Legibility under reading lights using white LED

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M.Yamagishi, F.Kawasaki, K.Yamaba, M.Nagata, Legibility under reading lights using white LED. Gerontechnology 2006; 5(3):231-236. This paper deals with legibility under in-vehicle reading lights. In this study, five light sources (incandescent lamp, fluorescent lamp, bicolor LED and two types of white LED) were used in order to evaluate legibility, perceptual whiteness, and perceptual brightness. The illuminance of the text paper was set constant at 40 lx. The first experiment showed that there is a relationship between legibility and perceptual whiteness. The second experiment - a comparison between four kinds of light sources without the bicolor LED as to subjects' preferences - showed that the whitest LED is the best light source for elderly people. A third experiment confirmed this result as to direct subjective preferences.

Keywords: legibility, LED, in-vehicle reading, visual characteristics, elderly

Recently, LEDs have been applied to many lighting situations: they provide both high electrical efficiency and long life. As blue LEDs and improved white LEDs are being developed with a higher luminance, LEDs are in the future also likely to be used for household lighting. This paper addresses legibility under in-vehicle lighting conditions of a range of reading lights, including colored and white LEDs. It discusses experimental investigations of legibility, related factors of whiteness and visual clarity, and reading light preferences.

Generally, in-vehicle reading lights are installed on the back seat of so-called luxury cars for the use of the passenger sitting there. It is likely elderly passengers will use them. Visual function decreases with age, owing to declining visual acuity and increasing lens opacity and yellowing[1]. Thus, the in-vehicle reading lights should have specifications that will enable elderly people to read easily.

In-vehicle reading lights have several kinds of specification but these designs do not necessarily reflect age-related

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changes in visual function. Hopefully, in the future it will become standard practice to take age-related changes into account when drawing up design specifications.

LEGIBILITY UNDER EACH LIGHT SOURCE

The first experiment examines whether legibility and visual acuity show variations under different LED light sources. The results are discussed in terms of age-related differences.

Methods

Subjects

Seven younger subjects (Mean (M) = 25.7 years old, standard deviation (SD) = 6.7; no males, seven females) participated in this experiment; five of these younger subjects wore spectacles or contact lenses. The subjects were volunteers selected from the graduate students and administrative office at the university. A further 16 elderly subjects (M=66.9 years old, SD=4.9; 15 males, one female) took part in the experiment; they were recruited from the Silver Human Resources Center. Of the elderly subjects, 14 wore their habitual spectacles or contact lenses. All subjects had normal linguistic ability and were able to read a text; they suffered no specific visual impairments.

Sample Light Sources

Five kinds of light sources were used (*Table 1*). Of the five light sources samples D and E are both white LEDs, but there are two differences: the correlated color temperature and the relative spectral distribution. Sample D contains two kinds of spectral energy, at a short wavelength (near 470 nm) and at a middle wavelength (near 580 nm), whereas sample E contains three kinds of spectral energy, at a short wavelength (from 400 nm to 470 nm), a middle wavelength (near 520 nm) and a long wavelength (near 620 nm). As a result these light sources differ in color rendering and color appearance. Figure 1 shows the relative spectral distribution of samples D and E.

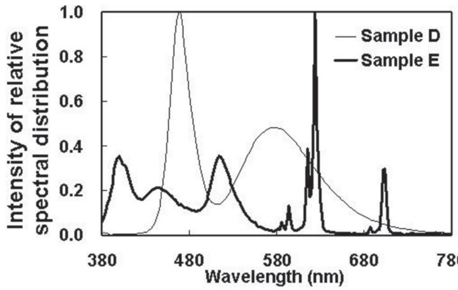

Figure 1. Relative spectral distribution of samples D and E

In addition, illuminance on the paper surface was set at a constant level of 40.0±1.0 lx as measured by a MINOLTA Corporation T-1H digital illuminance meter, that follows the CIE spectral sensitivity standard. This illuminance was chosen because it corresponds to the specification for the back seats of cars.

Experiment

Five illumination boxes with internal light sources were used in the experiment. Figure 2 illustrates the experimental conditions. The distance between the subject's eyes and the

Table 1. Sample light sources

Characteristics	Samples				
	A	B	C	D	E
Light source	Incandescent lamp	Fluorescent lamp	Bicolor LED	White LED	White LED
LED Properties	-	-	Blue-green + red LED	Blue LED + yellow phosphor	Purple LED + RGB phosphor
Correlated color temperature, K	2,300	7,200	6,500	7,100	11,000

Figure 2. Experimental layout

paper within the box was constant, at 40 cm. The visual object used to investigate legibility was a vertically written text of about 200 Japanese characters, consisting of 60% Kana and 40% Kanji. Prior to the experiment, subjects got accustomed to the darkness in a room, and were then brought to the dark experiment room. There they were given time to adapt to the illuminance resulting from the sample light source, after which the experiment started.

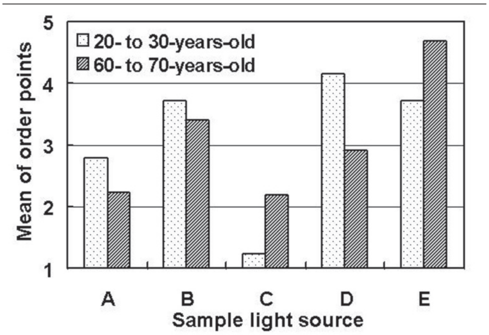

Figure 3. Relative legibility rating in two different age categories

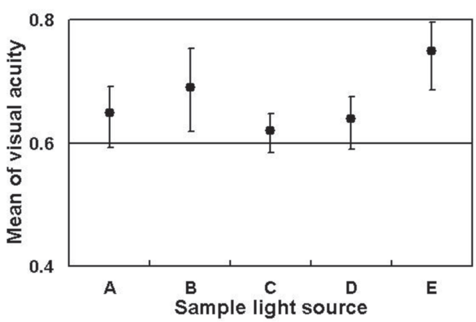

Figure 4. Visual acuity of elderly subjects for the five light sources, A to E

Evaluation

Subjects were asked to estimate legibility by the interval-scale method. They were instructed to read the paper under a light source and then rate the source according to legibility on a clearness estimate scale, a visual fatigue estimate scale, and a legibility estimate scale of 0-10, with 0 signifying poor and 10 signifying excellent legibility. Evaluations were made immediately after exposure to each light source.

Furthermore, 21 elderly subjects (M=66.6 years, SD=4.5), among whom elderly who participated in the legibility evaluation study, had their visual acuity measured under each of the sample light sources. They wore their habitual spectacles. In this experiment the standard viewing distance of 30 cm was used, as recommended by the Research Institute of Human Engineering for Quality Life (HQL)[2].

Results

The evaluation scale of 0 to 10 is subjective and the data obtained vary widely between individuals. By contrast, the relative preferences for light sources are ordered more consistently by subjects. The five light sources were arranged from the highest to the lowest evaluation point. Then, they were rated, on a scale of 1 to 5 in ascending order.

Legibility ratings for a whitish paper were compared for younger and elderly subjects using the aforementioned ordering method. Elderly rated sample E (white LED) as providing the highest legibility of all the light sources (*Figure 3*).

Figure 4 indicates the visual acuity of elderly subjects at each sample light source. Elderly subjects gained the highest level of visual acuity for sample E (white LED). The correlation between the value of visual acuity and the legibility rating was also tested, and the result

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indicate that there is a strong positive correlation (r=.93).

Rating whiteness and visual clarity

In the second experiment, subjects were asked to rate whiteness and visual clarity, as legibility-related factors, of the paper surface under each light source. 'Whiteness' refers to the color of the paper surface, and 'clarity' refers to brightness of the paper surface. The results are compared with the legibility results obtained in the first experiment.

Methods

Subjects

In this experiment, sixteen younger graduate students volunteered as subjects (M=21.8 yrs, SD=0.54; 5 males, 12 females); 15 elderly subjects (M=69.2 yrs, SD=3.6; 11 males, 4 females) volunteered. These elderly subjects are enrolled in a lifelong learning course. In this experiment, most of the subjects happened to be habitual wearers of spectacles or contact lenses. All subjects had normal linguistic ability.

Sample Light Sources

In this experiment, four kinds of sample light sources were used, excluding sample C (*Table 1*). The first experiment indicated that both younger and elderly subjects rated sample C as having the lowest legibility of the five kinds of light sources. Illuminance of the paper surface was set at 40.0±1.0 lx as measured by a MINOLTA Corporation T-1H digital illuminance meter.

Experiment

A dark room was equipped with two illumination boxes placed side by side (*Figure 2*). A vertically written text was used to rate whiteness and visual clarity. This text of a general social and easily understood topic, consisted of about 300 Japanese characters containing 60% Kana and 40% Kanji. Before the start of this experiment, subjects were given about 2 minutes to adapt to the dark, during which time the experiment was explained to them.

Evaluation

After the subject read the paper text placed in each box, he or she was asked to estimate the whiteness and visual clarity of the paper surface under each sample light source using the Scheffe method of paired comparison[3]. More specifically, the subjects were asked to look at and read the paper text placed in two neighboring illumination boxes. They were then asked to compare the legibility of the two sample light sources by rating intensity, from extremely high to extremely low difference in terms of whiteness and visual clarity.

Results

The paired-comparison results were similar for the younger and the elderly subjects. As there were no significant differences the analyses discussed below are based only on the results of the elderly. Figure 5 shows results for the degree of whiteness, Figure 6 for the degree of visual clarity.

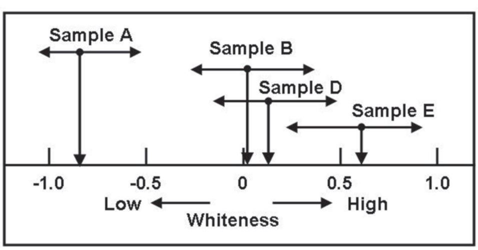

Figure 5. Degree of whiteness for elderly subjects of 4 light source samples (paired comparison)

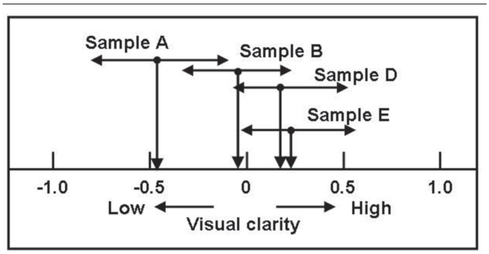

Figure 6. Degree of visual clarity for elderly subjects of 4 light source samples (paired comparison)

Four sample lights (A, B, D, and E) were compared for whiteness and an ANOVA was carried out, resulting in a significant main effect for sample lights ($F(3, 90)=1.232$, $p < .01$). Similarly, for visual clarity, a four-sample light (A, B, D, and E) ANOVA was carried out, resulting in a significant main effect for sample lights ($F(3, 90)=3.857$, $p < .05$).

The results of Figures 5 and 6 suggest that sample E (white LED) received a higher estimation for both whiteness and visual clarity than the other light sources.

Comparing legibility and whiteness

To confirm the validity of legibility-related factors, the relationship between the results of legibility estimation (first experiment) and whiteness rating (second experiment) was tested.

Figure 8 shows a correlation based on a computed approximation formula:

$$Y = 0.443 + 0.248 X \quad (R^2 = 0.952) \qquad (1)$$

In Figure 7, the vertical axis signifies the scaled estimate of legibility (= Estimate / 10), as in Figure 3. The horizontal axis denotes the degree of whiteness, as in Figure 5. Figure 7 reveals a strong positive correlation between legibility (first experiment) and whiteness (second experiment). Thus, we may conclude that the whiter light source enhances legibility, especially for elderly.

Preference between light sources

The results of the previous experiments suggest that for the elderly a light source is most effective as reading light if it makes the background appear as white as possible. From our experiments we can conclude that the white LED used in sample E in this study is most suitable for the elderly. However, it should be remembered that if such LEDs were to be used generally around the house, it is important to know how LED lighting affects humans. Preferences for particular reading lights among these sample light sources are discussed in a third experiment.

Methods

Subjects

In this experiment 16 younger subjects and 15 elderly subjects took part. These were the same participants as in the second experiment.

Sample light sources

Both experiments used the same four sample light sources. Their illuminance levels were also identical to those of previous experiments.

Experiment

Four illumination boxes were set up side by side (*Figure 2*). As in the previous experiment, subjects adapted to the dark prior to the experiment. The same visual object (i.e., text) was presented to the subjects.

Evaluation

Subjects were instructed to indicate which of the four light sources they preferred.

Results

Figure 8 shows selected preferences for each light source. The χ^2 test was performed on both age groups (younger

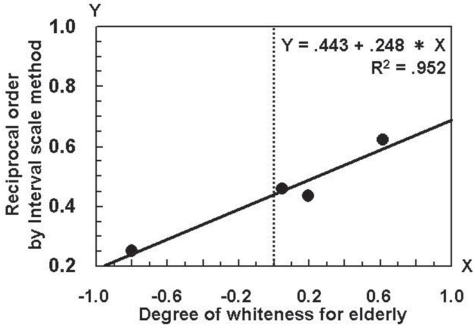

Figure 7. Correlation of legibility estimate and whiteness for light source samples A, B, D and E

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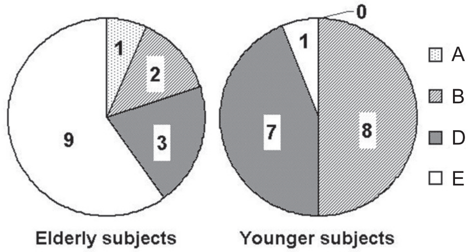

Figure 8. Preferences for reading lights of 15 elderly and 16 younger subjects when testing 4 light source samples (A, B, D, and E)

and elderly) under four sample lights (A, B, D, and E). The age-related difference is significant ($\chi^2(3)=12.58$, $p < .01$). The number of elderly choosing sample B (n=2) is smaller than the number of the younger subjects (n=8). The number of elderly choosing sample E (n=9) is larger than the number of younger subjects (n=1). Indeed, the majority of the elderly indicated that sample E (white LED) is the best light source. These results are clearly consistent with the estimation of legibility (first experiment) and whiteness (second experiment).

Conclusion

This research focused on the visual characteristics of the elderly, and discussed legibility under a variety of reading lights. Of the sample lights investigated - in terms of legibility for the elderly - a significant preference was found for white LED (11,000 K correlated color temperature). This white LED has the highest correlated color temperature and consists of comprehensive wavelengths: both short, middle and long wavelength. This means that the spectral characteristics of objects are accurately reflected. White LED, therefore, results in the highest estimation of whiteness by elderly people. In other words, white paper looks most white. This is important as a high contrast between characters and background optimizes legibility, in particular for elderly people who suffer yellowing of their lenses.

White LED has been called the new light source for the 21st century. This research suggests that the white LED used in these experiments could be of great benefit to the elderly. This research also has implications for the general use of LEDs as a light source.

Future developments

LEDs are increasingly illuminous and are getting cheaper. So far they have been used in traffic signs and displays, but not yet as lighting in households due to some unresolved problems, such as insufficient illuminance, and a lack of understanding of the effects of LED lights on humans. Undoubtedly in the near future more powerful LED-colored lights will be developed that have sufficient illuminance to be used as lighting. It would therefore be timely to research the psychological and physiological effects of LEDs.

Acknowledgement

We would like to thank Dr. Sam Landsberger of California State University, Los Angeles, for his cooperation in preparing this paper.

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