Interface Color Design of Intelligent Vehicle Central Console

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Abstract. The development of intelligent automobiles puts forward higher requirements for HMI design. The information obtained by drivers through vision accounts for 80%. As a key part of visual perception, color affects driving performance. This article investigates vehicle interface design about icon-background contrast. Three colors commonly used in car-machine interface are chosen: red, green and blue, and contrast is divided into five levels under daytime and nighttime. The participants tested three colors and the five contrasts in an experiment using classic paradigm of secondary tasks. We collected data from their driving behavior and subjective experience, trying to find a most appropriate value. The results show that recommended contrast values under different lighting conditions are 3:1 to 4:1 for red, blue, and green during the day; 3:1 for red at night, and 5:1 for blue and green, so that the vehicle central console color design references are formed

Keywords: Car-machine interface design · Color contrast · Console

1 Introduction

With the increasing development of cloud platforms and 5G technology, smart cars are becoming an important direction for the world's future automobile industry. With its convenience, human-machine interface turns to be the main interactive means for users. Vehicle-machine interface contains many elements such as text, icons, colors, etc. According to brain's visual processing hierarchy rules [1], the user's ability to perceive color information is higher than other elements. Reasonable use of color can not only effectively assist other visual elements in vehicle-machine interface, but can also correctly guide the triggering and judgment of users' behavior, improve accuracy and driving safety, and reduce users' cognitive burden [2].

Three key attributes of color are hue, chroma (saturation), and value (lightness) [3]. Yeh and Wickens [4] believe that in map interface, the combination of hue and saturation is more conducive to isolate view. Lavie et al. [5] concluded that reducing the number of colors is beneficial to obtain optimal comfort. Cui and Yang [6] believe that reasonable color application will give people a sense of security and comfort. Since hue

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is the best way for human eyes to distinguish colors, most research has been focusing on hue of interface colors, and little attention has been paid to brightness and saturation. Additionally, the research is mostly been conducted in a qualitative way.

The aim of this study is to explore the impact of different contrasts on users' judgment of information accuracy based on color brightness. To address these research aims, we will follow these research questions.

- RQ1: Under different lighting conditions (diffuse reflection during the day, night), how does contrast value of different hues on vehicle-machine interface affect driving performance and vehicle control?
- RQ2: When designing vehicle-machine interface, how to choose the foreground and background color contrasts to achieve the best recognition?

Our contributions include the following three aspects. First, we verified that the recommended contrast value of vehicle-machine interface under different lighting conditions complies with ISO-15008. Second, we analyzed the subjective and objective data, concluded that different contrasts had different effects on drivers' color perception usability. Finally, we extended the recommended range of color contrasts to vehicle interface design. Therefore, a forward-looking reference value in human-computer interaction is achieved.

2 Experimental Design

2.1 Preliminary Preparations

In the early stage, vehicle interface of 22 models including Mercedes-Benz A200L were sorted out through network resources and 4S shop visiting. Based on theme colors, we found that the main colors are concentrated in blue, green and red, so the three colors were chosen as experimental objects. We then selected 5 models with better assessments and extracted the RGB values of the above three colors and backgrounds. Then adjustments were made using online tools WebAIM's Color Contrast Checker to derive experimental materials with different contrasts. We found that hue will be more diverse when applied to icons. Considering the influence of different color contrasts on driving performance, we applied foreground colors to icons.

According to ISO-15008, the minimum color contrast value is 3:1 under daytime diffuse lighting conditions and 5:1 at night [7]. Therefore, this experiment selected 2 contrasts that were different in front and rear ranges, the day color contrast was divided into 1.5:1, 2:1, 3:1, 4:1, 5:1, and 1.5:1, 3:1, 5:1, 7:1, 9:1 for night (Fig. 1).

Our main indicator of interest was the impact of brightness contrast on driving. So we used WestboroPhotonics WP6120E colorimetric brightness meter to test different areas of background and concluded that excluding the influence of environmental illuminance, different contrast between foreground and background colors had no difference under different screen brightness.

We decided to display important information in the field with a horizontal comfortable head movement angle and a vertical maximum eye movement angle of 15 to 45° [8]. Considering average human body size [8], circle with a distance of 10–40 cm

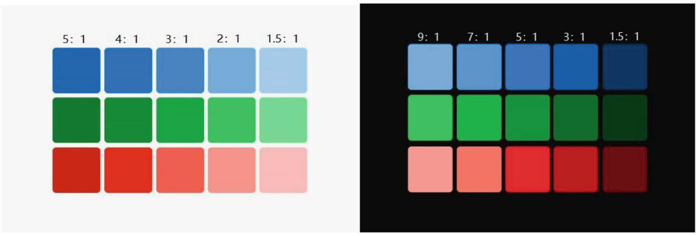

Fig. 1. Schematic diagram of color contrast selection-day (left), night (right)

from the shoulder point plane covers convenient area of most drivers' right-hand operation, so icons with different contrasts and different colors are distributed in this area.

Color has an influence on perception [9]. Surface colors can be diverse in different context [10], cognition and culture. According to our research on the interface of 22 vehicles, all colors corresponded to the following semantics: blue represented common color of vehicle interface, green represented a good state, and red meant alert. The images below are examples of experimental elements during day and night (Fig. 2).

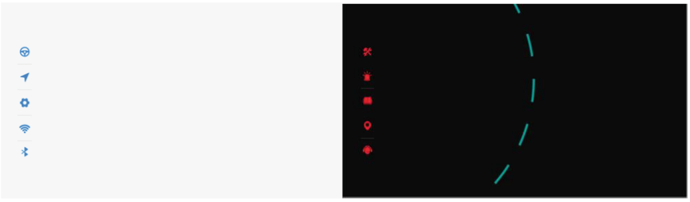

Fig. 2. Examples of color experiment elements-day (left), night (right)

2.2 Simulator Settings

Simulating the real driving environment, drivers can get a safer immersive experience [11]. The experiment was carried out on a car driving simulator. The simulator used in this experiment includes a seat, a steering wheel, a brake, an accelerator, and three screens with a resolution of 7680 * 1440 and a virtual road environment.

The light condition setting refers to SAE J1757/1: 2007 specification. We applied daytime conditions in diffuse ambient light using Fleisch LED lights. The ambient light measured on the display surface is 5klx $\pm$ 5%. We also applied the nighttime conditions in dark environment, which means the maximum illuminance of the measured object does not exceed 10lx with relative tolerance 5% [7] (Fig. 3).

Fig. 3. Overall view of the simulator-daytime lighting (left), nighttime lighting (right)

2.3 Driving Scene Settings

To distinguish specific phenomenon caused by secondary tasks from driving tasks, specific driving scenarios need to be set in driving simulator [8]. In order to verify the effectiveness of driving scenarios, we interviewed six professional test drivers. After evaluation by them, it was determined that the operation would be carried out only under safe road conditions such as low flow, and will not be used in non-safe conditions such as curves. Therefore, in the experiment, the road scene was set to a straight urban road, and the traffic flow was 2–3 vehicles/minute.

3 Experiment Execution

The experiment is composed of 30 similar tasks. The first 15 tasks are performed under daytime lighting conditions, and the latter are performed under nighttime lighting conditions. The task is to travel stable and straight on urban road at a speed of 30 km/h, and complete the identification and click operation of icons with different color contrasts. 31 subjects participated in the study (age M = 33.4, SD = 5.277) (Fig. 4).

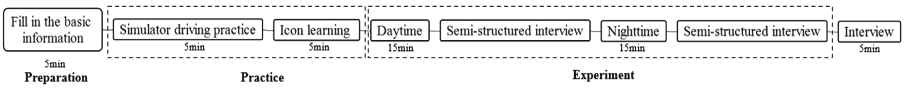

Fig. 4. Experimental process

4 Experimental Results

4.1 Data Collection

We used multi-directional method [12], and collected both subjective and objective data. The former includes workload and usability indicators (clarity, comfort, satisfaction); the latter includes task response time and vehicle speed standard deviation. We adopted a synthetic analysis method to obtain the appropriate recommended value of icon-background contrast under specific lighting conditions.

According to task completion quality and box diagram, the extreme outliers were eliminated. Since the data analyzed in SPSS did not satisfy the normal distribution, we used the Spearman coefficient to reflect the correlation between color contrast and subjective data. After examination, we found there was a strong correlation between color contrast and subjective data under daylight and night light conditions (Table 1).

Table 1. Spearman correlation coefficient-color contrast and subjective data

		Clarity	Comfort	Satisfaction	Usability	Workload
Day time	Mixed	.406**	.353**	.386**	.402**	–.274**
	Red	.516**	.431**	.490**	.508**	–.320**
	Blue	.511**	.475**	.473**	.502**	–.360**
	Green	.183*	.158*	.207**	.195*	–.145
Night time	Mixed	.273**	.270**	.261**	.275**	–.186**
	Red	.210**	.205**	.184**	.208**	–.118*
	Blue	.270**	.272**	.260**	.276**	–.189**
	Green	.259**	.278**	.270**	.290**	–.194**

4.2 Subjective Data

Subjective data includes usability and workload. Usability evaluation obtained data through scoring of clarity, comfort, and satisfaction. We used Likert's 7-level scale, 1–7 points represent gradually increasing usability. Workload is a multi-dimensional concept including mental strength, attention, physical burden, time pressure and frustration required to complete the current task [13]. Participants scored based on the workload needed to effectively maintain safe driving while browsing the screen. The score range is 0–10 points, the higher the score is, the greater the workload is.

When the subjective evaluation was inconsistent with the driver's behavior, a semi-structured interview would perform to ensure that the data was accurate. Based on subjective data, the results obtained are as follows (Fig. 5).

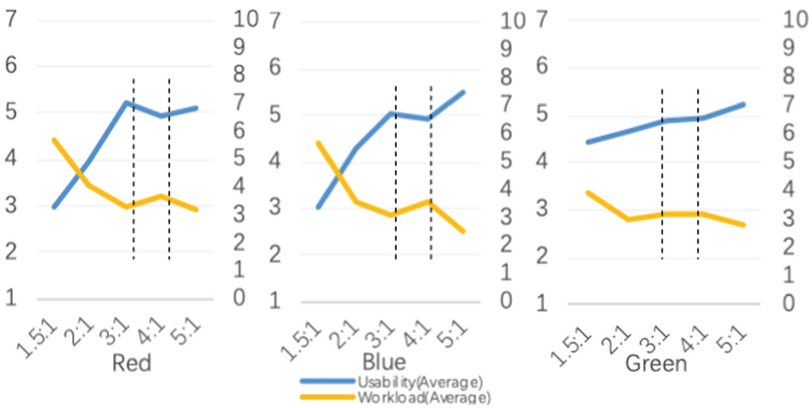

Fig. 5. Color contrast-usability, workload (daylight)

During daylight conditions, when hue is not separated, the change trend of subjective evaluation tends to be gentle with contrast changing from 3:1 to 4:1. When consider daytime color contrast of vehicle-machine interface, 3:1 and 4:1 can be chosen for debugging. This conclusion also applies to red, green, and blue. Under the circumstance that the RGB value of background color of central control screen is (245, 245, 245), the contrast of different hue of the icons and their corresponding RGB values are shown in the following Table 2 (Fig. 6).

Table 2. Recommended color contrast and corresponding RGB value during the day

Hue	Contrast ratio	R	G	B
Red	3:1	239	94	78
Red	4:1	233	43	22
Blue	3:1	5	143	255
Blue	4:1	0	121	219
Green	3:1	30	164	68
Green	4:1	25	138	55

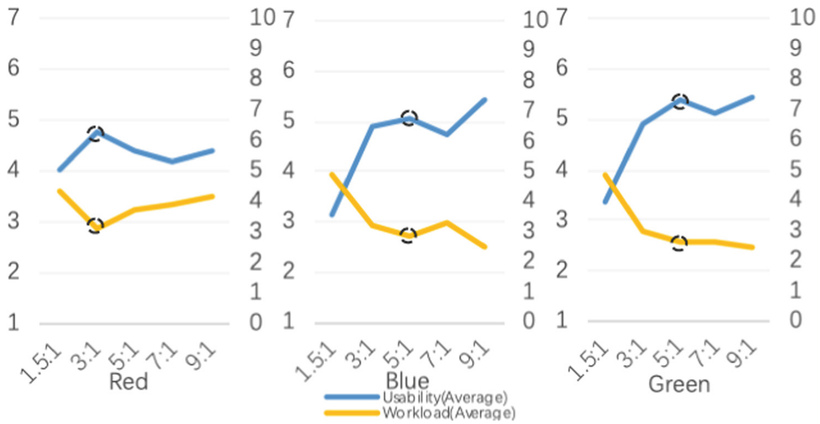

Fig. 6. Color contrast-usability, workload (nightlight)

Under night light conditions, when hue is not separated, the subjective evaluation tends to be flat between 3:1 to 7:1. Since they are both inflection points, while considering color contrast of car-machine interface at night, 5:1 is recommended, which can be debugged higher than 3:1. Further conclusion is that red is recommended to be debugged at a 3:1 at night, and 5:1 for blue and green. When RGB value of the background color of central control screen is (10, 10, 10), the contrast of different hue of the icons and their corresponding RGB values are shown in the following Table 3.

Table 3. Recommended color contrast and corresponding RGB value at night

Hue	Contrast ratio	R	G	B
Red	3:1	189	0	22
Blue	5:1	5	128	240
Green	5:1	27	147	61

4.3 Objective Data

Objective data includes task response time and vehicle speed standard deviation. Task response time can reflect how quickly the drivers distinguish different color contrasts during driving. Because the task requires the drivers to maintain a stable speed of about 30 km/h, the standard deviation of the vehicle speed is used as a metric for safe and attentive driving and the stability of driving control (Fig. 7).

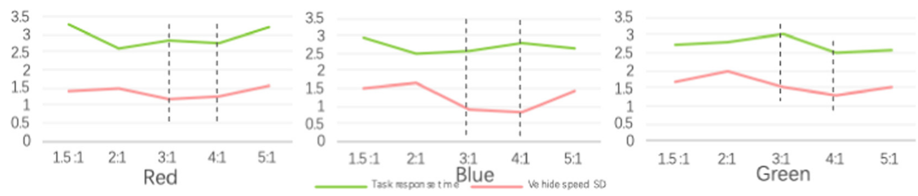

Fig. 7. Color contrast-task response time, speed SD (daylight)

Under daylight conditions, when contrast ratio is between 3:1 to 4:1, the change trend of vehicle speed standard deviation is relatively gentle. At this time, participants' control of the vehicle is stable and task response time is relatively short. Combined with subjective and objective data, when considering color design of vehicle interface in daytime, the contrast value between 3:1 and 4:1 should be selected (Fig. 8).

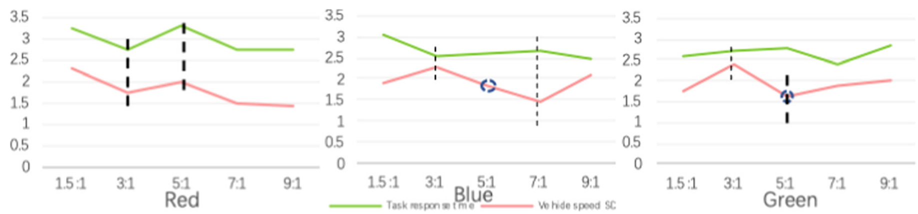

Fig. 8. Color contrast-task response time, speed SD (nightlight)

Under night light conditions, when the contrast of red is in the range of 3:1 to 5:1, task response time and speed standard deviation are on the rise. After the contrast is higher than 5:1, the objective data showed a downward trend; under comprehensive consideration, designers should choose 3:1 for red at night. As for blue, 3:1 and 7:1 are the turning points of data changes. When combining the subjective and objective data, we found that 5:1 is the appropriate contrast value for blue at night. When the contrast ratio of green is higher than 5:1, the standard deviation of vehicle speed tends to be flat, so green is recommended to debug at 5:1 at nighttime.

5 Discussion

The result from our study verifies the most recommended contrast value for vehicle interface design under different lighting conditions mentioned in ISO 15008, and furthermore extends this finding to include the three most widely used hue of vehicle interface: red, blue, green. Through reasonable analysis of subjective and objective data, the results obtained from the experiment can be extended to applications related to the car's central control screen. Blue is a common color. It can be used for setting, navigation, steering wheel, bluetooth, wireless network and others, indicating turing on or normal status display. Green indicates that the vehicle accessories are in good condition and can be used for icon colors such as telephone, voice, music, car lock, etc. Red indicates warning and reminders. It can be used for abnormal conditions such as alarm and tire pressure.

When choosing colors of the vehicle's central control screen design, all of hue in visible wavelength range can take the following steps: first determine the RGB value of the foreground / background color; then use online tools such as WebAIM's Color Contrast Cheker to enter the foreground and background color number, check whether the color contrast meets the experimental conclusion; finally, according to visual characteristics and functional requirements, the designer can use red to represent warning, blue as common color of the vehicle interface, and green to indicate turing on. Designers can choose color contrasts of vehicle-machine interface with reference to the recommended values. (During daytime, the contrasts of red, blue and green are all 3:1 to 4:1; during nighttime, 3:1 for red and 5:1 for blue and green).

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