The assessment of a new cockpit colour concept using the Occlusion Method

Martin Götze¹, Antonia S. Conti¹, Andreas Keinath², Tarek Said², & Klaus Bengler¹
¹Institute of Ergonomics, Technische Universität München
²BMW Group, München, Germany

Abstract

The first vehicle cockpit colour concepts were developed based on the light used in submarine vehicles. This was primarily because operators were not typically exposed to external light sources and operated under the scotopic visual range. Red lighting was used as it does not disrupt dark adaptation. Based on this, many automobile companies developed their night time concepts in red. However, when driving in an urban setting at night or twilight, the lighting level is described as mesopic. Because of this, a white cockpit colour concept becomes a viable option. In this study, two colour concepts were compared under mesopic vision conditions. The main objective was to assess whether both concepts yielded similar results in terms of interpretability, readability, and differentiability of information. For the experiment, 30 participants performed an occlusion task. A cockpit display with a speedometer in either colour appeared. The cockpit was presented for different duration times to simulate short glances at the speedometer. Statistical tests were performed to examine global response accuracy and mean accuracy for particular presentation times. No significant differences were found. In sum, this paper confirms that a white concept shows no disadvantages relative to a red concept under mesopic lighting conditions.

Introduction

Motivation

Operating a vehicle is visually, cognitively, and physically loading for the driver (Recarte & Nunes, 2003). The coordination of these processes is especially crucial for driving under specific conditions, like at night time or twilight (Eloholma et al., 2006): the driver is continually required to adjust and readapt (e.g. through accommodation and saccades) to items inside the car and on the road. By creating more efficient displays in the vehicle that draws not too much attention away from the primary driving task, will help to decrease workload and provide for a safer driving experience. Neale et al. (2005) present the consequences for a lack of concentration while driving. About 78% of traffic collisions and about 65% of near collisions occurred because of “driving-related inattention to the forward roadway and non-specific eye glance” as well as “secondary task engagement and fatigue”.

Illumination

The human visual system operates over a wide range of luminance from about $10^{-6}$ up to $10^6$ cd/m². There are three light levels defined for human vision: photopic, mesopic, and scotopic (Table 1). The luminance level for the photopic vision is defined as higher than $3-10$ cd/m², the mesopic vision range from $0.001$ up to $3-10$ cd/m² and the luminance level lower than $0.001$ cd/m² is defined as scotopic vision (Boyce & Rea, 1987; Dacheux & Raviola, 2000). It is today acknowledged that the upper luminance limit of the mesopic region cannot be precisely defined (Viikari et al., 2005; Plainis et al., 2005).

Table 1. Functional ranges of visual system capabilities (Boyce, 2006, p. 652)

<table>
<thead>
<tr>
<th>Name</th>
<th>Luminance Range (cd m⁻²)</th>
<th>Photoreceptor Active</th>
<th>Wavelength Range (nm)</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photopic</td>
<td>$&gt;3$</td>
<td>Cones</td>
<td>380–780</td>
<td>Color vision, good detail discrimination</td>
</tr>
<tr>
<td>Scotopic</td>
<td>$&lt;0.001$</td>
<td>Rods</td>
<td>380–780</td>
<td>No color vision, poor detail discrimination</td>
</tr>
<tr>
<td>Mesopic</td>
<td>$&gt;0.001$ and $&lt;3$</td>
<td>Cones and rods</td>
<td>380–780</td>
<td>Diminished color vision, reduced detail discrimination, and a shift in spectral sensitivity as adaptation luminance moves from photopic to scotopic</td>
</tr>
</tbody>
</table>

But the perception of certain stimuli under different luminance conditions does not show equal efficacy. Driving at night time is riskier than during the day. Although only 25% of all traffic is present at night, the number of accidents for night and day is the same (Rumar, 2002). Studies on visual performance while driving with different light levels show that stimuli are perceived differently. With a decreasing luminance level, the reaction time and error rate increases (Alferdinck, 2006).

Mesopic Vision in urban Areas

The first in-vehicle cockpit colour concepts were developed based on the light and luminance used in subaqueous vehicles because operators were deprived of external light sources and operated under the scotopic visual range as described above (Boyce, 2006). The visual system adapts to the dark in order to adjust to certain luminance conditions. This dark adaptation (Purkinje effect) applies to red lighting because the spectral luminous efficiency function shifts to lower wavelengths, where red (700 nm) is not affected (see Figure 1). The rods of the eye do not become saturated, which is one reason why the first colour concepts for in-vehicle cockpit displays were red.

Studies have shown that under low luminance levels and high travelling speeds, more errors occur and additional steering effort is needed (Alferdinck, 2006). Ordinarily, driving at night in rural areas is classified in the scotopic range. However, the light level in urban areas when driving at night or twilight is described as mesopic. The main reason for this is the higher luminance level caused by the signals, signs, street lights, and other vehicles (Stockman & Sharpe, 2006; Viikari, 2008). Additionally, internal light sources also contribute to the overall light level as many driver assistance and information systems, such as navigation or entertainment functions, are completely electronic. Since it is now proven that driving in urban
areas does not operate under the scotopic but rather mesopic range, the opportunity is presented for a new vehicle cockpit colour concept.

The main objective of this study was to assess whether a new cockpit colour yielded similar results in terms of the interpretability, readability, and differentiability of information compared to the old concept in red. However, only the interpretability and differentiability are discussed in this paper.

- Interpretability and differentiability: How accurate is the information read from each display? How efficient is the recognition and identification of the target?

Both objective and subjective data was collected. Participants performed two experiments and evaluated the aforementioned criteria with a questionnaire. In this paper, only experiment one is presented where the readability, interpretability and differentiability criteria were tested. The data of the questionnaire was published earlier (Götze et al., 2013). The analysis of the data of the second experiment is still ongoing.

![Figure 1. The CIE spectral luminous efficiency functions for photopic vision, V(λ) and V10(λ), and scotopic vision V'(λ) compared with an example of a tentative spectral mesopic function for a typical mesopic light level (Alferdinck, 2006)](image)

**Method**

**Occlusion technique**

The occlusion technique (ISO 16673:2007) is used to assess visual demands of a task (e.g. stimulus presented on a display). During the experiment there are two
main parameters to be varied: The time duration in which a certain stimulus is visible and the time frame between two stimuli (Baumann et al., 2004). Moreover, there are two different ways to perform an occlusion experiment. The participants either wear shutter glasses or the stimulus on a screen is shut on and off. In this study the latter was used to maintain mesopic vision throughout the experiment.

Framework conditions of the study

Displays
The study compared a currently used cockpit concept (Figure 2) in two different colours. It can be found in some mid-range cars. The size of the whole cockpit display on the screen was 316x117 mm. Both rings, the tachometer and the speedometer, had a diameter of 96.4 mm. These measures correspond to those of a real existing instrument cluster in automobiles. As a baseline colour concept, the red (603.2 nm) colour concept was used compared to white. White was chosen because it is the colour produced by the reflection, transmission or emission of all wavelength of visible light. The luminance level of the cockpit display was tailored for mesopic vision conditions and set to 7.8 cd/m² for the red display and 11.0 cd/m² for the white display.

![Figure 2](image)

Figure 2. The cockpit concept used in this study with its measurements

Experimental design
The study was conducted in an experimental room under mesopic lighting conditions in a range from 0.01 cd/m² up to 1 cd/m². Participants sat on a chair in front of the screen with their head on a chin rest to ensure a viewing distance of 70 cm (see Figure 3). The Screen was positioned in front of them. Between each presentations a fixation cross, located on the top part of the screen, was presented to simulate a saccade to the driving scene. Furthermore, a small fake camera was placed under the screen in order to motivate the participants not to anticipate the position of where the speedometer would be presented and to stimulate the small saccade of eye movement during the experiment.
cockpit colour concepts under mesopic lighting

Procedure

At the beginning of the experimental session, all participants performed a visual acuity test (Landolt ring test) to test visual acuity and to ensure that each participant met the minimum acuity for driving (0.5 according to Colenbrander and De Laey (2005)). While performing under mesopic conditions, a visual acuity of at least 0.2 is needed (Uvijls et al., 2001). Additionally, participants also performed a colour vision test. This was especially important considering the nature of the experiment. Afterwards, a demographical questionnaire was administered to participants. Test persons entered the experimental room under mesopic lighting followed by a mesopic adaptation procedure of 20 to 30 minutes (Lamb & Pugh, 2004).

The aim of this experiment was to evaluate under mesopic lighting, whether participants were able to accurately indicate the speed indicated on the cockpit speedometer. Four different display durations and two colour concepts were used for
this evaluation. It was additionally important to be able to compare the two colour concepts in order to investigate which concept, if any, would yield better performance in the task. Participants verbally reported the displayed speed to the experimenter. Performance was not based on the quickness of the report; however, the speed was to be reported before the next stimulus was presented.

**Pre-experiment**

A pre-experiment was run for this study. Six participants performed 58 trials each colour, in addition to a training session in the beginning. The aim of the pre-experiment was to find the perfect occlusion times for the main experiment. Three presentation times were used in this pre-experiment: 300, 350 and 400 ms. The results revealed that the accuracy and misses did not differ much between all three times. Therefore, in the main experiment, the display durations were shifted down in order to test lower times and provoke errors.

![Figure 4 Time sequence of stimuli presented in the experiment. The screen remained black until the participant was ready (A). Afterwards, a white fixation cross on the top of the screen was presented for 1000 ms (B). The cross disappeared and participants were presented a cockpit display on the bottom of the screen in the respective colour of the block, where a certain speed was indicated (C). After the presentation time, the screen turned black again until the next stimuli was presented (D).](image)

**Main experiment**

Figure 4 shows the procedure of the main experiment. All participants performed a training block before the experiment began. During the training, participants were familiarized with the task and were given feedback on the correctness of their report. No such feedback was given in the main experiment. The experiment was presented to participants as per the sequence shown in Figure 4. The cockpits were displayed for 4 durations: 200, 250, 300, and 350 ms. Possible speeds indicated were 30, 60, 90, 130, 140, 160, 180, 200, and 220 km/h indicated by the speedometer. Participants were not informed that only specific speeds would be shown. The
different distances between speeds were chosen to decrease predictability. Minimum and maximum speeds were excluded from the experiment as they were considered too easy.

Data acquisition

All presentations in this study were prepared and executed with E-Prime 2.0 (Psychology Software Tools, Inc.). Performance metrics (viz. accuracy rates) were also recorded with E-Prime.

Participants

Thirty healthy volunteers participated in this study. The 6 participants that took part in the pre-experiment were not included in the main analysis. Only male subjects were recruited for this study, as several studies show the effects of sex and age on visual performance. Another part of the experiment consisted of a choice reaction time (CRT) task. While simple reaction time (SRT) tasks are associated with age and sex (for example, males perform some SRT tasks faster than females across the life span, whereas women are more accurate (Der & Deary, 2006)), mean CRT tasks tend to be very inconsistent in the considered age range (~25-55). For example, the CRT increases and becomes more variable with age while gender shows no regularity as seen in Figure 5. Additionally, there seems to be different RT patterns for females and males as a function of stimulus location (Adam et al., 1999). Although RT was not relevant in this experiment, this was a crucial factor to the second experiment not reported here. Only males were accepted as participants in order to control the homogeneity of the sample.

Figure 5. Choice reaction time (CRT) mean of a visual performance study of male (solid) and female (dashed) participants (Der & Deary, 2006)
Results

Participants

All participants were between 24-54 years of age with a mean of 43 years. No participants reported to suffer from any visual or motoric impairment. The driving experience varied from 15-36 years with a mean of 24.6 years and an average driving distance of 25171 km per year (ranging from 8000 to 70000 km).

Occlusion Task

Each participant was presented with 32 training trials and 64 experimental trials, for both colours, red and white. The mean accuracy rate for each presentation duration and the mean global accuracy rate (across all presentation durations) were calculated for all 30 participants. Only accurately reported speeds were considered correct. No response or reporting an inaccurate speed were considered errors.

Mean global accuracy

The mean global accuracy for all participants and all four time frame conditions was calculated. A paired-sampled t-test was performed to examine any difference in global accuracy rate. The mean and SDs for each colour concept can be found in Table 2; Figure 6 graphically depicts these findings. No significant difference between the two colour concepts in terms of global accuracy was found.

Table 2. Mean global response accuracy for two display colour concepts (N = 30)

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.75</td>
<td>0.74</td>
</tr>
<tr>
<td>SD</td>
<td>0.13</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Figure 6. Mean global accuracy with standard deviation for responses across all participants and presentation times for the two colour concepts
Mean accuracy for different presentation times
The mean accuracy for all four different presentation times and both colours was calculated. Accuracy percentages are given in Table 3.

Table 3. Mean accuracy for different presentation times for two display colour concepts

<table>
<thead>
<tr>
<th></th>
<th>200 ms</th>
<th>250 ms</th>
<th>300 ms</th>
<th>350 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>0.68</td>
<td>0.75</td>
<td>0.76</td>
<td>0.83</td>
</tr>
<tr>
<td>SD White</td>
<td>0.129</td>
<td>0.125</td>
<td>0.152</td>
<td>0.115</td>
</tr>
<tr>
<td>Red</td>
<td>0.65</td>
<td>0.73</td>
<td>0.77</td>
<td>0.80</td>
</tr>
<tr>
<td>SD Red</td>
<td>0.186</td>
<td>0.190</td>
<td>0.137</td>
<td>0.167</td>
</tr>
</tbody>
</table>

A one-way repeated measures ANOVA was done. Mauchly’s test indicated that the assumption of sphericity had been violated, $X^2(5) = 11.35, p = .045$, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity $(\varepsilon = .804)$. The results show that there was no significant effect of colour concept on mean accuracy for the different presentation durations $F(1, 29) = .409, p = .53$. These results suggest that the colour concept has no effect on the accuracy of reading and reporting a speed from the cockpit (Figure 7).

![Figure 7. Mean accuracy for all presentation times with each cockpit colour](image_url)
Additionally, there was a significant main effect of presentation time, \( F(2.41, 69.98) = 44.80, \ p \leq 0.001 \), suggesting that presentation time significantly affected mean accuracy (Figure 8).

![Figure 8. Mean accuracy including both colours for all presentation times](image)

Post-hoc Bonferroni comparisons indicated that all presentation times were significantly different from each other, \( p \leq 0.001 \), except for 250ms and 300ms, \( p = 0.12 \) where no difference was found. These results suggest that it gets significantly better to read a specific speed accurate in a cockpit display no matter which colour but depending on the presentation time. Shorter presentation times lead to significantly less accurate answers than longer presentation times.

**Non-inferiority**

Since a main aim of this study was to compare the new colour (white) cockpit concept to the already established one (red), a non-inferiority test was also carried out. With non-inferiority testing, the margin must be smaller than or equal to “the smallest value that would represent a meaningful difference, or the largest value that would represent a meaningless difference. The determination of this margin must be based on both statistical reasoning and [expert] judgment” (Henaff et al., 2006, pg. 1147). It is usually expressed with the confidence interval of:

\[
\bar{x} \pm z \frac{\sigma}{\sqrt{n}}
\]
A “meaningful difference” is typically defined case by case. Since 3 of 4 presentation times are already more accurate for the new white colour concept, only accuracy for the presentation time of 300 ms is important in this test. Figure 9 shows the 95% confidence interval for the mean accuracy of each colour and each of the four presentation times. The graph shows that there is no meaningful difference between the both colour concepts.

![Figure 9. 95% Confidence Intervals for the mean accuracy of both colours and all presentation times](image)

**Discussion**

In the current study, two car cockpit colour concepts (white and red) were compared in order to examine them in terms of readability of information under mesopic lighting conditions. The occlusion technique was used to facilitate a comparison between the readability of a displayed speed for specific presentation duration. The aim was to investigate whether two display colours yielded the same results for the presentation times 200, 250, 300, and 350 ms. Mean accuracy and global accuracy were included in the analysis. No significant differences between the two colours were found. A significant main effect of the presentation time was found, meaning that the longer the presentation time was, the more correct responses were reported. This result is in line with studies reporting increased visual performance according to an increase in stimulus presentation time (Baumann et al., 2004). A final non-inferiority test showed no meaningful difference between the two colour concepts, implying that both colour concepts are associated with the same performance outcomes. The NHTSA report (Klauer et al., 2010) shows that there is a “2-second rule” which is based on research by Rockwell (1988). His studies showed that the 85th percentile eye glance length was about 1.9s. Still some researchers like Green (1999), Wierwille (1993) or Dingus et al. (1989) suggested a time not greater than 1.5s to look away from the forward roadway. The results of the experiment show,
independently of the colour the speed can be read even in very short presentation times. The lighting colour of the cockpit concept is not important under mesopic vision as long as the driver stays adapted to those luminance levels.

**Conclusion**

In short, the study shows that a new cockpit colour concept, as tested, has no objective disadvantage over the currently used red colour concept under mesopic lighting. These results will help designers of displays or car manufacturers with new possibilities for interior lighting concepts for night-time driving in urban areas.

**Acknowledgments**

The authors would like to acknowledge the cooperation with the BMW Group on this project. We appreciate the opportunity to have carried out this study.

**References**


ISO 16673:2007. Road vehicles -- Ergonomic aspects of transport information and control systems -- Occlusion method to assess visual demand due to the use of in-vehicle systems


