Influences of Contrast Sensitivity on Text Readability in the Context of a Graphical User Interface

Benjamin A. Parker

Dr. Lauren F. V. Scharff

Stephen F. Austin State University

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Abstract

Three visual factors involved in the readability of text within a Graphical User Interface (GUI) were investigated: age related decline in contrast sensitivity, degree of contrast and contrast polarity. Degree of contrast was manipulated among four levels: high, medium-high, medium-low, and low; contrast polarity was varied from negative to positive polarity. Subjects included 14 young adults (18-25 yrs) and 14 older adults (45+ yrs). Participants' reaction times to identify target words embedded in paragraphs of text were measured. Participants also completed a subjective report of their contrast preferences, which were later compared to experimental findings. High contrast levels and negative contrast were anticipated to produce the fastest RTs. Younger adults were expected to perform better than older adults due to normal age-related changes in the visual system. More importantly, the three factors were expected to interact; RTs for older adults were expected to be slower than those for younger adults in low, positive contrast conditions. Results (Figures 1 and 2) indicate that high contrast and negative polarity do produce faster RTs, and RTs for older adults were shown to be significantly slower than those of younger adults. Furthermore, level of contrast and polarity were shown to interact, such that only at the highest contrast level does negative polarity differ from positive polarity. Finally, the significant interaction between age and contrast polarity suggests that polarity influences RT only for the older age group. Experimental findings and subjective reports were not systematically related.

*For a summary of additional research over the readablity of websites comparing different font types, word styles, and foreground/background color combinations, please click here.

Introduction

Recent developments in operating systems as well as Internet and World Wide Web access have given users more powerful and easier means of manipulating or interacting with information. These developments have often focused on improving the content or visual appeal of a Graphical User Interface (GUI). Such interfaces place a heavy emphasis on vision and perceptual abilities such as dynamic vision, visual search and contrast sensitivity. Given this emphasis, it is important to understand the role vision plays in effectively communicating information. Individual differences among users can affect the way they perceive the visual features of a GUI such as text, contrast, and color. Older adults, for instance, have different visual capabilities than those of younger adults. These differences influence perception and can affect important factors in communication such as the readability of text. An understanding of the individual differences in vision associated with a GUI is vital to developing more efficient and accessible interfaces.

Contrast polarity may influence how well the stimuli of a GUI are perceived. Positive contrast refers to light shades of text on darker background shades; negative contrast refers to dark shades of text on lighter background shades. Lalomia and Happ (1987) assert that displays which use negative contrast are less effective than those that use positive contrast; thus, maximum flexibility in creating effective GUIs can be achieved with light text on dark backgrounds. On a similar note, Horton (1990) suggests that positive contrast be used for online documents in order to enhance fine lines or subtle colors. However, such assertions are based on research that does not control text and background luminance ratios, and other evidence suggests the opposite recommendation. Negative contrast has been demonstrated to reduce errors and improve response times to visual stimuli (Bauer and Cavonius, 1980). Similarly, negative contrast has been found to improve legibility (Van Nes, 1986). Reading experience along with halation (the tendency of white characters or text to "glow" when presented on a black background) may account for the beneficial influence of negative contrast.

Degree of contrast is perhaps one of the most influential factors on the readability of text within a GUI. Lalomia and Happ (1987) suggest that the least effective foreground/background combinations are those with low contrast, such as light text on light backgrounds. High contrast foreground/background combinations, such as light text on dark backgrounds, increase effective presentation. Shurtleff (1982) also asserts that legibility, and subsequently readability, depends on adequate text/background contrast. Response time and accuracy are improved as text/background contrast is increased (Buck, 1983).

Even if degree of contrast is held fixed, not all individuals are able to equally perceive the displayed information. Thus, contrast sensitivity is an influential factor in the perception of contrast and related stimuli in a GUI . One's contrast sensitivity determines the extent to which visual stimuli that differ in spatial frequency as well as contrast are perceivable. In general, humans best perceive low contrast at intermediate spatial frequency levels. High contrast is needed in order to perceive extremely low or extremely high frequencies. Contrast sensitivity, along with other visual functions, changes as the eye ages due to senescence, the pattern of changes associated with the normal aging process. Especially at high spatial frequencies a decline in contrast sensitivity is apparent for older adults (Owsley, Sekuler and Siemsen, 1983), with frequencies of 2 cycles/degree and higher being sufficient to produce differences in contrast sensitivity between younger and older adults. Owsley et. al, found that significant declines in spatial contrast sensitivity begin between the ages of 40 and 50. Older adults, therefore, require more contrast in order to see stimuli with intermediate or high spatial frequencies.

The current research examines the influences of contrast level, contrast polarity, and age on the readability of text in a GUI and, more importantly, how these three factors interact to influence perception. Because individuals of all ages perceive high spatial frequencies better at high contrast and because response times and accuracy have been shown to improve with higher contrast (Buck, 1983), high contrast conditions are expected to produce the fastest reaction times and low contrast the slowest reaction times. Due to the influences of prior reading experience and halation, negative polarity is expected to produce faster responses than positive polarity for all age groups. Given that the text of a GUI is of moderate to high spatial frequency and that spatial contrast sensitivity declines with age, older adults (45+ years) should show an increase in response times for low contrast conditions when compared to younger adults (18-25 years).

In their investigation of effective foreground/background color combinations, Lalomia and Happ (1987) compared experimental results to participants' self-reported preferences. This approach seems particularly appropriate to the study of human factors and may provide a useful supplement to the research at hand. Thus, a subjective report of preferences is included in the current research in order to investigate the relationship between reported preferences and measured reation times to the various contrast conditions.

Method

Participants

Subjects consisted of 14 young adults (M = 19.29 yrs) and 14 older adults (M = 52.32 yrs). Participants were required to be between the ages of 18 and 25 for the young group or 45+ for the older group, and to have normal or corrected to normal visual acuity.

Apparatus

The experiment was developed and run using B/C Power Laboratory (a Macintosh-based experiment design package). Experiment execution was carried out on Macintosh Power PC 7200/120 computers. Non-interlaced Apple monitors were used on all systems. Controls for contrast and brightness were set to their default positions.

Stimuli

Four contrast levels were used: high, medium-high, medium-low, and low. Each level of contrast was configured to have either negative (black text on light backgrounds) or positive (white text on dark backgrounds) contrast polarity. Thus, there were eight possible stimuli conditions. Exact settings for each condition can be found in Table 1. The default contrast setting for Netscape Navigator was determined to have a value of 0 for text and 73 for background (as in the medium-high contrast condition).

Table 1: Text and background brightness values

Degree of Contrast

• **Polarity**	• **High**	• **Medium-High**	• **Medium-low**	• **Low**
• **Positive**	• 100, 0	• 100, 27	• 100, 50	• 100, 73
• **Negative**	• 0, 100	• 0, 73	• 0, 50	• 0, 27

Note: The higher the value is, the lighter the shade is (white=100, black=0)

Font type was set to Times New Roman (Netscape default) with a point value of 12. Ten excerpts of text were used in each of the eight stimuli conditions; these excerpts were drawn directly from previous research endeavors (Hill & Scharff, 1997). In order to keep readability consistent across the text stimuli, selection of the current ten excerpts was based on three criteria: word count, Flesch Grade Level (FGL), and ranking on the Flesch Reading Ease Scale (FRES). The text stimuli were, on average, written at an 8th grade level with an overall standard reading difficulty.

Embedded within each of the text stimuli was a target word (circle, square, triangle, diamond, or star) corresponding to an actual shape at the bottom of the monitor display. The ten text stimuli were randomly presented within all of the eight contrast conditions for a total of 80 trials.

Procedure

Sixteen practice trials preceded the eighty experiment trials. For each trial, participants were required to search for a single target word (square, circle, triangle, star, or diamond) within the text and, once found, to indicate that word by selecting a corresponding shape on their display using a mouse pointer. Participants were instructed to perform this task as accurately and quickly as possible. Stimulus conditions were randomly presented during the experiment.

Following completion of all trials, participants completed the subjective portion of the experiment. On-screen examples of the contrast levels were given, and participants indicated the most and least preferred contrast levels for each polarity condition. Preference responses on the subjective test were paired with trial results for later analysis and comparison.

Design

A 2x4x2 mixed design was employed using the variables Age (young, old), Level of Contrast (high, medium-high, medium-low, low), and Polarity (positive, negative). Between-subjects assignment was used for Age, and within-subjects assignment for Level of Contrast and Polarity. Reaction time to the target word in each condition was the dependent variable used to imply legibility. For each participant, median reaction times were calculated for correct target responses in each stimulus condition. A participant's data was not included in final analyses if associated with greater than a 10% error rate.

Results

Particpant medians obtained for each condition were used to perform a three factor analysis of variance. The findings are discussed in detail below.

Significant differences between the various levels of Level of Contrast (High, Medium-high, Medium-low, Low) were revealed (F=25.58, p<.01). High contrast produced the fastest reaction times (M=12190 ms) and low contrast produced the slowest reaction times (M=17763ms). Subsequent comparisons (Tukey HSD) indicate that all contrast levels are significantly different from one another except for medium-high contrast when compared to low contrast or medium-low contrast.

The two levels of Polarity (negative, positive) were also significantly different (F=19.35, p<.01), with negative contrast polarity producing faster response times than positive polarity, (Means = 14426 ms and 16220 ms, respectively). A significant main effect was also indicated for the two age groups (F=6.98, p<.05) with the older group responding more slowly (M=16737 ms) than the younger group (M=13911 ms).

The above main effects are meaningful, but must be qualified by the two significant interactions that were also found. The Level of Contrast by Polarity interaction (F=7.505, p<.01) revealed that positive and negative polarities only produce significantly different reaction times at the highest level of contrast. This interaction is shown in Figure 1.

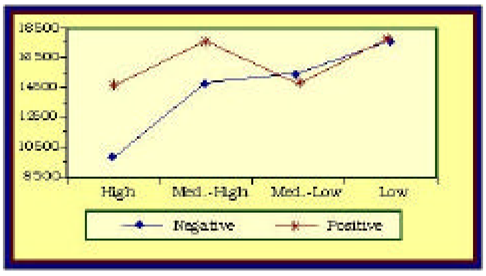

Figure 1. Interaction of amount of contrast and contrast polarity. Y-axis shows response time in ms. Polarity is significantly different only at the highest contrast level.

The analysis of the Age by Polarity interaction (F=4.708, p<.05) indicates that positive contrast only produces significantly slower RTs for the older age group; it does not significantly affect the reaction times of the younger viewers. Age and Contrast do not interact nor is there a significant 3-way interaction. Figure 2 shows the data pattern for all three variables.

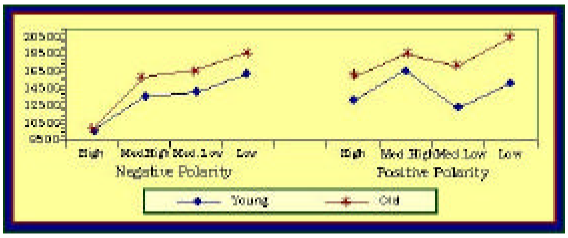

Figure 2. 3-way interaction between age, level of contrast, and polarity. Y-axis shows response time in ms. This is not a significant interaction, but it summerizes the data very well.

Finally, correlations (Pearson product-moment coefficients) were calculated between the objective data (medians RTs for each condition) and the four subjective preference categories: (1) most preferred negative contrast level; (2) least preferred negative contrast level; (3) most preferred positive contrast level; (4) least preferred positive contrast level. No correlation was found between a participant's experimental reaction time and his or her contrast preference (r=0.09, 0.05, -0.10, and -0.05, respectively).

Discussion

From the results it is clear that the level of contrast used in a GUI has a strong influence on the readability of graphically presented text. High contrast appears to be the most efficient to communicate graphically presented material; medium-high, medium-low and especially low contrasts appear to be less efficient. It is also apparent that contrast polarity influences the readability of text. In particular, black text presented on light backgrounds (negative contrast) appears to communicate information faster than white text presented on dark backgrounds (positive contrast). An individual's age also plays a role in how well graphically presented text is communicated, with older adults tending to perform more slowly than younger adults.

Most importantly, the readability of a graphical user interface is influenced by interactions between the above variables. For example, white text presented on a black background (high-contrast, positive polarity) slows reaction times compared with black text on a white background (high-contrast, negative polarity). At the other contrast levels, polarity makes no significant difference. Of equal interest is the finding that the effect of polarity is only significant for the older age group.

Because the text stimuli of a typical interface is of relatively high spatial frequency, it is not surprising to learn that high contrast produces the best results and low contrast the worst results in terms of GUI readability. Meanwhile, the observed difference in performance between older adults and younger adults can probably be explained by senescent changes in the visual system. Specifically, the normal age-related decline in contrast sensitivity, which begins between the ages of 40 and 50, impairs the perception of higher frequencies in older individuals. Further, as the eye ages, less light reaches the retina, which decreases available contrast for the system. Older adults are, therefore, less able to perceive low contrast conditions than younger adults, especially when they include high spatial frequencies.

The main effect of polarity may be explained by prior reading experience. Most printed material (e.g. books, newspapers, etc.) and many GUI interfaces use negatively configured text/background combinations; the introduction of media which present light text on dark backgrounds has been a fairly recent phenomenon. Thus, the increase in performance observed with negative contrast may be due to an individual's reading experience. However, although it is also slower in other conditions, white text presented on a dark background (positive contrast) only significantly impairs readability of text in the highest contrast condition. This is consistent with the hypothesized "glowing " effect of halation, which impairs readability by making graphically presented text appear less distinctive and, therefore, less legible. At low and medium contrast levels, halation is reduced; only with high contrast is the characteristic effect of halation seen.

Positive contrast polarity slows the performance of older individuals but does not seem to systematically influence the performance of younger adults. As mentioned above, normal changes in contrast sensitivity reduce the capacity of older adults to perform visual tasks in comparison to younger adults. Additional changes may explain the age-related effect of polarity: older adults also develop an increased sensitivity to glare and refracted light. Thus, when presented with visual stimuli which produce glaring or glowing effects, older adults will show less efficient processing than younger adults. Because of the "glowing" effect produced by halation, positive contrast is prone to produce the precise conditions under which older individuals are visually disadvantaged.

The relationship between an individual's most or least optimal contrast condition and his or her preferred contrast condition is not clear at this point: there appears to be no systematic relationship between performance and preference. In other words, individuals do not show their best performance in conditions they consider to be most preferable.

Generally speaking, it can be said that GUI readability and accessibility may be improved with the proper choice of contrast conditions. Because individual differences exist in GUI readability no universal set of conditions can provide every user with optimal access. However, it would appear that black text presented on a white background is the best choice for most users. When considering the needs of individual users, it is important to realize that older users have a much narrower range of visual function, and that this acts to reduce readability under contrast conditions which pose no difficulty to younger users. Of additional practical concern is that readability of text is significantly slower for all viewers when presented with medium-high contrast than when presented with high contrast, and the medium-high contrast level is used as the default setting for at least one popular web browser. (However, note that Hill and Scharff (1997) found mixed results regarding the comparison between high and med-high contrast on readability.)

Declines in performance are also important when one considers the cumulative impact that they may have on a user's efficiency in performing tasks within a GUI. For example, under positive contrast older individuals take, on average, 2.6 seconds longer to identify a text target than if the target was presented in negative contrast (~12% slower). Multiply this deficit by the innumerable visual scans and searches a typical user performs while reading the text of a GUI such as an online document.

In conclusion, although the ultimate decision to use a particular contrast configuration may often be based on preference rather than empirical evidence, the findings of the current type of research will be of particular importance for the future development of digital media. As graphical user interfaces become more complex and demanding of the visual system, and as the typical user becomes older (a result of the "baby-boom" generation) the need to understand factors involved in GUI readability (e.g. age related declines in contrast sensitivity, contrast level and contrast polarity) will continue to increase.

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