An Exploratory Study of Visual and Psychological Correlates of Preference for Onscreen Subpixel-Rendered Text

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Font-rendering technologies play a critical role in presenting clear and aesthetic fonts to enhance the experience of reading from computer screens. This article presents three studies investigating visual and psychological correlates of people's preferences toward different onscreen text enhancements such as ClearType developed by Microsoft. Findings suggested that (a) people's acuity and hue sensitivity were two major factors that affect their preferences to ClearType's color filtering of subpixels on fonts, and (b) specific personality traits such as disagreeableness also could correlate with people's impressions of different onscreen text enhancements that were used. These empirical data would inform digital typographers and human–computer interaction scientists who aim to develop better systems of onscreen reading.

Introduction

Reading is the most important task that people perform on computers. It is the core task not only in reading news and other content on the Web but also in composing office documents and spreadsheets as well as communicating via e-mail and text messaging on mobile phones. The amount of time we spend reading from fixed and mobile computers is only

growing. Nearly everyone agrees that reading from computers is not as pleasant as reading from a beautiful leather-bound book or from a glossy, well-designed magazine. Research has shown, over two decades, that reading performance from computers has been inferior to that from hard copy (e.g., Gould & Grischkowsky, 1984). The goal of this project is to improve the experience of reading from computers, and the goal of our research is to understand how selected perceptual and personality variables may correlate with user preference for subpixel rendered text.

A lot of technology is involved in placing letters on a screen. In the 15th century, Gutenberg automated the process of book making by creating reusable punches that imposed letters on a page. Modern computer fonts use high-resolution outlines of letters that are scaled down to the desired size. Publishing systems use these outlines to replicate what Gutenberg accomplished centuries ago, without the lead-poisoning problems. The task of reading from paper tends to be easier because paper resolutions of 1,200 or 2,400 dots per inch (dpi) are commonplace. Screen resolutions are not nearly as high.

There are few examples of Cathode Ray Tube (CRT) displays with resolutions greater than 100 dpi, and 72 dpi was the most common resolution throughout the 1980s and early 1990s. Liquid Crystal Displays (LCD) have become the most popular kind of display this decade because they are thinner, lighter, and consume less power than do CRTs. LCDs also have provided modest resolution improvements over

CRTs. While most stand-alone LCD monitors have resolutions less than 100 dpi, it is common to find laptops with 117 or 133 dpi. Some phones have resolutions up to 200 dpi (with Apple's iPhone at 160 dpi). Although these improvements provide noticeable benefits to onscreen reading, the quality of onscreen letters still has not yet reached that of print (Larson, 2007). To bridge such a hardware gap in resolution between computer screens and paper, software enhancements offer an alternative solution to improve onscreen text quality.

Many software-driven enhancements have been improving text quality on low-resolution computer displays. The three main directions that digital-text developers have taken to improve text for low-resolution computer displays are font design, font hinting, and rendering technologies. Some new font designs, such as Verdana and Georgia, were designed specifically for screens. These designs attempt to eliminate the use of hairlines that could be equal to a small percentage of the width of a pixel, and minimize the use of round and diagonal strokes that are difficult to display on a square-oriented grid.

Font hinting, the second thrust, involves making changes to the letter outlines themselves to fit the pixels that are available for a letter. The most basic hinting involves making sure that the heights and stroke weights of letters will always round to the same number of pixels. It was once common for the two vertical strokes in the letter *H* to have different weights (i.e., widths) to improve its readability within the constraints of low-resolution displays. For example, the left stroke would be 2 pixels wide, and the right stroke 1 pixel wide. However, mismatches in symmetry like this are noticeable, distracting, and reported to be ugly (e.g., Larson, 2007).

Rendering technologies comprise a third area of development for improving text quality. Black-and-white rendering is the simplest method. Each letter outline is placed on top of the given pixel grid. The pixel is turned black (assuming a light background) if the center of the pixel falls inside the outline, and white if the center falls outside of the outline. This method provides acceptable results when combined with font hinting. Black-and-white rendering is the default font rendering at most text sizes in Microsoft's Windows XP operating system. Anti-aliasing is another kind of rendering. Instead of making a binary decision if the pixel is inside or outside of a letter outline, each pixel is divided into four or more virtual pixels. If half of the virtual pixels fall inside the outline, then the pixel is set to a half-gray. This technique has the benefit of more accurately representing the letter outline, but with some loss of contrast. This is the default rendering in many Adobe products and in Windows XP at larger point sizes.

Microsoft's ClearType technology is the most recent advance in rendering technologies. ClearType leverages the underlying hardware structure to gain extra resolution on LCDs, such as laptop screens, Pocket PC screens, and flat-panel monitors (Betrisey et al., 2000). A single square white pixel on an LCD screen can be seen under magnification as three separate, colored, rectangular pixels: red, green, and blue. Humans see white when all three are turned completely on, gray when all three are turned partially on, black when all three are turned off, and different colors when one colored pixel is on more intensely than the others. ClearType works by treating these colored, vertical, rectangular *subpixels* as spatial units that are finer than the entire pixel.

A side effect of getting extra resolution from subpixels is that the transitions between the inside and outside of an outline around the letter become colorful. To overcome this colorfulness, the S-CIELAB model of human color vision was used to predict a smoothing filter that would allow as much of the spatial accuracy while minimizing the perception of color (Platt, 2000). The model recognizes that human perception is most sensitive to error in the luminance channel, less sensitive in the red/green color channel, and least sensitive in the blue/yellow color channel. Thus, the filter predicts that inaccuracies in the blue/yellow color channel are more acceptable than are inaccuracies in the luminance channel.

While ClearType as seen in Windows Vista attempts to select the best trade-off, there are other possible ClearType-based renderings. For example, it is possible to make a version of ClearType that optimizes for spatial accuracy to get the best letter shapes possible. This version is perceived as being very colorful. It is also possible to optimize for color accuracy and completely remove the color, but this rendering tends to be perceived as more blurry. This colorless version resembles traditional gray scale, but is asymmetric because it is built for vertically oriented subpixels. This is advantageous for Latin text, which has many more vertically oriented features than horizontally oriented features, but not so for English.

Adding to two decades of investigation of the readability of text from computer screens (see Dillon, 1992; Gould, Alfaro, Finn, Haupt, & Minuto, 1987; Hill, 1999), several recent studies have investigated performance differences with ClearType font rendering on word recognition (e.g., Aten, Gugerty, & Tyrrell, 2002; Gugerty et al., 2004), in the comprehension of sentences (Edmonds, Stephenson, Gugerty, & Tyrrell, 2003), in the reading of running prose (Tyrrell, Pasquale, & Aten, 2001; Slattery & Rayner, in press), on office worker application productivity (Dillon, Kleinman, Choi, & Bias, 2006), and on programmer productivity (Bias, Williams, Chung, & Burns, 2005). On average, these studies have shown a small, but consistent, effect on performance (on the order of 5.6 to ~7.2% faster in scanning and text seeking) and a consistent effect on satisfaction (with ~85% of test participants preferring text in ClearType); people tend to prefer onscreen text in ClearType rendering to black-and-white rendering (Bias et al., 2005; Dillon et al., 2006).

But while there is a consistent and large majority of adult readers who express a preference for the ClearType text, it is not unanimous; there is a consistent and adamant minority who explicitly do not like ClearType text. Who are these people? What is it about them—their visual system, their psychological make-up—that causes a preference for black-and-white text rendering? Answering these questions will inspire new rendering techniques that will improve onscreen text quality for all readers.

Dillon et al. (2006) found that ClearType was preferred by approximately 80% of test participants, across a variety

of fonts, type sizes, and lengths of test stimuli up to a few paragraphs. In a second study, addressing the effects of ClearType on user performance in simple office tasks (Dillon et al., 2006), similar preference data were obtained. However, preference, a subjective evaluation, does not always parallel performance; users do not necessarily perform better with the materials or tools they prefer (Nielsen & Levy, 1994), so there is value in obtaining performance data as well.

In addition, Aten et al. (2002) found that user-preference data often served as an independent indication of the participant's first impression of ClearType that is disassociated with the performance data. Therefore, there must be other unexplored factors that influence people's preferences for ClearType or different onscreen text enhancements.

This article aims to investigate visual and psychological correlates of people's preferences for ClearType. One initial goal of this study is to gather user-preference data with a large and representative sample to see how this ClearType preference is distributed in different demographic categories. Another explicit goal is to look deeper into these preference data and address the hypothesis that those who do not prefer ClearType comprise a distinct subgroup with shared visual-system or psychological characteristics.

So which characteristics should we test? Platt (2000) addressed the trade-off between color accuracy and spatial accuracy with subpixel rendered text. Color sensitivity and visual acuity are the obvious human measurements of this trade-off. Age is highly related to visual acuity. On the psychological side, another vision scientist, James Sheedy, suggested to us that the "sharpeners/levelers" distinction (Ehrman & Leaver, 2003) might be important in the preference for subpixel rendering of online text; in addition, we administered a Big 5 psychological test of personality (Gosling, Rentfrow, & Swann, 2003) simply to explore other possibilities.

Research Questions

Four specific questions were addressed in this study:

- Do different demographic categories such as age differentially predict user preference for ClearType?
- Does preference for ClearType change with different choices on the color accuracy versus spatial accuracy trade-off? Does preference for different typefaces interact with rendering technologies?
- Do physiological differences such as color sensitivity and visual acuity predict ClearType preference?
- Do personality differences predict ClearType preference?

Three studies were conducted to address these questions. All three studies examined the same version of subpixel-positioned ClearType with different gray scale, color, or special variables set up for evaluation. The first study was a pilot study undertaken to determine if there were any indications of correlations between preference for ClearType and physiological variables. The second study collected a large sample of ClearType preference data along with demographic data. The third study investigated the correlation between ClearType preference and visual acuity, color sensitivity, and personality among users from the second study who did *not* prefer ClearType.

Study 1: Pilot

Methods

Ten participants (mean age = 20 years, $SD = 2$ years; 6 males, 4 females) were recruited for this study. All participants were screened to self-report having 20/20 natural or corrected visual acuity and good color vision.

Materials

Text samples were displayed on a 106-dpi SGI LCD display. The text string consisted of an English sentence that contained every letter of the alphabet (i.e., "The quick brown fox jumps over the lazy dog"), taking up two lines, followed by seven lines of faux Latin text with character properties similar to English. Participants were shown text samples from six kinds of rendering: Two are the default rendering in Windows XP and Windows Vista, and the other four are variants of ClearType that are rare, but available as options in a new graphics platform. The six variants are: (a) black-and-white, the rendering default for Windows XP; (b) asymmetrical gray scale ClearType, a variant that minimizes color error and accepts greater spatial error; (c) partially gray scale ClearType, a less extreme form of the gray scale ClearType that allows less color error; (d) default ClearType, the rendering default for Windows Vista, a trade-off between color and spatial error; (e) partially colorful ClearType, which accepts more color error and a small amount of spatial error; and (f) colorful ClearType, a variant than minimizes spatial error. In all text samples, 10-point Verdana was the font used.

Procedure

Each participant completed four tasks. The first task was a preference test where participants were shown four repetitions of each possible pairing of the six text samples, side by side, and asked which text they would prefer to read for a long document. All items were randomized and appeared as the left option half of the time. Participants were required to choose the left or right text sample with the 1 or 2 button, respectively, on the keyboard. The second task was the Farnsworth–Munsell 100 (FM 100) hue color sensitivity test (Farnsworth, 1957), a test where participants "arrange four sets of precisely colored caps in order from one hue to another. The caps differ from one another subtly, so that each wrong placement reveals a different type of color deficiency" (FM 100 Hue Color Vision Test, 2009). The third task was a software version of the Bailey–Lovie visual acuity test (cited in Keirl & Christie, 2007) taken from a distance of 4 m, a standard test of visual acuity measuring the smallest letters a person can see from a certain distance. The fourth task was a color-sensitivity test based on the Bailey–Lovie visual acuity test, but employing letters with reduced contrast. Both the

TABLE 1. Study 1 results: Average number of four pairwise preferences of the left-hand column rendering, in comparison with the top-row rendering, of a possible score of 4.

	Black-and-white	GrayScale ClearType	Partially Gray	Default ClearType	Partially Colorful	Colorful ClearType
Black-and-white	–	0.82	0.55	0.45	1.18	1.82
GrayScale ClearType	3.18	–	2.00	1.36	2.45	3.09
Partially Gray	3.45	2.00	–	1.73	3.18	3.27
Default ClearType	3.55	2.64	2.27	–	2.82	3.18
Partially Colorful	2.82	1.55	0.82	1.18	–	2.82
Colorful ClearType	2.18	0.91	0.73	0.82	1.18	–

visual acuity test and contrast sensitivity test were conducted with the software Test Chart 2000 by Thompson Software.

Results

The preference data showed a strong preference for ClearType rendering over black-and-white rendering. Table 1 shows the average number of times that each item was selected over the comparison. This table shows the average number of times that the item in the left column of the table was selected over the item in the top row of the table. For example, the default ClearType text sample was chosen over the black-and-white text sample 3.55 of 4 times (89%).

Color sensitivity was measured using the FM 100 hue test. We used the standard error scoring method where the farther each chip is placed from its optimal location, the greater the participant's error score. Small numbers mean greater color sensitivity. Per the FM 100 Hue Test manual (1957), "About 16% of the population (exclusive of color defectives) has been found to [have] . . . total error scores of 0 to 16. This may be taken as the range of superior color discrimination." More recent normative data (Kinnear & Sahraie, 2002) have shown that 5% of the people between ages 16 and 39 years have a score of 9.0 or less.

Visual acuity was measured in LogMAR units with the Bailey–Lovie visual acuity test from a distance of 4 m. A LogMAR score of 0 is equivalent to the gold standard of 20/20 vision. All participants in this study averaged better than 0, and some much better.

Contrast sensitivity also was measured from a distance of 4 m with the same procedure used for measuring visual acuity. Contrast was reduced in 6 log steps, with each step halving the available contrast. The smaller the letter that is still visible at each size indicates better vision at each contrast level. Contrast sensitivity is the slope generated over the seven measurements. Flat slopes mean that vision continues to be good in decreased settings, and therefore the participant has greater contrast sensitivity. Lower numbers mean greater contrast sensitivity.

With these four subtests, we can see if any of the three physiological tests (color sensitivity, visual acuity, and contrast sensitivity) correlate with preference for colorful ClearType. It would be easy to understand the results if one of the tests correlated highly and the other tests did not correlate at all. Unfortunately, we found that all four of the tests

TABLE 2. Correlations among the four variables in Study 1.

	ClearType preference	Color sensitivity	Contrast sensitivity	Visual acuity
ClearType preference	–			
Color sensitivity	−0.3494	–		
Contrast sensitivity	0.1424	−0.3770	–	
Visual acuity	0.5135	0.2435	−0.1197	–

TABLE 3. Partial correlations among the four variables in Study 1.

	ClearType preference	Color sensitivity	Contrast sensitivity	Visual acuity
ClearType preference	–			
Color sensitivity	−0.5342	–		
Contrast sensitivity	0.0435	−0.2819	–	
Visual acuity	0.6594	0.4893	−0.0520	–

correlate with each other to some degree. Table 2 shows all correlations.

Because of the strong inter-correlations, we examined the tests' partial correlations. Partial correlations in this instance act to isolate the correlation between two tests while holding the values for the other two tests constant. Table 3 shows all partial correlations.

The partial correlations between ClearType preference and color sensitivity and the partial correlation between ClearType preference (subpixel positioned ClearType) and visual acuity are independent and quite strong. The partial correlation between ClearType preference and contrast is not strong.

Results from Study 1 offer some initial evidence that suggests that there are relationships between human physiology and preference for different types of ClearType. The positive correlation with visual acuity suggests that people with better visual acuity will prefer ClearType with higher levels of color. The negative correlation with color sensitivity suggests that people with greater color sensitivity will prefer ClearType with lower levels of color. These findings motivated Studies 2 and 3, where we sought to identify a sample of those who do *not* prefer ClearType and then identify physiological and psychological traits therein.

Study 2: Large-*N* Study of ClearType Preference

Method

Study 2 was a large sample study of 422 participants. Of these, 202 were recruited for onsite testing, and 220 took the test online. Students, faculty, and staff at the University of Texas at Austin with standard or corrected vision without reading disabilities or color blindness were recruited for this study. For the onsite testing, a questionnaire was used to collect participants' basic background information. The online-based questionnaire was the same as in the onsite testing, covering computer experience, visual acuity, and known refractive errors.

After a participant finished the administrative questionnaire, a preference evaluation was administered. For the online testing, a participant completed the questionnaire and the preference evaluation at his or her own workstation.

Materials

The testing material contained nine Web pages of sample images of ClearType and regular text in uncompressed bitmap format. Each Web page had two images of the same short paragraph placed side by side. The short paragraph of text was identical in length (126 words), content, image size (364 × 474 pixels), and format (bitmap images) in all experimental conditions. One paragraph of text was rendered by one of three ClearType renderings, and the other was black-and-white rendering. The order of the comparisons was fixed, though the appearance of any particular condition as the left or right paragraph was counterbalanced, and randomized as to specific order within the constraint of counterbalancing. Each page also included seven options of the preference scale between these two images (*strongly prefer left*, *prefer left*, *slightly prefer left*, *neutral*, *slightly prefer right*, *prefer right*, *strongly prefer right*—To make the presentation of the results clear, we translated these scale items to "strongly prefer CT" through "strongly prefer b&w.") The participants were asked to choose which image they preferred and to select one from the scale options provided. A final independent variable, orthogonal with rendering and also counterbalanced as to left–right location, was typeface, with three levels: Times New Roman, Verdana, and Consolas. The screen test also entailed a simplified hue test to measure test participants' color sensitivity. The testing material was simply a standard color strip (360 color hues) in JPEG format adapted from Adobe Photoshop Version 7.0, with lossless compression. We asked participants to determine how many shades of each of the three primary colors they could see. The page included questions that asked the participants to identify the number of colors they recognized, from among three ranges of numbers provided. We did not want to take the time for the more accurate FM 100 hue test used in Study 1, as we just wanted an early indication of color sensitivity, and knew that we would return to the use of the FM 100 hue test in Study 3.

The evaluations were prepared for both onsite and online test. For the onsite evaluation, all participants' data were collected from a single laptop computer with the following controlled settings:

- Computer hardware: a Dell Latitude D800 (laptop computer) and a wireless mouse
- Operational system: Windows XP, Professional ed.
- Physical monitor size: 13 × 8 inches, 16:9 wide screen
- Screen resolution: 1,920 × 1,200 pixels, color quality 32 bit
- Web browser: Mozilla Firefox Version 1.5.0.8 positioned at the center of the screen.

All test participants also were given a short, online questionnaire to provide us with demographic information on age, gender, computer experience and frequency of usage, 20/20 vision, and familiarity with ClearType to identify any potential confounds between these variables and the online versus onsite test condition.

Procedure

Onsite participants were recruited in the lobby of an academic library by incidental sampling. Evaluations were done on the machine prepared by the test administrator and took place in an open area of the library. The test environment of onsite participants represented the situation where people use computers in a public place such as at a kiosk. Online participants were recruited by e-mail advertising in several university departments (convenience samples). Online participants completed the evaluation by accessing the testing Web site with their own machines. Since the testing materials provided image samples of ClearType-rendered text, we did not ask online participants to locally turn on ClearType. The factors that might make the presentation differ between onsite and online participants were physical monitor size, monitor pixel density, setting the operating system to the monitor's native resolution, and the Web browser of online participants' computers. We designed the Hypertext Preprocessor (PHP) pages in principle to minimize the possible effects caused by these differences. We assumed that the test environment of online participants represented the situation where people use their own computers in the office place or home. Participants' data were stored electronically on a secure server of the University of Texas at Austin School of Information and the investigator's personal computer for later analyses.

This test evaluated preference for black-and-white rendering versus three different kinds of rendering techniques: Grayscale ClearType, Default ClearType, and Colorful ClearType. These rendering techniques are described in Study 1. Additionally, we compared preference for these rendering techniques in each of three typefaces: Times New Roman, Verdana, and Consolas. Times New Roman is a serif typeface designed in 1931 for use in newspapers. The typeface was not designed for black-and-white rendering or for ClearType rendering, but has gone through tuning by Microsoft for both rendering systems. Verdana is a sans serif typeface designed in 1996 specifically for black-and-white rendering. The letter outlines were designed specifically to conform to full pixels on computer screens. Consolas is

TABLE 4. Two-factor design with repeated measures in two sample groups.

	Times New Roman			Verdana			Consolas		
	Grayscale ClearType	Default ClearType	Colorful ClearType	Grayscale Cleatype	Default ClearType	Colorful ClearType	Grayscale ClearType	Default ClearType	Colorful ClearType
Onsite	Q6	Q4	Q1	Q5	Q2	Q8	Q9	Q7	Q3
Online	Q6	Q4	Q1	Q5	Q2	Q8	Q9	Q7	Q3

a monospaced typeface designed in 2004 specifically for ClearType rendering (Berry, 2004). Its shapes are optimized for subpixel rendering, and the typeface lacks hints necessary for excellent black-and-white rendering.

Data Analysis

We undertook three approaches to our data analysis. First, the descriptive statistics showed that there is a major portion of the participants who prefer ClearType over black-and-white. Mean comparison analysis will help us determine if there is a statistically significant difference in the frequency of choices between ClearType and black-and-white.

Second, the analysis for independent variables (font and color filtering), according to the experimental design of our test procedure, is a two-factor design with repeated measures in two sample groups (see Table 4), designed to measure the effects of different levels of color filtering and different types of font that would influence people's preferences in ClearType. Table 4 indicates that we offered the nine trials in a fixed order with a sequence chosen to minimize participants' habituation and prediction of presented choices.

Other potential between-group variables besides onsite/online (environment) include age, gender, years of computer experience, hours per day of computer usage, hours per day of onscreen reading, acuity, and prior knowledge about ClearType.

Analysis of variance (ANOVA) was applied to this two-factor design to investigate possible effects of font and color filtering on participants' preferences of ClearType versus black-and-white text. In an ANOVA, if there are only two levels of a factor, the problem of sphericity does not arise. If there are three or more levels, the analysis has to guard against it. The design of Study 2 had two main factors, and each factor had three levels (see Table 4). Therefore, our analysis included Mauchly's sphericity test and used the Greenhouse–Geisser corrections for the degree of freedom (*df*) in the ANOVA of the data in Study 2 (c.f. Mauchly, 1940; Geisser & Greenhouse, 1958). Every ANOVA was checked for possible problems of sphericity, and Greenhouse–Geisser corrections were employed only when needed.

Finally, the analyses also included Pearson correlation coefficients of color sensitivity and ClearType preference. Reviews have shown that ClearType's subpixel addressing technique that uses a spatial filtering method yields a certain amount of red-green-blue (RGB) display around the edge of the text (e.g., Sheedy, Tai, Subbaram, Gowrisankaran, &

Hayes, 2008). Here, we wished to test the hypothesis that people having higher color sensitivity (i.e., higher score in hue-sensitivity evaluation) would likely prefer black-and-white text (i.e., score lower in ClearType preference evaluation).

Results

Demographic Data of Participants

Table 5 characterizes the 422 test participants. There was a tendency for the online test participants to be older, have more computer experience, to use a computer more, and to be more likely than the onsite participants to have heard of ClearType. Both groups had about the same gender make-up ($\sim$52% female) and percentage of participants with normal or correct-to-normal vision ($\sim$85%).

Participant Preference

Figures 1 to 3 present an overview of the preference data for the 422 onsite and online participants in each of the fonts tested: Times New Roman, Verdana, and Consolas. Note that the trends for both Grayscale ClearType and Default ClearType are similar across the three fonts, with the most participants claiming to "Prefer ClearType," and a smaller, but noticeable, group of participants claiming to "Prefer b&w" (i.e., non-ClearType) text. In the Colorful ClearType case, responses are even more bimodal; we correctly hypothesized that the color fragments around the edges of letters in this case are highly visible and made this version of ClearType rendering the least preferred.

To test the null hypothesis that the aforementioned preference data were generated by participants' random selections between ClearType and black-and-white text, an ANOVA was conducted to see if there was a tendency of selection among ClearType text, black-and-white text, or no preference. Results showed that there was a significant tendency for participants *not* to be neutral, and they would choose to either prefer ClearType or black-and-white text, $F(1.271, 534.940) = 341.509, p < 0.001$ with the Greenhouse–Geisser corrected values of *df*. In addition, both pairwise comparisons of ClearType versus Neutral, Greenhouse–Geisser $F(1, 421) = 876.352, p < 0.001$, and black-and-white versus Neutral, Greenhouse–Geisser $F(1, 421) = 321.963, p < 0.001$, are significant. Test participants tended to voice a preference for ClearType text or black-and-white text rather than professing neutrality. These significant

TABLE 5. Participant demographics (Onsite $n_1 = 202$; Online $n_2 = 220$; $N = 422$).

|	Onsite n (%)	Online n (%)	Total (%)
Age			
19–25	118 (58.4)	91 (41.4)	209 (49.5)
26–35	57 (28.2)	83 (37.7)	140 (33.2)
36–45	18 (8.9)	23 (10.5)	41 (9.7)
45–55	6 (3.0)	18 (8.2)	24 (5.7)
55+	3 (1.5)	5 (2.3)	8 (1.9)
Gender			
Male	96 (47.5)	104 (47.3)	200 (47.4)
Female	102 (50.5)	116 (52.7)	218 (51.7)
Computer experience (years)			
1–5	24 (11.9)	9 (4.1)	33 (7.8)
6–10	87 (43.1)	57 (25.9)	144 (34.1)
10+	90 (44.6)	154 (70.0)	244 (57.8)
Frequency of computer usage			
Daily	192 (95.1)	220 (100)	412 (97.6)
Weekly	8 (4.0)	0 (0)	8 (1.9)
Frequency of daily computer usage (hr)			
1–4	131 (64.9)	67 (30.5)	198 (46.9)
5–7	52 (25.7)	107 (48.6)	159 (37.7)
8+	18 (8.9)	46 (20.9)	64 (15.2)
Frequency of onscreen reading			
Daily tasks	180 (89.1)	203 (93.6)	386 (91.5)
Weekly tasks	20 (9.9)	14 (6.4)	34 (8.1)
Monthly tasks	2 (1.0)	0 (0)	2 (0.5)
Frequency of daily onscreen reading (hr)			
1–4	161 (79.7)	123 (55.9)	284 (67.3)
5–7	31 (15.3)	73 (33.2)	104 (24.6)
8+	9 (4.5)	24 (10.9)	33 (7.8)
20/20 vision?			
Yes	171 (84.7)	190 (86.4)	361 (85.5)
No	30 (14.9)	30 (13.6)	60 (14.2)
Heard of ClearType?			
Yes	19 (9.4)	64 (29.1)	83 (19.7)
No	182 (90.1)	156 (70.9)	338 (80.1)
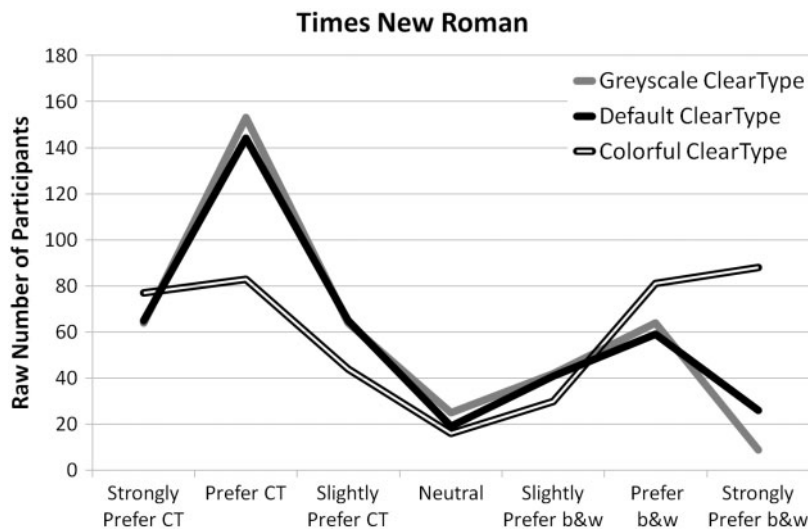
FIG. 1. Preference data, Times New Roman.

differences also confirmed that during the repeated measures evaluation, participants expressed distinctive preference between ClearType and black-and-white. Even after teasing out the effects of font and color filtering, test participants would select either ClearType or black-and-white text. Therefore, differences in the data represented in Figures 1 through 3 are not products of randomness.
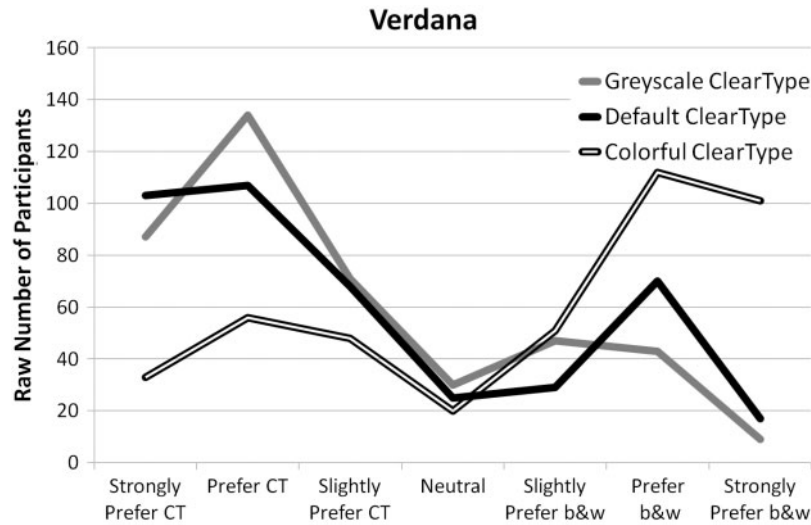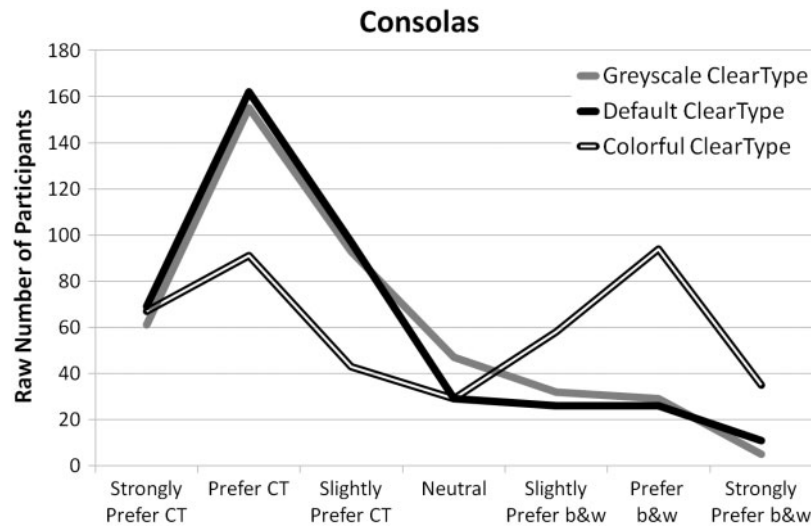
FIG. 2.   Preference data, Verdana.

FIG. 3.   Preference data, Consolas.

Figures 1 through 3 show that most of the participants preferred ClearType, having more often selected ClearType text over black-and-white text in the nine comparisons presented. According to the experimental design of Study 2, there were three possible effects that would influence participants' preferences of ClearType text over black-and-white text: (a) the effect of font, (b) the effect of ClearType's color filtering, and (c) the interaction between the effects of font and ClearType's color filtering. Three ANOVAs were conducted to test these effects.

There was a significant main effect of font, $F(2, 842) = 32.183$, $p < 0.001$. This suggested that after ignoring the level of color filtering that was used, participants still preferred some fonts over others. Estimates of means on fonts showed that the effect on ClearType preference is: Consolas (mean preference score = 4.85) > Times New Roman (4.52) = Verdana (4.39). Pairwise comparisons indicated that participants preferred Consolas over Times New

Roman (mean difference = 0.33, $p < 0.001$) and preferred Consolas over Verdana (mean difference = 0.46, $p < 0.001$).

There also was a significant main effect of ClearType's color filtering, Greenhouse–Geisser $F(1.752, 737.385) = 172.028$, $p < 0.001$. This suggested that after ignoring the type of font that was used, participants' preference for ClearType was different per levels of color filtering. Estimates of means on color filtering showed that the effect on ClearType Preferences was: Grayscale ClearType (mean preference score = 5.02) > Default ClearType (4.92) > Colorful ClearType (3.81). Pairwise comparisons indicated that ClearType was preferred significantly less with Colorful ClearType than with Grayscale ClearType (mean difference = −1.21, $p < 0.001$), and ClearType is less preferred with Colorful ClearType than with Default ClearType (mean difference = −1.11, $p < 0.001$).

In addition, there was a significant interaction between types of font used and levels of color filtering associated with

the font, Greenhouse–Geisser $F(3.805, 1601.941) = 20.282$, $p < 0.001$. This suggested that the level of color filtering used had a different effect depending on the font. Preference for Grayscale ClearType was stronger than Default ClearType and Colorful ClearType, especially for Verdana and Times New Roman text, but not for Consolas text. Ratings of Colorful ClearType were lower than Grayscale ClearType and Default ClearType across fonts, especially when Verdana was used.

All results of three ANOVAs reported earlier further confirmed the findings that are presented in Figures 1 through 3: Consolas and Grayscale ClearType was the best combination and was most preferred by the participants whereas Verdana and Colorful ClearType was the worst presentation for onscreen reading.

Correlations of Color Sensitivity and ClearType Preference

Pointing toward the third study, we wished to identify individuals who consistently did *not* prefer ClearType rendering. We assigned a score of 1 for every "Strongly prefer black-and-white" rating (in each of the nine conditions), and assigned a score of 7 for every "Strongly prefer ClearType." We then, for each participant, summed the scores across all nine trials. Thus, possible scores for each participant ranged from 9 (9×1) to 63 (9×7), with a consistent "no preference" score yielding a score of 36. We found a mean score of 41, or about halfway between "Slightly prefer" ClearType and "Prefer" ClearType. We calculated the critical low and high scores of ClearType preference based on the assumption of the higher and lower 5% critical region of the sampling distribution. Participants who obtained a score lower than the standard score (z score) of -1.96 in the ClearType preference evaluation were considered to persistently prefer black-and-white text. Likewise, participants who obtained a score higher than the standard score (z score) of 1.96 in the ClearType preference evaluation were considered to persistently prefer ClearType. We will revisit these extreme cases in the introduction to Study 3.

One possible factor that would influence the score of ClearType preference was the participant's hue sensitivity. Study 2 also collected participants' scores of their hue sensitivity. Participants achieved a higher score if they reported that they could identify more shades of each of the three primary colors in a strip of 360 hues. By conducting analyses of Pearson correlation coefficients between participants' scores of ClearType preference and hue sensitivity, there were two interesting findings. First, the hue sensitivity score was negatively correlated with the overall score of ClearType Preference ($r = -0.120$, $p = 0.01$). Participants who scored lower in ClearType Preference had higher scores in the hue sensitivity test. Second and relatedly, the hue sensitivity score was positively correlated with the frequency of selecting black-and-white text ($r = 0.113$, $p = 0.05$). Those who had higher scores in the hue sensitivity test also more frequently chose black-and-white text over ClearType text. These two findings suggested that there might be physiological traits of people's visual systems that could predict dislike for ClearType text.

Discussion

Findings of Study 2 demonstrated that effects of ClearType-rendering, font types, and levels of color filtering all contributed to influence participants' preferences of onscreen text. The significant negative correlation between hue sensitivity and ClearType preference supports our hypothesis from Study 1 that the people who do not to prefer ClearType tend to be those with better hue sensitivity.

Study 3: Acuity and Psychological Testing of "ClearType Haters"

Method

Those who expressed a stronger preference for black-and-white rendering in Study 2 (i.e., those who scored more than 1 *SD* below average on the overall measure of preference for ClearType) were contacted via e-mail. We identified 39 prospective participants who met this criterion and invited them to be in the subject pool for Study 3. We tested 18 participants who responded to our invitation and showed up for the study: Twenty-four participants were scheduled; 5 did not show up, and 1 who did show was revealed not to have served in Study 2. A more detailed and formal battery of vision tests was administered in conjunction with Austin Retina Associates (Austin, TX office). In addition, we administered a Big 5 psychological test of personality (Gosling et al., 2003), plus a test to distinguish between "sharpeners" and "levelers," plus we repeated the evaluation of the Study 2 ClearType preference test.

Materials and Procedure

The full evaluation included the following tests, in the following order:

1. Participant's current prescription (if applicable).
2. The FM 100 hue test: The FM 100 hue has been designed to detect all types of color vision abnormality from the mildest red–green defect to total achromatopsia. It separates people with normal color vision into classes of superior, average, and low color discrimination and measures the axes or zones of color confusion in those with defective color vision. The FM 100 hue test has been included in this study to examine whether individuals with superior color discrimination are more inclined to dislike Default or Colorful ClearType because of the slight color banding on the edges of characters.
3. Contrast sensitivity test (Pelli–Robson chart, Pelli, Robson, & Wilkins, 1988): The Pelli–Robson chart determines the contrast required to read large letters of a fixed size. The Pelli–Robson chart varies the contrast level of fixed-size letters to determine the point where an individual loses the ability to discriminate a letter from its background.

4. Early Treatment Diabetic Retinopathy Study (ETDRS charts): The ETDRS acuity test (Watt, 2003) was developed to aid in evaluating the changes in vision following panretinal photocoagulation in patients with diabetic retinopathy, and is a standard and common test of visual acuity.
5. Refraction test: This test uses an autorefractor, a special instrument that has interchangeable lenses of different strengths, to measure how well the participant sees objects at various distances. It is the main instrument used to determine whether an individual is near- or far-sighted.
6. The same ClearType preference test from Study 2 where preference for three rendering conditions by three typeface conditions were compared against black-and-white rendering: The same fixed presentation order used in Study 2 was repeated in Study 3 to maximize the comparativeness between the two studies.
7. The "Big 5" psychological test (Gosling et al., 2003): This test measures what many psychologists consider to be the five fundamental dimensions of personality (extraversion, agreeableness, conscientiousness, emotional stability, and openness to new experiences).
8. A Sharpener/Leveler test: This test distinguishes between sharpeners (i.e., those who are more likely to see differences between things) and levelers (i.e., those who are more likely to see similarities between things).
9. A semidirected interview about why the participants preferred or did not prefer ClearType.

We felt that this battery of tests represented a combination of all the likely visual and psychological variables that had been considered in previous studies of ClearType preference (both ours and others') as well as a few exploratory variables that might yield new significant correlations with preferences.

Results

We discovered that Participant 5 was color-blind, and removed his data, selectively, from future analyses.

About 90% of the participants were myopic (i.e., near-sighted) compared to a population norm of about 25%. All our test participants except the color-blind one had above-average color discrimination, and 47% of them had color discrimination that fell into the "superior" range (compared to 16% of the at-large population). The color-blind participant did however have good discrimination in the hues he saw "normally." Most of our participants (15, or 83%) were sharpeners. We found no population norms for leveler/sharpener, but in a series of other studies performed on participants sampled from the same general population (i.e., University of Texas at Austin college students), one of our authors (Aumer-Ryan, 2009) found that 234 of 316 test participants (75.5%) were sharpeners. Additionally, on average, the 18 participants in Study 3 were 0.5 *SD*s below the population mean on Agreeableness.

One surprising finding is that these participants, chosen because of their preference for black-and-white rendering in Study 2, did not consistently prefer black-and-white rendering in this study. Might people have "adapted" to ClearType?

TABLE 6. Number of Study 3 participants who did *not* prefer ClearType in each study.

	Study 2	Study 3
Onsite	9	4
Online	9	1
Total	18	5

Was it only the people who were tested remotely (whose home machine may have been ill tuned) who now prefer ClearType? Table 6 reveals that half of the Study 3 participants had been onsite participants from Study 2, and half had been tested online, remotely, in Study 2. Of the 5 who still did *not* prefer ClearType, only one of them had been a "remote" test participant in Study 2. This is captured in the Table 6.

Thus, of the 9 people who did not prefer ClearType in Study 2 who were tested onsite (where a display used to administer tests was well-tuned), 4 participants still did not prefer ClearType in Study 3. Of the 9 people who did not prefer ClearType in Study 2 who were tested online (where we were unsure that their display was well-tuned), only 1 participant still did not prefer ClearType. Chi-square tests revealed that there was a significant overall difference in total number of test participants who did not prefer ClearType (χ^2 with 1 $df = 8.5$, $p < 0.01$), but not a significant difference between the onsite and online conditions (χ^2 with 1 $df = 1.8$, $p > 0.05$). (If this trend should remain, the facile explanation would be that some of the "online" flip-flops were a result of true flip-flopping and some were a result of artifactually low ClearType preference scores in Study 2 due to poor display tuning on online participants' home machines.) The following figure summarizes the ClearType preference scores, and illustrates the flip-flopping. The previous ClearType preference scores were converted from 1 to 7 into -3 to $+3$, so positive scores reflect preference for ClearType and negative scores reflect preference for black-and-white text.

Figure 4 suggests that with only one exception (P2), those onsite participants who most strongly disliked ClearType (the longest, striped, descending bars) did *not* flip-flop. In fact, an ANOVA revealed that the 18 participants' overall ClearType preference score is significantly improved, Greenhouse–Geisser $F(1, 17) = 30.921$, $p < 0.01$. They seemed to not "hate" ClearType as they did in Study 2. So the main set of correlations (i.e., between Study 2/Study 3 ClearType preference scores and agreeableness, color sensitivity, and sharpener/leveler score) were not significant, but they were in the same direction. Table 7 shows the correlations for the 18 non-color-blind participants who returned in Study 3 between ClearType preference in each Study and agreeableness, color sensitivity, and sharpener/leveler.

Table 8 presents significant correlations from some post hoc comparisons.

Discussion

This being an exploratory study, we chose to bring back and test only those Study 2 participants who relatively

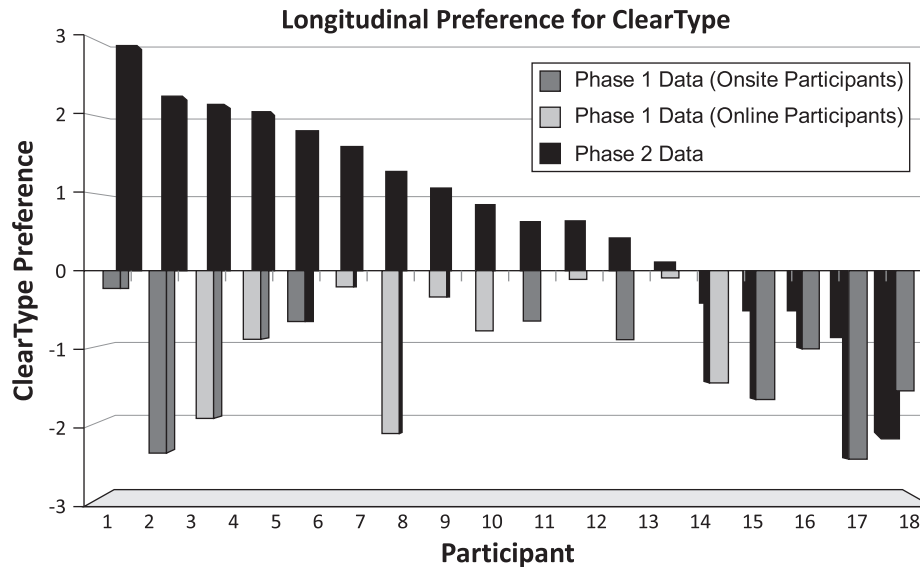**Longitudinal Preference for ClearType**

FIG. 4. Longitudinal preference for ClearType.

TABLE 7. Correlations between ClearType preference and agreeableness, color sensitivity, and sharpener/leveler.

	Study 2 ClearType preference score	Study 3 ClearType preference score
Agreeableness		
Pearson correlation	0.099	0.381
Significance (two-tailed)	0.707	0.132
df	17	17
Color sensitivity		
Pearson correlation	−0.406	−0.219
Significance (two-tailed)	0.106	0.399
df	17	17
Sharpener/leveler		
Pearson correlation	0.251	0.183
Significance (two-tailed)	0.332	0.483
df	17	17

strongly did *not* prefer ClearType text. Thus, our experimental design did not afford us the ability to compare directly two distributions of test participants (those who prefer ClearType and those who do not). Rather, we were depending on our ability to note differences between our ClearType "haters" and population norms for a variety of visual system and psychological variables.

Our test participants who had at one point shown a dislike for ClearType showed a strong tendency to be myopic (i.e., near-sighted) (∼90%, compared with ∼25% of the general population); all (except the color-blind participant) had above-average color discrimination, with 47% of them exhibiting "superior" color discrimination (compared to 16% of the population); most (*n* = 15, or 83%) were sharpeners; and on average, they were low on Agreeableness (0.5 *SD* below the population mean).

We were surprised by a strong tendency for test participants to flip-flop in their preference of ClearType text, with 13 of the 18 ClearType "haters" from Study 2 now showing a preference for ClearType. This will require systematic study in the future. One possibility that should be considered is that being present in the company of a researcher may influence stated preferences.[1]

We found significant correlations for these one-time ClearType "haters" with (a) strength of their vision correction; (b) the difference in strength of correction between their two eyes; and as in Study 2, (c) color sensitivity, with the more sensitive test participants tending *not* to prefer ClearType.

Summary and Conclusions

From this series of studies, we have learned much about people's preference for ClearType. The pilot study drove us to believe that preference for ClearType was not an entirely random function but something tied to physiological variables. Specifically, the correlations suggested that people who preferred the more colorful variation of ClearType were more likely to have higher visual acuity and more likely to have lower color sensitivity.

Study 2 investigated preference for different versions of ClearType versus traditional black-and-white rendering. We found that preference for ClearType was not a binary function; most people did not strongly prefer ClearType rendering or black-and-white rendering but tended to have more moderate preferences that leaned to ClearType text. These preferences interacted with the color filtering of ClearType rendering being used and also with the typefaces being rendered. Preferences for Default ClearType and Grayscale ClearType were stronger than was preference for Colorful ClearType. Preference for the typeface Consolas, which was designed for ClearType rendering, tended to be stronger with ClearType than with the typefaces Verdana and Times New Roman. The percentage of our sample who voiced preference

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[1]We thank an anonymous reviewer for this consideration.

TABLE 8. Variables that showed significant correlations with ClearType preference.

Factors	Significance
Between current vision prescription and Study 3 ClearType preference scores (i.e., stronger prescriptions related to lower preference scores).	*right eye: $r(15) = .692$, $p < 0.027$; *left eye: $r(15) = 0.659$, $p < 0.038$
Between the difference between each eye's prescription and the Study 2 absolute value of their z score (i.e., the larger the difference between left/right eye prescriptions, the more ClearType is disliked).	*$r(15) = 0.482$ $p < 0.050$
Between Study 2 z score category (absolute value) (1 or 2, with 2s at or below $z = -2$, and 1s between -1 and -2 z) and color sensitivity (This is similar to the strongest correlation from the main set above.).	*$r(15) = -0.548$ $p < 0.023$

for ClearType was on par with previous studies of ClearType (e.g., Dillon et al., 2006). Indeed, this whole project meshes well with the Dillon et al. (2006) article, which specifically found that there were individual differences both in the performance and preference data.

Study 3 was in some sense the inverse of Study 1. In Study 1, all 10 participants showed a preference for ClearType rendering; in Study 3, we recruited 18 participants who were known to prefer black-and-white rendering. Our goal was to learn if there were commonalities among these participants that would drive preference for this kind of rendering. The key difference between ClearType and black-and-white rendering is that ClearType uses extra resolution in color LCD displays to create letterforms that are closer to their intended shape. Black-and-white rendering, on the other hand, yields letters less close to their intended shapes, but it does have the advantage of superior contrast: There is a very sharp transition between the white and black edges of letters.

As predicted from Study 1, people who did not prefer ClearType tended to have poorer than average visual acuity; 16 of the 18 were myopic. Also as predicted from Study 1, 17 of 18 participants had greater than average color sensitivity. These two findings in combination are very sensible; the high contrast edges of black-and-white rendering would reduce the difficulty in detecting small letter features for people with lower visual acuity. Greater than average color sensitivity would make the color artifacts in ClearType rendering more noticeable.

Most surprising from Study 3 was that preference for ClearType increased from Study 2 to Study 3. Because we did not bring in a ClearType-preferring control group, it is impossible to know if this is simply an effect of regression to the mean, a reflection of unreliability of our dependent measure, or something else altogether. There was a tendency for people who preferred black-and-white rendering to be very vocal in their preference, and we expected preference to remain consistent. Thirteen of 18 participants changed from expressing preference for black-and-white rendering to expressing preference for ClearType rendering.

Another unexpected finding was that in addition to the correlations between physiological variables and ClearType preference, we also found a positive correlation between ClearType preference and the Big 5 personality characteristic of agreeableness. Perhaps personality traits or context-dependent attitudes influence how likely people are to overlook some of the negative side effects of the subpixel

rendering of text (e.g., colorful edges). Preference for ClearType is not exclusively predicted by the visual system.

In our Introduction, we asked who is that consistent minority of readers who do *not* prefer ClearType? The answer from our exploratory study is: "ClearType-haters" tend to be disagreeable sharpeners with below-average visual acuity, but above-average color discrimination.

The next empirical challenge we face is to find experimental corroboration of these correlational data that can afford confidence in the predictive strength of these four variables (agreeable/disagreeable; sharpener/leveler; high/low visual acuity; high/low color discrimination). Another future challenge is to discern how to use this information to develop new rendering technologies that will improve on both ClearType and black-and-white rendering. For instance, a simple test employing these or other variables during computer set-up could help identify which rendering to employ to maximize text readability for a particular user. Besides individual customization, perhaps the most promising future development is to investigate the trade-offs between the three visual-system channels used in the ClearType color-filtering system. ClearType used the S-CIELAB model of visual perception to determine the relative amount of error acceptable in the luminance (black/white) channel, the red/green color channel, and the blue/yellow color channel. The difference between Grayscale ClearType and Colorful ClearType is the relative error accepted by the luminance channel versus the two color channels. There is more luminance error in Grayscale ClearType and more color error in the Colorful ClearType. By looking at the relative importance of the two color channels, we might find participants who are more sensitive to error in one color channel than in the other.

Centuries ago, typographers used an early understanding of visual perception to create overshoots and undershoots in round letters that went below the baseline and above the capline. They knew that if the height of the letter *O* was exactly equal to the letter *I*, the letter *O* would look too small. Just as typographers leveraged visual perception, digital enhancement of onscreen text and studies of human–computer interaction need to leverage visual perception to solve challenges in making onscreen text that is both beautiful and efficient to read. It is our hope that the findings in this article will offer information that may be particularly useful to professionals in digital typography, human–computer interaction, and usability who aim to improve people's experience and performance in reading from computer screens.

Acknowledgments

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