Evaluation of a New Cockpit Color Concept under Mesopic Lighting for Urban Driving

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Abstract. This paper compares two different cockpit color concepts in mid-range cars under mesopic lighting. The analysis tries to confirm that new concepts with white illumination are no worse than the red concepts presently in use. Thirty participants took part in two experiments to determine whether they yielded the same results in terms of interpretability, readability, and differentiability of information. A modified PSSUQ was used to evaluate those factors. The subjective results show that there is no meaningful difference between a white and red color cockpit concept.

Keywords: Illumination, cockpit, color, readability, differentiability, mesopic, scotopic, vision, urban, driving, car, occlusion, PSSUQ, night-time, subjective.

1 Introduction

The first color concepts for car cockpits to be used for night-time driving were adapted from sea or underground vehicles, such as submarines. Typically, when operating a subaqueous vehicle, one is not exposed to exterior lighting or moonlight and therefore visual adaptation remains in the scotopic range [1]. The color chosen for those concepts was red since the Purkinje effect (dark adaptation) applies. At low illumination levels, the sensitivity of the human eye shifts toward the blue end of the color spectrum (figure 1). If the eye perceives only red light, then the rods of the eye do not become saturated and stay adjusted to the dark because they are not sensitive to long-wavelength red light.

Ordinarily, vision at night is classified as scotopic. However, when a subject is driving in an urban setting at night or twilight, the lighting level is described as mesopic. This is primarily because of the many signals, signs, other vehicles and street lamps found in urban areas that serve as additional light sources [3, 4]. In addition to these extra external sources of light, many new human-machine interaction concepts, such as navigation and entertainment systems, also contribute internally to the overall lighting. Since it is now known that urban driving does not operate under scotopic vision, this knowledge opens up the possibility of a new color concept. In this study, red and white display concepts were compared under mesopic vision conditions.

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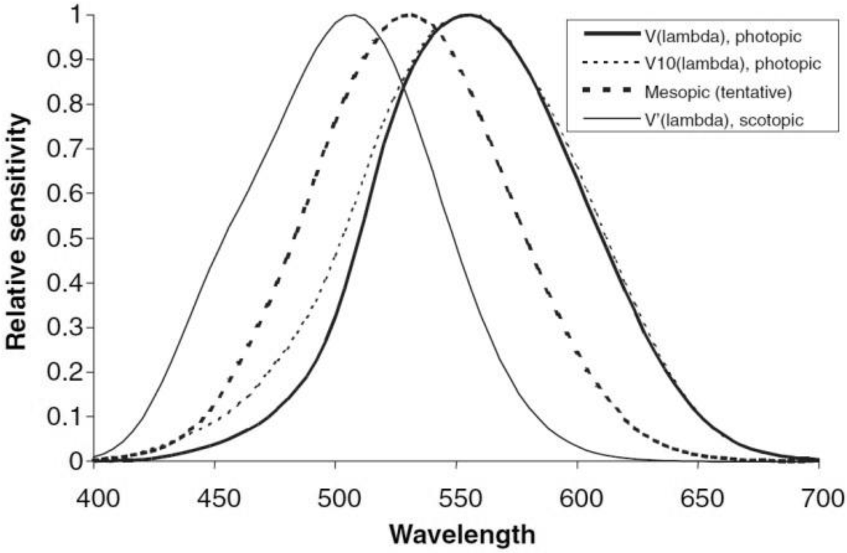

Fig. 1. The CIE spectral luminous efficiency functions for photopic vision, V(k) and V10(k), and scotopic vision V'(k) compared with an example of a tentative spectral mesopic function for a typical mesopic light level [2]

Table 1. Functional ranges of visual system capabilities. Luminance level for photopic vision is defined as higher than 3-10 cd/m^2 (here: 3 cd/m^2), and mesopic vision range lies between 0.001 and 10 cd/m^2 (here: 0.001-3 cd/m^2), whereas scotopic vision is defined as the level lower than 0.001 cd/m^2 [5]

Name	Luminance Range (cd m^{-2})	Photoreceptor Active	Wavelength Range (nm)	Capabilities
Photopic	>3	Cones	380–780	Color vision, good detail discrimination
Scotopic	<0.001	Rods	380–780	No color vision, poor detail discrimination
Mesopic	>0.001 and <3	Cones and rods	380–780	Diminished color vision, reduced detail discrimination, and a shift in spectral sensitivity as adaptation luminance moves from photopic to scotopic

The main objective was to assess whether both studies yielded similar results in terms of the interpretability, readability, and differentiability of information. Participants performed both experiments and evaluated the aforementioned criteria with the help of a questionnaire. In this paper, only the subjective data is presented.

- **Readability.** Can the information presented in each cockpit be seen with the same efficacy? What is the detection threshold for information presented on the display?
- **Attention.** How quickly can the information be read from the display? For night-time driving, reaction times play an important role for safe driving.
- **Interpretability and differentiability.** How accurate is the information read from each display? How efficient is the recognition and identification of the target?

2 Method

2.1 Framework Conditions of the Study

Displays

The cockpit colors used in this experiment were chosen based on colors currently used in automobiles. The luminance level of the cockpit displays were tailored to mesopic conditions as well as the luminance of the experimental room (0.01-0.1 cd/m²). The white cockpit color concept is a potential new color concept, while the red one is a currently used color concept seen in some mid-range cars. Figure 2 shows the white display concept used in this study. The exact size of the cockpit display presented on the screens was 316x117 mm. The tachometer and speedometer each had a diameter of 96.4 mm, which equals the real size of an instrument cluster.

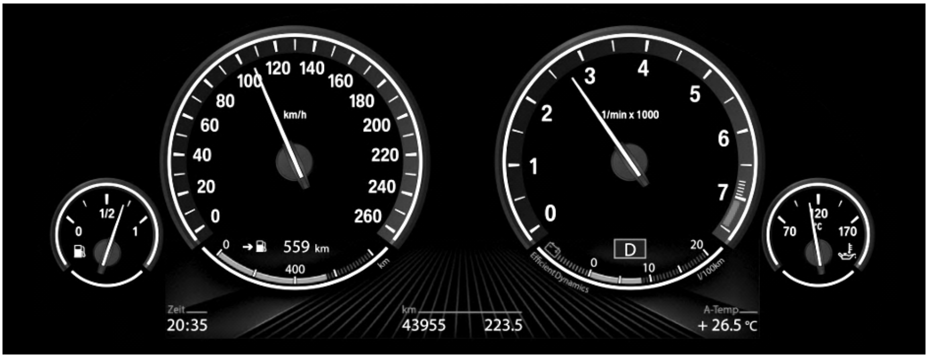

Fig. 2. The display used in this study with a white color concept

Procedure

After participants arrived at the laboratory, information about the study was provided. They had to perform a visual test for acuity as well as a color vision test to be sure none of them suffered from any visual impairments. After they finished a demographic questionnaire, the dark adaptation began (at least 20 minutes). Participants performed two experiments in random order. For each experiment, participants had to fill out a usability questionnaire evaluating the different color concepts.

2.2 Discriminating Warning and Information Signals

Experiment 1

For experiment 1, participants sat in a vehicle mock-up and performed a continuous tracking task (CTT) [6] on a larger display operating a joystick (right hand) to simulate a driving task (figure 3). While they performed the CTT, randomized arrows in different colors were shown on a smaller display where an automobile cockpit was presented in the specific color. Using a key pad (left hand), participants had to respond as quickly as possible to the arrow direction shown on the display.

Fig. 3. Experimental setting of experiment 1. Participants sat in a car seat and performed two tasks simultaneously. All distances were recreated based on a real car.

Each participant performed two blocks with a white cockpit display and two blocks with a red cockpit display. Cockpit color sequences were randomized across participants. After every two-block segment, the participants filled out a questionnaire to rate the most recent color concept.

The luminance level of the cockpit display was measured and tailored to mesopic conditions. Each experimental part (either white or red) began with a test block containing some trials to prevent training effects. Between the two parts, a five-minute block containing only the CTT without a discrimination task was performed. This established a baseline level for the CTT performance. Experiment 1 took approx. 35-45 minutes.

2.3 Readability of Speed

Experiment 2

The second experiment took place at a normal desk with the head resting on a chin rest in front of a single PC monitor. Participants had to perform an occlusion task [7, 8]. A fixation cross, located on the top portion of the screen, was provided before the stimuli were shown. In a randomized order, a cockpit display with a speedometer in either white or red appeared below the cross, and the participants had to indicate the speed shown. The cockpit was presented for different duration times to simulate short glances at the speedometer as they would occur in a real car. Participants had to speak their guesses aloud as to which speed was shown. It was not important how fast they responded as long as they reported the speed shown before the next stimulus was presented.

Additionally, a fake camera was placed near the monitor in order to motivate the participants to fixate on the cross before the presentation of the cockpit display allowed them to make a saccade in the direction of the stimulus.

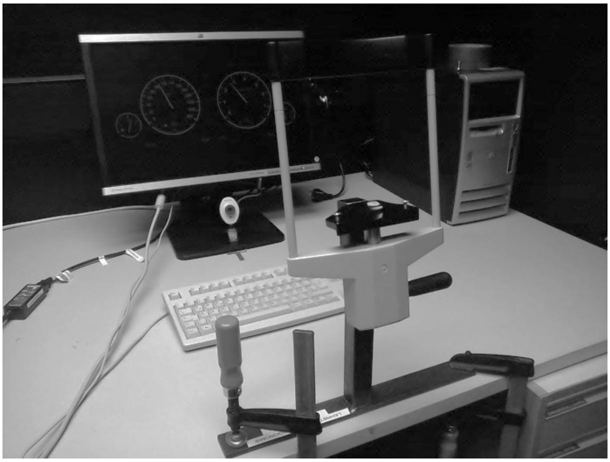

Fig. 4. Set-up of Experiment 2. Participants sat on a chair with the head resting on a chin rest while pictures with cockpit displays showing different speeds were presented on the screen.

As in Experiment 1, the luminance level was tailored to the mesopic conditions in this study. Participants performed a training block with some trials first and one block for each color concept afterward. In the test block, participants were presented with the correct answer on the screen after each trial. They did not know whether their responses were wrong or right in the real experimental blocks. Experiment 2 took approx. 30 minutes.

2.4 Data Collection with a Modified Post-Study Usability Questionnaire (PSSUQ)

PSSUQ

The questionnaire used to collect data is based on the PSSUQ [9], with some changes to the questions to suit the needs for evaluating display color concepts. The original questionnaire is a 19-item instrument used for evaluating satisfaction of a (computer) system. It was designed by IBM to measure system usability and usability problems as well as performance and user satisfaction. It is composed of three main sections and a final question (question 19) to evaluate the usefulness of the system (1-8), the quality of information (9-15) and the interface quality (16-18).

Modified Version

In this study only 12 items were used, and some were highly modified to fit the needs of evaluating different cockpit color concepts. As in the original version, a 7-point Likert scale was used, with the option of not answering the question. The score 1 means “I fully agree”, while a higher score up to 7 means “I do not agree at all”.

Overall, all questions were asked four times for each participant; there was one answer for each of the two experiments and one for each of the two display color concepts. See figure 5 for a list of all the questions asked. Half of the questions (1-5, 12) were positive questions while the other half (6-11) were negative ones.

1. I could effectively complete the tasks and scenarios using this cockpit system.
2. It was easy to find the information I needed.
3. The interface of the cockpit system was pleasant.
4. I liked using the interface of this cockpit system.
5. The arrow signals/speedometer displayed on the cockpit were/was easy to read.
6. Reading information from the cockpit display was physically effortful.
7. Reading information from the cockpit display was mentally effortful.
8. The cockpit displayed information in a way that caused me fatigue.
9. The cockpit display color distracted me from completing tasks.
10. The overall cockpit display color was difficult to pay attention to.
11. The color of the displayed information prevented me from reading the cockpit display.
12. The color of the cockpit display allowed me to detect signals very easily.

Fig. 5. All questions used in the modified PSSUQ. Overall twelve questions were asked four times each to rate the most recently used cockpit color concept.

2.5 Participants

Thirty healthy volunteers participated in this study. Only men were used to keep it homogeneous, since males perform significantly faster in simple reaction time than females at all ages [10].

For the analysis of the questionnaire, the answers of only 25 of the participants were used. The ones not used skipped at least five questions for one or both colors. All of the 25 volunteers had driving experience (M=24.6 years) and drove a distance between 8,000 km and 70,000 km (M=25,171 km) annually. None of them had any color vision impairments.

3 Results

Figure 6 shows the average Likert score (and standard error) for each question and color concept. As mentioned earlier in this paper, a lower score for questions 1-5 and 12 is considered good, while a higher score for questions 6-11 is good. As can be seen in figure 6, there is no major difference between the two color concepts.

The first question received an average Likert score of 1.6 (white)/1.5 (red). Question two has 1.9 for both colors, while question three received 2.2 (w)/2.1 (r). The fourth question resulted in 2.3 (w)/2.2 (r), and the fifth one in 2.6 (w)/2.8 (r). The last positive question is question number twelve, with an average score of 2.4 (w)/2.9 (r). The first negative question was question six, with a score of 5.1 (w)/5.2 (r). Question seven received a score of 4.2 (w)/4.4 (r), number eight received 4.9 (w)/4.7 (r), and the ninth one resulted in a score of 5.9 (w)/5.8 (r). The last two negative questions, ten and eleven, showed scores of 5.9 (w)/5.7 (r) and 6.0 (w)/5.7 (r).

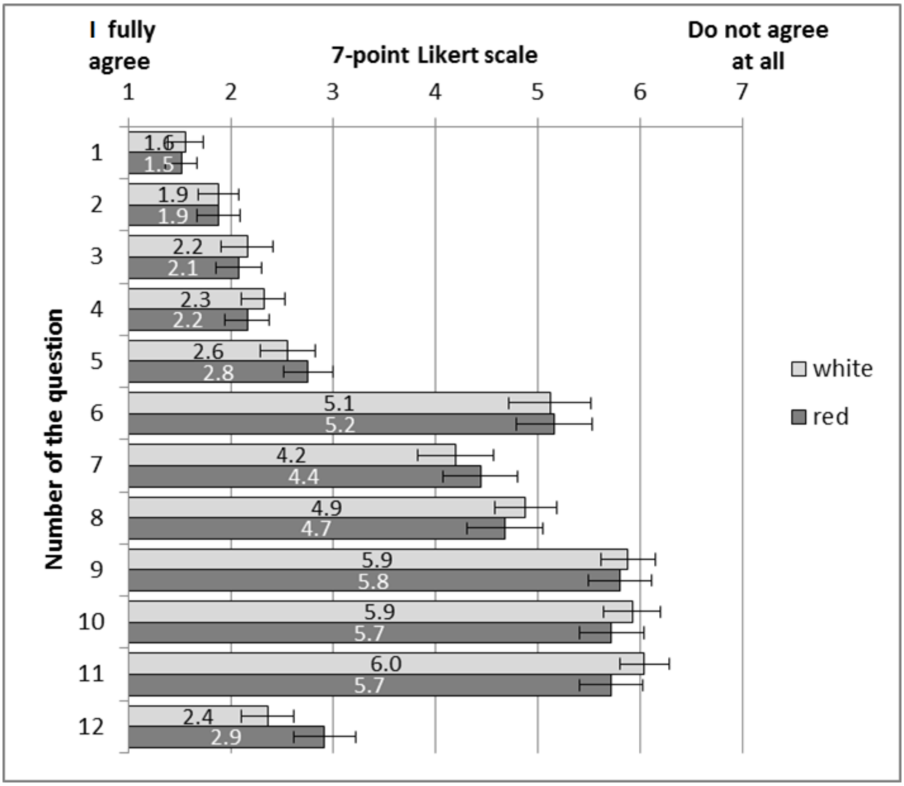

Fig. 6. Analysis of the questionnaire with standard errors. All questions were rated with the Likert scale for each color concept. The graph shows that most of the scores are close to each other, with just the last two questions showing a small gap.

For the statistics, a t-test was used. In order to increase the power of the analysis, the alpha-error rate for the t-test was established at a level of 25%. Simultaneously, the beta-error was decreased to an error-level of 75%. As expected, no significant differences were found between the red and the white color cockpit concept.

4 Discussion

The main aim of this study was to show that the new white cockpit color concept is either equal to or at least no worse than the red color concept under mesopic conditions. It was not intended to answer the question of which concept is better.

Looking at the results of the questionnaire (figure 7), only 5 of 12 questions show a small disadvantage for the white color concept (1, 3, 4, 6, 7). However, those gaps are too small to show a meaningful difference between red and white.

In short, the study shows that a white color concept in fact has no subjective disadvantages over a red color concept under mesopic lighting conditions. This will give car manufacturers more freedom when designing car interiors for night-time driving.

They are no longer bound to red lighting to make sure their concept yields the same subjective results in terms of interpretability, readability, and differentiability of information.

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