Visibility Rating of Achromatic Web-Safe Color Using Weber-Fechner’s Law

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Abstract: Web page visibility gained importance due to the rapid dissemination of the World Wide Web. Since combinations of foreground and background colors are crucial in providing good visibility and an investigation of all possible color combinations is extremely difficult to conduct, a model or empirical formula for estimating color combination visibility is needed. In this study, a visibility rating method of color combinations is proposed. The visibilities of several web-safe color combinations were examined using a psychological method, a paired comparison. Twenty students with normal color sensations ranging from ages 19 to 26 were recruited. They were instructed to look at two different colored rings simultaneously on the same background and identify which one enabled them to see better. When examining the relationship between the psychological rankings of color combinations and visual sensations, the visibility of each color combination was first scored by Thurstone’s paired comparisons technique. The visual sensations were then deduced by applying Weber-Fechner’s law to the luminance of the stimuli. We found that color combination ranking has a positive monotonic relationship with sensation magnitude. This indicates that the visibilities of color combinations can be rated by applying Weber-Fechner’s law to the luminance pairs of foreground and background colors.

Keywords: Visibility Rating, Achromatic Web Safe Color, Thurstone’s Technique, Weber-Fechner’s Law.

1. Introduction

Opportunities for the use of the World Wide Web (WWW) have increased in our daily lives due to the dissemination of the Internet, and the quest of web page usability becomes an ongoing important research topic. A major element of usability is accessibility [1], and much research on this has been conducted [2-5]. The WWW Consortium published the Web Content Accessibility Guidelines 2.0 for designing web pages with lower web accessibility barriers for people with disabilities [6]. Here, one of the accessibility elements is visibility, which is the condition or quality of being easily seen. Checkpoint 1.5 in the guidelines specifies that the foreground content should be easily differentiable from the background content for both auditory and visual presentations. In order to adhere to this checkpoint for the creation of web pages, some quantitative indexes are needed. However, these indexes have not yet been provided. There are only a few studies that have been conducted and have served web creators' needs as quantitative indexes of web page visibility [7]. Visibility is affected by many factors, such as target characteristics, the environment in which it is viewed, and the observers. Therefore, research on visibility is necessary in developing web pages, and color combinations of foregrounds and backgrounds are crucial factors in providing sufficient visibility.

In previous studies, we examined psychophysiological indicators, the latency and amplitude of event-related brain potential, P300, and a performance indicator, reaction time, in order to obtain quantitative indexes of web page visibility. We found that the significant differences in both of the indicators resulted from the difference between the high contrast color combinations and the low contrast color combinations [8, 9].

Since the investigation of all color combinations is extremely difficult to conduct, a model or an empirical formula for estimating color combination visibility is needed. In the present study, the visibilities of achromatic web-safe color combinations of foreground and background colors were examined using a paired comparison test [10]. Visual sensations were then deduced by applying Weber-Fechner’s law [11] to the stimuli’s luminances. Finally, the relationship between the psychological rankings of the color combinations and the visual sensations were studied.

2. Color combination visibility rated by a paired comparison

When looking into the visibility relationship between psychological data and physical data, it is first
necessary to estimate visibility. In this section, a psychological method is proposed to obtain subjective data regarding visibility.

Subjects are typically not good at making absolute judgments but are good at making comparative judgments. Thus, a paired comparison test, which is widely used in psychological research, was employed to produce subjective data regarding visibility. In this test, when two alternatives were presented, a subject made a decision about which one was closer to an internally defined standard. Since the two alternatives were viewed simultaneously, the comparisons could be made without making any absolute judgment. All of the alternatives were compared with each other to collect subjective data from all of the subjects.

Thurstone assumed that a subject makes a decision about a pair of alternatives based on the pair's value difference. Thurstone's technique [12, 13] can provide each alternative with the subjects' relative rankings. This technique was applied to the data of a subject's group. The group results were then compiled as follows.

Using the paired comparison results, the probability \( p_{jk} \) is calculated to indicate how often the subjects preferred the j-th object to the k-th object. This probability relates to the relative visibility degree. The probability distribution is assumed to be normal; therefore, the probabilities can be converted to z-values, which are values from a normal distribution with a mean of 0 and a standard deviation of 1.

Assuming that \( Z_{jk} \) is the score of the j-th object to the k-th object, its value can be obtained as follows:

\[
Z_{jk} = \begin{cases} 
  Z & \left( p_{jk} - 0.5 \geq 0 \right) \\
  -Z & \left( p_{jk} - 0.5 < 0 \right) 
\end{cases},
\]

where \( Z \) is the z-score. The visibility score of the j-th object can be obtained by the following equation,

\[
Z_j = \frac{1}{N} \sum_{k=1}^{N} Z_{jk},
\]

where \( N \) is the number of objects to be compared. This score is utilized to rate the visibilities of alternatives on an interval scale.

### 3. Visual sensation deduced by Weber-Fechner's law

Luminance is a physical quantity and brightness is a sensation quantity. Luminance alternations change the sensation magnitudes. The smallest variation in a noticeable stimulus is called the just noticeable difference (JND). Weber proclaimed that the JND bears a roughly constant relationship with the reference stimulus magnitude over a useful range. For example, a JND in luminance \( \Delta L \) leads to the constant ratio \( \Delta L/L \), which is called the Weber fraction. 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,

\[
S = k \cdot \log I + C \tag{2}
\]

where \( S \) is the sensation magnitude, \( k \) and \( C \) are constants that depend upon the kind of sense, and \( I \) is the stimulus intensity. Here, \( k > 0 \) due to the sensation magnitude increase that results from physical stimuli elevation. Eq. (2) describes the relationship between the magnitude of a physical quantity and the magnitude of a psychological sense.

When the intensity pair of a foreground color and a background color is the same, a subject cannot differentiate the sensation of the foreground color from the background color, Eq. (2) becomes

\[
0 = k \cdot \log I_b + C \tag{3}
\]

where \( I_b \) is the background intensity. Thus, the difference in the sensations a subject perceives from a foreground color and a background color is presented in the following equation:

\[
S = k \cdot \log I_f - k \cdot \log I_b = k \cdot \log \left( \frac{I_f}{I_b} \right) \tag{4}
\]

where \( I_f \) denotes the foreground intensity. Eq. (4) means that the ratio, i.e., a contrast, is better adapted to the sensations that a subject felt than to the physical luminance.

In this study, since achromatic web safe colors are utilized as visual stimuli, a main factor affecting visibility is the contrast between a foreground color and a background color. When the contrast is within a proper range in which a glare is not produced, formula (4) can be used to estimate the visual sensation from only the physical data, which is a pair of certain intensities.

### 4. Experiment

In this study, the visibilities of several achromatic web-safe colors were examined using the paired comparison test, and the visibility of each color combination was rated.

Twenty students (3 females and 17 males) with ages
ranging from 19 to 26 years (average 23.4) were recruited, and all had normal color sensations.

A visual stimulus was shown on a CRT display in sRGB mode, which is a calibrated RGB color space utilized to specify colors within the gamut of the color space in a device-independent way. Each stimulus is composed of three components, a background and two different colored Landolt rings lined up beside each other in a row (Fig. 1). The five representative achromatic web-safe colors used in the experiment are listed in Table 1. These web safe colors ensure that all visitors to a site can obtain the same experience on a wide variety of platforms.

In our test, each of the 60 stimuli, which were produced by considering the permutation of three components and the counterbalance of any possible position effects, was presented to each of the subjects in a random order. The subjects were instructed to look at two different colored rings and identify which one enabled them to see better. The time for making a decision was unlimited. Three timed tests containing 60 paired-comparison trials were conducted with a five-minute rest between consecutive tests. A total of 180 paired-comparison results were collected from each subject. The illuminance on a display screen was 100 lux under artificial lighting. The distance between a seated subject's eyes and the display screen was about 80 cm, and the view angle of the ring was 2 degrees.

5. Result
We use the term “positive” contrast when the luminance of a background color is higher than that of a ring color. “Negative” contrast is used when the luminance of a background color is lower than that of the ring color. Here, we define the $X$ value as the right side of Eq. (4) when $k = 1$, i.e., $X = \log(z_l/z_b)$. Fig. 2 respectively shows the relationships between the color scores and the $X$ values. Here, $BG$ is a background color code and the ring-color symbols are the same as given in Table 1. Each color was scored by Thurstone's paired comparisons technique, using 3600 paired-comparison results.

When $BG = \#000000$, i.e. black, all of the stimuli were “negative” contrasts. As the score increases almost linearly with the $X$ value, it is easy to estimate the relative visibility of a certain contrast using the difference between a background color and a ring in the luminance.

For the $\#666666$ background color, the closed circle represents a “positive” contrast and the other symbols denote “negative” contrasts. The color score increases with the $X$ value and the three “negative” symbols indicate that the linear increase is similar to that for the black background. As shown above, this figure demonstrates that it is possible to estimate the relative visibility by using the $X$ value.

For the background color $\#999999$, the closed circle and closed triangle are “negative” contrasts, and the other two symbols represent “positive” contrasts. In this figure, it is clear that the scores also increase with $X$, but the linearity cannot be confirmed because of the smaller number of symbols in both contrasts.

When $BG = \#CCCCCC$, all of the symbols except for the open circle are “positive” contrasts. Since the score of the open circle is not much larger than that of the gray diamond, this figure shows that the color scores do not always increase with the $X$ values.

For the white background, $\#FFFFFF$, all of the symbols are "positive" contrasts. The scores of the ring colors monotonically increase over the luminance range; however, it is not a linear increase. The slope of this curve and that of the $\#CCCCCC$ curve both gradually decrease with $X$. This result shows that high luminance colors, such as $\#FFFFFF$, tend to have higher scores than those of lower luminance colors even though their $X$ values are the same. It is also demonstrated here that the color scores do not always increase monotonically and linearly with $X$.

6. Discussion

<table>
<thead>
<tr>
<th>RGB code</th>
<th>Luminance (cd/m$^2$)</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>$#000000$</td>
<td>2.3</td>
<td>●</td>
</tr>
<tr>
<td>$#666666$</td>
<td>11.2</td>
<td>▲</td>
</tr>
<tr>
<td>$#999999$</td>
<td>22.4</td>
<td>●</td>
</tr>
<tr>
<td>$#CCCCCC$</td>
<td>44.1</td>
<td>▲</td>
</tr>
<tr>
<td>$#FFFFFF$</td>
<td>71.1</td>
<td>○</td>
</tr>
</tbody>
</table>

Table 1 Achromatic Web Safe Colors
Hira et al. reported that the significant differences of the latency and amplitude of event-related brain potential, P300, resulted from the difference between high contrast color combinations and low contrast color combinations [9] on the psychophysiological side, while Sclar et al. argued the action potential firing rate in the primary visual cortex of a cat increases in proportion to the contrast increase of a visual stimulus [14] on the neurophysiology side. In our experiment, the scores approximately increased with the X value, and this indicates the visibility rating of the achromatic web-safe colors depend on the contrasts between foreground and background colors on the psychological side. These results share certain similarities in that each index increases monotonically as the contrast increases in achromatic colors.

It is important not to overlook the existence of a lateral inhibition network. Lateral inhibition refers to the inhibition that neighboring neurons influence on each other. In a visual system, this process greatly increases the ability to respond to edges of a surface because neurons responding to the edge of a stimulus respond more strongly than neurons responding to the middle. The mechanism is that the neurons in the edge receive inhibition only from neighbors on one side, while, on the other hand, neurons stimulated from the middle of a surface receive inhibition from all sides. That is, the difference in the contrast between foreground and background colors is more emphasized in the boundary by this mechanism, and we therefore conclude that the result of our experiment is reasonable.

Consider how the visibilities are on the same background between the same values of Xs in "negative" and "positive" contrasts. Fig.2 shows approximately the same scores of #666666 and #CCCCCC in the same values of X on the background color, #999999, furthermore indicates the similar scores of #CCCCCC and #000000 on #666666 and those of #FFFFFF and #999999 on #CCCCCC. Therefore, it is reasonable to believe that the visibility is rated by the contrast between foreground and background colors in the achromatic colors and is almost irrelevant to whether a stimulus is a "negative" or "positive" contrast.

In Fig.2, we discovered that at the "negative" contrasts, the scores showed a linear increase with X. In other words, at the "negative" contrast, linear regression attempts can explain the relationships between the scores calculated with Thurstone’s method and the magnitude of the sensations obtained by using Weber-Fechner’s law. Furthermore, it is possible to calculate the relative visibilities of certain contrasts using regression lines. On the other hand, the linearity disappeared for the "positive" contrast. The scores of the "positive" contrast, however, represented upward convex increases. Thus, it is possible to estimate the relative visibilities of contrasts by using these curves. Since regression lines are no longer applicable, it is

Fig. 2 Visibility Scores and Visual Sensation
BG is a background color. See Table 1 for symbols representing ring colors.
necessary to define certain curves to fit the score increases when calculating visibility.

When we take these visibility characteristics into consideration, it is reasonable to find an empirical formula for representing the visibility changes in both the “negative” and “positive” contrasts simultaneously. The fact that each visibility alteration shows monotonic increase suggests that we are able to use a power function as an empirical formula and the exponent value of the power function is between 0 and 1 because there were no downward convex increases. The value of the exponent is 1 when the curve is a linear curve and the value of the exponent is less than 1 when the curve is upwards convex. In future work, we would like to calculate the parameters of power functions to obtain an empirical formula.

For young adults, in the experimental tests, we observed the monotonic changes of the visibility. Of primary interest in this study was whether healthy, older adults would be able to display the same characteristics as younger adults due to effects of normal aging on the visibility.

7. Conclusion

In this study, the relationship between the psychological rankings of color combinations and the visual sensations was examined. The achromatic web-safe color combinations were scored by Thurstone's paired comparisons technique, and the visual sensation was then deduced by applying Weber-Fechner’s law to the stimuli’s luminances. As a result, we discovered that the color combination ranking has a positive monotonic relationship with the sensation magnitude. This indicates that the visibility ratings of the achromatic web-safe color combinations depend on only the contrast between foreground and background colors and was made possible by applying Weber-Fechner’s law to the luminance pairs of foreground and background colors.

Visual functions decline with age, and easily accessible web sites are important for elderly people because in an aged society, many elderly people have harnessed the aforementioned information environment. Therefore, extensive studies are needed to investigate and catalog the visibility characteristics of elderly people.

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References


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