Color Visibility Evaluation of In-Vehicle AR-HUD Under Different Illuminance

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Abstract. Drivers' visual distraction serves as the main cause of traffic accidents, different ambient illuminance can also exert a considerable impact on the drivers' cognition efficiency. It is therefore very important to study the color visibility of AR-HUD interface under different illuminance. In this study, an evaluation experiment of digital character was carried out through an in-vehicle AR-HUD based on three variables: seven colors (R, G, B, Y,P, YR, W) of character, the outlines(white, grey, none) of character and ambient illuminance(daytime, night). A total of 19 stimuli were displayed to evaluate color visibility, visual fatigue, color preference and visual intrusion. The experimental results showed that (1): Y (4.12) and G (3.92) had apparent visibility in daytime, while R (3.88) and Y (3.80) were significantly obvious in night. (2): For the outlined character, the visibility with white outline is higher than that of grey outline, and visibility is affected by the luminance contrast between character and outline. (3): For the non-outlined character, windshield turns into the display background, the luminance contrast of character reaches greater visibility.

Keywords: AR-HUD, color visibility, luminance contrast, driving information, cognition efficiency

1 Introduction

According to data released by the Ministry of Public Security of China in 2016, the main cause of traffic accidents is the driver's inattention and distraction while driving[1], bringing about a large number of traffic crashes and vehicle collisions[2]. With the increasing use of smartphones, central control displays and navigation systems, the severity of distraction is further deepened[3]. Mimura[4] found that if the driver 's sight deviates more than 2 seconds from the driveway, the threat of traffic accidents increases. In order to acquire suitable driving assistance, the driver perceives driving information through various internal and external displays. Particularly, 80% of information is visually perceived[5, 6]. However, since the driver's FOV (field of view) is

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downward, the forward gaze rate has greatly been reduced. The driver ' s visual distraction is due to lack of attention to the front FOV, visual distraction refers to the driver ' s head and eye out of the front FOV.

Therefore, providing necessary information during driving with maintaining driver's FOV on the road, can be an effective way to decrease the threat of traffic accidents[7]. Much of the information needed by the driver relies on the display screen. In recent years, first-tier automobile enterprises have begun to implement AR-HUD (Augmented Reality Head-Up Display), i.e. A "virtual display" that the driver can watch with his head up, projecting real-time driving information, such as speed, navigation and warning signals et al. The driver can obtain driving information while looking ahead, which could reduce the risk of traffic accidents that may occur due to the driver's visual distraction[8]. The optical breakthrough of AR-HUD provides a more natural image processing method. This technology has also become the main development trend of automobile human-machine interface (HMI)[9]. Using the whole windshield as the display medium, the display image and other information are fused with the real environment[10]. The AR-HUD system is a device that can not only reduce the driver ' s cognitive load, but also reduce the danger of accidents caused by line-of-sight deviation[11]. AR-HUD is developed to overcome the visual restrictions required in the aviation field[12]. AR graphics can increase drivers' forward situational awareness and cognition while minimizing distraction[13-15]. It helps to assure the visual clearness and prevent the occurrence of hazardous situations in a few seconds when the driver observes the dashboard[16].

However, there is still much work needed to better understand how AR interface design affects user's perception of AR interface elements. In terms of color, under ordinary circumstances, the greater the difference in color, luminance, and chromaticity between the background color, character, icons and other information objects, the higher the visibility. In addition, visibility varies from light intensity. i.e. In strong light, white objects on a black background are most evident, and in weak light, black objects on a white background are the clearest[17].

At present, due to the different sizes of AR-HUD system FOV installed by automobile manufacturers, the colors used are different as well, the research on the colors relevant to AR-HUD has not yet reached the results. AR-HUD is optically projected to the front of the windshield of the vehicle, so it will be affected by external light such as sunlight and artificial lighting when recognizing driving information. When driving, the driver's FOV is focused on the road, so the road color may become its background color. In fact, the color of the road is almost the same, but it may look different according to the external light intensity. Therefore, from the macroscopic point of view, it is necessary to divide the experiment into two parts: daytime and night. In this paper, we present an experiment approach to assess color visibility, and the evaluation scale was used as an important indicator for statistical analysis.

2 Method

In this study, the sample vehicle equipped with an AR-HUD system was used as carrier to execute an experimental study on the color visibility evaluation of AR-HUD driving information. In the experiment, we evaluated the visibility, fatigue, preference and visual intrusion of color by issuing questionnaires. Rebhan et al.[18] believed that more than 90% of driving-related information was gathered through visual activities. Therefore, this study used stimuli obtained through visual activities, in which stimuli for visual information other than color were excluded, and the color-centric study was conducted.

The augmented reality information projected in the experiment is the most core and most concerned information during driving—speed[19]. According to the changes of the driving environment, whether the recognition of the driving information projected by AR-HUD will be affected by the color is explored through experiments.

2.1 Environment

Vehicle environment

This experiment uses a smart car prototype, which is equipped with an AR-HUD system, and its FOV is 12˚ × 5˚. As shown in Figure 1, the driving road environment is simulated through a large curved projection screen, which maximizes the realization of a vehicle simulation environment similar to the driving environment.

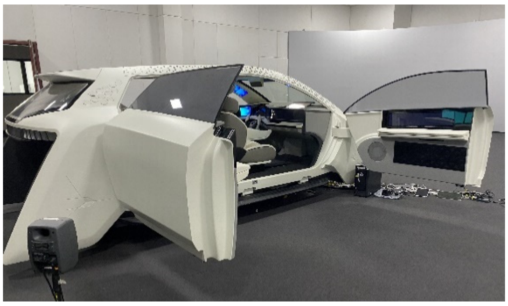


Figure 1. Vehicle simulation environment.

Luminance environment

In order to carry out the experiments, it is first stated that the ambient illumination has a great influence on the luminance of the driving information. Choi [20] assessed the most important basic variables—luminance and chromaticity for analyzing the visibility of LED road electro-optical signage systems. In this study, since luminance is affected by ambient illumination, considering the illuminance conditions for each time period, basically it is necessary to proceed with low character luminance at night and high character luminance during daytime so that the driver does not feel uncomfortable in reading driving information. Table 1 shows the road illuminance standard endorsed by the China Illuminating Engineering Society (CIES), which is the illuminance standard currently applied in China[21]. We choose the main road as the driving area, and 30lx as the illumination standard for the night driving environment.

Table 1. Standard value of motor vehicle lane illuminance(nigh).

Road type	Area	Average illuminance(lx)
Fast road, main road	Downtown, commercial area	20~30
Secondary trunk road	Cargo area	15~20
Branch road	Residential area	8~10

Table 2. illumination simulated in a laboratory environment.

Experimental Environment	Illuminance(lx)	Simulation conditions
Daytime	100,000	Turn on all the lights (converging lights and ceiling lightings), turn up the screen luminance.
Night	30	Turn off all the lights, only screen video.

Table 2 shows the illumination simulated in a real road environment in a laboratory environment, and Figure 2 shows the simulated daytime driving environment (left) and night driving environment (right). Turn off all the lights in the laboratory, only output images of night driving from the projection screen, and replicate the night driving with an ambient illumination of 30lx. When all the fluorescent lamps in the laboratory are turned on, and in this state, the image of the daytime driving is output through the projector, and the bright sunlight during the day (midday) can be reproduced.

Figure 2. Laboratory simulated driving conditions: daytime(left) and night(right).

2.2 Experiment materials

Variables

The colors of the driving information were selected from a total of 7 colors: Red, Orange (YR), Yellow, Green, Blue, Purple, White (hereinafter referred to as R, YR, Y, G, B, P, W). In addition to the basic 5 colors R, Y, G, B, P in the Munsell Color System[22], YR and W were also used as the colors of traffic lights.

As shown in Table 3, the measurement of luminance and color value of driving information for each color was performed using a spectrophotometer. Since the luminance is affected by the ambient illuminance, the environmental illuminance during daytime driving and the ambient illuminance during night driving were measured separately.

Table 3. Luminance value of each color of driving information.

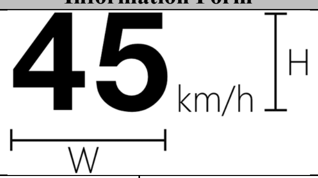
Driving information	Lv (cd/m²), x, y					
	Daytime(100000lx)			Night(30lx)		
	Lv	x	y	Lv	x	y
None (Environment)	92.66	-	-	15.8	-	-
R	98.71	0.271	0.28	16.92	0.366	0.314
YR	106.1	0.275	0.289	19.23	0.365	0.336
Y	115.3	0.275	0.301	34.38	0.35	0.407
G	110.4	0.264	0.299	31.21	0.298	0.422
B	96.35	0.256	0.273	13.95	0.251	0.261
P	91.89	0.259	0.277	14.06	0.256	0.263
White	117.2	0.27	0.294	34.85	0.317	0.359
Grey	95.35	-	-	16.23	-	-

Stimuli

Kim[17]conducted a questionnaire survey on 100 drivers who use the most instrument types in the instrument panel. The results of the questionnaire survey showed that 82% of the respondents believed that they looked at the speedometer most often. Referring to this result, this study recommended speed information as the driving information, taking 45km/h out of the speed limit of 30km/h~60km/h on the city's general arterial roads as the information form, and its color visibility, fatigue, preference, visual reference was assessed.

Table 4. Form of experimental driving information.

Information Form



Font Size	W: 242mm	H: 142mm
Font Style	Helvetica	
Character Outline ratio	20%	

As shown in Table 4, the font of driving information is based on the purpose of concentrating on color evaluation, and the Helvetica font with large area and good readability was used. To avoid other design elements from intrusion with the experiments, only character and navigation assistance closely associated to the driving task were presented in the AR-HUD interface. Since the speed information is the driver's highest concern and is usually placed in a prominent position, the font size was 242mm in width and 142mm in height, the vertical FOV is 10°, and the horizontal FOV is 17°. The outline of the character of the driving information accounts for 20% of the entire character.

In the experiments, a vehicle simulation environment similar to the driving environment was constructed to the maximal extent, and the driving information used as the experimental stimuli had 7 monochrome characters (R, YR, Y, G, B, P, W) and among the 7 monochromatic characters, 6 characters except W have white outline and grey outline respectively. Twelve characters with outlines were made. All experiment materials are shown in Figure 3.

Figure 3. Experimental Visual Stimulus Materials.

2.3 Procedures

A total of 25 drivers were recruited in the experiment. Participants were aged between 20~40(Mean=28.4, SD=4.33), with at least two years of driving experience. They are all automotive company R&D staff who had the experience of using AR-HUD. All subjects had normal visual acuity and no achromatopsia. They were informed to do ocular gymnastic before the experiment.

In the formal experiment, the subjects need to sit in the driver's seat and adjust the seat to make it conform to their own driving habits, and then verbally inform the experimenter that they are ready. The simulated driving program in the experiment was controlled by the SCANeR automatically, i.e. the subjects did not need to operate the steering wheel, and only needed to evaluate the color visibility, visual fatigue, color preference and visual disturbance of each stimulus material in the simulated driving environment during the daytime and night. The upper limit of the presentation time of each stimulus is 10 seconds, and the driving will automatically stop at that time. The subjects are required to observe the stimulus carefully within 10 seconds, and evaluate each question on a 5-point Likert scale (very poor-poor-average-good-very good), and Table 5 shows the list of questionnaires for each evaluation item. After the evaluation, the experimenter was told to continue the experiment and presented the next stimulus at the same time until all stimuli were evaluated. The overall experimental process for each subject was about 15 minutes.

Table 5. Evaluation Project Questionnaire Checklist.

Driving information	Evaluation items	Question list
Each color (R, YR, Y, G, B, P, W)	visibility	Can you read character clearly?
	fatigue	Are your eyes fatigued?
	preference	Do you like this color?
AR-HUD	Driver distraction	Does character obstruct vision?

If the simulated driving experiment in the daytime is carried out first, due to the large ambient illumination demanded during the day, the laboratory lights are too bright, which may leave a residual image in FOV, affecting subsequent experiments. In order to rule out this problem, the experiment was firstly carried out under the illumination environment of driving at night, and then the experiment was carried out under the illumination environment of daytime driving. The subjects proceeded the dark adaptation and then performed the night driving experiment. Figure 4 shows the experimental state under the night driving illumination environment. Figure 5 shows the experimental images in the illumination environment during daytime driving.

Figure 4. Night driving simulation.

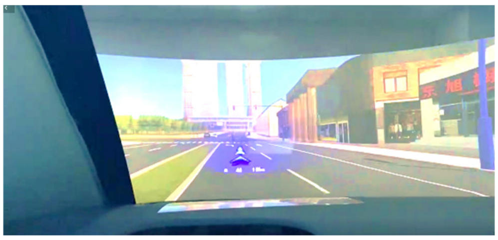


Figure 5. Daytime driving simulation.

3 RESULT

In order to evaluate the visibility of AR-HUD driving information perceived by drivers in simulated driving environment, the color of information (R, YR, Y, G, B, P) was selected as the visibility evaluation factor. As an analysis method, each color, the luminance with or without outline were paired to determine whether the visibility difference between the two variables is statistically significant, the confidence interval is set at 95%.

3.1 Outline of character

Fig. 6 and Fig. 7 show the visibility evaluation results of whether the character has an outline in the daytime and night driving environment. (e.g. R means no outline, R1 means with white outline, and R2 means with grey outline)

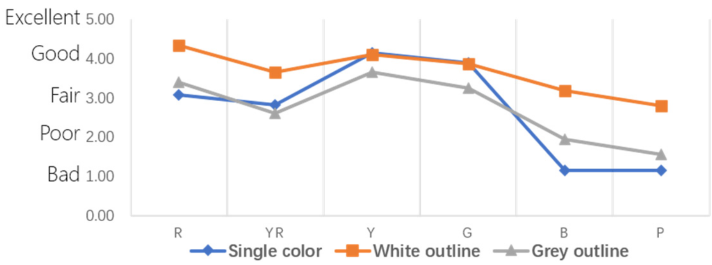


Figure 6. Color Visibility (daytime).

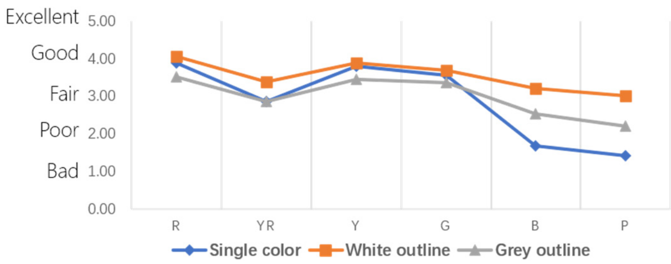


Figure 7. Color Visibility (night).

In daytime mode, the visibility of white outline is higher than that of grey outline in stimuli other than Y (R2 < R1, YR2 < YR1, G2 < G1, B2 < B1, P2 < P1). The average visibility of night mode shows that the visibility of white outline is the highest among all colors.

As shown in Table 6 and Table 7, the corresponding sample t-tests of the three visibility of the color of the driving information were carried out, including the non-outlined (R, YR, Y, G, B, P), the white outline (R1, YR1, Y1, G1, B1, P1), and the grey outline (R2, YR2, G2, B2, P2).

Table 6 Visibility assessment for character outline (daytime)

Stimuli	Visibility	Matching	p-Value	Result
R	3.08	R-R1	.000	R<R1
R1	**4.35**	R1-R2	.000	**R2<R1**
R2	3.39	R2-R	.215	
YR	2.83	YR-YR1	.000	YR<YR1
YR1	**3.65**	YR1-YR2	.000	**YR2<YR1**
YR2	2.60	YR2-YR	.341	
Y	**4.15**	Y-Y1	.857	

Y1	4.10	Y1-Y2	.067	
Y2	3.65	Y2-Y	.102	
G	**3.90**	G-G1	.802	
G1	3.86	G1-G2	.002	**G2<G1**
G2	3.25	G2-G	.001	G2<G
B	1.15	B-B1	.000	B<B1
B1	**3.18**	B1-B2	.000	**B2<B1**
B2	1.95	B2-B	.002	B<B2
P	1.15	P-P1	.000	P<P1
P1	**2.80**	P1-P2	.000	**P2<P1**
P2	1.55	P2-P	.088	

Table 7: Visibility assessment for character outline (night)

Stimuli	Visibility	Matching	p-Value	Result
R	3.89	R-R1	.045	
R1	**4.05**	R1-R2	.012	**R2<R1**
R2	3.51	R2-R	.095	
YR	2.85	YR-YR1	.034	YR<YR1
YR1	**3.37**	YR1-YR2	.045	**YR2<YR1**
YR2	2.85	YR2-YR	1.000	
Y	3.80	Y-Y1	.647	Y<Y1
Y1	**3.89**	Y1-Y2	.045	**Y2<Y1**
Y2	3.45	Y2-Y	.047	
G	3.55	G-G1	.600	
G1	**3.68**	G1-G2	.148	
G2	3.36	G2-G	.284	
B	1.68	B-B1	.000	B<B1
B1	**3.20**	B1-B2	.003	**B2<B1**
B2	2.53	B2-B	.001	B<B2
P	1.40	P-P1	.000	P<P1
P1	**3.00**	P1-P2	.001	**P2<P1**
P2	2.20	P2-P	.006	P<P2

In daytime mode, the visibility of white outline was higher than that of grey outline in stimuli other than Y (R2 < R1, YR2 < YR1, G2 < G1, B2 < B1, P2 < P1). In the night mode, the visibility of white outline was higher than that of grey outline under other color stimuli except G (R2 < R1, YR2 < YR1, Y2 < Y1, B2 < B1, P2 < P1). Wang[24] pointed out that luminance contrast has a greater impact on readability in color contrast and luminance contrast, so it can be ascribed to the luminance contrast between high luminance white outline and non-outline character.

Therefore, due to the comparatively low color luminance (R, YR, B, P) and the luminance contrast between the white outline is larger, it can be seen that the visibility of driving information with white outline is higher than that of grey outline. Lin[25] conducted a visual performance test of the difference between the luminance of each color of character and the luminance of a grey background. The study found that the greater the contrast between the background and the character, the better the visual performance. Under a certain contrast circumstance, the color of the character has no significant effect on the visual performance.

When the stimulus material used in this experiment was projected on the windshield, the outlines of the character acted as the background. Therefore, as shown in Fig. 8 and Fig. 9, since the contrast between the luminance of the character color and the luminance of the outline is greater in the case of the white outline, the visibility of the driving information of the white outline is deemed to be higher than that of the grey outline. (e.g. the Ratio of R1=Lv(White)/Lv(R), the Ratio of R2=Lv(Grey)/Lv(R))

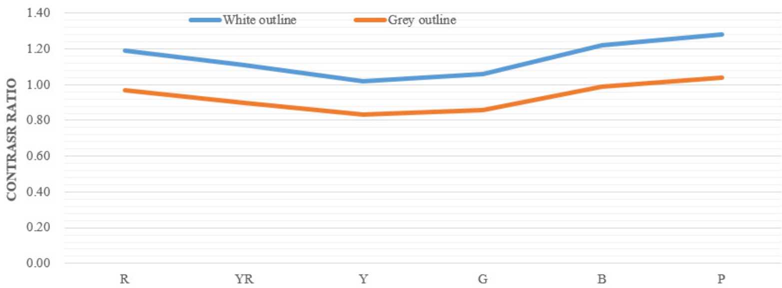


Figure 8: Contrast Ratio for Outline-Character color (daytime)

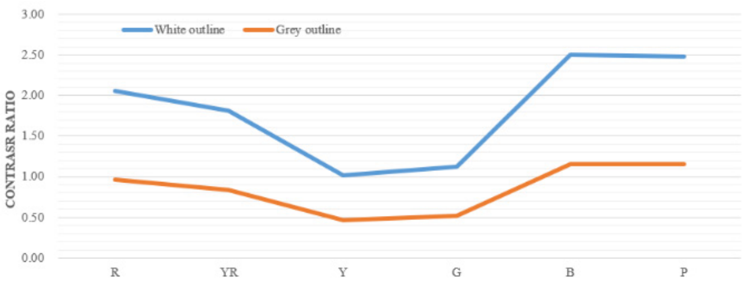


Figure 9: Contrast Ratio for Outline-Character color (night)

In the daytime mode, the luminance of the white outline (117.2) and the luminance of the Y character (115.3) were not significantly different, and the t-test of the corresponding samples showed that the difference in the visibility of Y and Y1 is not significant. This may be because, as with simultaneous contrast, human visual perception is more sensitive to the contrast of light intensity than to the intensity of pure light[26]. Due to the low luminance contrast of Y1 with white outline, it can be seen that subjects did not detect a significant difference in visibility between Y and Y1.

In addition, the luminance of B (96.35) and P (91.89) is significantly lower than that of other colors, and the visibility evaluation results of character information (B1, B2, P1, P2) with white and grey outlines were different from those without outlines. The visibility evaluation results of (B, P) were significantly different, which can also be seen as the effect of luminance contrast.

3.2 Color visibility of character

Test whether the difference in visibility of different colors without outline character information on AR-HUD is statistically significant, as shown in Table 8 and Table 9, during the daytime Y, G>R, YR>B=P, R, Y, G > YR > B, visibility was found to be significant in order of *p*-Value.

Table 8: Color visibility assessment (daytime)

Color	Y	G	R	YR	B	P	
Visibility	4.12	3.92	3.08	2.84	1.16	1.16	Y, G > R, YR > B=P
Significant	Y						
		G					
			R				R > B, P
				YR			YR > B, P
					B		
						P	

Table 9: Color visibility assessment (night)

Color	R	Y	G	YR	B	P	
Visibility	3.88	3.80	3.56	2.84	1.68	1.40	R, Y, G > R, YR > B, P
Significant	R						R > YR, B, P
		Y					Y > YR, B, P
			G				G > YR, B, P
				YR			R, Y, G > YR > B, P
					B		R, Y, G > YR > B, P
						P	

Reviewing prior studies on visibility in VDTs (Visual Display Terminals) environments, it was found that differences in color visibility were attributed to the differences in luminance between the attributes of the colors themselves[27]. Therefore, the reason for the high visibility of the Y and G during the day can be recognized as the high luminance of the color itself.

In night mode, as shown in Figure 10, the luminance of R (16.92) was at 4th place behind Y (34.38), G (31.21), and YR (19.23), but R has the highest average score for color visibility. Statistically, Y and G were evaluated at the same level. This is thought to be due to the luminance of the windshield with no driving information displayed, i.e. The luminance contrasts between the background and color itself.

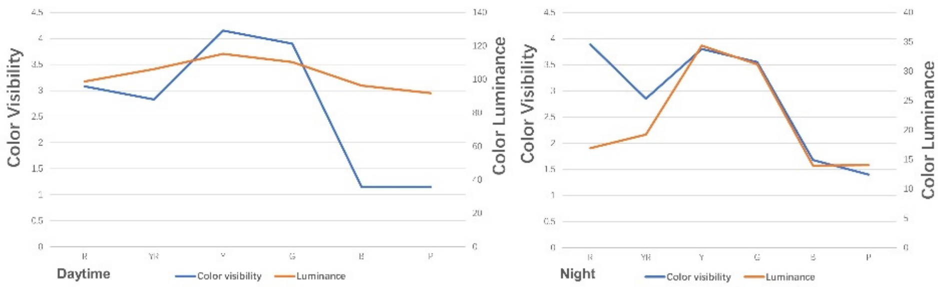


Figure 10: Contrast Ratio for Outline-Character color (night)

Figure 11 showed the luminance contrast of the background and color in daytime and night mode. At night, the luminance contrast between the background and R is relatively higher than the luminance contrast between the background and Y and G. As a consequence, the higher luminance resulting in higher visibility. Although the luminance of color itself affects the visibility of AR-HUD driving information, it can be seen that the luminance contrast with the background also acts as an important factor.

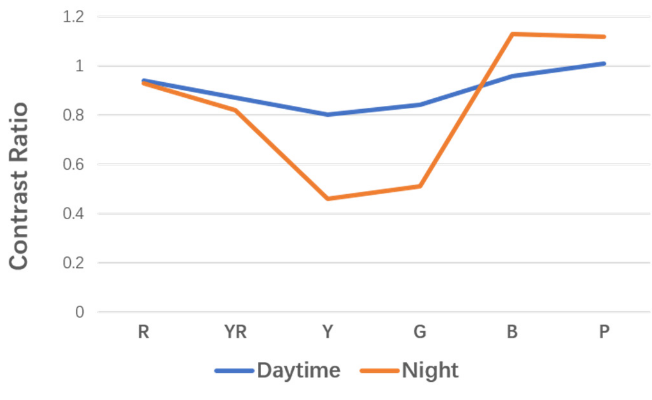


Figure 11: Contrast ratio of Background character color

3.3 Discussion

Through the simulation of daytime and night driving in this study, the experimental results showed that in the color visibility evaluation of the AR-HUD interface, the color luminance of characters and outlines have a significant impact on the visibility. The experimental data showed that when the color is B or P, the visibility is the lowest, so it should be avoided when designing the vehicle AR-HUD interface, so as not to reduce the driver's cognitive efficiency.

By analyzing the luminance of different colors of characters and outlines, it can be seen that the white outline has a significant impact on the visibility, and the grey outline has no significant impact on the visibility. Luminance contrast also affects visibility, indicating that luminance and luminance contrast are very important design factors when designing augmented reality interface colors such as AR-HUD. Suitable luminance and luminance contrast can effectively increase the driver's cognitive efficiency. Reduce visual fatigue and improve the interface performance of in-vehicle systems.

This study only explored the luminance and outline of speed characters, and did not further analyze the elements of color (hue, color value, chromaticity). When more necessary information is presented in the AR-HUD interface, further research is required to determine whether the color, luminance and contrast of each information is appropriate. In addition, another limitation of this paper is that the study was conducted in a laboratory, not a real driving environment, and the psychological impact of road accidents was ignored in the experiment. The conclusions can be used as a reference for the color design of vehicle AR-HUD interface characters.

4 Conclusion

(1) In daytime mode, when the luminance of color itself is high, the visibility is high accordingly. In night mode, R was found to have higher visibility than Y and G (both have high luminance). This was because visibility is enhanced by the luminance contrast from the background rather than the luminance of the character itself. B or P (low visibility) should be avoided in design process.

(2) With an outline, the outline acts as a background color to provide luminance contrast with the character, thus affecting visibility. The visibility of characters with white outlines is greater than that of gray outlines, and it is also greater than that of non-outlined characters (except for daytime Y), so white outer outlines should be considered in the design to improve visibility.

(3) Without outline, the luminance of the vehicle windshield as the that of the background color, when the luminance contrast of the character is huge, the visibility is high. The main factor that affects visibility when there is no outline is the luminance of the color, but the luminance contrast between the background and the color can also affect visibility.

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