A Study on the Effects of Fatigue Driving and Drunk Driving on Drivers’ Physical Characteristics

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Objective: The purpose of this study was to analyze the effects of fatigue driving and drunk driving on drivers’ physical characteristics; to analyze the differences in drivers’ physical characteristics affected by different kinds of fatigue; and to compare the differences in the effects of the 2 driving states, fatigue driving and drunk driving.

Methods: Twenty-five participants’ physical characteristics were collected under 5 controlled situations: normal, tired driving, drowsy driving, drowsiness + tired driving, and drunk driving. In this article, fatigue driving refers to tiredness and drowsiness and includes 3 situations: tired driving, drowsy driving, and drowsiness + tired driving. The drivers’ physical characteristics were measured in terms of 9 parameters: systolic blood pressure (SBP), heart rate (HR), eyesight, dynamic visual acuity (DVA), time for dark adaption (TDA), reaction time to sound (RTS), reaction time to light (RTL), deviation of depth perception (DDP), and time deviation of speed anticipation (TDSA). They were analyzed using analysis of variance (ANOVA) with repeated measures. Binary logistical regression analysis was used to explain the relationship between drivers’ physical characteristics and the two driving states.

Results: Most of the drivers’ physical characteristic parameters were found to be significantly different under the influence of different situations. Four indicators are significantly affected by fatigue driving during deep fatigue (in decreasing order of influence): HR, RTL, SBP and RTS. HR and RTL are significant in the logistical regression model of the drowsiness + tired driving situation and normal situations. Six indicators of the drivers’ physical characteristics are significantly affected by drunk driving (in decreasing order of influence): SBP, RTL, DDP, eyesight, RTS, and TDSA. SBP and DDP have a significant effect in the logistical regression model of the drunk driving situation and the normal situation.

Conclusions: Both fatigue driving and drunk driving are found to impair drivers’ physical characteristics. However, their impacts on the parameters SBP, HR, eyesight, and TDSA are different. A driver’s physical characteristics will be impaired more seriously when he continues driving while drowsy, compared to driving under normal situation. These findings contribute to the current research on identifying drivers’ driving state and quantifying the effects of fatigue driving and drunk driving on driving ability and driving behavior.

Keywords: fatigue driving, drunk driving, drivers’ physical characteristics, impairment, influence mechanism

Introduction

Driving is a process that is related closely with the driver’s physical characteristics. A decline in the drivers’ physical characteristics, which include physiological aspects, eyesight, dynamic visual acuity, night acuity, speed anticipation, and depth perception, will affect driving ability. Therefore, the National Standard of Physical Qualifications for Automobile Drivers and Their Test Protocol has been formulated in China to assess a driver’s ability to drive, and the parameters of the drivers’ physical characteristics used in the test are termed driving adaptation indicators (PRC National Standard 2001). It is important to assess drivers’ driving abilities and adaption under different driving states. These indicators provide a reference framework for driving safety analysis and for studying the changes in drivers’ physical characteristics under different driving states.

Williamson et al. (1996) defined fatigue driving as a state with reduced mental alertness that impairs cognitive and psychomotor performance during driving. The studied factors most commonly associated with fatigue driving are monotonous environments, duration of driving, sleep deprivation, chronic sleepiness, and drug use (Hack et al. 2001; Lumley et al. 1987; Nilsson et al. 1997; Wesensten et al. 2002). Both tiredness resulting from a long period of physical work and drowsiness resulting from lack of sleep are fatigue driving. It is well known that fatigue driving and drunk driving are 2 dangerous driving states and are responsible for serious traffic accidents. Fatigue has been identified as a contributing factor of road transportation accidents in many countries (Williamson et al. 2011). Brandt et al. (2004) presented...
statistics showing that 20 percent of all accidents are caused by fatigue and lack of attention. Nordbakke and Sagberg (2007) also stated that driver fatigue is involved in 10–15 percent of all severe crashes according to a conservative estimate. In the United States, drowsy driving caused 83,000 crashes and over 1000 fatalities annually from 2005 to 2009 (NHTSA 2011). In China, about 20 percent of traffic crashes were related to fatigue driving, and fatigue driving caused 3 percent of deaths in all traffic accidents in 2011 (Qi 2013). At the same time, drunk driving is also a serious problem and the leading cause of death on highways (Dang 2008). In Australia, a blood alcohol concentration (BAC) at or above 0.05 percent has been found in about 30 percent of all drivers fatally injured in crashes (Drummer et al. 2003). Drinking driving led to about 20 percent of all road fatalities in Europe each year (Sørensen and Assum 2008). In the United States, approximately 31 percent of all traffic fatalities are caused by alcohol-impaired driving (NHTSA 2010). Y. Li et al. (2012) revealed that 34.1 percent of road crashes in China were alcohol related. From data on drunk driving and traffic accidents collected over a 10-year period in Japan, Fujita and Shibata (2006) reported that alcohol use before driving increases the risk of fatality in traffic by 4-fold.

The danger of these 2 driving states may be due to their impairment on drivers’ physical conditions. The connection between fatigue driving and drivers’ physical characteristics has been studied from the aspects of the causes of fatigue, drivers’ physiology, and reaction times. For example, Desmond et al. (1998) explained that drivers would experience increasing physical and perceptual tiredness and fatigue with increased driving time. From the aspect of physiology, heart rate and heart rate variability were proven to be highly relevant to fatigue and were used as indicators to estimate fatigue (Oron-Gilad and Rone 2007; Patel et al. 2011). There have been studies examining the relationship between drivers’ reaction time and fatigue. Welford (1980) revealed that the reaction time increased when the subject was fatigued. Philip et al. (2004) concluded that 24 hours’ sleep deprivation lengthened the reaction time of 20- to 25-year-old subjects but had no effect on 52- to 63-year-old subjects.

The effects of alcohol on the drivers’ physical characteristics in previous research were mainly focused on the aspects of physiology, vigilance, and reaction. For example, Ohira et al. (2009) revealed the pattern of heart rate under the influence of alcohol for people with different drinking habits over 24 hours. Moskwitz et al. (1993) showed that alcohol impairs drivers’ visual functions. Alcohol’s effects on visual performance have been found to be most obvious when it comes to the judgment of moving objects and to the processing of different information at the same time (Adams et al. 1978; NHTSA 1980). Regarding vigilance, Nash (1962) demonstrated that drivers’ concentration was impaired by alcohol when they were asked to complete certain tasks. Starmer (1989) indicated that the most consistent finding is an increase in error rates for drunk drivers. Though a driver’s reaction time is generally found to increase while drunk driving (Howland et al. 2011), studies have also shown that expectations of alcohol-induced impairment can produce adaptive responses to alcohol that serve to reduce the degree of behavioral impairment displayed. Fillmore and Blackburn (2002) found that subjects who had been warned that the alcohol would slow their reaction time after drinking actually displayed faster reaction times than those subjects who had not been warned.

The above studies revealed various effects of fatigue driving and drunk driving on drivers’ physical characteristics. These results are useful in explaining how these 2 driving states affect driving safety and how they may be detected. However, most of the existing studies involve only a single aspect of drivers’ physical or physiological characteristics and cannot draw comparisons of the relative effects of fatigue driving and drunk driving on different driver characteristics. In this study, we analyze the effects of fatigue driving and drunk driving on multiple indicators of drivers’ physical characteristics, including the aspects of physiology, vigilance and judgment, visual sense, and reaction time. Experiments were designed to induce different driving states. Due to the risk of drunk driving and fatigue driving, driving tasks were carried out in a driving simulator environment. Drivers were recruited for the experiments and the drivers’ physical characteristic data were collected in the laboratory. The purposes of this study are to (1) analyze the effects on drivers’ physical characteristics imposed by fatigue driving and drunk driving and (2) analyze the differences between the influence of the 2 driving states on drivers’ physical characteristics. The results from this study are expected to provide useful references for research on identifying driving state, developing countermeasures for risky driving states, and quantifying the effects of fatigue driving and drunk driving on driving ability and driving behavior.

Methods

Participants

It is common knowledge that there are significant differences in the effect characteristics between male and female drivers and among different age groups. It was found that young male drivers account for much of the nighttime traffic, which may lead to fatigue driving, and they are overrepresented in fatal accidents (McFarland 1962; Williams 1985; Zylman 1973). Nagoshi et al. (1991) showed that male drivers were more impulsive and sensation-seeking than female drivers under the influence of alcohol. It has also been found that for the same BAC, young drivers have a higher relative risk of accident than older drivers (Mayhew et al. 1986; Zador 1991). Therefore, young male drivers were the only subject group in this study. Twenty-five young male drivers were recruited to participate in the experiment. Their average age was 25 (SD = 4.1, range = 20–35 years). All participants had possessed a valid driving license for more than 3 years (average = 3.6). Before recruitment, each driver was required to fill out a questionnaire, which included information such as age, driving age, sleep rhythm, and so on. Other selection criteria included regular sleep time cycle and no drug use. All drivers drank enough to become drunk. They also had to pass a test showing that they could perform tasks according to our requirement when their BAC level reached at least 0.1 percent. They agreed and
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signed an informed consent before participating in the study and received payment for the experiment.

Equipment

The driving tests were conducted in a laboratory environment. Drivers’ physical characteristics were collected in this driving adaptation laboratory, which was established according to the National Standard of Physical Qualifications for Automobile Drivers and their test protocol (PRC National Standard 2001). Various detectors are installed in the laboratory to collect 9 different parameters of drivers’ physical characteristics.

- A physiology detector used to record systolic blood pressure and heart rate.
- A vision tester, used to assess eyesight, dynamic visual acuity (the vision to accurately judge a moving target), and night acuity (how long a driver needed for adaption when the environment changed from bright to dark). The vision data were measured using the international standard for visual acuity.
- A reaction detector, used to collect reaction time for light and sound (how long a driver took to respond after seeing a light or hearing a sound).
- A depth perception detector, used to obtain the position deviation in depth perception (the distance between the expected position in depth direction and the actual position of an object, which was controlled by the subject with a distance of 2 m).
- A speed anticipation tester, used to collect the time deviation of speed anticipation. (On the tester, a red point first moved 0.4 m with a uniform velocity of 0.25 m/s, and then the red point was hidden and continued moving the remaining 0.3 m at the same speed to the end. The subject was required to anticipate the time when the red point would reach the end according to the red point’s movement across the previous 0.4 m. The time deviation was recorded. If the subject anticipated an earlier time, the deviation was positive; otherwise, it was negative.)

The driving simulator provides the participants with virtual 3-dimensional driving scenarios with a screen with a 130° view in the front, 2 rearview mirrors on either side, and one screen in the rear. The simulated scenario was designed as an urban road environment. The simulator can collect driving behavior data such as speed, lane position, accelerator, brake, and steering wheel angle with a sampling frequency of 30 Hz.

Another apparatus was a blowing-type BAC detector, which was used in the experiment to test drivers’ BAC levels. The detector is the same as the one used by traffic police in Beijing (EnviteC AlcoQuant 6020).

Experimental Design and Procedure

In the experimental design, the key point is to induce a fatigue state and a drunken state. Here, fatigue is used generally to include tiredness and drowsiness. The experimental designed included 3 fatigue situations:

1. Tired driving: the state after simulated driving for a long time.
2. Drowsy driving: lack of sleep and feeling sleepy.
3. Drowsiness + tired driving: the combination of tiredness and drowsiness, the state after simulated driving for a long time when drowsy.

In this article, the drunk driving situation was designed as the state of simulated driving under the influence of alcohol. In addition, a normal situation was designed as the base case scenario. Five situations were considered in this study: normal (NOR), tired driving (TIRD), drowsy driving (DROD), drowsiness + tired driving (DRTID), and drunk driving (DRUD).

The test procedure was designed to run through the 5 situations for each subject in 3 visits. The procedure of the experiment is shown in Table 1.

Each participant was required to perform the experiment on 3 visits in a random order on 3 separate days to reduce the learning effects. There were 6 random orders for the 3 visits. The 25 participants were divided into 6 groups randomly, one group with 5 persons and each of other groups with 4 persons. They performed the experiment at intervals of 5 days to avoid residual effects from the previous experiment. The drivers’ physical characteristic data for the NOR and TIRD situations were collected in visit 1. Visit 2 was designed to collect the data of the DROD and DRTID situations. Visit 3 was designed for the DRUD situation.

A questionnaire was used in this study to collect data on subjective fatigue degree, which was set to 7 levels: (1) active, alert, or wide awake; (2) functioning at high levels but not at peak or unable to concentrate; (3) somewhat foggy or let down;

Table 1. Experimental procedure

| Target situation | Visit 1 | Visit 2 | Visit 3 |
|------------------|---------|---------|---------|
| NOR and TIRD     | DROD and DRTID | DRUD |
| Time             | 2:00 p.m. | 2:00 a.m. | 2:00 p.m. |
| Step 1           | Questionnaire survey and Practice driving | Questionnaire survey and Practice driving | Drink to BAC = 0.09% |
| Step 2           | Drivers’ physical characteristic test for NOR situation | Drivers’ physical characteristic test for DROD situation | Questionnaire survey and practice driving |
| Step 3           | Simulator driving for 100 min | Simulator driving for 100 min | Simulator driving for about 35 min |
| Step 4           | Drivers’ physical characteristic test for TIRD situation | Drivers’ physical characteristic test for DRTID situation | Drivers’ physical characteristic test for DRUD situation |
| Step 5           | Questionnaire survey | Questionnaire survey | Questionnaire survey |
(4) foggy, losing interest in remaining awake or slowed down; (5) sleepy, woozy, or prefer to lie down; (6) sleep onset soon or having dream-like thoughts; and (7) asleep. The experiment time was designed according to the drivers’ sleep rhythm. The recruitment survey showed that generally the participants slept from 11 p.m. to 7 a.m., had a noon break between 11:30 a.m. and 1 p.m., and began working at 1:30 p.m. According to an analysis in China, most fatigue driving accidents happen approximately between 2 am and 6 am and between 3 pm and 4 pm (D. H. Li et al. 2010). Fatigue driving is mainly due to drowsiness in the former period and because of the work tasks over a long time in the latter period. These results provided a reference for the experimental design.

For visit 1, the participants were required to sleep well at least 3 days before and refrain from having any stimulating food or beverage, such as drugs, coffee, alcohol, and energy drinks. They were also asked to have a noon break at least one hour before the experiment on the day of the visit. The experiments for all subjects were carried out at 2 p.m. according to the aforementioned results. Each participant was asked to fill out a questionnaire regarding subjective fatigue. To avoid the interference of fatigue, only drivers whose fatigue level was at level 1 or 2 before the experiment were allowed to perform the test. The 100-min simulated driving task was designed to induce tiredness.

In visit 2, the participants were required to get up before 8 a.m. on the previous day and not to sleep before the experiment. The experiment was carried out at 2 a.m., when the participants would easily become drowsy. Participants were only allowed to perform the experiment if they reached at least level 4 fatigue. Otherwise, the participant would be asked to wait without sleep until his fatigue level met the criterion. Similar to visit 1, the driving task was designed to induce tiredness. According to a pilot experiment, most drivers were found to be unable to keep driving for longer than 100 min before they became drowsy. Therefore, in order to make comparisons, the length of driving time in the visits 1 and 2 was designed to be the same. Participants were required to drive in the simulator for 100 min on both visits.

For visit 3, participants were required to be in a normal state before the experiment. The experiment also began at 2 p.m. and each driver’s fatigue level had to be at level 1 or 2. In the drunk driving experiment, participants were required to drink until their BAC reached 0.09 percent, which is considered drunk driving in China. We calculated alcohol dose for each subject using Eq. (1) to achieve the expected BAC level according to Watson’s research (Watson 1989).

\[
\text{Alcohol dose (g)} = \left( \frac{10 \times \text{BAL} \times \text{TBW}}{0.8} + 10 \times \text{MR} \right) \times (\text{DDP} + \text{TPB}) \times \left( \frac{\text{TBW}}{0.8} \right), \tag{1}
\]

where BAL is the target blood alcohol level, TBW is the total body water amount, MR is the metabolic rate (generally 0.015 g/100 mL/h), DDP is the duration of the drinking period, and TPB is the time to peak BAL (generally 0.5 h).

Generally, TBW for men is as Eq. (2):

\[
\text{Men’sTBW} = 2.447 - 0.09516 \times \text{Age} + 0.1074 \times \text{Height (cm)} + 0.3362 \times \text{Weight (kg)}. \tag{2}
\]

Chinese liquor (46% alcohol content) was used for the participants’ drinking in the experiments. About 15 min after drinking, participants’ BAC levels were measured with the blowing-type detector every 5 min. To minimize measurement errors, the BAC levels of participants were measured 5 times each testing and the mean BAC level was used. A given participant’s experiment began when his BAC value reached the target level and he felt obviously affected by alcohol. Generally, the participants’ BAC levels reached the target level within 25–30 min. In the experiments, the simulated driving task was designed to ensure that the drivers remained in the state of drunk driving, and they were required to drive for only about 35 min to reduce the impairment of tiredness. Considering the aforementioned conclusions of Fillmore and Blackburn (2002), for the DRUD situation, no warnings or reminders were given to the participants to avoid the effects of expectancies.

Data Measurement and Analysis

The drivers’ physical characteristics data for 25 participants in each of the 5 situations were measured in the experiment. The measurements included systolic blood pressure (SBP), heart rate (HR), eyesight, dynamic visual acuity (DVA), time for dark adaption (TDA), reaction time to sound (RTS), reaction time to light (RTL), deviation of depth perception (DDP), and time deviation of speed anticipation (TDSA). Driving behavior data were collected from the driving simulator. We mainly focused on the effects of fatigue driving and drunk driving on drivers’ physical characteristics. It is expected that the results of this article will provide a reference for the analysis of driving behavior data in following studies.

The drivers’ physical characteristics data were analyzed to study the effects of different situations on drivers’ physical characteristics and to identify any correlation between the parameters and fatigue driving and drunk driving states. The data were analyzed according to the following methods:

- Descriptive statistics analysis: Descriptive statistics were used to show the trend of the influence of different situations on the drivers’ physical characteristics.
- Effect characteristics analysis: Analysis of variance (ANOVA) with repeated measures was used to analyze the differences for each physical parameter among the 5 situations. Pairwise comparison was analyzed using a post hoc test.
- Relationship analysis: Binary logistical regression was used to study the relationship between the physical characteristics and the 2 driving states: fatigue driving and drunk driving.
Fig. 1. Means of degree of fatigue in each situation.

Result

**Descriptive Statistics Analysis**

Figures A1 through A9 (see online supplement) show the means and standard deviations (as error bars) of the 9 physical characteristics in the 5 situations. The data are also presented in Table A1 (see online supplement). The results show clear influences of the 5 situations on the parameters SBP, HR, eyesight, RTS, TDA, and DDP.

Figure 1 presents the mean fatigue levels in each situation according to the questionnaire result. It shows that the fatigue level in the DRTID situation (average = 5.8) was the highest, followed by the DROD situation (average = 4.3) and TIRD situation (average = 3.6). They were all higher than in the NOR situation (average = 1.8) and DRUD situation (average = 2.2).

**Effect Characteristics Analysis**

ANOVA with repeated measures was used to analyze the effects of TIRD, DROD, DRTID, and DRUD on drivers’ physical characteristics, and a post hoc test was used in the contrast analysis. The ANOVA results and the significance of some contrasts are shown in Table 2.

According to the results of the contrast analysis of DRTID vs. NOR and DRUD vs. NOR in Table 2, 4 indicators of the drivers’ physical characteristics were selected to study the DRTID situation: SBP, HR, RTS, and RTL. Six parameters for the drivers’ physical characteristics were selected as the effect indicators of the DRUD situation: SBP, eyesight, RTS, RTL, DDP, and TDSA. These indicators were analyzed for further study. The detailed statistical results of each parameter are as follow.

1. **SBP**: Results of the ANOVA showed that different situations have significant effects on SBP, \( F(4,96) = 17.011, P < .001 \). A contrasts analysis revealed that the SBPs in DRUD and DRTID were significantly lower than they were in the other situations \( (P < .01\) in all contrasts) and the SBP in DRUD was the lowest \( (P = .007\) contrasted with the SBP in DRTID).

2. **HR**: The ANOVA analysis of heart rate indicated a significant effect of different situations on heart rate, \( F(4,96) = 26.415, P < .001 \). The contrast analysis demonstrated that the heart rates in TIRD, DROD, and DRTID were all significantly lower than in the NOR situation \( (P < .001\) and the heart rate in DRTID was the lowest \( (P < .001\) contrasted with the other situations). No significant difference was found between the NOR situation and DRUD situation \( (P = .059\).

3. **Eyesight**: The ANOVA analysis results for eyesight also reflected significant differences in different situations, \( F(4,96) = 4.516, P = .010 \). The contrast analysis indicated that eyesight in DRUD was significantly lower than it was in the NOR situation \( (P = .002\). No significant difference was found in the other contrasts.

4. **DVA**: No significant effects of different situations on dynamic visual acuity were found in this study, \( F(4,96) = 0.140, P = .967\).

5. **TDA**: There was no significant difference in time for dark adaption among the different situations, \( F(4,96) = 2.097, P = .087\).

6. **RTS**: The reaction time to sound showed significant differences in the effects of different situations, \( F(4,96) = 5.442, P = .002\). The contrast analysis showed that reaction time to sound in the NOR situation was significantly shorter than it was in the DRUD situation \( (P = .016\) and DRTID situation \( (P = .001\). It was longer in the DRTID situation than in the DROD situation \( (P = .001\).

7. **RTL**: The ANOVA analysis of reaction time to light showed significant differences in different situations, \( F(4,96) = 7.519, P < .001\). The contrast results showed that reaction

| Parameters | ANOVA | Significance of contrast between 2 situations |
|------------|-------|---------------------------------------------|
|            | F     | P   | TIRD vs. NOR | DROD vs. NOR | DRTID vs. NOR | DRUD vs. NOR | DRTID vs. DROD | DRUD vs. DRTID |
| SBP        | 17.011** | .000 | 0.111 | 0.364 | 0.001** | 0.000** | 0.001** | 0.007** |
| HR         | 26.415** | .000 | 0.000** | 0.000** | 0.000** | 0.059 | 0.000** | 0.000** |
| Eyesight   | 4.516* | .010 | 0.754 | 0.056 | 0.174 | 0.002** | 0.083 | 0.036* |
| DVA        | 0.140 | .967 | — | — | — | — | — | — |
| TDA        | 2.097 | .087 | — | — | — | — | — | — |
| RTS        | 5.442** | .002 | 0.462 | 0.841 | 0.001** | 0.016* | 0.001** | 0.097 |
| RTL        | 7.519** | .000 | 0.489 | 0.066 | 0.002** | 0.003** | 0.003** | 0.648 |
| DDP        | 6.098** | .001 | 0.274 | 0.095 | 0.082 | 0.003** | 0.645 | 0.196 |
| TDSA       | 4.858** | .008 | 0.599 | 0.792 | 0.216 | 0.004** | 0.316 | 0.027* |

*P < .05, **P < .01.
times to light in the DRUD and DRTID situation were longer than they were in the NOR situation (\(P = .003\) and \(P = .002\)). Participants also reacted more slowly in the DRTID situation than the DROD situation (\(P = .003\)).

8. DDP: The analysis of deviation of depth perception also showed significant differences, \(F(4,96) = 6.098, \ P = .001\). The contrast analysis indicated that the deviation of depth perception in the DRUD situation was significantly higher than it was in the NOR situation (\(P = .003\)). No significant differences were found in other contrasts.

9. TDSA: The ANOVA analysis results showed a significant difference in different situations, \(F(4,96) = 4.858, \ P = .008\). The contrast analysis result showed that the time deviation of speed anticipation in the DRUD situation was lower than it was in any other situation (\(P < .05\) in all contrasts). According to the data from the DRUD situation (average = \(-0.065, \ SD = 0.648\)), most drivers can respond earlier than the exact time (the TDSA was lower than 0).

**Relationship Analysis**

A binary logistical regression analysis was conducted to determine indicators that helped to distinguish different situations. Because the fatigue level of DRTID was the highest, we took this situation as representative of fatigue driving to be further analyzed. The 4 effective indicators of the DRTID situation were used in the binary logistical regression analyses to compare the DRTID and NOR situations. The regression coefficients, chi-square tests, odds ratios, and 95 percent confidence intervals for the indicators are presented in Table A2 (see online supplement). Although the 4 indicators were significantly affected, the results revealed that only 2 indicators (HR and RTL) were significant in the regression model. This indicates that HR and RTL represent 2 different main aspects affected by DRTID.

The 6 indicators of the DRUD situation were used in the binary logistical regression analysis to compare the DRUD and NOR situations. The parameters of regression are shown in Table A3 (see online supplement), which indicates that only 2 indicators (SBP and DDP) were significant in the regression model. They represent 2 different main aspects of drivers under the influence of alcohol.

The logistical regression model can be used to distinguish driving states. We can also obtain scores for each indicator in the logistical regression, as shown in Table 3. The results indicate that most of the indicators were significant in the regression when the indicators were imported in the model singly. It is helpful to list the order of the degree to which indicators were affected by the DRTID situation and DRUD situation. A higher score indicates a greater degree of effect. Therefore, under the influence of DRTID, the decreasing order was HR, RTL, SBP, and RTS. Under the influence of DRUD, the decreasing order was SBP, RTL, DDP, eyesight, RTS, and TDSA.

**Discussion**

The analysis results show that most of the parameters for drivers' physical characteristics are significantly different under different driving situations. Regarding fatigue diving, similar to the findings widely reported in the literature (Oron-Gilad and Rone 2007; Patel et al. 2011), HR was found to be closely related to fatigue. Figure A10 (see online supplement) showed that the degree of fatigue increased gradually in the NOR, TIRD, DROD, and DRTID situations. The results also revealed that HR was gradually lower in these situations. This indicates the remarkable effect of fatigue on HR. The results for the TIRD situation also confirmed that the driving task itself would lead to driving fatigue. Undoubtedly, the degree of fatigue depends on the driving time. In the DRTID situation, in which the fatigue level was the highest, SBP, HR, RTS, and RTL were all significantly affected. The contrast analysis of DRTID vs. DROD showed significant differences in the parameters SBP, HR, RTS, and RTL, but the contrast analysis of TIRD vs. NOR revealed a significant difference only in the parameter HR. Considering the same tasks in visits 1 and 2, these results indicate that a driver's physical characteristics will become increasingly impaired if he continues to drive while drowsy.

Regarding drunk driving, the analysis results showed that many aspects of the drivers' physical characteristics were affected significantly. Drivers' blood pressures were affected; in addition, eyesight, reaction time, and perception were all impaired significantly. It was also proven that most of the drunk drivers had the features of impulsivity and sensation-seeking (Nagoshi et al. 1991). Therefore, drunk drivers will have a high probability of serious accidents.

The binary logistical regression model showed that most drivers' physical characteristics have significant relationships with the different situations. The significant indicators in the model are the major representatives of drivers' physical characteristics that are affected by driving state. Both of the regression models had 2 significant indicators, but the indicators for the 2 models were different. This indicates that alcohol and fatigue impair drivers' physical characteristics in different ways.

Based on the score test results in the logistical regression, we can compare the degree of influence on each indicator and their order. These may be helpful in discussions of the similarities and differences in the effects of fatigue and alcohol. The orders suggest that both fatigue and alcohol will primary affect drivers' physiological characteristics, followed by external performances.

According to the decreasing order of indicators under the influence of DRTID, HR was the most significant indicator of fatigue. The second indicator affected by fatigue was RTL.
which was related to eyesight. However, there was no significant effect of fatigue on eyesight. This illustrates that the RTL’s growth was only due to the decline of cognitive function. The next 2 indicators were SBP and RTS. The decrease in blood pressure might be correlated with the decrease in HR, and RTS might have the same influence mechanism as RTL. In addition to the physiological characteristics, reaction time was significantly affected by fatigue. In the process of driving, which includes perception, making decisions, and taking action, reaction time means the interval from perception to taking action. According to the analysis results, for fatigued drivers, there is no significant decrease in perception but it takes to take action. This and the slower HR may imply that fatigue mainly slows down drivers’ cognitive functions.

Many drivers’ physical characteristics were significantly affected by alcohol, and SBP was the most significant, followed by RTL, DDP, and eyesight, which were all related to visual sense. This means that the drivers’ perceptual abilities were impaired. The effect of drunk driving on TDSA may also support this idea. The significant changes in RTL and RTS may still reveal that alcohol can slow down drivers’ cognitive functions. Therefore, we can infer that alcohol impairs not only drivers’ perceptual abilities but also their cognitive functions.

It has also been proven by some researchers that drivers’ physical characteristics are highly related to driving ability (De Waard and Brookhuis 1991; Karel et al. 2010; Quimby and Waitts 1981; Rau 2001). Therefore, the effects of fatigue driving and drunk driving on drivers’ physical characteristics are helpful in explaining their influence mechanisms on driving ability. Although driving ability is affected by both fatigue and alcohol, their influence mechanisms are different. Though fatigue may slow down cognitive functions, which further impairs driving ability, alcohol’s impairment of drivers concentrates on both cognitive functions and perceptual abilities.

There are some limitations of this study. Firstly, only young male drivers were recruited for the experiment; therefore, the result may not be applicable to the whole population. Secondly, the study of drinking driving only concentrated on drunk driving with BAC levels higher than 0.08 percent. The results do not show how different levels of alcohol consumption affect drivers’ physical characteristics. Thirdly, the interaction effects of fatigue and drunk driving were not studied in this research. More extensive experiments with different types of drivers and different BAC levels should be researched in future studies. Furthermore, a fatigue + drunk driving situation should be designed in the new experiment.

In summary, this study designed a simulated driving experiment to collect 9 parameters of drivers’ physical characteristics, including systolic blood pressure, heart rate, eyesight, dynamic visual acuity, time for dark adaption, reaction time to sound, reaction time to light, deviation of depth perception, and time deviation of speed anticipation, under 5 different situations: normal, tired driving, drowsy driving, drowsiness + tired driving, and drunk driving. The effects of fatigue driving and drunk driving on drivers’ physical characteristics were explored. The conclusions can be summarized as follows:

- Drivers’ physical characteristics are affected differently when drivers are in different situations. More drivers’ physical characteristics will be impaired at higher level of fatigue degree. Furthermore, a driver’s physical characteristics will be impaired more seriously if he continues driving while drowsy compared to normal driving.
- In decreasing order of degree of influence of fatigue driving, the indicators are HR, RTL, SBP, and RTS at high fatigue level. Under the influence of fatigue, HR and SBP will be lower, and RTL and RTS will be longer.
- Drunk driving also affects many drivers’ physical characteristics significantly. In decreasing order, the indicators are SBP, RTL, DDP, eyesight, RTS, and TDSA. Drunk driving will decrease SBP and eyesight, lengthen RTL and RTS, and make DDP longer and TDSA earlier.
- According to the results of logistical regression, HR and RTL are representative of drivers’ physical characteristics affected by fatigue driving. SBP and DDP are representative of the indicators influenced by drunk driving. There are significant differences in the indicators affected by drowsiness + tired driving and drunk driving: SBP, HR, eyesight, and TDSA. In the drunk driving situation, SBP will be lower, HR will be higher, eyesight will be more impaired, and TDSA will be earlier.

Both fatigue driving and drunk driving impair drivers’ physical characteristics in many aspects, but the aspects and levels of their effects on drivers’ physical characteristics are different. Drivers’ physical characteristics affected by different kinds of fatigue are also different.

Analyzing drivers’ physical characteristics is the basis for studying risky driving states. This research has revealed some drivers’ physical characteristics that are affected by fatigue driving and drunk driving. This will help to distinguish drivers’ risky driving states and create countermeasures against them. The research also illustrated the similarities and differences between the effects of fatigue driving and drunk driving on drivers’ physical characteristics. Based on the conclusions, we will analyze the characteristics of driving behavior under the influence of fatigue and drinking in further studies. The results make it easier to acquire indicators of driving behavior. At the same time, the results can promote the further study of the effect of driving state on driving ability.

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**Supplemental Material**

Supplemental data for this article can be accessed on the publisher’s website.
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