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A Study on the Relationship between In-Vehicle Systems and Driving Safety Based on Drivers' Visual Features

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Abstract:

The use of in-vehicle systems has become a potential factor in traffic accidents, resulting in increased driving workload. The driver's visual features could be used to represent the change of driving workload. Therefore, this study examined the influence of in-vehicle systems on drivers' visual features through a real-vehicle test on urban roads. Devices including eye trackers and navigation systems were installed in the test vehicle, and four urban routes were selected to conduct the on-vehicle experiment. A comparison was made regarding the difference of subjects' fixation and saccadic behavior with or without the condition of in-vehicle systems, with devices at different positions and different information release modes. Within-vehicle systems used, drivers' saccadic times and duration, as well as small-scale saccadic behavior all increased significantly, and the average saccadic speed was greater. Besides, drivers' fixation area and the average fixation proportion towards the road ahead both reduced significantly, with the fixation location closer to the ground, but the fixation duration remained unchanged. When the in-vehicle systems was installed above the shelf and provided voice broadcast information, drivers' saccadic frequency, scope, and speed were low. The fixation distribution area and fixation times towards the road ahead changed the least. These results indicate that in-vehicle systems occupies more cognitive resources, resulting in more mental workload and less driving safety. The influence on driving safety could be mitigated by optimizing the position of in-vehicle systems and information release mode.

Keywords*: Traffic safety, drivers, in-vehicle systems, visual features, mental workload*

I. INTRODUCTION

With the rapid development of in-vehicle communication technology, the IVIS (In-vehicle Information Systems) has been widely applied to provide subjects with entertainment, navigation, real-time traffic status, even taxi orders, and payment service [1-4]. While providing subjects with convenience, IVIS also requires them to finish both primary tasks like vehicle control and in-vehicle secondary tasks [5, 6]. Vision is the major pathway from which subjects acquire external information [4], and visual features compose the basis of their information-processing model [7]. Under the circumstance where driving primary tasks

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and secondary tasks compete with each other for resources, subjects' visual features have changed [8], which turns out to be a factor in a traffic accident. Therefore, it is necessary to study the subject's visual features when using the IVIS to further reveal subjects' information-processing models and optimize the human-computer system.

Currently, many studies have shifted to focus on the influence of IVIS. Researchers like Lin Caixia reviewed the current situation of IVIS, proposing the necessity to study the relationship between IVIS and driving safety [9]. Wang Ying reviewed the theoretical basis and experiment methods of IVIS for driving safety, suggesting the importance of IVIS being well and safely designed [7]. Benedett adopted a virtual secondary task to prove the influence of IVIS on drivers [10]. Yang proved that IVIS could change drivers' behaviors [11]. Xie Chenjiang studied the influence of secondary tasks on driving safety based on subjects' visual features [12]. Leng Xue studied the influence of IVIS on subjects' vision, action, and cognition in different traffic states [13]. These studies mainly focused on the impact of IVIS on drivers, and rarely discussed the location of IVIS and the way of information release.

The previous research emphasized the influence of the in-vehicle information service, including its secondary tasks, the necessity of further studies was hence demonstrated [14]. Wickens' multi-resource theory and task conflict model theoretically analyzed the reason for such influence [15], in which it was especially noted that visual resource distribution would change with other pathways' occupation. Research qualitatively showed that when subjects were in constant access to in-vehicle information, the height of their fixation center would be unconsciously reduced, resulting in a smaller dynamic field of vision [14]. In such cases, drivers' fixation indicators, such as fixation frequency, duration [16], and distribution range [17], often highlighted their information acquirement performance, which was of great significance for a deeper exploration.

Saccadic behavior refers to the process in which eyes search for a target, viz the movement where the fixation point moves from one object to another as needed, or the eyeball rotation due to a specific stimulus in the peripheral visual field. Several studies have shown a strong link between saccade and mental workload [16-18]. Above all, previous studies have proved the influence of in-vehicle information on drivers. Qualitative analysis of visual features under such influence has also been conducted, but it still requires empirical study, especially on-vehicle experiments.

Therefore, to clarify the relationship between IVIS and driving safety, and provide the theoretical foundation for IVIS design, installation, and use, an on-vehicle experiment was designed. Subjects' visual features were collected, and the differences with or without the condition of IVIS usage, with devices set at different positions, and in different information release modes, were summarized.

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II. METHODS

2.1 Experiment Design

The subjects included eight drivers of different occupations, ages, genders, and driving years. They were required to have a driving license and normal eyesight or corrected visual acuity. The information of the subjects was shown in TABLE 1.

EyeLink II head-mounted eye tracker was adopted to collect subjects' saccadic behavior. The eye tracker includes a host, camera, fixed frame among others. The experiment vehicle is a 2007 KIA New Carens equipped with Newman movable S480 touch navigation device, which could control the voice output mode. Other devices include power supplies, inverters, wires, data loggers, etc. IVIS adopted a 7-inch screen in-vehicle navigation device, with simultaneous voice and image prompt. Subjects and staff sat in the front row of the test vehicle, whereas the eye tracker, host, and electric devices were placed in the back row. Before the experiment, preparation needed to be done. All subjects were told about the experiment requirements, then subjects tested the vehicle and IVIS as required and wore an eye tracker. After mastering how to use the devices, subjects could start the experiment at the assigned start point. Subjects would be allowed to rest for 5 to 10 minutes. Each testing stage would last 20 minutes.

Sunny and non-traffic peak hours in the daytime were selected as the experiment period, and the four main urban roads with similar traffic conditions were selected as the experiment sections. An in-group experiment was adopted, requiring each subject to complete different tasks, to compare the differences in subjects' visual features under different conditions. The tasks are shown in TABLE 2. Task 1 was conducted to make subjects adjusted to the testing device and task 2, as well as task 9, were used to collect the subject's visual data with or without the condition of IVIS respectively. Other tasks were carried out to collect data with IVIS set at different positions or with different release modes. Position A, B, and C refer to the middle part of the windshield, the upper and the lower part of the vehicle shelf respectively. They were common position settings on the same vertical plane.

TABLE I. The Statistics of Subjects

Number of Subjects	**Gender Male/Female**	**Average age**	**Average driving years**
8	6/2	32.5	3.4

TABLE II. Experimental Scheme Design

Task Serial	**In-Vehicle Information Service**	**Position Setting**	**Release Mode**	**Record**
1	x	—	—	x
2	x	—	—	√

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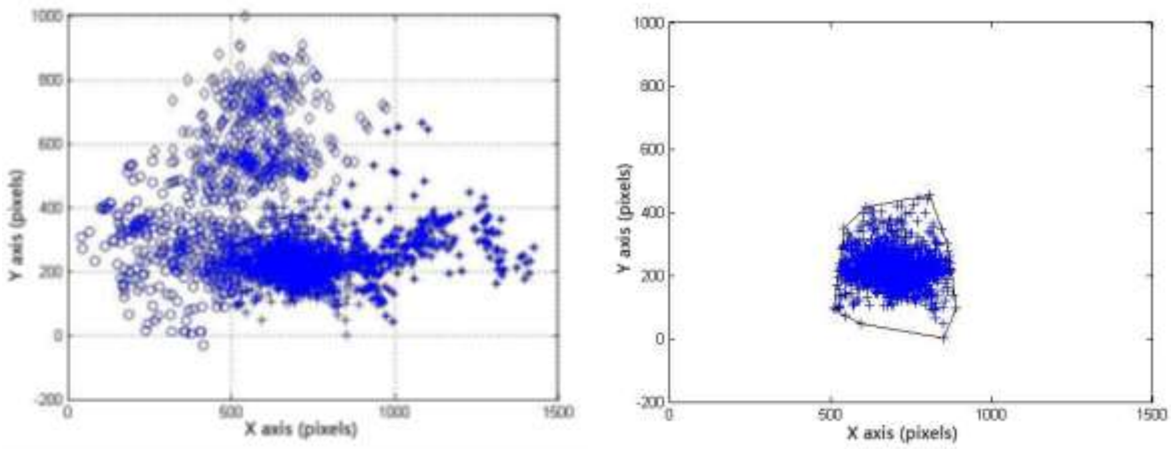
3	√	position A	image	√
4	√	position B	image	√
5	√	position C	image	√
6	v	position A	voice+image	√
7	√	position B	voice+image	√
8	√	position C	voice+image	√
9	x	—	—	√

2.2 Data Processing

The location data of subjects' fixation was acquired. See Fig.1 for data match in the coordinate system. In order to more intuitively describe the driver's fixation features, the field of view was often divided into visual interest areas such as the road ahead and dashboard area before determining the relationship between fixation and these visual interest areas. The commonly used division methods include the empirical division method and clustering method. Given subjects' differences, the empirical partition may bring errors, this study used K-means clustering method to divide the major visual interest areas including the left rear mirror, the road ahead area, dashboard, and IVIS.

The K-means clustering method took the Euclidean distance as the category similarity measure, established the optimization objective function, and then used the function extreme value method to iterate to obtain the classification results. To further verify the rationality of classification, a one-way ANOVA analysis was conducted. The result showed there was a significant difference between each classification (*p*.=0.000).



(a) Visual interest areas before clustering (b) The road ahead area

Fig 1: Fixation distribution of the subject

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Ⅲ. FIXATION FEATURES UNDER IN-VEHICLE INFORMATION SERVICE

The subjects' fixation spatial distribution range and location, fixation frequency and the proportion of fixation times to total ones, and the proportion of single fixation times to accumulative ones were mainly analyzed in this part.

3.1 Spatial Distribution Range and Location

The hull algorithm was used to calculate the fixation area. Based on this, the area change coefficient was introduced to measure the change of fixation area with or without the condition of IVIS.

$$\phi = \frac{A_0 - A_I}{A_0} \tag{1}$$

A_I was the visual search area influenced by IVIS, A_0 was the one without IVIS, ϕ is the area change coefficient. If ϕ was greater than 0, then the fixation area became smaller, and vice versa.

After using IVIS, the change coefficient of subjects' fixation area towards the road ahead area was greater than zero. The results showed that there was no significant difference in the variance between the two groups (p.= 0.328 >0.05). One-way ANOVA analysis results showed that the use of IVIS had a significant effect on the change coefficient of fixation area (p.=0.016<0.05). Above all, the use of IVIS resulted in a significant reduction of fixation area in the road ahead area.

The location of fixation also changed significantly, as shown in Fig.2. After using IVIS, the vertical distribution of fixation point tended to reduce, with the mean value increased. In the coordinate system adopted by the eye tracker, the results showed a closer test point to the ground. The significance test was conducted after the variance homogeneity test, which showed a huge difference in fixation vertical distribution before and after the use of IVIS (p.=0.000<0.05).

After using IVIS, the mean value of the change coefficient of the road ahead area was greater than the baseline. At position A, the mean value was the greatest, viz the influence on fixation distribution area was the greatest; at position B, the mean value of change coefficient was the lowest, viz the degree of fixation reduction was the lowest, as shown in TABLE 3.

One-way ANOVA analysis results showed that the location of IVIS had a significant influence on the change coefficient of the road ahead area (p.=0.044<0.05). As shown in TABLE 4, IVIS set at all three positions had a significant influence on the change coefficient of the road ahead area by using the T-test of two-paired samples. After comparing the change coefficient with IVIS set at the three positions, data showed that there was also a significant difference.

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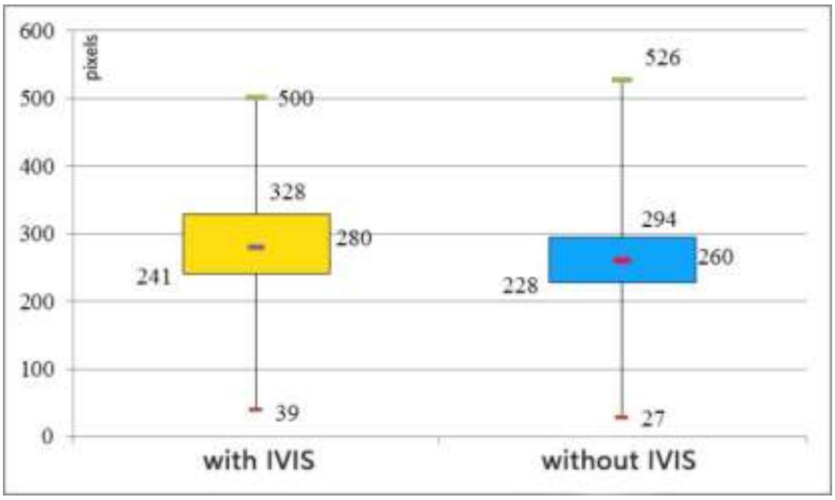

Fig 2: Vertical distribution of fixation point

TABLE III. The Average Area Change Coefficient of Different Groups

Groups	Average Area Change Coefficient
baseline	0.00
position A	0.71
position B	0.51
position C	0.65

TABLE IV. T-test Results of Different Pairs

Pairs	*P*-value
position A—baseline	0.000
Position B—baseline	0.000
position C—baseline	0.000
position A—position C	0.004
position A—position B	0.043
position C—position B	0.027

3.2 Proportion of Fixation Times

The proportion of fixation times referred to the proportion of subjects' fixation times towards a certain area to the whole visual area. The fixation proportion reflected subjects' relative focus degree towards a certain fixation area. With the use of IVIS, the average fixation proportion of the road ahead area was

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reduced. The variance homogeneity test showed there was no significant difference(*p.* =0.202>0.05). One-way ANOVA analysis results showed that the use of IVIS had a significant influence on drivers' fixation proportion of the road ahead area.

As shown in Fig.3, in terms of fixation times proportion of the road ahead area, position B and position A showed the least and greatest difference with the baseline respectively. The one-way ANOVA analysis showed IVIS at different positions had a significant influence on the fixation proportion of the road ahead area (*p.* =0.015<0.05). The two-paired t-test was used to examine the influence of IVIS at different positions on the fixation proportion of the road ahead area as shown in TABLE 5. It turned out that position A, B, and C had a significant difference from the baseline. After comparing the fixation times proportion with IVIS set at three positions, data showed it also differed between each position.

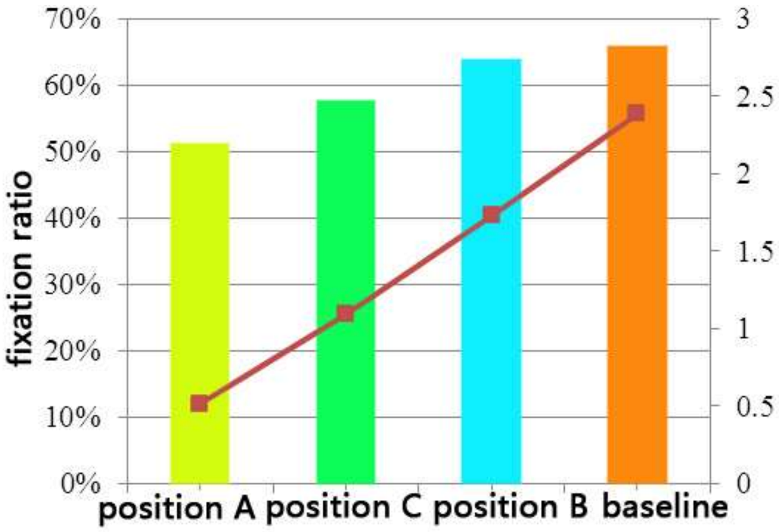

Fig. 3: The fixation ratio of the road ahead area in different IVIS positions

TABLE V. T-test Results of Different Pairs

Pairs	**P-value**
position A—baseline	0.000
Position B—baseline	0.000
position C—baseline	0.048
position A—position C	0.015
position C—position B	0.022
position B—position A	0.007

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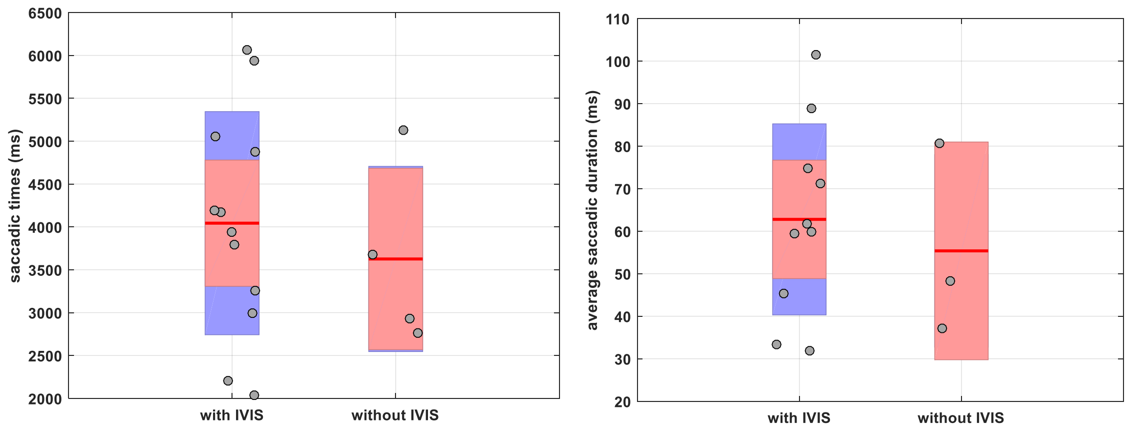
IV. SACCADIC FEATURES UNDER IN-VEHICLE INFORMATION SERVICE

4.1 Saccadic Frequency

There was a huge division between the saccadic times and average duration with or without the condition of IVIS, see Fig.4. With IVIS used, the saccadic times and average duration were obviously greater. The maximum and quartile also presented the same features.

These features suggested the use of IVIS resulted in lower visual search efficiency and longer information processing time of the same goal. Information processing time reflected the size of resources needed for mobilizing working memory [19]. When there was a limited capacity of working memory, it took a longer time to process information and lead to more mental workload. Therefore, it could be assumed that IVIS occupied more cognitive resources.



(a)Saccadic times (b) Average saccadic duration

Fig. 4: Box plots for saccadic behavior with or without the use of IVIS

Fig.5 provided the difference of subjects' saccadic frequency with IVIS set at different positions. With IVIS installed at position A or C, the saccadic frequency was higher, viz the subjects searched for the same goal many times during the same period, leading to lower visual search efficiency and more mental workload. To compare the influence of in-vehicle navigation voice prompt on saccadic frequency, it was found that voice prompt service improved visual search and driving efficiency.

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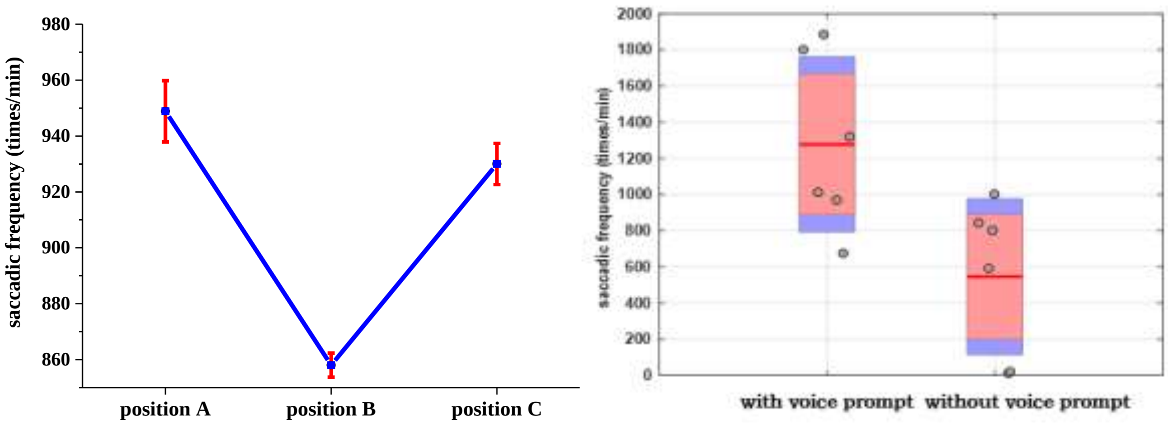


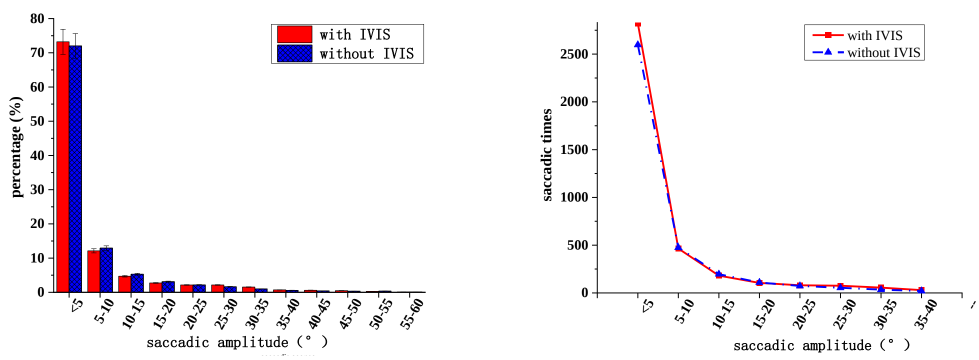
(a)Comparison of installation positions (b) Comparison of information release modes

Fig. 5: Box plots for the saccadic frequency of drivers

4.2 Saccadic Amplitude

Fig.6 compared the distribution pattern with or without the condition of IVIS and collected data with the saccadic amplitude set at 5°. The saccadic amplitude of drivers mainly ranged from 0° to 40°. Saccadic behavior with a scope less than 5° accounted for about 70%. After using IVIS, the percentage of saccadic amplitude less than 5° increased significantly, and the percentage of small-scale saccadic behaviors also increased.

Besides, when IVIS was set at position A or C, there were more saccade behaviors in a small range. Voice prompt reduced such behaviors. Research showed the average saccadic amplitude was positively associated with the mental workload [18]. Therefore, it could be seen that the use of IVIS would increase drivers' mental workload. However, its negative effects could be mitigated by improving its installation location and information release mode.



(a) Percentage of saccadic amplitude (b) Saccadic times in different saccadic amplitude

Fig. 6: Statistics of saccadic amplitude with or without the condition of IVIS

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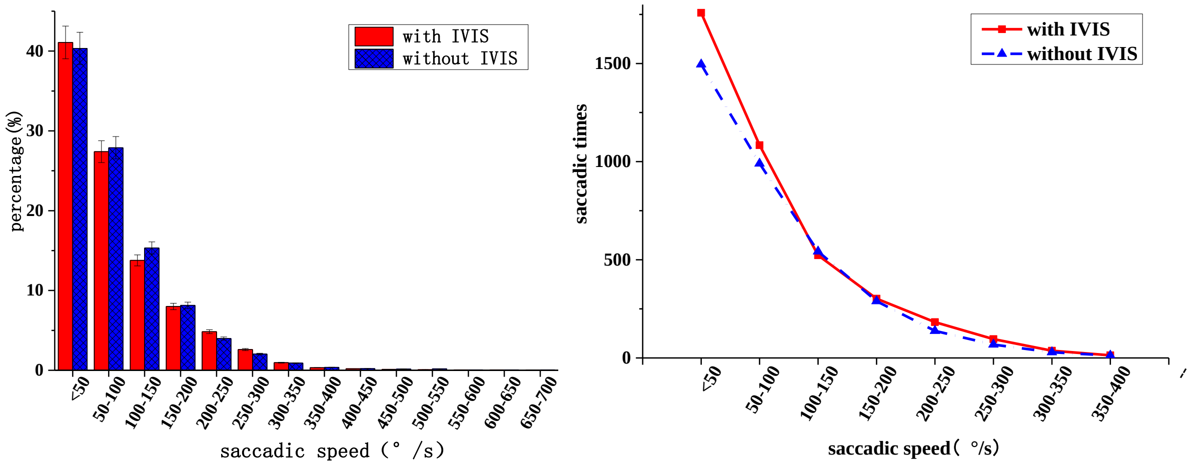
4.3 Saccadic Speed

Fig.7 compared drivers' saccadic speeds with or without IVIS. It was found that most saccadic speeds ranged from 0 to 400°/s, and 40% of saccadic speed was between 0 to 50°/s. With more focus on drivers' saccadic speeds in the range of 0° to 400°/s, the distribution of saccadic speed in different ranges could be compared.



(a) Percentage of saccadic speed (b) Saccadic times in different saccadic speed

Fig. 7: Statistics of saccadic speed with or without the condition of IVIS

Fig.7 showed that while the distribution of saccadic speed was similar, there were some differences with or without the condition of IVIS. IVIS markedly increased the times when saccadic speed was below 50°/s, leading to greater average saccadic speed and more discrete data distribution.

Fig. 8(a) showed that when IVIS was installed at position A, saccadic times in each section were all higher compared with those under other positions. There was no significant difference in the distribution of saccade speed between position C and position B. Fig 8(b) showed that the voice prompt could reduce the average saccadic speed. Research suggested the lower the average saccadic speed was, the less information that needed to be processed, and the less mental workload was. Therefore, the use of IVIS would increase drivers' average saccadic speeds.

When set at position B and equipped with a voice prompt, IVIS could ease drivers' mental workload to a certain extent. In other words, when IVIS released information via visual and auditory channels simultaneously, drivers could select appropriate information channels to reduce the occupation of psychological resources.

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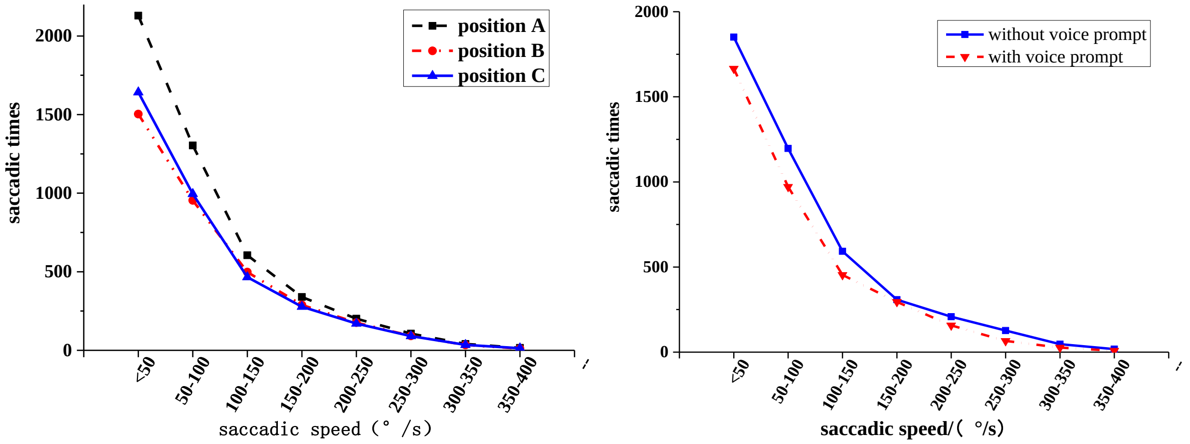

(a) At different positions (b) With or without voice prompt

Fig. 8: Statistics of saccadic speed in different conditions

Ⅴ. DISCUSSIONS

Fixations reflect the area of driver's attention in visual space. The eyes will combine previous experience to focus on noticeable and subjectively-perceived important areas spontaneously. According to the psychological theory, the concentration of fixation points could be used as a measure of peripheral detection performance, which is related to vehicle control [20]. There is no correlation between the number of fixation points and the difficulty of information to be processed, but has something to do with the amount of information. The fixation ratio of sub regions could be used to measure the relative importance of the region. The more fixation times, the more important the region is.

Data difference in the experiment showed that the use of IVIS reduced drivers' acquisition range of the road area ahead, with lowered fixation position, decreased information amount, and a perception of lower degree of importance compared with other areas. Overall, the above-mentioned changes would have an indirect impact on driving efficiency.

Fixation duration (counted by milliseconds) refers to the duration when the optical axis remains unchanged, which can measure the time spent in processing perceived information and to some extent reflect the difficulty degree of information extraction and processing. During the information search, the more difficult the information processing is, the longer the fixation duration would be. Long-time fixation suggests that the object needs to spend more time recognizing, reading, and understanding the object at the fixation spot. Statistical analysis results revealed that there was no significant difference in the difficulty of perceiving information after using IVIS, indicating that there was no difference in the overall difficulty. However, the variance was different, which showed much higher difficulty in perceiving the information in a short time.

After a further analysis on IVIS position setting, data showed that IVIS had significant differences, which varied from the greatest degree to the least when set at position A, C, or B respectively.

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Ⅵ. CONCLUSIONS

This study investigated the influence of IVIS on drivers' visual features through an on-vehicle experiment on urban roads. The following conclusions were obtained.

Drivers' fixation areas of the road ahead reduced significantly with the use of IVIS, which suggested a decrease in the amount of acquired information. Besides, the fixation location distribution changed significantly, becoming closer to the ground. The average fixation ratio to the road ahead decreased significantly, proving a less degree of importance compared with other areas. However, the fixation duration had no significant change, which showed no significant difference in the difficulty of information extraction before or after the use of IVIS. The difference in variance indicated that it may be difficult to perceive information in a short time.

When IVIS was set at position A, the mean value of area change coefficient was the maximum, indicating the effect on fixation distribution area was the most noticeable. IVIS set at position B saw the minimum mean value of area change coefficient, suggesting the fixation level reduced the least. There was a huge difference among the three position settings. The fixation proportion of the road ahead area shared the least difference with the baseline at position B and the greatest at position A. Above all, IVIS showed significant differences which varied from the greatest degree to the least when set at position A, C, or B respectively.

The use of IVIS increased the driver's saccadic frequency, indicating lower visual search efficiency and more mental workload. When set at position B or equipped with voice prompt, IVIS could improve visual search performance and driving efficiency. The average saccadic amplitude increased after using IVIS, showing more mental workload. When set at position B or equipped with voice prompt, IVIS would reduce small-scale saccadic behaviors and the average saccadic amplitude, which could mitigate the negative effect of IVIS.

After adopting IVIS, the distribution of saccadic speed that ranged from 100°/s to 150°/s showed no significant change, whereas that below 50°/s increased significantly, indicating much more mental workload. When set at position B or equipped with voice prompt, IVIS would reduce drivers' mental workload to some extent.

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