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A Biosignal Based Driving Experience Analysis for Curved Road: An Initial Implementation*

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Abstract— **This study presents a biosignal based driving experience analysis of an actual-vehicle experiment. A total of 10 subjects were enrolled during the experimental study. Based on their driving mileages per year, subjects were divided into novice and skilled ones at first, and then electromyography (EMG) signals of upper trapezius and sternocleidomastoid muscles were acquired continuously to evaluate a subject response to dynamic motions of the vehicle during the curve, with a driving speed of 30, 40 and 50 km/h respectively. Meanwhile, an EMG evaluation index of a normalized root mean square (RMS) was proposed to reflect the variance of EMG signals. From the experimental results, the RMS based evaluation of right upper trapezius muscle were significantly different between novice and skilled drivers, while driving with a higher speed on curve road. In addition, the RMS based evaluation of right sternocleidomastoid muscle were significantly different between novice and skilled drivers, while driving with a higher or a lower speed on curved road. It indicate that the skilled driver may have a better driving experience than that of novice ones for most curve driving conditions.**

I. Introduction

In a vehicle-driver-road closed-loop system, drivers are a core element of the system; therefore, a driver-oriented design is the critical demand to achieve a high quality interactive coordination for human-machine systems of automobile. Consequently, in the process of vehicle design and test, human driving experience is becoming one of the most important factors that are considered. It is a crucial factor that influences operating comfort, user acceptance, and long-term travel quality of automobile products.

Well-known active safety systems, direct yaw-moment control and electronic stability program are designed with the application of model matching control theory, in order to regulate the body side slip angle and track the desired trajectory specified by interpreting the driver commands, which is triggered in dangerous situations [1, 2].

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However, activation times of these systems or intensities differ between drivers as their driving experiences. Different types of drivers have different driving maneuvers and behaviors, which can lead to different driving experiences to a vehicle's longitudinal or lateral acceleration. So in order to fully exert optimal effect, these active safety systems should be designed considering the influence of driver experience which was neglected by the past research.

Generally, driving experience is a subjective feeling generated from manipulating the vehicle and the according vehicle dynamics feedback for drivers [3]. Undesirable motions of a vehicle result in feelings of discomfort, especially in curve road [4]. Previous studies indicated that a physiological signal has a close relation with driving experience, which can be used to interpret the discomfort of a passenger in response to dynamic motions [5]. Therefore, there are several physiological signals that can be used to evaluate the driving feelings or comfort of a human, such as electrocardiography (ECG), electroencephalography (EEG), and electromyography (EMG), etc. Among them, an EMG signal can indicate a continuous estimation of driving feel [6].

The previous works have concentrated on EMG based comfort evaluation of a driver or passage in terms of a vehicle seat, steering or suspension design and test [7-13]. In [3], the EMG signal of a sternocleidomastoid muscle activity was adopted to make an objective assessment of riding comfort during the slalom driving for vehicle suspension optimal design. The paper found that the sternocleidomastoid muscle as a neck muscle on the side opposite the direction of the car's lateral acceleration contracts to keep the head stable against the body shaking.

Several former experiments found that upper trapezius muscles had a close relation with physiological stress while driving [14, 15]. It takes on a great burden since the neck muscle tension for keeping the head stable is activated by the motions of the vehicle transmitted to the head. Thus it is a suitable way for comfort assessment of vehicle motion using neck muscle activities. However, up to now, there is no clear understanding of the relation of neck muscle activity and driving experience in curve road.

In line with the above background, the motivation of this study is therefore to evaluate driving experience of different type drivers, by investigation of physiological characteristics of neck muscle during curve driving with different speed conditions in an actual-vehicle experiment.

The remainder of this paper is constructed as follows. The actual-vehicle experimental design for curve driving is described at first. Then, biosignal measurement and processing are presented related to EMG signals. In the following section, a detailed analysis of neck muscular activity for driving experience is presented. After the interpretation of results, conclusions are provided in the last section.

II. Methodology

A. Subjects

The actual-vehicle experiment was conducted by 10 male drivers in good health. Before the experiment, drivers recruited were surveyed their basic driving information. Their ages are between 23 and 40 years, with an average age of 27.7 and a standard deviation (SD) of 6.2. Their driving years are between 1 and 20 years, with an average year of 6 and a standard deviation (SD) of 6.2. Their driving mileages range from 5 thousand to 20 thousand kilometers (Mean = 5.4 thousands, SD = 6.3 thousands).

According to their driving mileages per year, subjects were preliminarily divided into two types as novice and skilled drivers (see Table I). Subjects whose driving mileages per year is less than 10000km/year are considered as novice ones. To avoid affecting the experiment's accuracy, all subjects should not drink alcohol and take any drugs before the driving test. All subjects were instructed on the test procedure of actual-vehicle driving, and they signed a legal document agreeing to the participation and publication of the results.

TABLE I. SUBJECT INFORMATION.

Driver Number	Age (year)	Driving Years	Driving Mileages (km)	Style
D1	23	1	5000	novice
D2	23	1	5000	novice
D3	24	1	5000	novice
D4	23	3	15000	novice
D5	23	2	15000	novice
D6	25	3	30000	skilled
D7	28	9	60000	skilled
D8	33	10	100000	skilled
D9	35	10	100000	skilled
D10	40	20	200000	skilled

B. Apparatus

A Trumpchi GS7 manufactured by Guangzhou Automobile Group of China is utilized as the actual-vehicle experimental platform. It is a midsize SUV with a 2.0 L turbocharged engine and 6 speed tiptronic gearbox. It also has the capability to achieve the maximum power of 201 horsepower/5200 rpm and the maximum torque of 320 Nm/1750-4000 rpm.

Data acquisition equipment includes Flexible network interfaces for CAN (Vector vn1630a, Germany), and wireless physiology recorder system (Biopac MP150, USA). Based on Vector vn1630a, steering wheel angle, longitudinal acceleration, lateral acceleration, speed, engine speed and yaw rate can be acquired from vehicle amounted on-board diagnostic interface with a sampling frequency of 1000 Hz. In the experiment, EMG signals of neck muscles are collected with a sampling rate of 1000 Hz by a wireless physiology recorder system. The system consists of biosignal reflector module, conductor module, wireless signal amplifier module, and receiver module. In order to reduce the influence by factors of the external environment, a medical disposable patch electrode is used for the EMG signal collection.

(a) Experimental vehicle of Trumpchi GS7.

(b) Wireless physiology recorder.

Figure 1. Actual-vehicle experimental platform and EMG recorder: (a) Trumpchi GS7, and (b) wireless physiology recorder.

C. Task Description

The experiment was conducted on an open suburban site with smooth pavement and fewer cars. Before the experiment, a 7.5m-width and 25m-radius semicircle curve road was constructed with traffic cones, shown in Fig. 2. Traffic cones were located every 5m inside and outside of the curve road boundaries. For the preparation of the experiment, each participant was asked to paste the electrodes and wear the EMG signal transmitting module on the neck. There were four muscles of each driver for testing in this study, left upper trapezius muscle (LTM), left sternocleidomastoid muscle (LSM), right upper trapezius muscle (RTM) and right sternocleidomastoid muscle (RSM). Employing the principle of differential amplification, two electrodes were pasted on each muscle about 20 mm apart. The reference electrode was pasted on the collarbone, since there is a little skeletal muscle under the skin of the collarbone [16]. And then subjects operated the testing vehicle and experienced the driving field for about 10 minutes until they familiarized themselves with the driving environment. During the experiment, all subjects were asked to enter at the curve entrance and make a left U-turn at 30, 40 and 50 km/h respectively, with a safe and comfortable speed that reflected their real driving style.

A subjective evaluation was executed after each driving condition of the experiment. Participants were asked to complete a questionnaire about their driving comfort for the different driving speeds. There were five levels of driving comfort from which to select, and the five levels of evaluation were 1 = discomfort, 2 = a little discomfort, 3 = normal, 4 = a little comfort, and 5 = comfort.

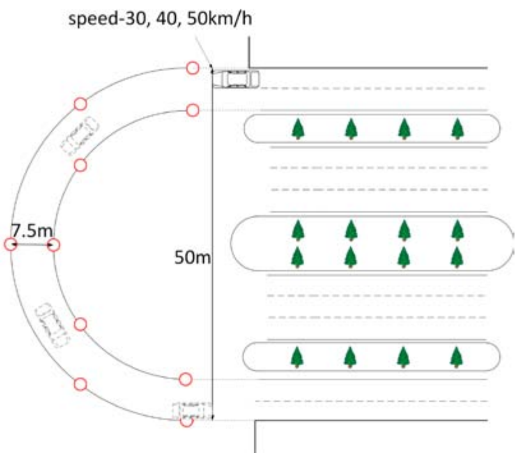

Figure 2. Designed curved road for the driving experiment.

III. BIOSIGNAL PROCESSING

In this study, the EMG signals of LTM, LSM, RTM and RSM four muscles were used to clarify physiological characteristics, which responds to vehicle dynamics during curve driving with different speeds. An EMG signal of the neck muscle is an electrical signal that is activated by isometric and isotonic muscle contractions, and it is considered to represent muscle activity. A sudden acceleration stimuli can induce abrupt peaks in the EMG signal. When a subject feels high mental stress, the related muscles spontaneously contract.

Due to differences of the thickness of fat beneath the skin and skin resistance between individuals, it is crucial to normalize or standardize the measured EMG signals. In previous studies, the ratio of the measured EMG signal to the EMG signal produced in maximal voluntary contraction (MVC) is usually used as the normalization index. However, upper trapezius and sternocleidomastoid muscles are seldom in high muscular tension in everyday life. It's difficult to achieve the real MVC condition of each muscle.

In this study, the root mean square (RMS) value is applied as an effective index for measuring range of the EMG signal. The RMS value of the EMG signal is collected according to

$$RMS(k) = \frac{1}{T}\left(\int_{(k-1)T}^{kT} f^2(t+\tau)d\tau\right)^{\frac{1}{2}}, \tag{1}$$

where $f(t)$ is the EMG signal, $((k\text{-}1)T, kT)$ is a single sampling range, and τ is the step length of sampling. The RMS value represents the EMG signal fluctuations in a fixed time interval.

And then collecting n RMSs in no-motion state as the RMS Standard Value. In order to avoid data fluctuations, the RMS Standard Value is calculated as

$$RMS_s = \frac{1}{n}\sum_{k=0}^{n} RMS(k)\,. \tag{2}$$

Furthermore, all RMSs in curve motion state are collected as the RMS Motion Value. In order to better evaluate the muscular activity reflecting to car motion performance, all of RMSs in curve motion state are sorted. And then the mean of the m largest ones can be extracted. The RMS Motion Value is calculated as

$$RMS_m = \frac{1}{m}\sum_{k=0}^{m} rank(RMS(k))\,, \tag{3}$$

where m and n are equal to 10.

Finally, a modified RMS evaluation index can be calculated with the difference between the RMS motion value and the RMS standard value as

$$RMS = RMS_m - RMS_s\,. \tag{4}$$

IV. RESULT

A. EMG Activity of Curve Driving

In Fig. 3, the data curve of 1st row is lateral acceleration (G_y), data curves from 2nd row to the 5th row, are the Raw EMG signals of LTM, LSM, RTM and RSM, respectively. From the figure, we can see that with the variety of G_y during the curve driving, these four neck muscles are more or less involved in driving motions and have corresponding signal responses.

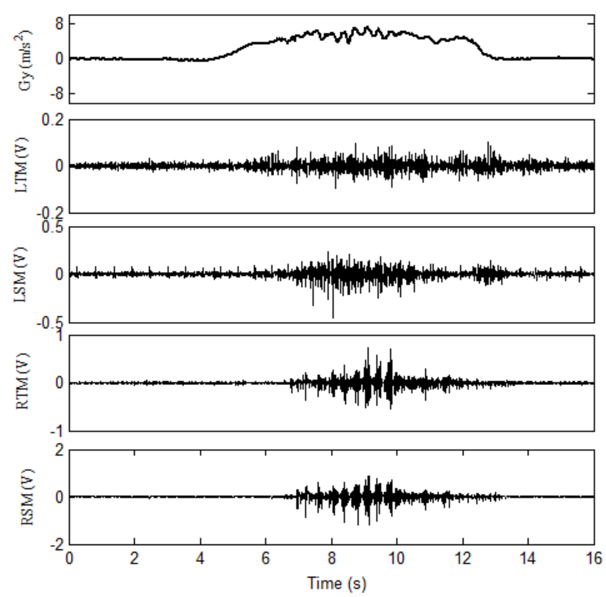

Figure 3. Lateral acceleration and raw EMG signals of a skilled subject collected during the curved road.

Among them, the right two muscles respond more obviously since the experiment is a left U-turn curve driving. The test results are consistent with the conclusion in the literature that neck muscles on the side opposite the direction of the car's lateral acceleration contracts to keep the head stable against the body shaking [3]. Therefore, the right two neck muscles are as the analysis objects in this study.

B. Results Analysis of RTM Muscle

The results of physiological evaluation of two neck muscles with three speed conditions are presented in Figs. 4-11, respectively. The results are presented as mean values and SD (Mean ± SD) collected from the actual vehicle driving experiments of 10 subjects.

As shown in Fig. 4, the results of RMS evaluation indexes of RTM are presented for the two type drivers with a speed of 30 km/h. At a confidence level of 0.05, the results of RMS evaluation indexes for RTM were not significantly different between the novice drivers and skilled ones (Independent sample t-test, $p = 0.0740 > 0.05$). It indicates that the RMS evaluation indexes of RTM of the different type drivers were no significantly different, with a lower speed curve driving.

As shown in Fig. 5, the results of RMS evaluation indexes of RTM are demonstrated for the two type drivers with a speed of 40 km/h. At a confidence level of 0.05, the results of RMS evaluation indexes for RTM were significantly different between the novice drivers and skilled ones (Independent sample t-test, $p = 0.0064 < 0.05$). It indicates that the RMS evaluation indexes of RTM of drivers in different types were significantly different, with a 40 km/h speed curve driving.

As shown in Fig. 6, from statistical analysis at a confidence level of 0.05, the results of RMS evaluation indexes for RTM were significantly different between the novice drivers and skilled ones with a speed of 50 km/h (Independent sample t-test, $p = 0.0248 < 0.05$). It indicates that the RMS evaluation indexes of RTM of drivers in different types were significantly different, with a higher speed curve driving.

Figure 7 shows statistical analysis results of RTM mean evaluation of the total 3 speed conditions for the two types of subjects. At a confidence level of 0.05, the results of RTM mean evaluation were significantly different between the novice drivers and skilled ones (Independent sample t-test, $p = 0.0185 < 0.05$). It indicates that the RMS evaluation index of RTM were significantly different for curve driving experience representation.

C. Results Analysis of RSM Muscle

As presented in Fig. 8, the results of RMS evaluation indexes of RSM are collected for the two type drivers with a speed of 30 km/h. At a confidence level of 0.05, the results of RMS evaluation indexes for RSM were significantly different between the novice drivers and skilled ones (Independent sample t-test, $p = 0.0391 < 0.05$). It indicates that the RMS evaluation indexes of RSM of drivers in different types were significantly different, with a lower speed curve driving.

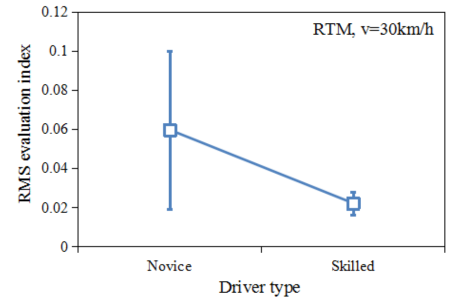

Figure 4. RMS evaluation indexes of RTM muscle for the different type drivers (Mean ± SD): v = 30 km/h.

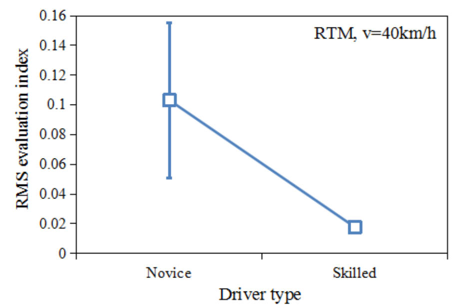

Figure 5. RMS evaluation indexes of RTM muscle for the different type drivers (Mean ± SD): v = 40 km/h.

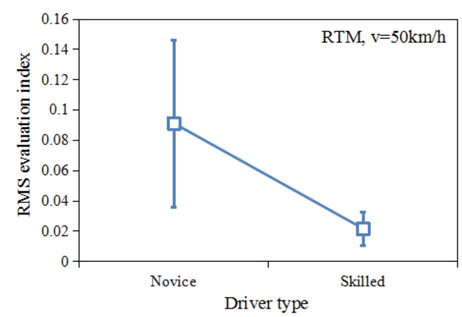

Figure 6. RMS evaluation indexes of RTM muscle for the different type drivers (Mean ± SD): v = 50km/h.

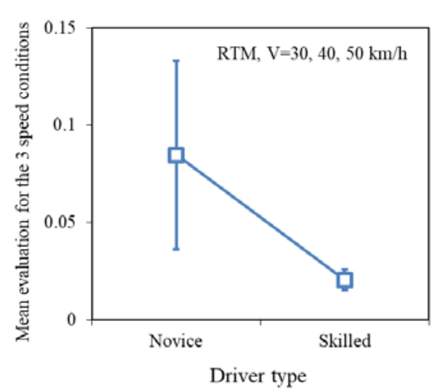

Figure 7. RTM mean evaluation results for the three speed conditions (Mean ± SD).

As shown in Fig. 9, although the average RMS index of skilled drivers' was obviously lower than that of novice ones under 40km/h speed conditions, the differences of RMS evaluation indexes of RSM between these two types of drivers were not significant from the results of the t-test analysis (Independent sample t-test, $p = 0.1832 > 0.05$).

In Fig. 10, from statistical analysis at a confidence level of 0.05, the results of RMS evaluation indexes for RSM were significantly different between the novice drivers and skilled ones with a speed of 50 km/h (Independent sample t-test, $p = 0.0489 < 0.05$). It indicates that the RMS evaluation indexes of RSM of drivers in different types were significantly different, with a higher speed curve driving.

Figure 11 shows statistical results of RSM mean evaluation of the total 3 speed conditions for the two types of subjects. The results of RSM mean evaluation were no significantly different between the novice drivers and skilled ones (Independent sample t-test, $p = 0.0651 > 0.05$). It indicates that RSM mean evaluation of different drivers were no significantly different, with a curve driving.

D. Subjective Evaluation

Each subject was asked to complete a questionnaire about driving comfort for different driving speeds. The results of average subjective evaluation are presented in Fig. 12. At a confidence level of 0.05, the results of subjective evaluation rates were no significantly different between the novice and skilled drivers (Independent sample t-test, $p = 0.4937$). It indicates that subjective evaluations of different drivers were no significantly different for a curve driving experience.

Figure 13 shows statistical analysis results about standard deviation (SD) of subjective evaluation results, which are used to verify the adaptive ability for curve driving for the three speed conditions between novice and skilled drivers. At a confidence level of 0.05, the results of subjective evaluations for the three speed conditions were significantly different between the novice and skilled drivers (Independent sample t-test, $p = 0.0278 < 0.05$). It indicates that SD of subjective evaluation results by drivers in different types were significantly different. Furthermore, the variance of rating for three driving speeds is lower for skilled drivers, but higher for novice ones. The skilled ones may have higher adaptive ability dependent on their driving experience than that of the novice driver for different driving speeds.

From the above analyses, it can be observed that it is always difficult to clearly express what driving experience is and how it is by subjective evaluation, neither novice drivers nor skilled ones. However, normally, in the face of changing of driving conditions or environments, skilled drivers are more stable in operation performance, and this study indicated that the skilled drivers may have lower mental stress in psycho-physiological conditions than that of novice ones. Due to the accumulation of driving time, the skilled drivers may be easier adapted to complex driving conditions and road environments. So they may have better driving experience in most driving conditions. For novice drivers, they will endure more psychological and physical burden than skilled ones when facing with the same driving task.

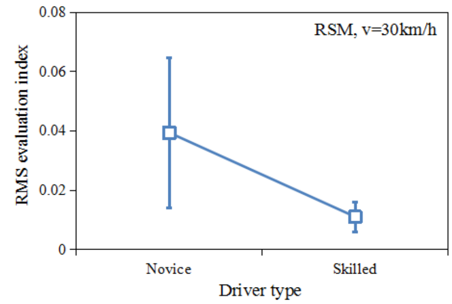

Figure 8. RMS evaluation indexes of RSM muscle for the different type drivers (Mean ± SD): v = 30 km/h.

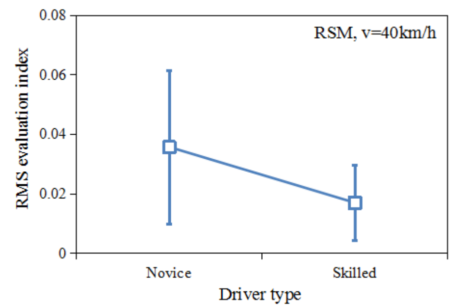

Figure 9. RMS evaluation indexes of RSM muscle for the different type drivers (Mean ± SD): v = 40 km/h.

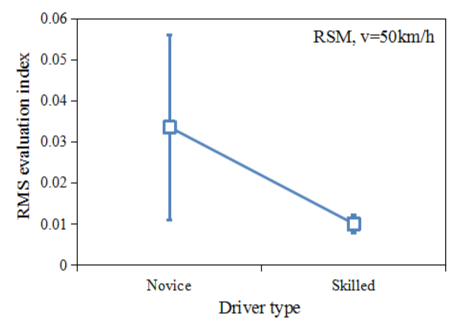

Figure 10. RMS evaluation indexes of RSM muscle for the different type drivers (Mean ± SD): v = 50 km/h.

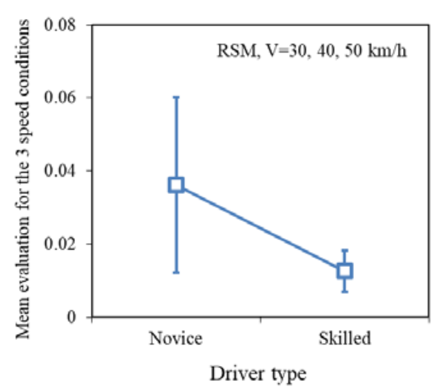

Figure 11. RSM mean evaluation results for the three speed conditions (Mean ± SD).

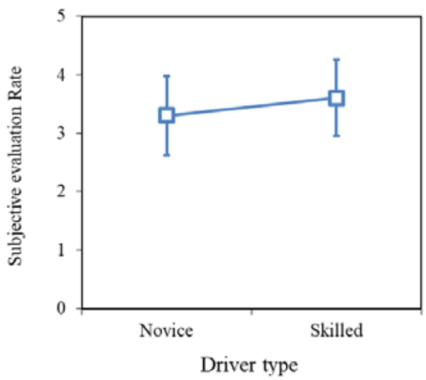

Figure 12. Average subjective evaluation results for the three speed conditions (Mean ± SD).

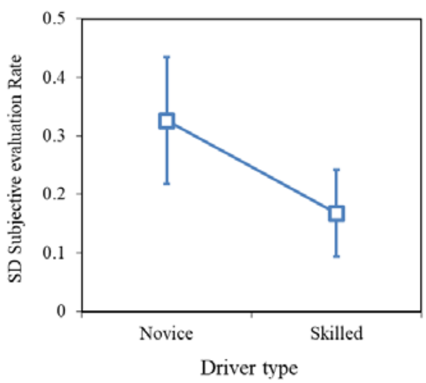

Figure 13. Standard deviation of subjective evaluation results for the three speed conditions (Mean ± SD).

V. CONCLUSION

To evaluate driving experience of drivers in different types, EMG signals of upper trapezius and sternocleidomastoid muscles are analyzed for 10 subjects with different speeds conditions, during a curve driving of an actual-vehicle experiment. Through analyses of the normalized EMG evaluation indexes, it is concluded that the RMS based evaluation of RTM and RSM muscles are significantly lower for the skilled drivers than that of the novice ones, while they were driving with a higher speed on curved road. For a lower speed, there are significantly different between the novice and skilled drivers only in EMG signals of the RSM muscle.

By the objective evaluation results, it can be observed that the variance of rating for three driving speeds is lower for skilled drivers but higher for novice ones. It means skilled drivers are more stable in operation performance and have lower mental stress than novice ones in the face of changing of driving conditions, which is consistent with the results of biosignal analysis.

The research results are valuable to study the driving experience measurement and evaluation of drivers and human-oriented intelligent vehicle development in the future. On the basis of this article, the future research work mainly focuses on the following aspects: the actual-vehicle experiment was only conducted with 10 drivers. Therefore, future research will further increase the test sample and make a detailed comparative analysis of more types of people in driving experience; the driving experience is a complex psycho-physiological index, and people in the face of different changes in stress will trigger a variety of driving experiences, and therefore a further insight on physiological experience is necessary by application of multiple biosignals.

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