Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

The effect of Age on Web-safe Color Visibility for a White Background

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Abstract— **This paper investigates the effect of subject's age on web-safe color visibility on a white background. An evaluation of website accessibility is necessary because of the rapid dissemination of information on the World Wide Web. One important factor to be considered when developing accessible websites is the foreground color and the background color combination. In this study, the visibility of 21 chromatic web-safe colors on a white background was examined using a psychological methodology, i.e. a paired comparison. The participants in the experiment were 12 young adults, 17 middle-aged adults and 11 elderly adults. The young adults conducted three tests involving 420 paired-comparison trials while the other groups' participants conducted the test in consideration of the physical burden.**

It was found that the chromaticity of the foreground color influenced the assessment of the page's visibility by the young adult group more strongly than that by the other groups. It was also found that the contrast between the foreground and background colors affected the assessment of the page's visibility by the middle-aged and elderly groups more strongly than that by the young adult group. This indicated that the ageing effect in the visibility increases the effect of the contrast and decreases the effect of the chromaticity.

I. Introduction

OPPORTUNITIES for using the World Wide Web (WWW) have increased because of the greater distribution of the Internet. As a result, many elderly people, as members of an information society, are expected to be able to use this technology. Therefore, web page usability is an important ongoing research topic. A major element of usability is accessibility [1], and considerable research on this topic has been conducted [2-5]. Both the WWW Consortium and the Japan Industrial Standards (JIS) have published Web Content Accessibility Guidelines for designing web pages having lower web accessibility barriers for people with disabilities [6]. One of the aspects of accessibility is visibility, which is defined as the condition or quality of being easy to see. The above-mentioned guidelines specify that the foreground content should be easily distinguishable from the background content in both auditory and visual presentations [1, 6]. In order to satisfy this requirement when creating web pages, some quantitative indexes are needed. However, few indexes are available. Few studies have been conducted that meet the needs of web creators for quantitative indexes of web page visibility [7]. Visibility is affected by many factors including the environment in which the web page is viewed, the target characteristics, and the observer. Consequently, research into visibility is necessary for developing web pages, and for selecting appropriate color combinations for the foreground and background, which is a crucial factor for achieving sufficient visibility.

In this study, the visibility of several web-safe color combinations was examined using a psychological methodology, i.e. the paired comparison method. Results from young adults and middle-aged and elderly subjects were compared to determine the effect of age on a web page visibility.

Manuscript received April 3, 2006. This work was supported in part by a Grant-in-Aid for Scientific Research (15500142) from the Japan Society for the Promotion of Science.

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II. Visibility Of Color Combination for the Foreground And Background Rated By the Paired Comparison Method

A. Scoring for visibility using Thurstone's method of paired comparisons

In this section, a psychological technique for obtaining subjective data regarding the visibility of a web page and a method for scoring the visibility are proposed. Subjects in experimental studies are typically not good at making absolute judgments but are generally good at making comparative judgments. For this reason, a paired comparison test, which is widely used in psychological research, was employed to obtain subjective data regarding visibility. In this test, two alternatives are shown to the subject and he/she is asked to decide which one is closer to an internally defined standard. Since the two alternatives are viewed simultaneously, comparisons can be made without the need for making any absolute judgments. In the test, each object is compared with all the others so as to collect subjective data from all of the objects.

Thurstone assumed that a subject makes a decision about a pair of alternatives based on the pair's value difference. Thurstone's technique [8, 9] can provide each alternative with the subjects' relative rankings. This technique was applied to the data from a subject's group**.** The group results were then compiled using the following procedure. Using the paired comparison results the probability, P_{ij}, which expresses how often a subject preferred the *i*-th object to the *j*-th object, was calculated. This probability indicates the relative visibility degree of the two objects. The probability distribution is assumed to be normal allowing the probabilities to be converted to *Z*-values, which are values for a normal distribution having a mean of 0 and a standard deviation of 1.

Assuming that Z_{ij} is the score of the *i*-th object to the *j*-th object, its value can be obtained as follows:

$$Z_{ij} = \begin{cases} Z & \text{where } P_{ij} - 0.5 \geq 0 \\ -Z & \text{where } P_{ij} - 0.5 < 0 \end{cases},$$

where Z is the z-score. The visibility score for the i-th object can be obtained from the following equation,

$$Z_i = \sum_{j=1}^{a} \frac{Z_{ij}}{a - 1} \quad \cdots(1),$$

where *a* is the number of objects to be compared. This score was utilized to rate the visibilities of color combinations on an interval scale.

B. Visual sensation deduced by Weber-Fechner's law

Luminance is a physical quantity while brightness is a quantity expressing the degree of sensation. It is thus necessary to convert luminance values to sensation magnitudes; Weber-Fechner's law is generally used for doing this [10]. In this study, Weber-Fechner's law was used for converting luminance to sensation magnitudes.

In general, variations in physical stimuli change the sensation magnitudes. The smallest variation in a noticeable stimulus is called the just noticeable difference (JND). For example, the JND in luminance ΔL can be used to calculate the contrast ratio $\Delta L/L$, which is referred to as the Weber function. Fechner extended the psychophysics relationship into the Weber-Fechner's law, which states that the sensation magnitude is approximately proportional to the logarithm of stimulus intensity. That is,

$$S = k \cdot \ln I + C \quad \cdots(2)$$

where *S* is the sensation magnitude, *k* and *C* are constants that depend upon the nature of the sense, and *I* is the stimulus intensity. In this study, $k > 0$ since the sensation magnitude increases as the intensity of the physical stimulus increases. Equation (2) describes the relationship between the magnitude of a physical quantity and the magnitude of the psychological sensation.

When the foreground color and the background color are identical, a subject cannot distinguish the sensation of the foreground color from the background color, and (2) becomes,

$$0 = k \cdot \ln I_b + C \quad \cdots(3)$$

where I_b is the background color. Thus, the difference in the sensation a subject perceives from the foreground color and the background color is given in the following equation:

$$S = k \cdot \ln I_f - k \cdot \ln I_b,$$

$$S = k \cdot \ln\left(\frac{I_f}{I_b}\right), \quad \cdots(4)$$

where I_f denotes the foreground color. Equation (4) means that the ratio I_f/I_b is more appropriate for indicating the sensations that a subject felt than the physical luminance.

C. Experimental method

Stimuli were presented on a 17-inch CRT display equipped with standard RGB mode (sRGB) the colors of which satisfy an international standard for color reproduction by International Electrotechnical Commission (IEC). Each stimulus was composed of three components, a white background and two differently colored character strings displayed next to each other in columns (Fig. 1). The character string was composed of symmetrical Chinese characters that were ordered randomly so that they did not convey any meaning. The height of the character strings was 10 mm and the font type used was MS Gothic. The default font size was 11 points, however when elderly subjects could not see the characters the font size was increased. The distance between the subject and the display screen was

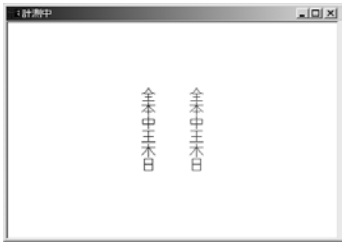


Fig. 1 Visual stimulus displayed for paired comparison

Fig. 2 Experimental booth

TABLE 1 LUMINANCE, CHROMATICITY AND *YXY* COLOR CODES FOR COLORS USED IN EXPERIMENT

Color	Color code	Luminance Y cd/m^2	Chromaticity	
			x	y
Blue	#000099	3.93	0.183	0.124
	#0000CC	5.73	0.165	0.096
	#0000FF	7.90	0.158	0.085
Red	#990000	6.96	0.527	0.353
	#CC0000	12.20	0.564	0.352
	#FF0000	19.00	0.582	0.351
Magenta	#990099	8.53	0.312	0.191
	#CC00CC	15.30	0.310	0.178
	#FF00FF	24.10	0.312	0.174
Green	#009900	16.50	0.301	0.541
	#00CC00	32.10	0.295	0.563
	#00FF00	51.00	0.292	0.571
Cyan	#009999	17.90	0.259	0.324
	#00CCCC	34.70	0.222	0.321
	#00FFFF	55.80	0.219	0.322
Yellow	#999900	21.10	0.397	0.482
	#CCCC00	41.50	0.402	0.491
	#FFFF00	67.00	0.405	0.493
Achromatics	#000000	2.28	0.342	0.361
	#999999	22.40	0.305	0.329
	#CCCCCC	44.10	0.303	0.328
	#FFFFFF	71.10	0.304	0.327

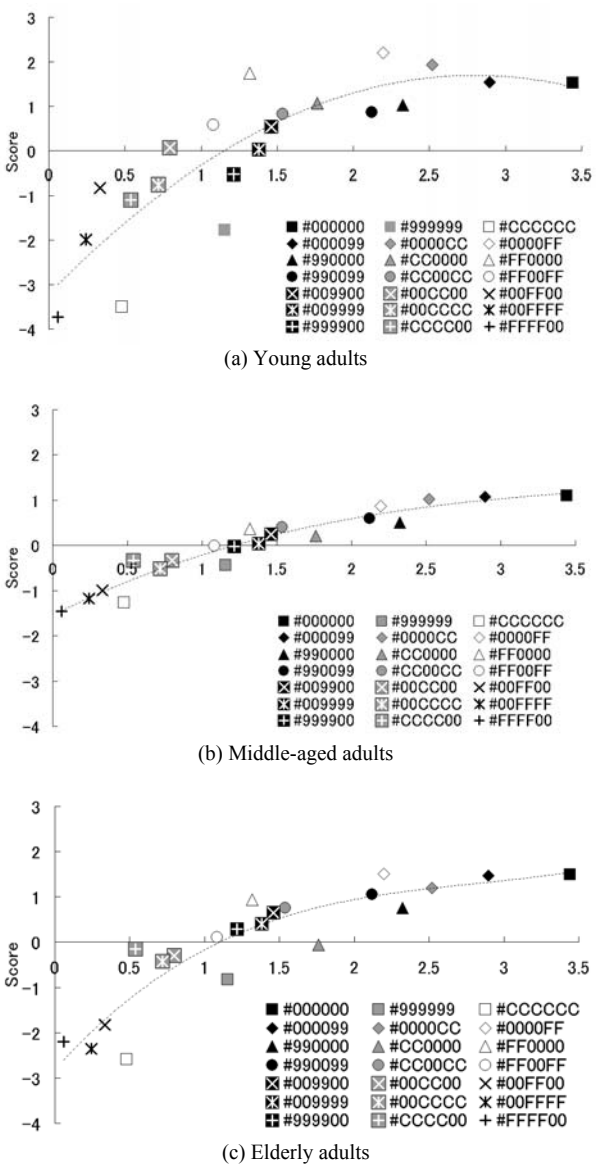
approximately 800 mm. The illuminance on the CRT display was 100 lux produced by artificial lighting and the experiment was conducted in the booth shown in Fig. 2.

The color code for white is #FFFFFF. White background was chosen since they are usually employed by major search engines on the WWW. The foreground colors were 18 representative chromatic and three achromatic web-safe colors listed in Table 1. The luminance and the chromaticity of these colors were measured by a colorimeter and the values are given in Table 1.

Subjects included 12 young adults ranging from 21 to 29 years old (average 22.9), 17 middle-aged adults ranging from age 55 to 64 years old (average 59.6) and eleven elderly adults ranging from age 65 to 72 years old (average 67.6). All subjects had normal color sensation.

The subjects simultaneously viewed two differently colored character strings against a white background. They were instructed to identify which color combination was clearest by clicking the left or right button of a mouse. There was no time limit imposed for the paired-comparison trial.

The young adults conducted three tests containing 420 paired-comparison trials resulting in a total of 15120 paired-comparison results being collected. The middle-aged adults and the elderly adults carried out the test resulting in 7140 and 4620 paired-comparison results being collected,



(a) Young adults

(b) Middle-aged adults

(c) Elderly adults

Fig. 3 Relationships between the psychological rankings of color combinations and visual sensations. These figures show the variation in the score as a function of S in (4). The horizontal axis was S calculated using Weber-Fechner's law to the contrast ratio of the foreground and background colors, and the vertical axis is the visibility score calculated by Thurstone's method of paired comparisons.

respectively.

When examining the relationship between the psychological rankings for the color combinations and the visual sensations, the visibility of each color combination was scored using Thurstone's method of paired comparisons. The visual sensations were then deduced by applying Weber-Fechner's law to the luminance of the stimuli.

III. RESULTS

The relationships between the psychological rankings of

color combinations and the visual sensations are shown in Fig. 3. The plots of Fig. 3 (a), (b) and (c) give the results for the young adults, the middle-aged persons and the elderly persons, respectively. The vertical axis shows the score of the visibility calculated using Thurstone's method of paired comparisons. The horizontal axis represents the visual sensation calculated by applying Weber-Fechner's law to the contrast ratio of the foreground and background colors. When this value increases, the sensation of a difference between the foreground and the background color increases. If the value of k in (4) is constant, the ranking of contrast for each foreground color does not change. We, therefore, define the k value to be 1. Thus, (4) becomes $S = \ln(I_f / I_b)$, and this S value was used to calculate horizontal axis values of Fig. 3. The dashed lines in Fig.3 represent approximation curves.

According to the approximation curves in Fig. 3, for all the groups, there is the tendency for the contrast to increase as the scores increase, and saturation occurs when the contrast exceeds 1.7. In addition, for the young adults only, when the contrast exceeds 2.8 the scores tend to decrease.

IV. Discussion

In Fig.3, the score variance of the colors of which contrasts are almost the same is larger in young-adult group than that in the other groups. For example, these values of #FF00FF, #999999 and #999900 are 1.46 in young-adult group, 0.364 in the middle-aged group and 0.860 in the elderly group. This indicates that the middle-aged adults and the elderly adults, in particular, were less strongly influenced by the chromaticity of the foreground colors than the young adults.

Fig. 3 (a) shows that although increasing the contrast improves the visibility, excessive contrast reduces the visibility. In addition, at high contrast there is the possibility of causing asthenopia. The nature of this problem is the same for all subject groups though it is likely to differ in degree. The following points were found:

i) The effect of increasing age of the subjects reduces the influence of chromaticity, and increases the influence of the contrast between the foreground color and a background color.
ii) It is clear that the contrast between the foreground and background colors needs to be in the range between 1.7 and 3.0 because of the consistently high scores obtained with contrasts in this range.

On the Internet, a person who is accustomed to using WWW can understand that the combination of a standard link color and an underline represents a link. In our experiment, the high-scoring colors for all subject groups were the colors of Blue, Red and Magenta given in Table 1. These colors are all standard link colors and have low luminance. Blue is used for links that have not been visited, Red is used for active links, and Magenta is used for links that have been visited. Because the visibility of these colors is high for all ages, these colors are appropriate to be used as link colors on a white background. Therefore, we consider that the combination of the standard link colors and an underline on a white background is very effective.

It is, however, necessary to change the link colors when different background colors are used. In the future, it will be necessary to investigate effective color combinations for the foreground and background and to determine and catalog the visibility characteristics for all age ranges when the background color is changed.

V. Conclusion

In order to investigate web-safe color visibility on a white background, a paired comparison test was performed with young adults, middle-aged adults and elderly adults, and the visibilities of 21 representative web-safe-colors were scored. It was found that the effect of increasing subject's age on visibility increased the influence of the contrast and decreased the influence of the chromaticity. We then determined the appropriate ranges the contrast that ensured high visibility for all age ranges. Moreover, we found the existing link colors (Blue, Red and Magenta) are effective against a white background. Since an investigation of all possible color combinations is extremely difficult to conduct, in the future we intend to investigate the visibility of the foreground web-safe colors for several representative background colors by constructing a model or empirical formula for estimating the color combination visibility.

Acknowledgment

We would like to thank everyone at the Univers Foundation who participated in the paired comparison test for middle-aged adults and elderly adults during the course of this present research.

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