5.4	4.9
4	They didn't realize their close-following distance.	4.2	4.3	5.7	4.7
5	They think that a long following distance inconveniences the driver of the car behind them.	4.5	4.7	4.3	4.5
6	They feel that the driver ahead drives too slowly.	4.7	4.1	4.6	4.5
7	Other drivers also drive with short following distances.	4.0	4.0	5.0	4.3
8	They don't know what a safe following distance is.	3.9	4.0	5.0	4.3
9	They are waiting for an opportunity to pass.	4.3	3.3	4.5	4.0
10	No special reason.	4.0	4.0	3.9	4.0
11	They think a long following distance will increase their travel time.	4.5	3.6	3.6	3.9
12	They trust their quick reactions will avoid an accident if the car ahead stops abruptly.	3.3	3.4	4.6	3.8
13	They think that they will not be caught for a short following distance.	3.3	3.0	3.2	3.2
14	They feel uncool driving with a long following distance.	2.8	2.9	3.3	3.0
15	They think it is easier to drive with a close following distance.	3.2	2.5	3.1	2.9
16	They worry people think they are poor drivers for their long following distance.	3.0	2.7	3.0	2.9
17	They consider long following distance driving dangerous because they lose their sharpness	2.8	3.0	2.6	2.8
18	They feel sleepy when they drive with a long following distance.	2.9	3.0	2.5	2.8
19	They want to take a risk.	2.4	2.2	2.7	2.4

consciousness. Second, our proposal provides scores and ranks in real time. The driver will know his or her score and rank at every stop, which will arouse a sense of competition. Although the driver in the former project knew his or her behavior points through in-car equipment in real time, he or she did not know his or her reward points because a formula converted the behavior points into reward points. Thus, the reward points had to be checked on the Internet on a daily basis.

3.2. Driving Score

There is a variety of scoring methods to assess driving safety. In this system, we utilized a driving score based on a POC (Probability of Collision), which we have previously proposed [10]. The POC shows the probability of a rear-end collision with the car ahead when the leading car stops quickly on the spot; in other words, the probability that the stopping distance exceeds the following distance. The stopping distance D_{st} consists of the thinking distance D_{th} and the braking distance D_{br}. These three variables are related as:

$$D_{st} = D_{th} + D_{br} .$$

D_{th} is the distance from the point when an event, which requires stopping, occurs to the point when the driver brakes. It is calculated as a product of the driver's reaction time T and the initial velocity v. D_{br} is the distance from the point where a driver begins to brake to the point where the vehicle actually stops. It is determined using a standard formula with the initial velocity v, the coefficient of friction between tires and roadway μ, and the acceleration of gravity g as:

$$D_{br} = v^2 / 2\mu g .$$

Therefore, the following distance D_f must satisfy the following requirements for a rear-end collision:

$$D_f \le Tv + v^2 / 2\mu g .$$

In this requirement, the reaction time T is only indeterminate in reality, and is impossible to precisely estimate. Therefore, the authors have tried to treat reaction time as a stochastic variable x and have assumed its probability density function $f(x)$. Also, the probability distribution for reaction time $F(x)$ is defined as:

$$F(x) = \int_{-\infty}^{x} f(t)dt .$$

Using $F(x)$, it is possible to obtain the POC. According to the above requirement for a rear-end collision, the necessary conditions in terms of reaction time T are given below:

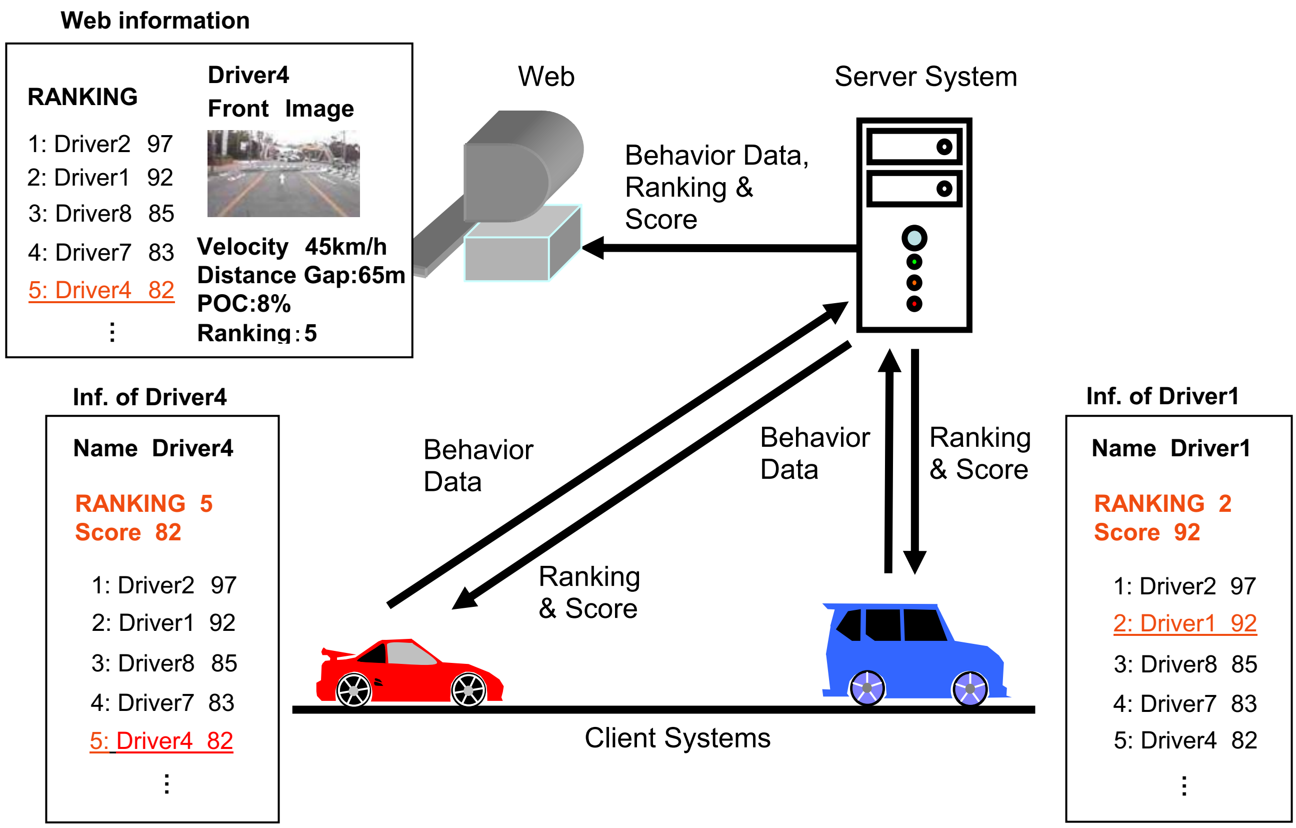

Figure 1. Outline of the proposed system

$$T \geq \frac{2\mu g D_f - v^2}{2\mu g v}.$$

Setting the right side of the above equation as T_c, it shows the minimum reaction time for a rear-end collision. Therefore, the POC is calculated by T_c and $F(x)$ as follows:

$$POC = 1 - F(T_c).$$

In the implimentation, we measured each driver's reaction times for a choice reaction task before driving, and assumed the probability density function for each driver based on the result. In addition, the velocity and the following distance were measured while driving, and the coefficient of friction and acceleration of gravity were set as 0.69 and 9.8m/s^2, respectively.

We then transformed the POC into a driving score using the method described below. A high score is difficult to improve, but easily plummets, while a low score is easy to improve, but difficult to plummet. We used both the POC and the score obtained from the POC transformation as indexes of safe driving because we felt that this combination was theoretically the best index of safe driving and because it was a comprehensive safety index, which covers other factors such as, velocity, following distance, and driver's reaction time.

The most important point of our proposal is that drivers actively competed against other drivers for their score and ranking. The effect of the system would decrease if the POC and the score were replaced with other indexes for safe driving. However, when a more powerful index is devised and used in this system, the effect would increase only if drivers recognize that the index reflects the degree of safety of their driving behavior.

3.3. The client system

The client system was composed of sensors, a microprocessor board (Akizuki Denshi Tsusho Co., Ltd., AKI-H8/3052), a laptop computer (IBM Japan, Ltd., Thinkpad R40), and a monitor (Quixum Co., Ltd., QT701AV).

3.3.1. Measurement of driving behavior. Figure 2 shows selected mounted sensors and the monitor. This system measured the velocity, following distance to the car ahead, and location. The velocity and a following distance were measured with a laser distance and velocity measuring system (Nissan Diesel Motor Co., Traffic Eye), which was mounted on the front grill. The location was identified with a GPS receiver (Pioneer Navicom Inc., GPS2003-ZZ). The outputs of this laser distance and velocity measuring system and GPS receiver were transmitted to the microprocessor board, which then transmitted the data to the laptop computer through RS232C once every second. The front view image from the car was also taken with a small NTSC video camera (Kyohritsu Electronic Industry Co., Ltd., Super mini), which was attached on the back of the rearview mirror. The camera images were transmitted to the laptop through NTSC to a USB conversion cable.

The laptop computer stored the data from the sensors and transmitted the data to the server system with a data communication PC-card (Japan Communications Inc., b-mobile BMH10-J) using a DDI Pocket PHS wireless packet network. The maximum transfer speed was 68 kbps (uplink) and 127 kbps (downlink). Except for the front view image, which was transferred every five seconds, all data was transferred every second. The data communication protocol was TCP. The OS of this laptop computer was Windows XP and client applications were programmed with Microsoft Visual C++ 6.0.

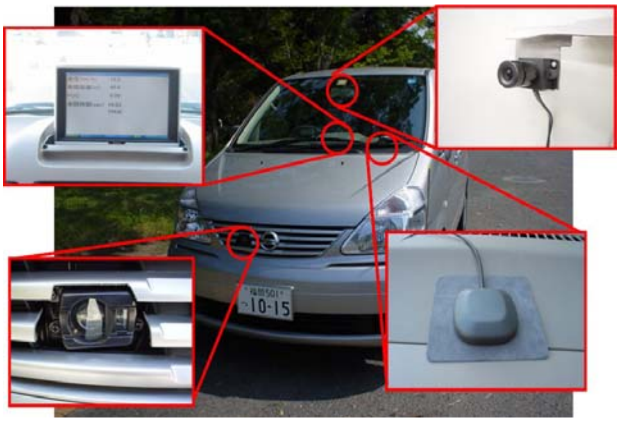

Figure 2. Sensors and monitor mounted on the vehicle

3.3.2. Display of driving behavior, driving score, and ranking. The monitor installed in the center of the dashboard displayed two types of information to the driver: the driver's present behavioral information and another driver's score and ranking data using a Web browser.

While the car was moving, the screen displayed the current velocity, current following distance, current time gap, current POC, and mean POC (Figure 3). The time gap (s) was calculated by following distance (m) divided by velocity (m/s). The current POC was shown digitally and by an indicator at the bottom of the screen. The mean POC was a one-minute average when the car was driving over 10 km/h and following another vehicle.

Visual and auditory warnings were simultaneously given to safely and easily informed to the driver of his or her status. The color of the background changed based on the current POC so that the driver easily knew the current state of the POC. The colors were gray at 0 - 0.5%, light blue at 0.5 - 20%, yellow-green at 20 - 40%, yellow at 40 - 60%, orange at 60 - 80%, and red at 80 - 100%.

Depending of the severity of the POC increase, the driver was warned with one of four different voice messages. Level 1 stated, "The mean POC is increasing." Level 2 stated, "The mean POC has been increasing. Keep a safe following distance." Level 3 stated, "The mean POC has been rapidly increasing." Level 4 stated, "The mean POC has been rapidly increasing. Keep a safe following distance and let the POC decrease." These messages were created by a text-to-speech engine (Microsoft Co., L&H TTS3000).

Rankings and scores were transferred from the server system every five second. When the car stopped, ranking and driving score were presented on a white screen (Figure 4). Information for other drivers was printed in black, while that of the driver was in red.

Figure 3. Screen of the monitor mounted on the vehicle while driving. Labels are velocity(km/h), following distance (m), time gap (sec), current POC, mean POC and an indicator of current POC.

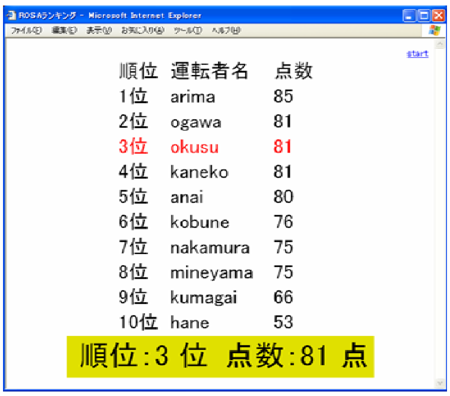

Figure 4. Screen of the monitor mounted on the vehicle while stopping. Labels are rank, driver's name and score from the left. Bottom is the rank and score of the driver.

3.4. The server system

The server system was two Linux (Vine Linux 3.1) desktop computers with global IP addresses. A server was installed with four applications written in C:

- To receive driving behavior data from the client systems
- To store data into a database
- To store front view images onto a hard disk
- To calculate the driving score

The other server served as the HTTP server and a database system. The HTTP server was Apache 1.3.33. The database management system was PostgreSQL 7.4.8. PHP 5.0.5 was used as the HTML script language.

3.4.1. Browsing system. The Web browser system extracted and displayed driving data from the database. Figure 5 shows a picture of a screen. Users can view ranking, score, a front view image, and three graphs (velocity, following distance, and POC) of a selected car. The graphs show the changes over 10 seconds.

Figure 5. Screen of the Web browser

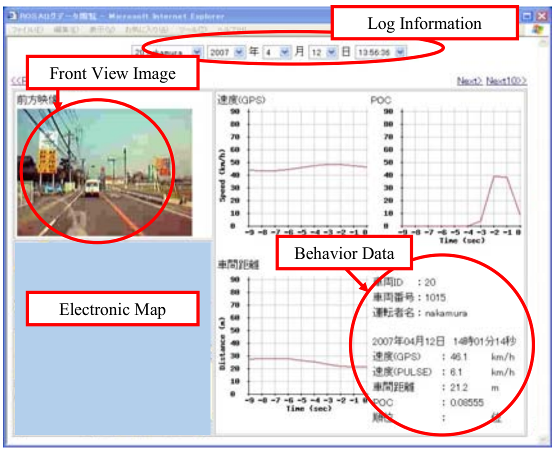

Figure 6. Screen of a logged-in viewer. The electronic map in this figure is not displayed for copyright.

In addition to this Web browser, only a logged in viewer (Figure 6) can identify the location. If a trucking company uses this system, then this electronic mapping function would be useful for their business.

4. Implementation

4.1. Purpose

The proposed system was implemented and verified. Impressions from the users were gathered to assess usability.

4.2. Method

4.2.1. Participants. Nine graduate and undergraduate students in their twenties with regular driver licenses partook in the experiment.

4.2.2. Procedure. The system was implemented on an experimental vehicle (Nissan Motor Co. Ltd., Serena UA-TC24). Participants drove the car on national highway number three in Fukuoka, Japan. The participants shuttled the car in a 14 km zone, which typically has three lanes, but occasionally two. They were instructed not to pass other vehicles and to remain in the same lane.

To calculate the POC, the coefficient of friction between tires and roadway, and the distribution of reaction time are required. Because the former cannot be obtained in real time, we set it at 0.69, which is a commonly observed figure on a fine day. To get the latter, we measured the choice reaction time of each participant with a driving simulator. While they drove this simulator, three types of signals were randomly presented on the center of the screen for three seconds. Participants were required to press down the accelerator pedal while driving. When the light was red, they had to release the accelerator pedal and press the brake pedal. When the light was yellow, they had to release the accelerator pedal. When the light was blue, they had to continue to press down the accelerator pedal. During a 20 minute drive, red, yellow, and blue signals were randomly presented 50, 30, and 20 times, respectively. The brake reaction times for red lights were measured.

We set four experimental conditions. All participants did the experimental conditions in this order. Although an experimenter was on board to ensure safety, he did not talk about safety, the POC, etc. while driving.

1. Normal condition: Participants drove an experimental car as usual.
2. Browsing condition: The participants were explained the POC and were shown their POCs from the normal condition before driving. They were aware that someone was observing their driving behaviors (velocity, following distance, and POC) through a Web browser. While driving, they drove freely.

3. POC display condition: Participants were presented their POCs in the browsing condition before driving. A monitor, which shows driving behaviors, was used. The monitor screen turned red when the present POC exceeded 0.5%. An audio warning was also presented as described above (3.3.2).
4. Score and Ranking display condition: Participants were presented their POCs from the POC display condition trial. Score and ranking information was displayed on the monitor when the car stopped. Because the experiment did not simultaneously use numerous experimental cars, the other driver's scores and rankings were those from the POC display condition. That is, the driver competed against other driver's behaviors in the POC display condition. The experimenter informed the participants about this. The color change of the monitor screen and voice warning were used as explained in section 3.3.2.

Participants were asked their impressions of the system after completing each condition, Browsing (2), POC display (3), and Score and Ranking display (4) conditions, using questionnaires.

4.3. Results and Discussion

The new safe driving promotion system was worked as intended.

4.3.1. Impressions of the system. Although numerous questions were asked, only some are described in detail. Almost all the questions were graded on a seven-point scale. After the browsing condition, participants rated how conscious they were of being seen on the Web by someone. Participants rated, "Did you feel that you were seen? (the range was from 1 = "I didn't feel so at all" to 7 = "I felt so strongly")" as almost neutral (mean=3.4, SD=1.3), suggesting that the driver was unaware of other people's observations.

After the POC display condition, the drivers were asked about visibility and usability. The visibility of the monitor was good (mean=5.3, SD=0.7, in this question, a rating of 1 meant it was very bad, while a rating of 7 meant it was very good). The unpleasantness of the voice warning was a little bit high, but it did not hinder driving (mean=4.2, SD=1.4, a rating of 1 meant the voice warning was very unpleasant, while a rating of 7 meant the voice warning was very unpleasant). Participants rated, "Was the voice warning more influential than display monitor information? (the range was from 1 = "I didn't feel so at all" to 7 = "I felt so strongly")" as 4.6 (SD=0.9), indicating that the drivers felt the audio warning was slightly more effective. However, the drivers were conscious of the monitor because the subjective frequency of viewing the monitor was every 2 minutes 2 seconds.

Unlike in the browsing condition, the participants seemed to be conscious of their scores reported to other drivers (mean=5.6, SD=0.7, a rating of 1 meant they were completely unaware, while a rating of 7 meant they were strongly aware) in the score and ranking display condition. Participants were also aware of other driver's scores (mean=5.3, SD=0.5, a rating of 1 meant they were completely unaware, while a rating of 7 meant they were strongly aware). They even tried to raise their ranking when it became lower (mean=5.4, SD=0.5, a rating of 1 meant they did not try to raise their scores at all, while a rating of 7 meant they tried to raise them eagerly). They reported that they watched the monitor to check their ranking mean 1.7 times/stop. Furthermore, participants indicated that they had competitive spirits (mean=5.6, SD=0.9, a rating of 1 meant they did not possess a competitive spirit at all, while a rating of 7 meant competitive spirits occurred strongly).

4.3.2. Safety. The participants felt that their driving behavior was safer using the proposed monitoring system. The subjective ratings of driving safety, ranging from 1 = "not safety" to 7 = "safety" were 4.7 (SD=1.3) in the normal condition, 5.3 (SD=1.0) in the browsing condition, 5.2 (SD=1.2) in the POC display condition, and 5.6 (SD=1.0) in the score and ranking display condition. The actual POCs in other three experimental conditions were lower than that in the normal condition. The POC in normal condition was 46.0% (SD=20.4), while those in the other three experimental conditions were 7.2% (SD=3.9), 3.1% (SD=1.1), and 3.2% (SD=1.8), respectively.

The main purposes of the study were to verify the operation of the developed system and to get the impressions of users. For this reason, this experiment did not have a control condition and had very few participants to confirm effectiveness. Thus, a future study is needed to confirm the effectiveness of this system.

5. Conclusion

We studied the reasons for close-following distances via a questionnaire survey, which indicated that close-following is due to hastiness and unawareness of driving behavior. We used this data to develop a new safe driving promotion system, which uses rivalry and self-consciousness of being watched. Then the usability of this system was assessed. Our findings indicate that this system has the potential to be accepted by users because it strives to change driving behaviors without coercion.

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