Study on Legibility of Characters for the Elderly
—Effects of Character Display Modes on Legibility—

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Abstract  It is more crucial than ever to consider the elderly when designing products. One of the important things to remember is the legibility of characters, since this influences the accessibility and usability of products. We studied the effects of character attributes on legibility using 70 subjects (60 aged 46–79 with no apparent ocular problems except presbyopia, and 10 aged 68–80 with cataracts). Thirty 10-key television remote control models were made. The characters on each were different, and were based on combinations of three attributes—height (5 levels), thickness (3 levels), and display mode (2 levels; positive: black characters on a white background, negative: white characters on a black background). Participants subjectively evaluated the legibility of the characters for each 10-key sample under two ambient illuminance conditions: 500 lx and 50 lx. They also performed paired comparisons on samples with the same height and thickness but different display modes.

Subjective data were analyzed using a three-way factorial ANOVA for character height, thickness, and display mode. Legibility was significantly affected by all factors for those without cataracts under both illuminance conditions, and the interaction between thickness and display mode was significant. A two-way factorial ANOVA was performed for height and display mode for each thickness. Legibility was, in general, better for thinner characters in negative mode and was better in negative mode under dark illuminance for those with and without cataracts. This tendency was more pronounced in the elderly (over 65 years old). Paired comparisons showed that legibility was better in negative mode under both illuminance conditions, especially with medium and thin characters, for those with and without cataracts.

Although there are few accounts of the effects of positive and negative modes in various existing guidelines, this finding would suggest that legibility can be enhanced by using the negative mode. J Physiol Anthropol 26(2): 159–164, 2007 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.26.159]

Keywords: universal design, legibility, positive display mode, negative display mode, elderly people, cataract

Introduction

Universal design refers to design practices to make products, systems, and environments usable for a greater number of people (Story, 1998; Vanderheiden, 2006). Activities to increase accessibility, to “allow use by as many people as possible,” and usability, to “make things easy to use by as many people as possible,” can be considered universal design. Japanese society is aging at a rapid pace and the elderly are becoming a force in the market, so the application of universal design concepts to product development is extremely important, and recently consideration has been given to the elderly and users with disabilities in various products. In the case of television sets, the remote control that serves as the main user interface requires high accessibility and usability. Of the various design elements, the legibility of the characters on the remote control is a factor that greatly influences its accessibility and usability. In addition to the font and the character height and thickness, the contrast between the background and character colors is an attribute that influences the legibility of the characters. Characters become easier to read as the contrast between the background and character colors increases (when the difference in brightness between the background and character colors increases). However, even with the same contrast, the background and character colors can be displayed using different combinations in two ways: a positive display mode that places a dark character color on a bright background color; or a negative display mode that places a bright character color on a dark background color. While there are various guidelines concerning character legibility, there are few accounts of the effects of positive and negative modes. This study looked at positive and negative display modes for remote control characters, and investigated them from the viewpoint of character legibility.
Methods

Test subjects

A total of 70 individuals participated in the tests. Of these, 60 individuals had no apparent ocular problems except presbyopia (group N), and 10 individuals had cataracts (group C). Group N comprised two groups: 30 individuals aged 46 to 64 and 30 individuals aged 65 to 79. There were 31 men and 29 women. Of the group N subjects, 39 participated in all of the tests. The 10 group C subjects comprised three men and seven women aged 68 to 80. All group C subjects participated in all of the tests.

Samples

The font used was the AXIS font, which has seven levels of thickness and both Japanese and English characters. Thirty samples that simulated TV remote controls were made using different combinations of five character height levels (2.5 mm, 3.5 mm, 4.5 mm, 5.5 mm, 6.5 mm), three character thickness levels (Light (AXIS Ultra Light), Regular (AXIS Regular), Bold (Axis Bold)), and two display mode levels (positive: black characters on a white background, negative: white characters on a black background) (Fig. 1). The characters printed on the samples included numbers, katakana (Japanese phonetic characters), and kanji (Chinese characters). The white characters and backgrounds had an equivalent brightness of N9.5, and the black characters and backgrounds had an equivalent brightness of N1, so the difference in brightness between the backgrounds and the characters was around 8.5 for both positive and negative display modes.

Test conditions and procedures

Two ambient illuminance levels were used: 500 lx, which approximates the light level of a living room in an ordinary household, and 50 lx, which approximates the light level of the inside of a theater room. Both values are the horizontal surface illuminance near the remote control surface. A chin support was used to regulate the viewing conditions, and the samples were presented on a stand at a viewing distance of 300 mm. For reference, evaluation was also performed under conditions of only 500 lx with the remote control held in the subject’s hand and the viewing distance optional, as in normal use.

Absolute evaluation: Groups were created of five samples with the same character thickness and display mode and character heights ranging from 2.5 mm to 6.5 mm. Within each group, the samples were presented in ascending order of character height, from left to right. The subjects verbally rated the overall easiness to read of the characters printed on each sample using a seven-point scale from “Very difficult to read” to “Very easy to read,” and these responses were recorded by the experimenter. The sample groups were presented in random order, and the number of subjects who evaluated the samples within each group in ascending or descending order of character height was counterbalanced. Figure 2 shows an
image of the absolute evaluation conditions.

Relative evaluation: Groups were created by arranging positive and negative mode samples with the same character thickness and character heights of 2.5 mm, 4.5 mm, and 6.5 mm side by side in pairs. All three pairs within a group were presented simultaneously, and relative evaluation was performed by having the subjects rate which of the sample characters were easier to read for each character height. A bipolar scale was used for the evaluation, with “about the same” in the center and three levels (very easy to read, easy to read, somewhat easy to read) on one side as the selection criteria. As in the absolute evaluation, the sample groups were presented in random order, and the evaluation order (ascending or descending character height) within each group was also random.

Results

The data were first analyzed using a three-way factorial ANOVA for character height, thickness and display mode. The character legibility ratings for group N under 500 lx of illuminance were analyzed for both fixed and optional viewing distances. All three factors significantly affected legibility under both fixed and optional viewing conditions, and the interaction between character thickness and display mode was also significant. In the following analysis, the viewing distance was fixed at 300 mm for all conditions.

An interaction was confirmed between character thickness and display mode, so character legibility under both illuminance conditions was analyzed for each character thickness using a two-way factorial ANOVA for character height and display mode (Table 1). Legibility was evaluated by all 60 group N subjects only for the “Regular” character thickness condition, and by 39 group N subjects for other character conditions. The results showed that the character height factor was significant ($p < .001$) for all conditions, and that in regard to the display mode factor, negative display mode offered significantly better legibility for “Light” character thickness under 500 lx conditions, and for “Light” and “Regular” character thickness under 50 lx conditions. Figure 3 shows the results for “Light” character thickness under 500 lx conditions and “Regular” character thickness under 50 lx conditions.

![Graph showing character legibility ratings for group N at 500 lx and 50 lx illuminance conditions.](image)

Table 1  Two-way ANOVA results for character legibility ratings for group N (subjects with no apparent ocular problems).

<table>
<thead>
<tr>
<th>Illuminance</th>
<th>Factor</th>
<th>Thickness</th>
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<tbody>
<tr>
<td></td>
<td>Height</td>
<td>Light</td>
</tr>
<tr>
<td>500 lx</td>
<td>Display mode</td>
<td>***</td>
</tr>
<tr>
<td>50 lx</td>
<td>Display mode</td>
<td>***</td>
</tr>
</tbody>
</table>

*** $p < .001$, ** $p < .01$, * $p < .05$

![Graph showing character legibility ratings for group N at 50 lx illuminance conditions.](image)

Figure 4 shows some of the relative evaluation results for positive and negative mode samples with the same character height and thickness. 39 group N subjects performed relative evaluations for all character thickness conditions. In order to investigate which display mode was easier to read, a 95% confidence interval of the ratings was obtained and then examined to determine whether the upper confidence interval limit value was smaller, or the lower limit value larger, than the equality rating of “4”.

![Graph showing relative evaluation results for positive and negative mode samples at 50 lx illuminance conditions.](image)
that for all character heights, negative modes had significantly better legibility for “Light” and “Regular” character thicknesses under 500 lx conditions, and for “Regular” character thicknesses under 50 lx conditions. However, in relative evaluations where positive and negative display mode samples with the same character height and thickness were presented at the same time, positive display mode conditions tended to provide better legibility with “Bold” characters that were 2.5 mm in height.

To further investigate the effects of different display modes, group N was divided into a group 64 years old and younger (U64) and a group 65 years old and older (O65) for separate analyses. Table 2 shows the results of two-way factorial ANOVAs for character height and display mode, and Figure 5 shows the character legibility ratings for the “Regular” character thickness under 50 lx conditions. Compared to the U64 group, the difference in ratings between positive and negative modes for “Regular” character thicknesses was more pronounced for the O65 group, with negative modes providing better legibility. Specifically, this difference was significant at 50 lx, and tended to be significant ($p = .075$) at 500 lx.

The effects of display mode on character legibility for those with cataracts were also investigated. Character legibility ratings by subjects with cataracts (Group C) were analyzed using a two-way factorial ANOVA for character height and display mode (Table 3). The difference in legibilities between positive and negative display modes was significant for “Light” character thicknesses under 50 lx conditions (Fig. 6), and tended to be significant ($p = .061$) for “Light” character thickness under 500 lx conditions and “Regular” character thickness under 50 lx conditions.
Discussion

As aging progresses, the eye lens becomes cloudy and yellowed, and loses its elasticity, causing the adjustment function of the lens to deteriorate. In addition, sensitivity to visual contrast also tends to decrease with aging, so things become difficult to identify unless the contrast and boundary lines are sharpened. This is because sensitivity to glare increases with aging. Lenses that have become thicker and yellowed scatter light and impede visual function. As a result, the elderly are susceptible to the effects of adverse conditions (Stuent and Offner, 2001; Numaga, 2003). Group N test subjects were divided into one group 65 years old and older (O65) and another group 64 years old and younger (U64), for each group to be analyzed separately. The results showed that the negative display mode tended to provide better legibility overall for the O65 group compared to the U64 group, and that this tendency became more pronounced under dark conditions. This is thought to suggest that the negative display mode is effective when users with deteriorated visual functions must recognize characters in particularly dark environments.

Cataracts are sometimes seen in people with diabetes and other illnesses, but they are also a product of the aging process. According to statistics issued by the Ministry of Health, Labour, and Welfare in 2002, it was estimated that approximately 1.3 million people were suffering from cataracts (Statistics and Information Department, 2002). When a person suffers from cataracts, the eye lens becomes cloudy, causing vision to deteriorate. The manner in which the eye lens becomes cloudy differs for each person, so the symptoms vary, producing such descriptions as “difficulty seeing in slightly dark locations,” “objects appear out of focus or blurry,” and “outdoor and backlit conditions are too bright.” (Numaga, 2003). The difference in how people with cataracts view positive and negative mode characters was investigated. The number of subjects was small, so significant differences could not be detected for some conditions, but the effects of display mode on legibility are thought to have approximately the same overall tendencies as for group N. These results are thought to suggest that negative display modes may also provide better legibility for users with cataracts in the same manner as for group N users.

Guidelines for characters used on industrial products and printed material recommend increasing the contrast between background and character colors to enhance legibility. However, almost no guidelines remark in detail on the effects of positive and negative display modes. There is some literature stating that positive display modes are easier for the elderly to read, but these tests were conducted for kanji (Chinese characters), hiragana (Japanese cursive phonetic characters), and English letters (Misaka and Hiza, 1992). In the ISO 9241-4 “Ergonomic requirements for office work with visual display terminals—Part 4: Keyboard requirements,” dark characters on a light background are recommended for keyboards (International Standards, 1998). The method for estimating character minimum size prescribed by JIS S 0032 “Estimation of minimum legible size for a Japanese single character,” issued in 2003, assumes a positive display with black characters on a white background. Negative modes with white characters on a black background are noted as an issue for future investigation (Japanese Industrial Standard, 2003).

This study focused on subjects who were middle-aged or older, and compared legibility for the two display methods with the highest contrast: positive display modes using black characters (approx. N1) on a white background (approx. N9.5), and negative display modes using white characters (approx. N9.5) on a black background (approx. N1). The results showed that, in general, negative modes provided better legibility for thin characters and in a dark environment. In addition, this tendency was more pronounced for those aged 65 or older, and similar tendencies were also confirmed for the subjects with cataracts.

The effects of positive and negative display modes on legibility for background and character colors with
intermediate contrast (for example, a difference in brightness of around 5) require further investigation. However, the results of this study suggest that legibility can also be enhanced by negative display modes with high contrast, which should contribute to increasing the degree of design freedom for applications such as characters printed on products.

References


This article was presented at the 8th International Congress of Physiological Anthropology, 2006 (ICPA 2006), in Kamakura, Japan.

Received: September 30, 2006
Accepted: November 7, 2006
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