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Legibility and Readability of Small Print: Effects of Font, Observer Age and Spatial
Vision

by

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Abstract

Age-related losses of visual function erode performance on many daily tasks, including reading. This research sought to 1) determine if age differences in the legibility and readability of small print vary with font characteristics, and 2) to determine the degree to which legibility and readability are related to acuity and/or contrast sensitivity. The legibility and readability of passages printed in four serif and four sans serif fonts were established for healthy young and elderly readers. Legibility thresholds were elevated among elderly readers, but there was no overall age effect on reading time or distance. Age differences on reading time varied significantly with font. Relationships between reading time and other reading measures were in the opposite direction for young versus elderly readers. Legibility was strongly predicted by acuity and less well by contrast sensitivity; readability was related to neither measure. Recommendations regarding font selection are provided and future research directions discussed.

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Research Objectives

The purpose of this study was to determine the characteristics of fonts that contribute to the legibility and readability of small print for adult readers of different age. Specifically, this investigation sought to: 1) determine the degree to which the legibility and readability of small print varies as a function of observer age, font, and font type (serif versus sans serif), 2) evaluate font usability on a number of subjective dimensions (e.g., preference, ease of use), and 3) assess the relationship between readability, legibility and spatial measures of vision for different fonts and font types for observers of different age.

Introduction

The Aging Visual System

Aging is associated with a gradual decline in visual functioning sufficient to affect performance on most everyday visual tasks. Much of this deficit is attributable to changes in the ocular media of the eyes, the balance to sensorineural changes in the retina and brain (Kline & Scialfa, 1996).

Ocular media. A reduction in pupil size (senile miosis), in conjunction with increased opacity in the ocular media, gradually reduces the amount of light reaching the older retina. It has been estimated that the 60-year-old retina receives only one-third as much light as its 20-year old counterpart (Weale, 1961). Most of this reduction is attributable to pupillary miosis and the increased opacity of the lens. In addition to the attenuation in retinal illuminance, light is increasingly scattered by the aging eye (Ijspeert, de Waard, van den Berg & de Jong, 1990), reducing contrast in the retinal image independent of refractive state and pupil size (Artal, Ferro, Miranda & Navarro, 1993). In addition to its increased opacity, the lens becomes thicker and sclerotic, reducing its accommodative power (i.e., presbyopia) causing a recession in the visual near point (the nearest distance at which the eye can focus). The associated yellowing of the lens causes a selective absorption of short wavelength light (i.e., blues and greens).

Retina. There is a 30% decrease in rod density in the central area of the retina, but apparently little loss of foveal cones (Curcio, Millican, Allen & Kalina, 1993). There is some evidence from ERG studies for an age-related decline in functioning of both rods and cones (Elsner, Berk, Burns & Rosenberg, 1988). There also appears to be a decline

in the number (e.g., Gao & Hollyfield, 1992) and function of retinal ganglion cells (e.g., Celesia, Kaufman & Cone, 1987; Porciatti, Burr, Morrone & Fiorentini, 1992).

Eye movements. There is an age-related decrement in saccadic latency (Huaman & Sharpe, 1993; Sharpe & Zackon, 1987; Whitaker, Shoptaugh & Haywood, 1986), as well as reductions in peak saccadic velocity (Pitt & Rawles, 1988) and accuracy (Huaman & Sharpe, 1993). Older adults, however, do not appear to lose the ability to maintain gaze while observing stationary stimuli, at least up to durations of 13 seconds (Kosnik, Kline, Fikre & Sekuler, 1987).

Visual pathways. The degree of senescent loss in the two major visual pathways is still unclear. There is some indication that loss of functioning in the parvocellular (sustained) pathway exceeds that in the magnocellular (transient) pathway (Spear, 1993; Elliott, Whitaker & MacVeigh, 1990).

Visual cortex. Studies suggest relatively little decline in neuronal density of striate cortex (e.g., Vincent, Peters & Tigges, 1989). Vincent et al. (1989), however, found some evidence of dendritic degradation.

Aging and Visual Functioning

Resolution acuity. Resolution acuity, the ability to see small detail in stationary targets, typically of high contrast, decreases progressively with age. Where most young observers are able to detect a target gap subtending 1 minute of arc (minarc) of visual angle (VA), the 70 year old has a near acuity of 1.5 minarc (Pits, 1982). In the Snellen acuity notation these correspond to 6/6 and 6/9 acuity respectively (the numerator in the Snellen fraction refers to the test distance in meters and the denominator refers to the distance at which a normal person with “good” vision could resolve a target of the same size). Examples of a common acuity-type tasks include reading of words or numbers on a distant billboard or license plate. Such acuity deficits can be seen by age 30 in uncorrected vision, and in corrected vision by age 70 (Gittings & Fozard, 1986). Due to the age-related decline in retinal illumination, age-related acuity effects are exacerbated in low light (Sturr, Kline & Taub, 1990).

Severe or debilitating acuity loss is also strongly age-related. About 46% of those who are legally blind (corrected acuity of 6/60 or less and/or a visual field of 20 degrees or smaller), and approximately 68% of those with severe visual impairment (unable to

read newspaper print at 40 cm with their best correction) are over the age of 65 (Kirchner & Lowman, 1988). Branch, Horowitz and Carr (1989) reported that visual impairment is the second most prevalent physical impairment among people over 65, and is perceived as more disabling than most other physical impairments.

Dynamic visual acuity (DVA). The ability to resolve detail in a moving target, known as dynamic visual acuity (DVA) declines with age (Scialfa et al., 1988), especially at high target velocities.

Contrast sensitivity. Contrast sensitivity (CS), the minimum light/dark differences that can be detected for targets of varied size (i.e., spatial frequency), shows progressive age loss for targets of intermediate and high spatial frequency (Elliott, 1987). This age loss is further exacerbated by stimulus motion (Scialfa, Garvey, Tyrrell & Leibowitz, 1992). Consistent with their general need for higher illumination levels, the CS Function of older observers is affected adversely by low light conditions (Sloane, Owsley & Alvarez, 1988). Neural factors also appear to contribute to this loss (Kline & Scialfa, 1996).

Glare susceptibility. Although more light is required for the older person to see well, the level, direction and distribution of the light becomes increasingly important (Kline & Scialfa, 1997). Due to changes in the ocular medium, the senescent eye is more susceptible to the effects of glare and also takes longer to recover from it (Elliott & Whitaker, 1990).

Aging, visual search and visual fields. Older people experience a visual deficit while searching for targets in complex stimulus arrays (conspicuity) as well as suffer from shrinking useful fields of view (Scialfa, Kline & Lyman, 1987). Older adults do not appear to suffer from a loss of vigilance (Monk, Buysse, Reynolds, Jarrett and Kupfer, 1992) under good viewing conditions, but an age-related deficit can be seen under degraded conditions (Parasuraman & Giambra, 1992; Parasuraman, Nestor & Greenwood, 1989). Older people are also more likely to be distracted by irrelevant stimulus (Rabbitt, 1965; Scialfa & Esau, 1993; Sekuler & Ball, 1986)

Aging eye problems and reading. Given their lack of accommodative ability, and the recession of the nearest point they can focus (presbyopia), older readers cannot compensate for small print by moving it closer to their eyes. Also important is the fact

that less light is reaching the sentient eye (senile miosis), making print more difficult to see. Not only is the overall luminance of the stimulus reduced, but so is its contrast. All of these factors make it more difficult to read stimuli, particularly under conditions of low light and small print.

Aging and self-reported visual problems. Even in the absence of visual pathology, many elderly people report increased difficulty on visual tasks including searching for objects, tracking moving text, near vision (reading), vision in low light and processing rapidly presented information (Kline et al., 1992; Kosnik, Winslow, Kline, Rasinski & Sekuler, 1988; Schieber, 1992; Szlyk, Arditi, Coffey & Laderman, 1990).

Typography

Typography refers to features of alphanumeric characters, both individually and as they are positioned in relation to each other in strings, words, and passages. A typeface or font is a distinct design of an alphabet of letters and related characters (Conover, 1990). The ability to create custom fonts on the personal computer has moved font creation and use from the professional printing facility to the desktop environment. Consequently, there has been an “explosion” in font types, and associated with this, markedly increased concern about the effects of various font characteristics on readability and legibility.

Size. Type size is the size of the capital letters and any space added to create space between lines and traditionally has been measured in points (1 point = 1/72 inch). The point size of letters actually refers to the “slug” on which they were set, rather than the letter itself. When considering the actual letter size, a “point” is about 1/100” of an inch (Sanders & McCormick, 1987). A somewhat more realistic way to denote the size of a typeface is by its “x-height” (Barnhurst, 1994; Poulton, 1972), which is the height of a lower case “x” (see Figure 1). Ascenders and descenders refer to the parts of a letter that rise above or fall below the x-height space, respectively.

Case. The “case” of a letter refers to its capitalization. Although upper-case letters are generally more legible (Kember & Varley, 1987) and may (Vartabedian, 1971) or may not (Bednall, 1992) aid in the speed of localizing a word within a list, reviews on designing text (Hartley, 1978; van Nes, 1986) recommend the use of mixed-case print. It is more characteristic, aids in the development of word forms (orthographic images), is

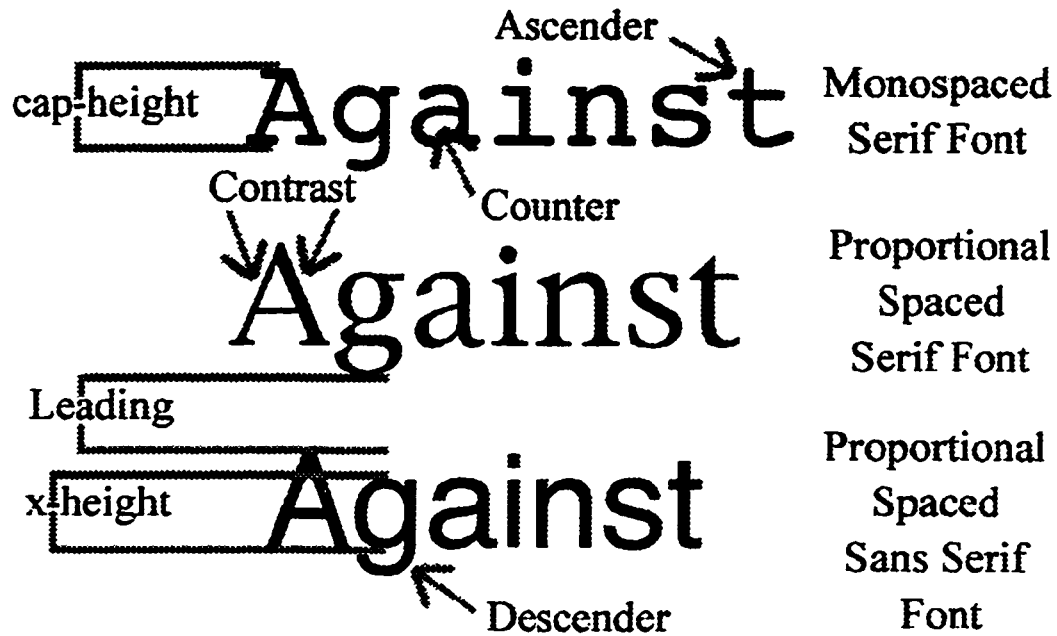


Figure 1. Font characteristics for a monospaced serif font and 2 proportional fonts, one serif and one sans serif.

subjectively preferred over all capitals (Tinker, 1963), and increases reading speed (Tinker, 1965),

Weight. The weight of a font refers to the relative thickness of the lines that compose the letters. The text on this page is printed in a normal weight print, thicker lines are used in bold print (e.g., **Bold**). Barnhurst (1994) states that bold print is more legible. Smither and Braun (1994) found that, although bold words are read faster, they result in more errors, and older readers feel that they are more difficult to read. Although Paterson and Tinker (1940) found no advantage to bold print, they reported that 70% of college students preferred normal weight type. Some fonts also have light versions that utilize thinner lines for the characters.

Spacing. Spacing refers to the amount of space allotted to each alphanumeric character (see Figure 1). Monospaced fonts assign uniform spacing to all characters, and are used primarily on typewriters where proportional spacing is not practical. In proportional spacing characters are spaced in relation to the area they occupy, with some letters (e.g., i, l) being allotted less space than others (e.g., m, w). Research has shown that proportional spaced fonts are easier to read (Beldie, Pastoor & Schwarz, 1983;

Smither & Braun, 1994). Although Times (a proportional spaced font) was read 4.7% faster than Courier (a monospaced font) for large print size (within the range of letter size that does not affect reading speed), for small print, Courier could be read twice as fast. They also found that the critical print size (the smallest size that does not degrade reading performance) and legibility were larger (not as good) for Times when compared to Courier. Arditi, Knoblauch and Grunwald (1990) also found this size difference when using Times and a monospaced font created from Times. Letters that are crowded in close proximity make reading more difficult (Anstis, 1974; Watannabe, 1994). Up to a point, legibility improves as inter-letter spacing is increased (Berger, 1956). Recommended spacing for maximum legibility and ease of reading is about 25% of the character size and not less than one stroke width (Degani, 1992). While tracking is the term used to describe uniform spacing between letters, kerning is special spacing (more or less) to remove “unsightly” gaps between certain letters (see Figure 2).



Figure 2. Example of kerning, used to remove unsightly gaps between letters.

Italics. Tilting the letters, Italics, allows more letters on a line of print and is usually restricted to a small portion of a larger passage to provide increased emphasis. Italics are usually restricted because they make reading more difficult (Tinker, 1955).

Leading. Leading, the space between lines of print, is a term derived from the lead plates that were inserted between lines of print to increase inter-line spacing. Leading is recommended to be at least 25 to 33% of the font size (Degani, 1992). Increased leading improves readability at reasonable levels, but in the extreme, detracts from it (Paterson & Tinker, 1947). Solid set print (with no leading, ascenders on one line touch descenders of the previous line) is not recommended (Tinker, 1963).

Line length. Line length is simply the distance from the left to right margin. Lines that are either very long or very short are difficult to read (Tinker, 1963). Lines of

between 50 and 60 characters are considered optimal (Morrell & Echt, 1997; Romano, 1984).

Justification. Justification refers to the manner in which letters or words are aligned. While Trollip and Sales (1986) found that full justification, having both the left and right margins lining up by adding whole spaces between words, slowed reading. Campbell, Marchetti and Mewhort (1981) found no difference between non-justified passages and justification by adding whole spaces between words, however, full justification by distributing small spaces proportionally between letters and words improved reading speed. Jubis and Lee (1991) found no effect in reading speed for justification when reading from a video screen.

Contrast. Contrast refers to the maximum difference in the thickness of strokes within a letter (see Figure 1). While providing for variations in style, very thick and thin lines within the same font make print hard to read and reproduce because the thin parts of the letters degrade visually more readily than do the thick parts (Spiekerman & Ginger, 1993). Thus, a font that has uniform lines (little contrast) is more legible than fonts with high contrast.

Contrast polarity. Contrast polarity refers to the alterations of printing dark letters on a light background or light letters on a dark background. Low vision readers with cloudy ocular media performed better with white letters on a dark background (Legge, Rubin, Pelli & Schleske, 1985). The authors suggested that this finding may be related to the resulting reduction in contrast due to increased light scatter by the cloudy ocular media, an effect which would be greater for black-on-white text than white-on-black. Legge, Pelli, Rubin and Schleske (1985), however, found that for readers with no visual pathology, there was no difference between the two contrast polarities.

Counter. The counter of a letter is the white space within the letters (see Figure 1). It is important that there is enough counter within letters so that they do not “fill in” when viewing small print or print viewed from far away.

Font type. Bell (1993) categorizes fonts into 3 general types: serif, sans serif, and “novelty” fonts. Serif fonts have formal strokes (called serifs) on the ends of some letters, while sans serif fonts do not (see Figure 1). Roman type refers to serif fonts,

while Gothic type is usually used to refer to sans serif fonts. The remaining category consists of script and other special-use fonts, and are not within the scope of this study.

It has been reported (Roethlein, 1912) that sans serif fonts are superior to serif fonts in terms of the identification of individual letters (legibility). For this reason highway signs and many headlines in newspapers are printed in sans serif fonts. There is, however, no consensus as to the effects of serif fonts on readability. Degani (1992) has suggested that serifs provide a guide for the eyes to follow across a printed page, facilitating horizontal movement. Reynolds (1984) suggests that serifs may contribute to the individuality of letters, thus aiding the recognition of word shapes. However, there are no empirical data to support either of these claims.

Sans serif fonts may be more readable (i.e., the speed and accuracy of reading) than serif fonts for low-vision adults, and partially sighted individuals may prefer them (Shaw, 1969). However, several other studies have reported a superiority for serif fonts (e.g., Nolan, 1959; Prince, 1966) for low vision readers. Romano (1984) recommends serif fonts for the general public and Rosenbloom (1994) recommended serif fonts over sans serif fonts to increase reading speed for older people. The advisability of this, however, is unclear. Although Sorg (1985) showed that Helvetica (a sans serif font) was easier to read than Century Schoolbook (a serif font), Vanderplas and Vanderplas (1980) found just the opposite. Neither Paterson and Tinker (1932), nor Poulton (1965) found a difference between serif and sans serif fonts in readability. Similarly, Smither and Braun (1994) found that for most dimensions (reading speed, errors, subjective ratings) there was no difference. Moriarty and Scheiner (1984) found no difference between serif and sans serif fonts even with minimal inter-letter spacing.

Reading

Reading involves a series of saccadic (ballistic) eye movements across the printed page with perception and comprehension of content occurring during the brief interspersed fixations that account for 90% of reading time (Solan, Feldman & Tujak, 1995). The duration and frequency of fixations vary directly with the difficulty of the text being read (Wickens, 1992). During fixations, identification of letters typically occurs in the high acuity central (foveal) region of the retina. The fovea is about one degree across, which allows identification of about 10 letters, depending on the size of

the print. In the parafoveal region, within an asymmetrical window of approximately 10 to 14 characters (slightly favoring the right), more global information such as word boundaries are extracted. Information from this region is used to determine the location of the next saccade. Saccades in the opposite direction (right to left) are called regressions and are used to review material already covered.

Reading speed also varies with the purpose of the reading (Wagenaar, Schreuder & Wijlhuizen, 1987). For example, when preparing to answer questions about content, reading is relatively slow compared to scanning for a particular “target” word within a passage. Carver (1990) suggests that there are five basic types of reading process. The scanning process involves lexical access and occurs at about 600 standard words (6 characters each) per minute (SW/min.). The skimming process (the second level) involves lexical access and semantic encoding and occurs at approximately 450 SW/min. Rouding (normal reading) involves those processes involved in lower reading processes, as well as sentence integration, and occurs at about 300 SW/min. The fourth reading process identified by Carver, learning, requires remembering and occurs at approximately 200 SW/min. The final type of reading, memorizing, requires fact rehearsal as well as all the processes used for the other types of reading, and is said to occur at about 138 SW/min.

Bottom-up processes. Reading is based on both bottom-up (stimulus-driven) and top-down (context-driven) processes. Wickens (1992) describes the bottom-up processes as occurring in a hierarchical fashion wherein features are integrated into letters, letters into words, and words into meaningful sentences. With increased reading experience, reading strategies are likely to change, proceeding from recognition of individual letters to letter-groups or whole-words (Reynolds, 1984). Relatedly, familiarity with particular words also affects how they can be read. Familiar words can be perceived automatically from their overall word shape (orthographic image) and do not have to be read letter-by-letter (Crowder & Wagner, 1992).

Top-down processes. Top-down processes in reading refer to additional information from memory and knowledge of language and impacts the reading process. Some top-down processes stem from contextual constraints in language and some from expectancies created by the context in which the information is found. Top-down

processes can affect perception at the level of letter or word recognition, to reduce uncertainty in reading. This can both aid and hinder the reading process dependent on the accuracy of the top-down effects. For example, ambiguity of letters can be reduced by knowledge of permissible letter combinations (Massaro, Taylor, Venezky, Jasterzembki & Lucas, 1980). Massaro, Taylor, Venezky, Jasterzembki and Lucas also state that the same processes also occurs at the level of word recognition based on the content of the sentence and passage. This redundancy of information aids in reading as long as all the information is in agreement, processing can be hindered when it is not. For example, proof reading is much more difficult when the wrong word is used within a sentence or when the incorrect letter does not alter the orthographic shape. Monk and Hulme (1983) for example, found that the ease of proof reading was directly related to the degree to which the orthographic image of words was disturbed. They suggested that information about the shape of words may be extracted either before or at the same time as letter information.

Measuring the Effectiveness of Visual Displays

The effectiveness of visual displays can be assessed in a variety of ways, each of which depends on a complex interaction between the observer's tasks, the observer's visual ability, the visual environment and a wide range of display parameters.

Legibility. Legibility, the degree to which the individual elements defining a display (e.g., letters) can be identified, depends largely on bottom-up processes (stimuli being resolved by identification of their component parts) that are a function of target parameters and/or observer spatial vision abilities. Up to some asymptotic level, legibility is enhanced by high luminance and colour contrast, larger targets, increased intra- and inter-target spacing, and high non-glare illuminance conditions (Sanders & McCormick, 1987). Observer visual variables that affect legibility include acuity, contrast sensitivity, glare susceptibility, and colour sensitivity (Owsley & Sloane, 1990).

Given that legibility increases with increases in letter size, it is most commonly indexed in terms of the minimum size of critical target elements needed for target identification (legibility size). Legibility can also be measured in terms of the greatest distance at which a target of a particular size can be identified (i.e., legibility distance). Since variations in size or distance both affect the angular retinal displacement of the

image (i.e., visual angle), by and large, these two measures are interchangeable. Legibility has also been evaluated in terms of the minimum exposure time required for correct identification (i.e., glance legibility).

Readability. Readability is normally concerned with continuous text and refers to the difficulty or ease with which material can be understood. Common measures of readability include reading rate, identification of misspelled words, searching for pre-specified letters, and/or words within word lists or passages. Less frequently used measurements of readability include exposure duration for comprehension, comprehension assessed as a percentage of content questions answered correctly after reading a passage, measurements of eye movements (e.g., number and duration), and reading fatigue.

Readability is affected by some of the same “bottom-up” variables that affect legibility, including luminance, contrast, letter size, and target spacing. However, the relationship between readability and these variables is not always the same as that for legibility. For example, although legibility improves directly with stimulus size, when letters become too large, readability can be adversely affected (Legge, Pelli et al., 1985). Stimuli that exist within a window of parameters have reading speeds independent of their component characteristics. For example, within reasonable limits, print size (Gould & Grischkowsky, 1986), contrast (Legge, Rubin & Luebker, 1987; Timmers, van Nes & Blommaert, 1980), and spatial resolution (Miyao, Haciosalihzade, Allen & Stark, 1989) do not affect the speed at which material is read. It is outside this range or when multiple sub-optimal dimension exists within the same display that readers, particularly older ones, may be disadvantaged. Very little research, however, has systematically examined the relationship between legibility and readability, and none has done so with regard to reader age.

Readability and legibility also differ in the degree to which they are influenced by such top-down factors as redundancy of information, stimulus familiarity, context, reader interests, and complexity of material (Wickens, 1992).

Effects of Aging on Reading

Given their spatial visual deficits and reported difficulties with small print (Vanderplas & Vanderplas, 1980), font characteristics might be expected to be more

important determinants of the effectiveness of small print for older readers than younger ones. Consistent with this, Kosnik, et al. (1988) found that older people reported greater difficulty reading small print than did their younger colleagues. Older respondents also reported more difficulty with near visual tasks, and taking longer on reading tasks. These findings were replicated by Kline et al. (1992).

Hartley, Stojack, Mushaney, Annon and Lee (1994), found that there were no age-related reading speed differences when readers were self-paced. Akutsu, Legge, Ross and Schuebel (1991) reported that although older people read as fast as younger people with materials of optimal size, they were more susceptible to deviations in optimum print size. Bouma, Legein, Mélotte and Zabel (1982) found that oral reading speed was invariant with print size for both older and younger readers. Luminance contrast becomes a more important variable for observers with low vision (Rubin & Legge, 1989) such as that found in the elderly. Older people also appear to have more difficulty following a line of text while reading (Szlyk et al., 1990). Reading tasks that are particularly challenging for older people include reading medicine bottles, phone books, price labels and mail (Horowitz, Teresi & Cassels, 1991). Vanderplas and Vanderplas (1980) found that older people are more disadvantaged by small print and low illumination than are younger people.

Print is often inadequate (e.g., small, low contrast) and/or presented under sub-optimal conditions (e.g., low luminance, high glare), even on critical tasks. For example, medicine labels are typically printed in small type, frequently on a colored background, reducing luminance contrast. This makes them difficult to read, particularly for older people in low light conditions (e.g., bathroom at night). Since the elderly are prescribed medications more frequently than any other age groups, low readability of print presents a potential health hazard. Gryfe and Gryfe (1984) for example, report that 84% of elderly medical patients took at least 1 prescription drug. Although people 65 years and older make up 11.6% of the population in Canada (Frideres & Bruce, 1994), they account for 25% of Canadian prescriptions (Gryfe & Gryfe, 1984). Kiernan and Isaacs (1981) found that elderly adults living on their own took, on average, 4.3 medications/person/ day. Park and Jones (1997) indicate that non-adherence is a significant contributor to hospital admissions for older adults. Although this is almost certainly more than a problem of

visual perception, it is also the case that if people cannot read the directions and warnings, they cannot comply with the information they provide.

Optimizing Print

A number of general recommendations have been offered for optimizing print legibility and/or readability. For example, Luckiesh (1937) recommended "...fonts devoid of needless details and with "openness" necessary for good legibility". Barnhurst (1994) recommends "...a simple font, fairly broad, with fairly thick limbs, but not too much contrast between thick and thin lines". Tinker (1963) suggested the use of simplified letter outlines, avoiding long heavy serifs and hair line strokes.

Print that is about two to three times larger than the threshold recognition size is often recommended for optimal readability (Smith, 1984). Once print is sufficiently large to be legible, font characteristics have minimal effects on readability. Thus, when the type is well above threshold size, well illuminated, high in figure-ground contrast, and has adequate letter and line spacing, small differences in print type (e.g., fonts type, font style) are likely to have little impact on readability. Conversely, font characteristics are most likely to affect small print under adverse conditions of low-contrast, poor vision and in poor illumination, such as are frequently encountered when reading medicine bottle labels, telephone books, maps, stamped tool labels, dictionaries, and some newspaper print.

Smith (1979) reported that, given adequate contrast and letter size, other factors influence legibility to a lesser degree. While Sanders and McCormick (1987) agree, they recommend using optimally designed print in certain circumstances (i.e., degraded viewing conditions, critical information being presented, when being read by people with poor vision). Yet Tinker (1965) notes that it is often traditional practices and "the artistic appearance" associated with a font that determines font use in particular applications.

Optimizing Print for Older Readers

When designing print for older readers, Kline and Lynk (1993) recommend the use of "...clean simple fonts..." (e.g., Helvetica, Chicago, Bookman) and "...avoid ornate ones as they appear cluttered and blurry". While there seems to be some consensus in the recommendation for simple "clean" fonts, the specific advantages and limitations of fonts with and without serifs for older readers has not been determined empirically. This

recommendation and those previously mentioned would seem to favor sans serif fonts over serif fonts, especially for readers with impaired spatial vision. Most print, however, including that for those with low-vision, is printed in serif fonts. An exception to this is the newspaper printed by the Canadian National Institute for the Blind, for low vision readers, which is printed in Helvetica (a sans serif font) with 14-point letters.

Considering the critical need of a fast aging population for effective printed materials, this study sought to identify factors that can enhance the effectiveness of print for readers of different ages, especially under sub-optimal viewing conditions. Under sub-optimal conditions (e.g., small print) the characteristics of font type may well be exaggerated for elderly and low vision readers. Designs that appear effective for younger populations in good visual health may not be optimal for elderly readers. The reverse, however, may not be true. For example, Kline and Fuchs (1993) showed that designs optimized for older viewers aided adult observers of all ages.

Hypotheses

The following hypotheses were evaluated:

- 1) Consistent with previous studies, near and far acuity and contrast sensitivity at higher spatial frequencies would be worse for elderly readers.
- 2) Font legibility, and readability, as assessed by reading time, would be superior for young adult readers compared to elderly readers.
- 3) Due to the age-related loss in accommodation, the comfortable reading distance of elderly readers would exceed that of young readers.
- 4) The legibility and readability of sans serif fonts would exceed that of serif fonts for both age groups.
- 5) The benefits of sans serif fonts over serif fonts for objectively measured reading performance would be greater among older readers (i.e., an age by font type interaction).
- 6) Subjectively, sans serif fonts would be rated as easier to read, producing less discomfort, having greater clarity, being more simple and preferred, than serif fonts, especially by elderly readers.
- 7) A significant positive relationship was expected between acuity, high cut-off measure of contrast sensitivity and print legibility.

- 8) The readability and legibility of fonts would be positively related for both young and elderly readers.
- 9) Due to contour interaction effects, the legibility and readability would be worse for condensed fonts than non-condensed fonts, especially for elderly readers (i.e., an age by font interaction).

Method

Participants

Twelve (6 men, 6 women) young (mean age 22.8 years, range 20 - 28), and twelve (6 men, 6 women) older community-resident volunteers (mean age 68.9 years, range 61 - 75) who were mobile and generally in good self-reported health, participated in this study.

Participants were tested for near and far acuity, contrast sensitivity, and astigmatism. They were also surveyed about their visual limitations and problems. Although the vision of adult observers can usually be improved refractively (Owsley, Sekuler & Siemsen, 1983), to enhance the real world generalizability of the results, and considering that all participants had reasonably good acuity (i.e., none worse than 1.75 minarc), all testing was carried out using participants' presenting optical correction.

Two younger participants and four elderly participants presented with an astigmatism. Self-reported visual problems were also more common among the elderly participants. One young participant reported a high level of light sensitivity; one older person reported a floater, two reported blurred vision when tired, and one experienced occasional double vision. No one reported having any chronic visual diseases (e.g., glaucoma, cataracts). Two young participants reported general health problems: one suffered from occasional headaches, and the other had asthma. Five of the elderly participants complained of health problems: two suffered from high blood pressure, two had high cholesterol, and one had osteoarthritis. The native reading language for all participants was English, although one young participant reported that English was his second language. Elderly participants were more likely than younger participants to require glasses (especially to read) and on average, more time had elapsed since they had received their last prescription (see Table 1).

Table 1

Background Information for 12 Young and 12 Elderly Participants

	Young	Elderly
English first language	11	12
Use corrective lenses	5	12
If use corrective lenses		
Years since last prescription	0.80	3.25
Single-vision glasses	4	5
Contact lenses	3	1
Multifocal lenses	0	7
lenses to read	0	10
lenses to drive	5	7

There were no age differences on either years of education ($t(22) = 0.53$ $p > .05$;) or WAIS-R vocabulary scores ($t(22) = 0.70$ $p > .05$).

For inclusion of their data in the study, participants were required to answer correctly at least one of the two comprehension questions associated with each passage, and overall to answer correctly 13 of the 16 questions. A liberal criterion was used to determine correct answers and thus the reading of passages was indoubt for those failing this criterion. For this reason the data from seven participants (five elderly males, an elderly female, and a young female) were not included in the study. Analysis of variance revealed that the elderly participants eliminated from the study did not differ significantly from those used in the study on any participant measure nor dependent measure (p s ranging from .973 to .164) except near peak CS frequency ($M = 2.33$ for those eliminated and $M = 3.67$ for those used in the study $t(16) = 2.28$, $p < .05$), and a mean vocabulary score slightly (but not significantly lower). An examination of the mean scores of the younger participant replaced indicated a slightly higher contrast sensitivity at lower frequencies for both near and far test distances and a lower acuity for the far test distance. No other scores fell outside the range of scores obtained by the other young participants.

The data were replaced by testing seven additional participants from the appropriate age/sex groups and test order.

Apparatus and Materials

Vision tests. Near (36 cm) and far (610 cm) acuity were assessed, with their presenting correction, using custom Landolt-C Acuity Charts. Near contrast sensitivity was determined for gratings of 1, 2, 4, 8 and 12 c/deg, and far contrast sensitivity was measured for gratings of 3, 6, 12, 24 and 36 c/deg utilizing the Vision Contrast Test System (VCTS) charts for near and far distances respectively. Participants were screened for astigmatism utilizing the AO Scientific Instruments Nearpoint Rotochart, and Green's Astigmatic Test Card for near and far distances, respectively.

Self-report survey. Background demographic information was obtained via oral questions (see Appendix A). Information on visual problems and reading was obtained using a participant completed questionnaire (see Appendix B).

Print materials. Eight fonts were evaluated in the study (see Appendix C); four were serif fonts (Century Old Style, Times New Roman, Garamond Condensed and Sabon), and four were sans serif fonts (Times New Roman Sans, Univers Condensed, Bell Gothic and The Sans). A serif font (Palatino) was used to familiarize participants with the legibility and readability tasks. It was also the font in which all non-test stimulus (e.g., instructions) were printed. The print materials were printed on plain white paper on a Laser Writer 16/600 PS printer at 600 dots/inch and presented at a luminance of 100 cd/m² as measured using a Minolta LS110 spot photometer.

The legibility of each font was evaluated using charts composed of lowercase letters in each of the nine fonts. Each chart contained 21 rows each of 16 letters arranged in four, four-letter horizontal clusters. The critical element of the print (i.e., 1/5 x-height) ranged in size from 0.5 minarc (equivalent to a 6/3 target) for the smallest size up to 2.5 minarc (6/15) in .1 minarc steps. Each line was composed to balance letters that were easy (e.g., p, z, c, m) or difficult to discriminate (e.g., e, i, j, t). All lines of the same letter size on each font chart contained the same letters (see Appendix D), but arranged in a different randomized order. Each four-letter cluster contained at least one riser or descender. Only one riser and/or one descender was permitted in each letter cluster. The position of ascender and descender letters was balanced across each of the four positions

in the clusters within a chart. To reduce possible differential “top-down” effects, the clusters did not form words or “word-like” groups. Uniform inter-cluster and row spacing was maintained across lines of the same size for each chart (see Table 2). To provide uniform open spacing between clusters a blank space in non-proportional font (e.g., Courier) was used.

Table 2

Uniform Inter-cluster Spacing and Row Height for Nine Legibility Charts

Letter Size (minarc)	Vertical Spacing (points)	Horizontal Spacing (points)	Letter Size (minarc) ctd.	Vertical Spacing. (points) ctd.	Horizontal Spacing. (points) ctd.
2.5	228	139	1.4	129	78
2.4	220	133	1.3	120	73
2.3	211	128	1.2	111	67
2.2	204	123	1.1	100	61
2.1	192	116	1.0	91	56
2.0	185	111	0.9	82	50
1.9	173	106	0.8	72	44
1.8	167	100	0.7	65	39
1.7	156	94	0.6	55	34
1.6	146	88	0.5	46	28
1.5	137	84			

For each of the nine fonts, passages of 200 words were constructed of near equivalent cognitive reading difficulty (standard reading difficulty or grade 7 - 8 reading level) as assessed by the Flesch Reading Ease ($M = 66.4$, $SD = 3.8$, range 59.5 to 71.9, possible range 0 - 100, Flesch, 1948), and (grade 9 reading level) Coleman-Liau Grade Level ($M = 9.4$, $SD = 0.9$, range 7.8 to 10.6, possible range 1 - 16, Coleman & Liau, 1975). The passages and their instructions were printed at 0.045 inch x-height with equal

inter-line spacing (see Appendix E). Two general comprehension questions were included for each passage to ensure the reading of each passage.

Reading ease/discomfort/clarity of type. Each passage was rated on a 7 point scale for Reading Ease, Reading Discomfort, and the Clarity of Type (see Appendix F). These questions were printed in the Palatino font.

Simplicity/complexity. A single short statement printed in each font was used as the basis for rating its Simplicity/Complexity. Font size was the same as that used in the readability passages (i.e., x-height = 0.045 inch). A different random order was used for each participant in each age by sex group (see Appendix G).

Preference. Font preference was assessed using the same sentence as those used to evaluate simplicity/complexity, but with a different random order for each participant in each age by sex group (see Appendix H).

Vocabulary. Vocabulary was assessed using the vocabulary subtest of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981).

Procedure

Participants were tested in a single self-paced session lasting 1 to 2 hours. Informed consent, and background information regarding issues such as education, health, visual problems were obtained at the beginning of the session. The far and near spatial measures were evaluated at the beginning of the legibility and readability sections, respectively. The repeated measure design was used to prevent differential motivational factors affecting different participants (and thus fonts). In this way motivational factors were controlled by having people act as their own controls and the counterbalancing of the font orders prevented systematic motivational differences in performance for any font.

Visual measures. Prior to the assessment of legibility or readability, visual performance was assessed. Acuity was measured by the determination of the smallest gap in a line of Landolt-Cs that could be correctly identified. This was followed by the identification of contrast sensitivity (the least contrast at which the orientation of lines could be identified) for various increasing frequencies. This information was used to create a contrast sensitivity function (an assessment of sensitivity for each frequency tested), and several composite measures of contrast sensitivity (frequency at which

greatest sensitivity occurred, Peak and Mean Sensitivity, and High Cutoff Frequency (the frequency above the Peak Frequency at which sensitivity drops to half Peak Sensitivity). Astigmatism was also assessed.

Legibility. Legibility thresholds, defined as the smallest print line ($1/5$ x-height in minarc) at which no more than 2 of the letters on each line of 16 were incorrectly identified, were determined for each of the eight fonts. This criterion was used to allow for some confusion between letters while still requiring correct identification. Beginning with a line that the participants indicated they could easily read, observers progressed down the chart, reading each line of successively smaller print until the first line was reached at which more than two errors were committed. Before beginning, observers received a practice trial using the Palatino font to familiarize them with the legibility task prior to testing.

Readability. Two measures of readability, Comfortable Reading Distance and Reading Time, were assessed for each of the 8 fonts. Comfortable Reading Distance between the eye and the plane at which the observer placed the materials was measured using a string as each participant read the task instructions printed in the same font/size as the test passage. Reading time was measured as the time the participants took to read each passage at the instructed “normal comfortable” reading speed. Participants were informed that two general comprehension questions would be asked immediately upon completion of the passage. After both questions were answered, the observer rated the font used in the passage in regard to its “Reading Ease”, its “Reading Discomfort” and its “Clarity of Print” on separate 7-point scales (see Appendix F). At the beginning of the readability trials, a practice trial was provided using the Palatino font to familiarize participants with the task.

Simplicity/complexity/preference. Once the readability assessments for all fonts were completed, participants rated the complexity of the letters composing each font on a 7-point scale (see Appendix G). Finally, corresponding preference for the eight fonts was assessed (see Appendix H) using a ranked forced distribution (i.e., 8-point scale using all 8 numbers).

Overall research design. One participant from each Age x Sex group received the exact same stimulus order (legibility, followed by readability, complexity rating, and

preference), which required 6 different sets of stimulus orders. Half of the participants in each Age X Sex group received the legibility task followed by the readability/simplicity/complexity/preference tasks, and the other half received the reverse order (i.e., readability, complexity rating, preference followed by legibility). At the end of the session, participants completed the WAIS-R vocabulary subtest.

Results

Participant Measures

Self-reported vision and reading measures. Young participants rated their near vision as significantly better than did older participants ($t(22) = 3.07, p < .05$). This self reported measure was not significantly correlated with near acuity ($r(22) = 0.379, p > .05$), however, it was correlated with near peak sensitivity ($r(22) = -0.434, p < .05$) and near mean sensitivity ($r(22) = -0.423, p < .05$). Elderly participants also reported more difficulty reading small print ($t(22) = 3.77, p < .05$). This rating was significantly related to near acuity ($r(22) = 0.683, p < .05$) as well as all near contrast sensitivity measures except near peak frequency and near high cutoff. No age group difference was reported in the amount of time spent reading ($t(22) = 0.65, p > .05$, see Table 3) nor on any other rating of near or far vision.

Acuity. The acuity of young participants was superior to that of the older participants ($F(1,22) = 38.53, p < .05$). Acuity did not differ significantly with test distance ($F(1,22) = 2.00, p > .05$), nor was there an interaction between age and test distance ($F(1,22) = .05, p > .05$). The latter finding suggested that the young and elderly participants were equivalently corrected for both distances (see Table 4).

Contrast sensitivity. An Age (2) by Spatial Frequency (5) mixed-model ANOVA on near contrast sensitivity (Geisser-Greenhouse corrected) was conducted. An overall difference was found in the CS function ($F(4,19) = 48.46, p < .05$). Younger participants demonstrated higher CS than elderly participants ($F(1,22) = 25.33, p < .05$). The CS function was not the same for both age groups ($F(4,19) = 4.42, p < .05$). Follow-up tests (with Bonferroni correction for 5 comparison, see Table 5) showed that the contrast sensitivity of the young participants was superior to that of the elderly participants at intermediate and higher spatial frequencies (i.e., 4, 8, and 12 c/deg). The age difference

Table 3

Self-Reported Vision and Reading for Young and Elderly Participants

	Young		Elderly		Diff.
	Mean	SD	Mean	SD	
Hours reading per day	2.50	1.67	2.94	1.62	n.s.
Rating of near vision	1.50	0.67	2.50	0.90	p<.05
Difficulty of reading close	1.25	0.45	2.33	0.89	p<.05
Frequency of reading newspaper/magazine	1.83	1.19	1.25	0.45	n.s.
Importance of reading close	3.17	1.11	3.58	0.51	n.s.
Problems with close work	2.00	1.04	2.42	0.79	n.s.
Rating of far vision	1.75	0.75	1.92	0.79	n.s.
Difficulty of distant reading	1.67	0.65	1.83	0.58	n.s.
Frequency of distant reading	1.33	0.65	2.08	1.44	n.s.
Importance of distant reading	3.50	0.67	3.17	1.03	n.s.

n.s. = Not significant

in near contrast sensitivity at the two lowest spatial frequencies (1 and 2 c/deg) was not significant.

For the far contrast sensitivity measure, 50% of the observers were unable to correctly detect the grating orientation at 36 c/deg even at the highest contrast level, so data for this spatial frequency were not included in the analyses. An Age (2) by Spatial Frequency (4) mixed-model ANOVA was conducted. Younger participants demonstrated higher CS than elderly participants ($F(1,22) = 18.01$ $p < .05$) as well as differences in the CS function ($F(4,19) = 36.68$ $p < .05$). A significant interaction between stimulus frequency and observer age ($F(4,19) = 3.55$ $p < .05$) was found. Follow-up tests (with Bonferroni correction for 4 comparison, see Table 5) showed that young participants had superior contrast sensitivity at intermediate spatial frequencies (6 and 12 c/deg). The differences at the highest and lowest spatial frequencies (i.e., 3 and

Table 4

Spatial Vision Characteristics of Young and Elderly Participants (df = 22)

	Young		Elderly		T	Sig.
	Mean	SD	Mean	SD		
Near Distance (36 cm)						
Acuity	0.68	0.08	1.22	0.28		p<.05
Peak Spatial Frequency	4.17	0.58	3.37	1.67	0.98	n.s.
Mean Peak Contrast Sensitivity	165.00	29.54	100.00	46.37	4.10	p<.05
Mean Contrast Sensitivity	105.00	15.59	57.37	28.84	5.03	p<.05
High Cutoff	8.88	1.48	8.10	2.16	1.04	n.s.
Far Distance (610 cm)						
Acuity	0.59	0.10	1.15	0.42		p<.05
Peak Spatial Frequency	7.00	2.34	7.25	2.99	0.23	n.s.
Mean Peak Contrast Sensitivity	141.25	37.91	81.42	40.61	3.73	p<.05
Mean Contrast Sensitivity	81.11	19.34	46.26	18.20	4.55	p<.05
High Cutoff	16.63	4.57	13.99	3.38	1.61	n.s.

n.s. = Not significant

Table 5

Follow-up Analysis of Contrast Sensitivity Function for Near and Far Test Distances(df = 22)

Near			Far		
C/deg	T Value	Sig.	C/deg	T Value	Sig.
1	2.68	n.s.	3	1.85	n.s.
2	2.74	n.s.	6	3.80	p<.0125
4	5.14	p<.01	12	3.37	p<.0125
8	4.35	p<.01	24*	1.92	n.s.
12	5.77	p<.01			

n.s. = Not significant

* df = 21

24 c/deg), however, did not reach significance. The very high variability at the 24 c/deg for both the young ($SD = 23.80$) and older observers ($SD = 14.58$) precluded the large mean differences at this spatial frequency from reaching statistical significance. Near and far contrast sensitivity functions for younger and elderly observers are presented in Figure 3.

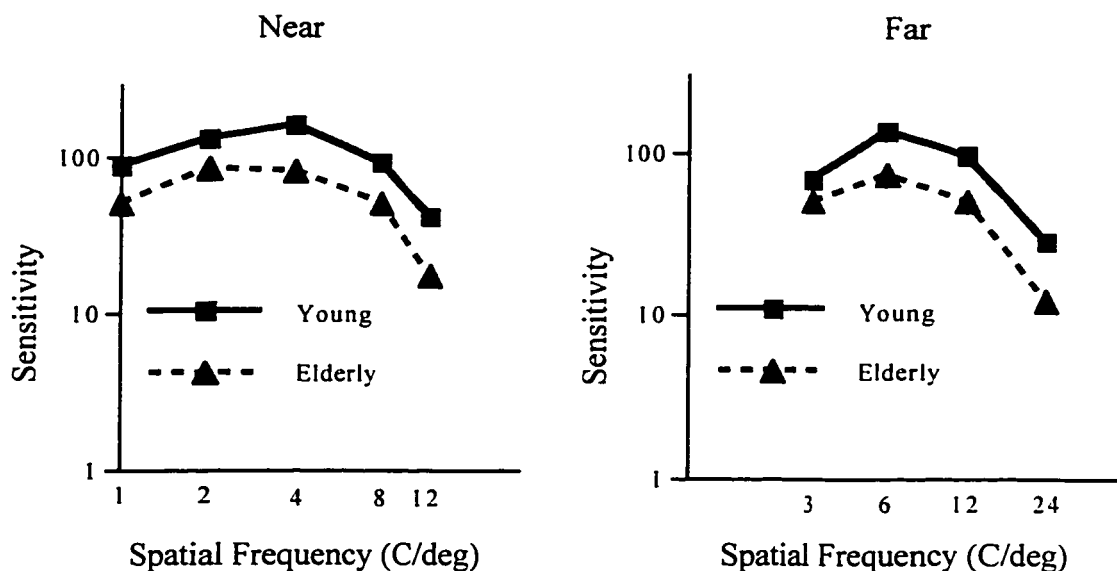


Figure 3. Near (36.0 cm) and far (610 cm) mean contrast sensitivity as a function of spatial frequency and age groups.

Age differences in contrast sensitivity were also evaluated using several “composite” measures, including Peak Spatial Frequency, Mean Peak Contrast Sensitivity, Mean Contrast Sensitivity, and High Cut-off (i.e., the spatial frequency above the peak at which sensitivity fell to one-half its peak level). Mean Peak Contrast Sensitivity for young observers exceeded that of elderly observers for both near and far test distances. A similar age difference was observed in Mean Contrast Sensitivity for both near, and far test distances (see Table 4). Neither the spatial frequency at which peak sensitivity occurred nor the high cutoff differed by age for either test distance.

Objective Reading Measures

Legibility size. A two-way repeated measures mixed-model ANOVA (2 Age groups X 8 Fonts) was carried out on the legibility threshold data. Legibility threshold varied significantly across fonts ($F(7,16) = 32.64, p < .05$), and while elderly observers

required larger letters for correct identification than did young participants ($F(1,22) = 13.88, p < .05$), the age difference did not interact with font type ($F(7,16) = 2.03, p > .05$).

Visual inspection of the mean threshold sizes for each font suggested that they fell into three general legibility groupings (see Figure 4). Pairwise ANOVA comparisons were conducted to determine if these groupings were verifiable by the pattern of pairwise differences between them. Multiple-comparison error rate was controlled using Bonferroni adjustment based on the number of significant pairwise differences (22 tests). Consistent with the legibility levels among the fonts tested, the least legible font (i.e., Garamond Condensed) differed significantly from all other fonts (see Table 6), while the legibility of the next two fonts, Univers Condensed and Century Old Style, were significantly lower than that of the three most legible fonts (The Sans, Sabon, and Times New Roman). No other pairwise comparisons were significant.

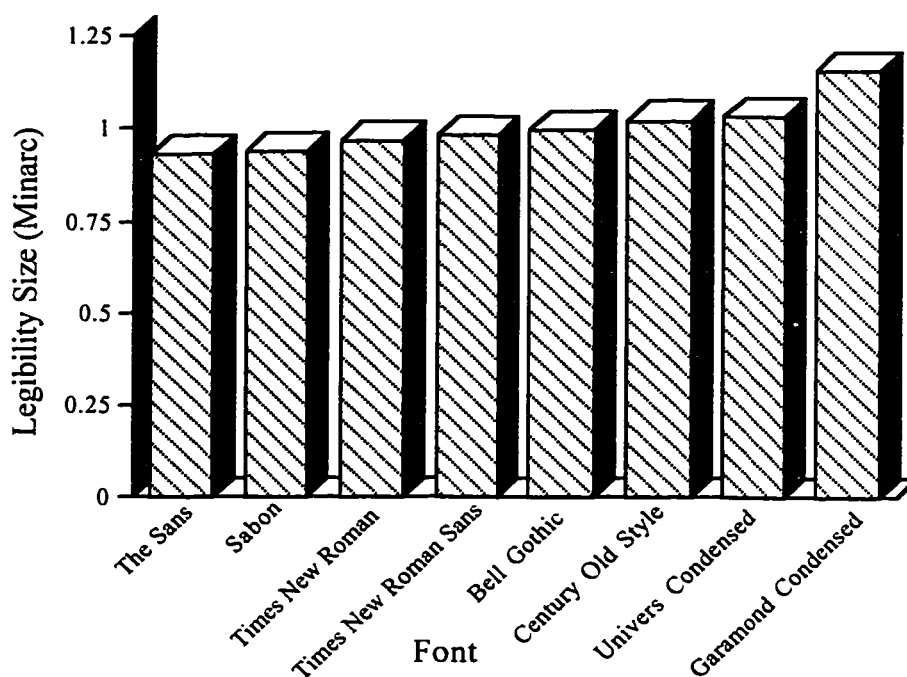


Figure 4. Mean overall legibility size of print as a function of font type.

Visual predictors of legibility. The correlations of far visual measures and mean overall font legibility for all participants and each age group separately are found in Table 7. Acuity was a strong predictor of mean overall font legibility. To a lesser extent, mean contrast sensitivity was also predictive of Mean Legibility Threshold. None of the other

Table 6
Significant T Values for Pairwise Comparisons of Legibility Size for all Participants
(p<.002)

Font	Garamond Condensed	Univers Condensed	Century Old Style
Univers Condensed	5.71		
Century Old Style	6.65		
Bell Gothic	7.85		
Times New Roman Sans	8.26		
Times New Roman	10.11	4.65	3.68
Sabon	12.99	5.47	5.00
The Sans	10.37	5.62	4.24

Table 7
Person Correlations Between Far Visual Measures and Average Legibility Overall, for
Young and Elderly Participants

	Overall	Young	Elderly
Acuity	0.894*	0.589*	0.837*
Frequency of Peak Sensitivity	0.076	-0.456	0.183
Peak Sensitivity	-0.374	0.410	-0.082
Mean Sensitivity	-0.518*	-0.003	-0.229
High-Cutoff	-0.251	-0.560	0.106

* = Significant at p<.05

composite contrast sensitivity measures were related to Mean Legibility Threshold. When the age groups were considered separately, it was found that spatial vision measures were generally more predictive of legibility among young observers than elderly ones. For young observers, legibility was related to acuity. High cut-off, frequency of peak sensitivity and peak sensitivity, approached, but did not reach significance in its predictability of mean overall font legibility for young observers. For

elderly observers, acuity was a good predictor of Mean Legibility Threshold size. None of the composite measures of contrast sensitivity, however, were related to legibility size.

Reading time. A two-way repeated measures mixed-model analysis of variance (2 Age groups X 8 Fonts) was applied to the reading time data. There were no reading-time differences among fonts ($F(7,16) = 1.23, p > .05$), nor was there a significant age effect ($F(1,22) = 1.18, p > .05$). The interaction between age group and font, however, was significant ($F(7,16) = 2.33, p < .05$). Tests of simple main effects revealed that Reading Time did not differ among fonts for young readers ($F(7,5) = 1.23, p > .025$). Although there was a significant font effect in the elderly group, the effect was not significant ($F(7,5) = 1.23, p > .025$) with Geisser-Greenhouse correction. There were no significant differences in Reading Time between young and older readers for any font (see Figure 5).

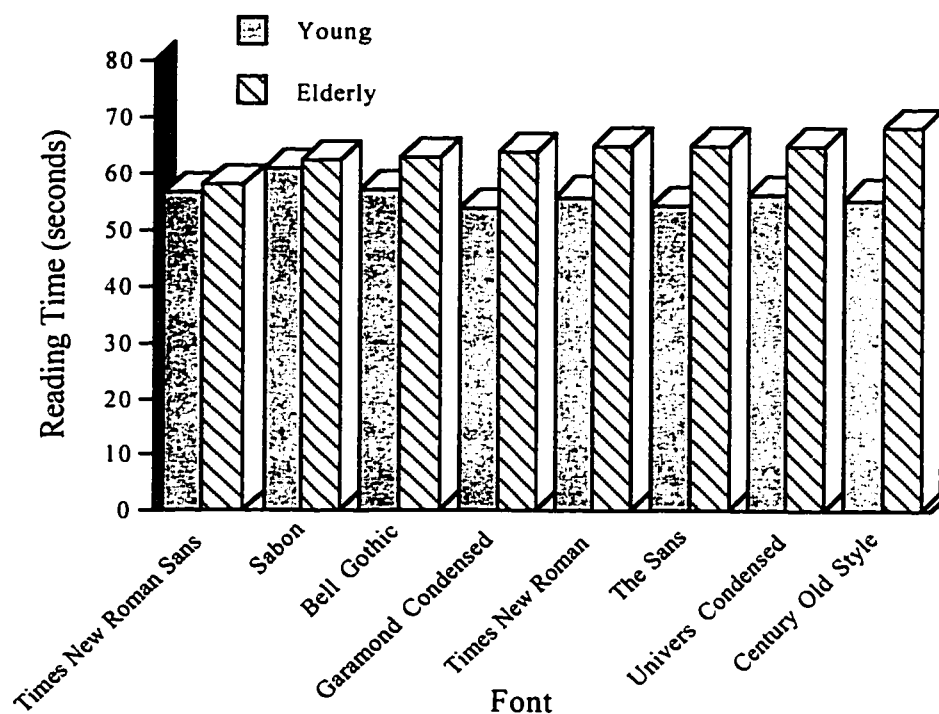


Figure 5. Age differences in comfortable reading time as a function of font type (presented in order of increasing time for elderly participants).

Visual predictors of reading time. The correlations of near visual measures and mean overall font reading time for all participants and each age group separately are

found in Table 8. Neither acuity nor composite contrast sensitivity measures correlated with the mean reading time overall across age groups, nor within either age group separately.

Table 8

Person Correlations Between Near Visual Measures and Average Reading Time Overall, for Young and Elderly Participants ($p < .05$)

	Overall	Young	Elderly
Acuity	0.084 n.s.	0.024 n.s.	-0.271 n.s.
Frequency of Peak Sensitivity	0.078 n.s.	0.113 n.s.	0.162 n.s.
Peak Sensitivity	-0.014 n.s.	0.115 n.s.	0.243 n.s.
Mean Sensitivity	0.064 n.s.	0.302 n.s.	0.405 n.s.
High-Cutoff	0.048 n.s.	-0.170 n.s.	0.313 n.s.

n.s. = Not significant

Comfortable reading distance. A two-way repeated measures mixed-model analysis of variance (2 Age groups X 8 Fonts) was conducted. Reading distance varied for the different fonts investigated ($F(7,16) = 3.61, p < .05$), but there was no difference between young and elderly readers ($F(1,22) = 0.01, p > .05$), nor was there an interaction between age and reading distance ($F(7,16) = 0.72, p > .05$).

Visual inspection of the mean reading distance data (see Figure 6) suggested a continuous progression of in reading distance among the fonts. These were evaluated using ANOVA pairwise comparisons. Error rate probability levels were corrected using Bonferroni adjustment for the number of significant differences (12 tests). The font manifesting the shortest comfortable reading distance (i.e., Century Old Style) differed significantly from both Times New Roman ($t(22) = 3.20, p < .004$), and Sabon ($t(22) = 4.62, p < .004$). The Sans was significantly different from Sabon ($t(22) = 3.84, p < .004$). No other pairwise comparisons were significant.

Visual predictors of comfortable reading distance. The correlations of near visual measures and mean overall font reading distance for all participants and each age group

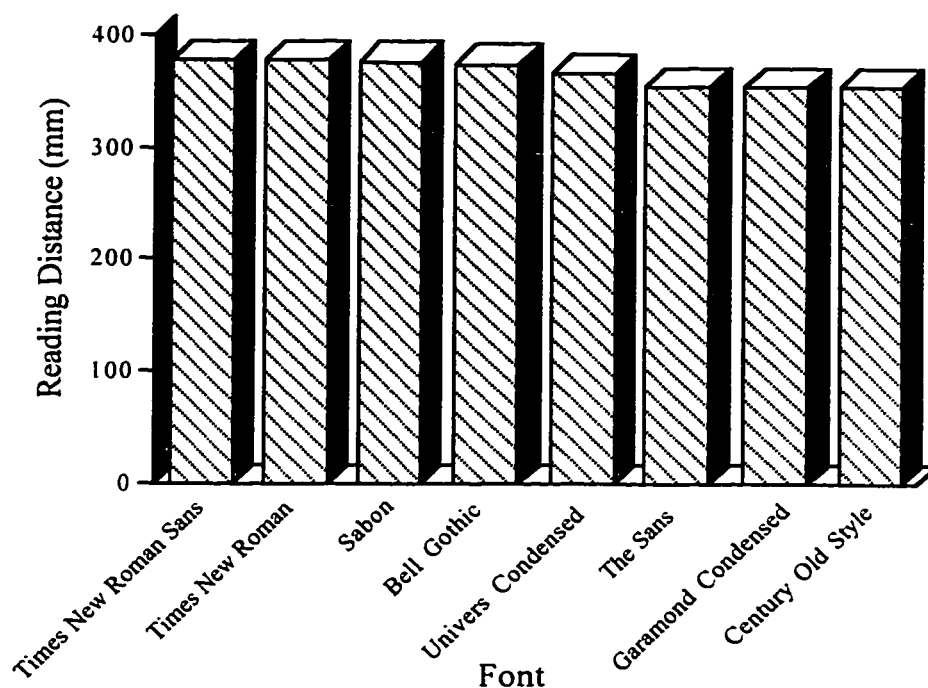


Figure 6. Mean overall comfortable reading distance of print as a function of font type.

separately are found in Table 9. There was no significant correlation between Mean Reading Distance and Acuity, nor between Reading Distance and any composite contrast sensitivity measure. For young observers, Acuity/Reading Distance relationship

Table 9

Person Correlations Between Near Visual Measures and Average Reading Distance
Overall, for Young and Elderly Participants ($p > .05$)

	Overall	Young	Elderly
Acuity	-0.206 n.s.	-0.488 n.s.	-0.452 n.s.
Frequency of Peak Sensitivity	-0.076 n.s.	-0.212 n.s.	-0.033 n.s.
Peak Sensitivity	0.153 n.s.	-0.093 n.s.	0.486 n.s.
Mean Sensitivity	0.214 n.s.	0.049 n.s.	0.572 n.s.
High-Cutoff	0.093 n.s.	-0.157 n.s.	0.319 n.s.

n.s. = Not significant

approached, but did not reach significance, while no composite contrast sensitivity measure did. For older observers the correlations between Reading Distance and Acuity, Peak Contrast Sensitivity and Mean Contrast Sensitivity approached but did not reach significance.

Subjective Reading Measures

Reading ease. A two-way repeated measures mixed-model analysis of variance (2 Age groups X 8 Fonts) was conducted on the data for rated Reading Ease. There was a difference among the various fonts tested ($F(7,16) = 3.48, p < .05$) but no age effect ($F(1,22) = 0.07, p > .05$), nor an interaction between the age and font ($F(7,16) = 0.79, p > .05$), on the ease of reading measure. Geisser-Greenhouse correction was used for repeated measures analysis to correct for violations of the sphericity assumption.

Visual inspection of the Mean Subjective Reading Ease for each font (see Figure 7) indicated two font groupings. These were tested using pairwise ANOVA comparisons, adjusted for the family of significant differences at the .05 level. Since nine comparisons were significant, Bonferroni correction for 9 tests was applied. The font that was judged as being the least easy to read (i.e., Century Old Style) differed

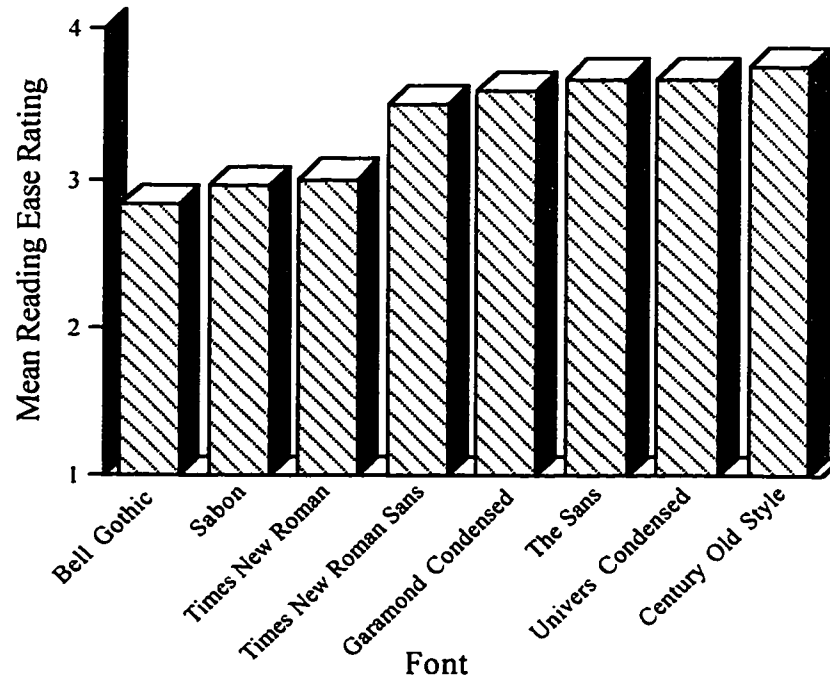


Figure 7. Mean overall subjective reading ease of print (1 = Very Easy; 7 = Very Difficult) as a function of font type.

significantly from Sabon ($t(22) = 3.02, p < .006$) and Times New Roman ($t(22) = 3.56, p < .006$). The Sans was significantly different from Bell Gothic ($t(22) = 3.05, p < .006$) and Times New Roman ($t(22) = 3.00, p < .006$). No other pairwise comparisons were significant.

Reading discomfort. A two-way repeated measures mixed-model analysis of variance (2 Age groups X 8 Fonts) was conducted on the reading discomfort data. A significant difference among fonts was observed ($F(7,16) = 5.20, p < .05$). There was no age effect ($F(1,22) = 0.02, p > .05$), nor an interaction between age and font ($F(7,16) = 0.74, p > .05$). Again, Geisser-Greenhouse correction for repeated measures analysis was used to correct for violations of the sphericity assumption.

Visual inspection of the Mean Subjective Reading Discomfort for each font (see Figure 8) suggested two font groups. Pairwise ANOVA comparisons adjusted using the Bonferroni correction for the number of significant differences at the .05 level were conducted. Ten comparisons reached significant at the .05 level and served as the basis for the Bonferroni correction. The font that was judged as producing the greatest discomfort (i.e., Garamond Condensed) was significantly different from the two fonts

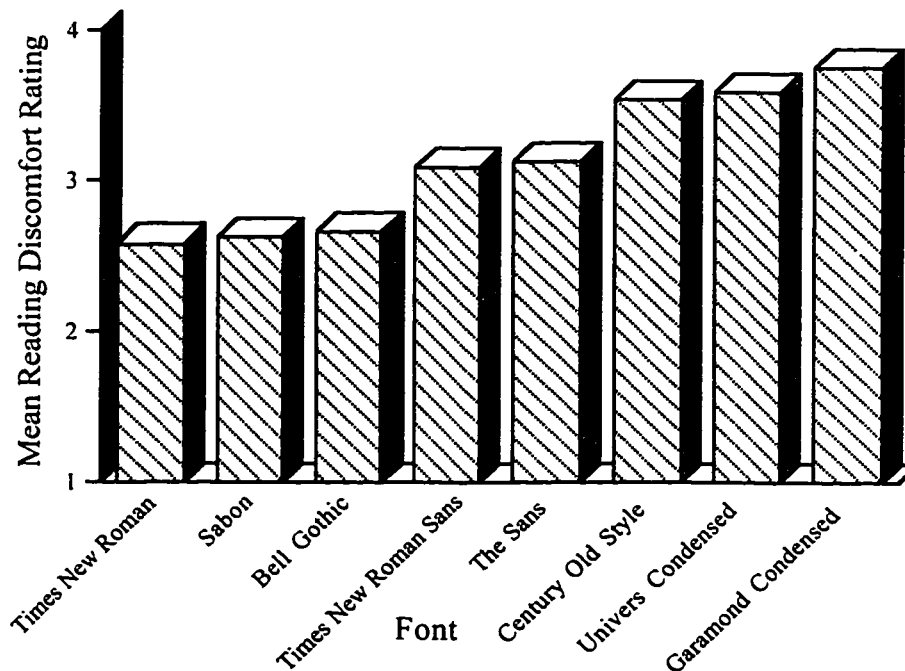


Figure 8. Mean overall subjective reading discomfort of print (1 = Very Little Discomfort; 7 = Very Much Discomfort) as a function of font type.

rated as having produced the least discomfort (Times New Roman, $t(22) = 3.56$, $p < .005$; and Sabon, $t(22) = 3.24$, $p < .005$). The font judged as having caused the next most discomfort (i.e., Univers Condensed) was also significantly different from Times New Roman ($t(22) = 3.54$, $p < .005$), and Sabon ($t(22) = 3.92$, $p < .005$). Century Old Style was rated as causing more discomfort than Times New Roman ($t(22) = 4.05$, $p < .005$), Sabon ($t(22) = 3.70$, $p < .005$) or Bell Gothic ($t(22) = 3.08$, $p < .005$). No other pairwise comparisons were significant.

Letter clarity. The letter clarity data were analyzed using a two-way repeated measures mixed-model analysis of variance (2 Age groups X 8 Fonts). While there was a difference among the various fonts tested ($F(7,16) = 3.51$, $p < .05$), there were no age effects ($F(1,22) = 1.02$, $p > .05$), nor an interaction between age and font ($F(7,16) = 0.60$, $p > .05$). Geisser-Greenhouse correction was used for repeated measures analysis to correct for violations of the sphericity assumption.

Visual inspection of the subjective Mean Letter Clarity for each font (see Figure 9) also indicated two font groupings. These were tested using pairwise ANOVA comparisons, adjusted by Bonferroni correction for the number of significant pairwise

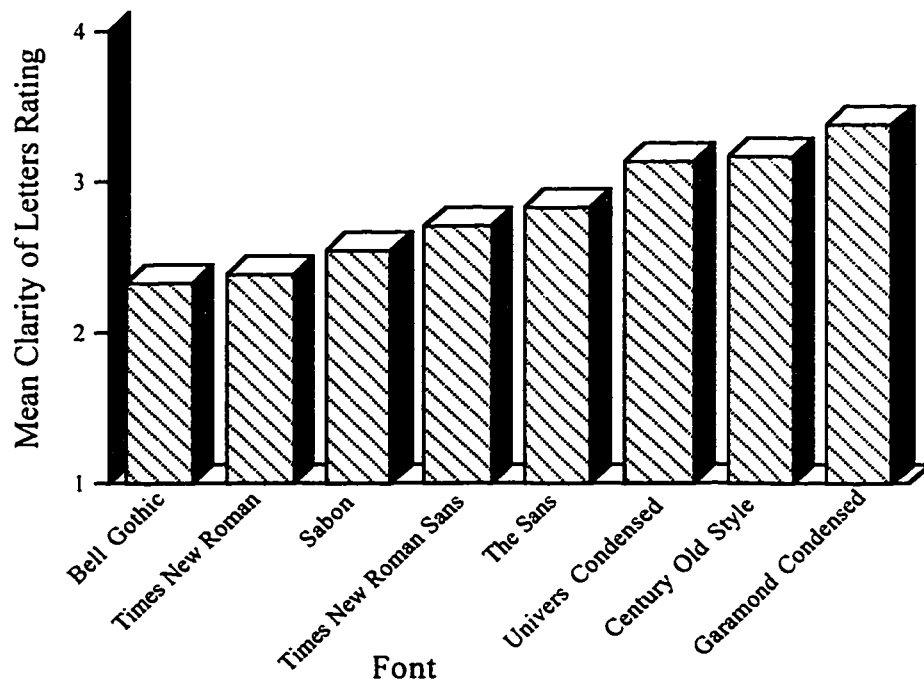


Figure 9. Mean overall subjective letter clarity of print (1 = Very Clear; 7 = Very Unclear) as a function of font type.

differences ($\alpha = .05$). Eleven significant comparisons were observed and used as the basis for the Bonferroni correction. Garamond Condensed was found to be significantly different from Times New Roman ($t(22) = 3.26, p < .005$). Century Old Style was significantly different from Bell Gothic ($t(22) = 3.39, p < .005$) and Times New Roman ($t(22) = 3.19, p < .005$). No other pairwise comparisons were significant.

Simplicity/complexity. The simplicity/complexity data were tested using a two-way repeated measures mixed-model ANOVA (2 Age groups X 8 Fonts). There was a significant difference among the various fonts tested ($F(7,16) = 11.11, p < .05$), and an interaction between age and font ($F(7,16) = 5.31, p < .05$). The age difference was not significant ($F(1,22) = 4.26, p > .05$). Geisser-Greenhouse correction was used for repeated measures analysis to correct for violations of the sphericity assumption. Follow-up tests of simple main effects found that complexity differed among fonts for young ($F(7,5) = 16.45, p < .025$), but not elderly observers ($F(7,5) = 2.47, p > .025$, See Figure 10). The Geisser-Greenhouse correction for repeated measures was applied to the data of

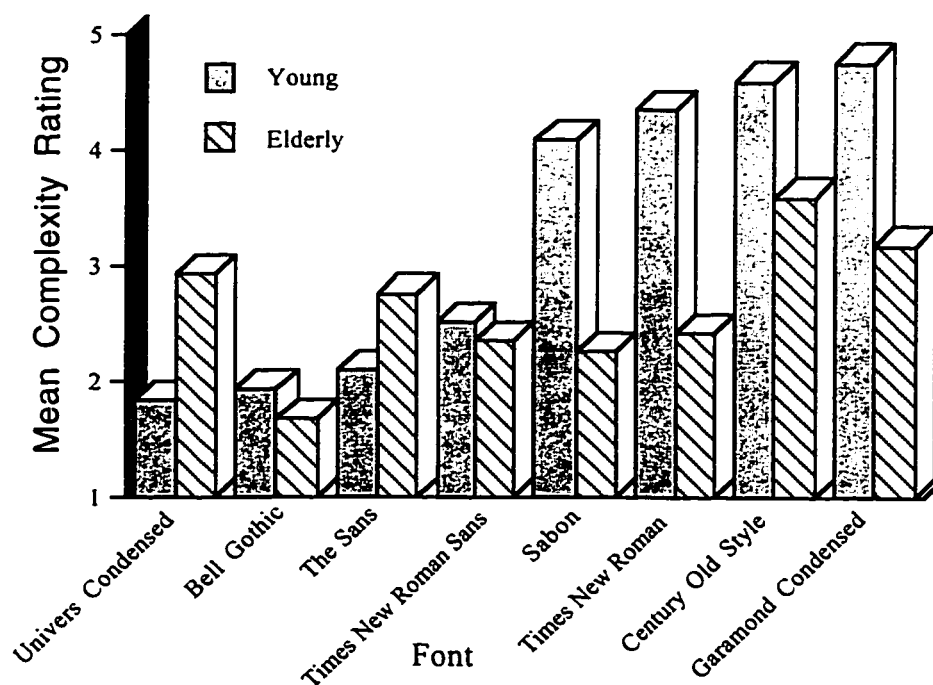


Figure 10. Age differences in subjective simplicity/complexity of print (1 = Simple; 7 = Complex) as a function of font presented in order of increasing complexity for young participants.

the elderly observers due to violations in the sphericity assumption. T-tests were used to analyze age differences on each of the fonts (Bonferroni corrected for eight tests). An age difference was seen for only two fonts, Sabon ($t(22) = 3.77, p < .0063$) and Times New Roman ($t(22) = 3.34, p < .0063$).

Although no real font differences emerged among the elderly on the Simplicity/Complexity measure visual inspection suggested two font groupings for younger participants (see Figure 10). Pairwise ANOVA with Bonferroni correction for the number of significant pairwise differences were conducted using a .025 level. Since 16 comparisons were significant at the .025 level, a Bonferroni correction for 16 tests was applied ($p = .0016$). The font rated as most complex (i.e., Garamond Condensed) was significantly different from all of the sans serif fonts (see Table 10). Century Old Style, Times New Roman and Sabon were significantly different from the three least complex fonts (i.e., Univers Condensed, Bell Gothic and The Sans). No other fonts were significantly different from each another.

Table 10

Significant T Values for Pairwise Comparisons of Simplicity/Complexity Ratings for Young Participants ($p < .0016$)

Font	Garamond Condensed	Century Old Style	Times New Roman	Sabon
Times New Roman Sans	5.48			
The Sans	7.09	6.27	4.86	5.74
Bell Gothic	5.98	4.48	4.05	4.57
Univers Condensed	6.46	5.40	4.38	4.55

Preference. Given that the preference measure was based on ordinal data they were analyzed using a Friedman two-way ANOVA. It yielded a significant difference among the fonts ($\chi^2(7, N = 24) = 57.90, p < .05$). Follow-up ANOVA's demonstrated that there were differences for both young ($\chi^2(7, N = 12) = 26.97, p < .025$) and older participants ($\chi^2(7, N = 12) = 38.72, p < .025$). Mann-Whitney tests to assess age differences however, showed no significant differences for any single font.

Visual inspection of the mean preference for each font indicated two or three possible font groupings (see Figure 11). These were tested using pairwise ANOVA comparisons corrected for the number of significant differences at the .05 level. With nineteen comparisons significant at the .05 level, a Bonferroni correction for 19 tests was used ($p = .0026$). The least preferred font (Univers Condensed) was significantly different from the four most preferred fonts (Times New Roman, Bell Gothic, Sabon and Times New Roman Sans, see Table 11). The second and third least preferred fonts (The Sans and Garamond Condensed) were significantly different from Times New Roman. The next least preferred font (Century Old Style) was significantly different from Times New Roman and Bell Gothic. No other pairwise comparisons were significant.

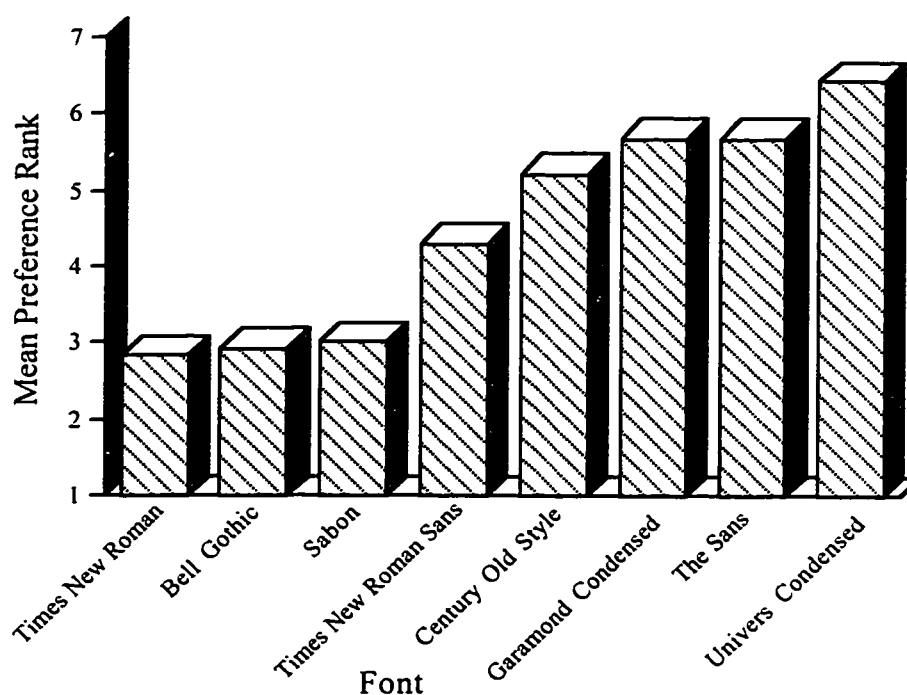


Figure 11. Mean overall subjective preference of print (1 = Most Preferred; 8 = Least Preferred) as a function of font type.

Relationships among Objective Reading Measures

The relationship among objective reading measures collapsed across age are found in Table 12. Mean Reading Time and Mean Legibility were significantly related. No relation was found between Mean Reading Distance and either Mean Legibility, or Mean Reading Time. The relationship among objective reading measures for each age

Table 11

Significant χ^2 Values for Pairwise Comparisons of Preference Ratings for all Participants
($p < .0026$)

Font	Univers Condensed	Garamond Condensed	The Sans	Century Old Style
Times New Roman Sans	10.67			
Sabon	10.67			
Bell Gothic	16.67			10.67
Times New Roman	13.50	13.50	10.67	16.67

Table 12

Overall Person Correlations Between Reading Measures Across Participants

	Distance	Time	Ease	Discomfort	Clarity	Simplicity
Reading Time	0.0386 n.s.					
Reading Ease	0.1956 n.s.	-0.1664 n.s.				
Reading Discomfort	0.1143 n.s.	-0.2096 n.s.	0.9439 p < .05			
Letter Clarity	0.0010 n.s.	-0.1283 n.s.	0.7171 p < .05	0.6667 p < .05		
Font Simplicity	-0.3537 n.s.	-0.0235 n.s.	-0.3813 n.s.	-0.2659 n.s.	-0.0968 n.s.	
Font Legibility	-0.0851 n.s.	0.4696 p < .05	-0.0422 n.s.	-0.0639 n.s.	-0.3731 n.s.	-0.2606 n.s.

n.s. = Not significant

group are found in Table 13. The relationship between Mean Reading Time and Mean Legibility only approached significance for both young and elderly participants. The relationship between Mean Legibility Threshold and Mean Reading Distance also

Table 13

Person Correlations Between Reading Measures Across Participants for Young and Elderly Participants

Young Participants

Measures	Distance	Time	Ease	Discomfort	Clarity	Simplicity
Reading Time	-0.0757 n.s.					
Reading Ease	0.0520 n.s.	0.1319 n.s.				
Reading Discomfort	0.0262 n.s.	0.0767 n.s.	0.9342 p<.05			
Letter Clarity	-0.4087 n.s.	0.4681 n.s.	0.6200 p<.05	0.5080 n.s.		
Font Simplicity	-0.2448 n.s.	0.3696 n.s.	0.0913 n.s.	0.1683 n.s.	0.4681 n.s.	
Font Legibility	-0.5113 n.s.	0.4187 n.s.	0.0910 n.s.	0.0965 n.s.	0.5027 n.s.	0.1181 n.s.

Elderly Participants

Measures	Distance	Time	Ease	Discomfort	Clarity	Simplicity
Reading Time	0.1803 n.s.					
Reading Ease	0.3268 n.s.	-0.4001 n.s.				
Reading Discomfort	0.2086 n.s.	-0.4792 n.s.	.9586 p<.05			
Letter Clarity	0.3356 n.s.	-0.4954 n.s.	.7799 p<.05	.7767 p<.05		
Font Simplicity	-0.5178 n.s.	-0.1854 n.s.	-.7030 p<.05	-.6250 p<.05	-0.5620 n.s.	
Font Legibility	-0.0277 n.s.	0.5352 n.s.	-0.0725 n.s.	-0.1033 n.s.	-0.4930 n.s.	-0.0466 n.s.

n.s. = Not significant

approached, but did not reach, significance for young observers. None of the other relationships among the objective reading measures even approached significance.

Relationships among Subjective Reading Measures

The relationship among subjective reading measures collapsed across age are found in Table 12. A significant overall relationship was seen between Mean Reading Ease and Mean Reading Discomfort, Mean Reading Ease and Clarity of Type, and Mean Reading Discomfort and Clarity of Type. No significant relationship occurred between Mean Simplicity/Complexity and the other subjective reading measures. The relationship among objective reading measures for each age group are found in Table 13. For young participants, there was a significant relationship between Mean Reading Ease and Mean Reading Discomfort, Mean Reading Ease and Mean Clarity of Type. The relationship between Mean Reading Discomfort and Mean Clarity of Type approached, but did not reach, significance. As for the data across age groups, no significant relationship was seen between Mean Simplicity and the other subjective measures among the young participants. For elderly participants, significant relationships were seen between Mean Reading Ease and Mean Reading Discomfort, Mean Reading Ease and Clarity of Type, and Mean Reading Discomfort and Clarity of Type. Mean simplicity/complexity was also correlated with both Mean Reading Ease and Mean Reading Discomfort. Mean Simplicity/Complexity approached, but did not manifest a significant relationship with Mean Clarity of Type.

Relationships between Objective and Subjective Reading Measures

There were no significant overall correlations between any objective and subjective reading measure across age, nor were any observed within either age group (see Table 12 and 13).

Relationships between Preference and other Reading Measures

The preference measure was based on a forced distribution in which observers ranked their preference for the eight fonts on a one-to-eight scale. Mean Font Preference Rankings were obtained by averaging the preference rank for each font across all participants and rank ordered the results. To facilitate analysis of the relationships between preference and the other reading measures, they were also transformed into scales for each font using the same approach. The relationships among the various reading measures were then examined using Spearman correlations. As can be seen in Table 14, Reading Ease, Reading Discomfort and Clarity of Type were all significantly

Table 14

Overall Spearman Correlations Between Ranked Reading Measures Across Fonts

Measures	Distance	Time	Ease	Discomfort	Clarity	Simplicity	Legibility
Reading Time	-0.120 n.s.						
Reading Ease	-0.651 p<.05	0.276 n.s.					
Reading Discomfort	-0.767 p<.05	0.143 n.s.	0.719 p<.05				
Letter Clarity	-0.755 p<.05	0.191 n.s.	0.826 p<.05	0.905 p<.05			
Font Simplicity	-0.386 n.s.	0.024 n.s.	0.380 n.s.	0.156 n.s.	0.515 n.s.		
Font Legibility	-0.479 n.s.	0.095 n.s.	0.287 n.s.	0.714 p<.05	0.571 n.s.	0.156 n.s.	
Font Preference	-0.633 p<.05	0.204 n.s.	0.765 p<.05	0.898 p<.05	0.826 p<.05	-0.018 n.s.	0.419 n.s.

n.s. = Not significant

related. Reading Discomfort was also related to Legibility. Reading Distance was inversely related to Reading Ease, Reading Discomfort, Clarity of Type and Preference. Preference was related to Reading Ease, Reading Discomfort, and Clarity of Type. No other relationships with Preference were significant.

The overall Spearman correlational analysis of the relationships among the font rankings on the various reading measures, as repeated for the young and elderly age-groups separately (see Table 15). The pattern of significant relationships among the reading measures as well as the number of reading measures that were significantly related to one another, differed between the elderly and young groups (19 vs. 14 respectively). Possible age differences in these relationships were evaluated using R-to-Z transformations (Glass & Hopkins, 1984), which are shown in Table 16. This revealed an age-related difference between Reading Time and Reading Distance, Reading Ease,

Table 15

Spearman Correlations Between Ranked Reading Measures Across Fonts for Young and Elderly Participants

Young Participants

Measures	Distance	Time	Ease	Discomfort	Clarity	Simplicity	Legibility
Reading Time	0.8095 p<.05						
Reading Ease	-0.527 n.s.	-0.4671 n.s.					
Reading Discomfort	-0.7857 p<.05	-0.691 p<.05	0.7306 p<.05				
Letter Clarity	-0.7952 p<.05	-0.711 p<.05	0.7273 p<.05	0.9639 p<.05			
Font Simplicity	-0.2381 n.s.	-0.381 n.s.	-0.3234 n.s.	0.1905 n.s.	0.1325 n.s.		
Font Legibility	-0.5988 n.s.	-0.5389 n.s.	0.5904 n.s.	0.8024 p<.05	0.703 p<.05	0.1557 n.s.	
Font Preference	-0.8539 p<.05	-0.903 p<.05	0.5768 n.s.	0.8295 p<.05	0.889 p<.05	0.1464 n.s.	0.5768 n.s.

Elderly Participants

Measures	Distance	Time	Ease	Discomfort	Clarity	Simplicity	Legibility
Reading Time	-0.5238 n.s.						
Reading Ease	-0.8144 p<.05	0.7665 p<.05					
Reading Discomfort	-0.7075 p<.05	0.6587 p<.05	0.8836 p<.05				
Letter Clarity	-0.6946 p<.05	0.6467 p<.05	0.9277 p<.05	0.8836 p<.05			
Font Simplicity	-0.7857 p<.05	0.6667 p<.05	0.9341 p<.05	0.8783 p<.05	0.8503 p<.05		
Font Legibility	-0.1078 n.s.	0.3114 n.s.	0.3133 n.s.	0.5522 n.s.	0.3675 n.s.	0.5389 n.s.	
Font Preference	-0.619 n.s.	0.9286 p<.05	0.7785 p<.05	0.7319 p<.05	0.7186 p<.05	0.7381 p<.05	0.3713 n.s.

n.s. = Not significant

Reading Discomfort, Letter Clarity, Simplicity, and Preference. There was also an age difference between Simplicity and Reading Ease, Reading Discomfort, and Clarity of Type.

Table 16

R-to-Z Transformations on Age-Related Differences in the Relationships between Reading Measures collapsed Across Font

Relationships		Young	Elderly	Difference
		R	R	Z
Reading Time/	Reading Distance	0.810 *	-0.524	2.699 *
Reading Time/	Reading Ease	-0.467	0.767 *	2.400 *
Reading Time/	Discomfort	-0.691 *	0.659 *	2.594 *
Reading Time/	Letter Clarity	-0.711 *	0.647 *	2.623 *
Reading Time/	Simplicity	-0.381	0.667 *	1.907 *
Reading Time/	Preference	-0.903 *	0.929 *	4.959 *
Reading Time/	Legibility	-0.539	0.311	1.138
Simplicity/	Reading Ease	-0.323	0.934 *	3.202 *
Simplicity/	Discomfort	0.191	0.878 *	1.859 *
Simplicity/	Clarity	0.133	0.850 *	1.777 *
Simplicity/	Reading Distance	-0.238	-0.786 *	1.292
Simplicity/	Preference	0.146	0.738 *	1.263
Clarity/	Legibility	0.703 *	0.368	0.771

* = Significant at $p < .05$

Structural Modeling

A preliminary structural model was proposed to account for the observed relationships between the reading and vision measures (see Figure 12). It was hypothesized that visual measures (Acuity, Mean CS and Peak CS) would determine the legibility of printed material, which would in turn predict its readability (i.e., Reading Time, Reading Distance and Composite Subjective Ratings, derived from Mean Reading Ease, Reading Difficulty, Clarity of Print and recoded Simplicity measure, due to its inverse relationship with the other subjective reading measures). The visual measures were interrelated (Far Acuity with Far Mean Contrast Sensitivity $r(22) = -0.61, p < .05$; Far Acuity with Near Peak Contrast Sensitivity $r(22) = -0.41, p < .05$; and Far Mean

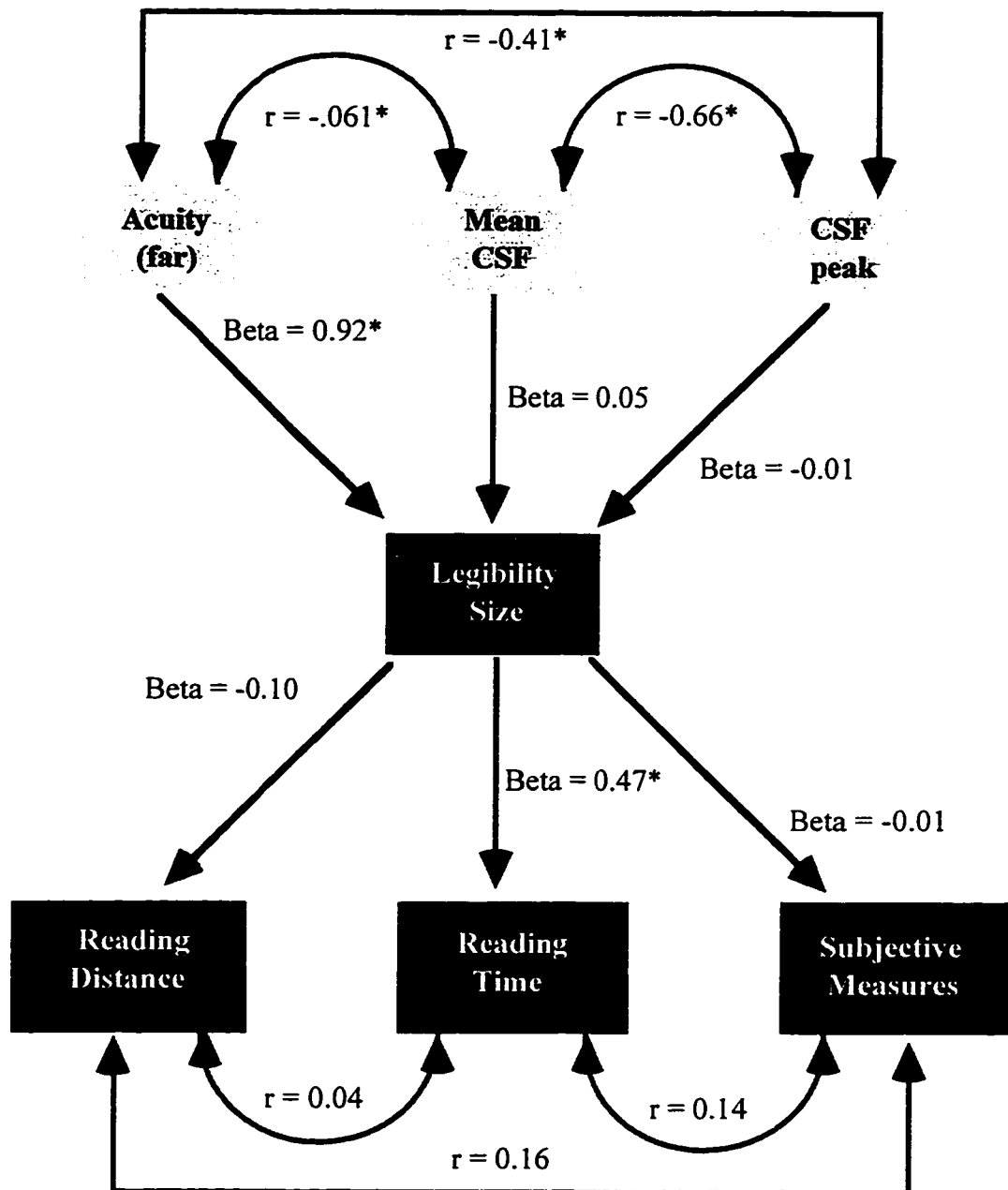


Figure 12. Initial proposed theoretical model of the relationship between vision, legibility and reading performance.

Contrast Sensitivity with Near Peak Contrast Sensitivity ($r(22) = -0.66, p < .05$) and all three variables predicted Legibility ($r(20) = 0.89, p < .05$). With all three visual measures predicting Legibility, only Far Acuity provided significant independent predictability for Legibility Size ($\text{Beta} = 0.92, p < .05$ for Far Acuity; $\text{Beta} = -0.01, p > .05$ for Near Peak Contrast Sensitivity; and $\text{Beta} = 0.05, p > .05$ for Far Mean Contrast Sensitivity). The

correlation between Far Acuity and Legibility was significant ($r(22) = 0.894, p < .05$) accounting independently for 80% of the variance in Legibility Size. The additional information provided by Mean Contrast Sensitivity and Near Peak Sensitivity only provided an additional 0.1% predictability in the Legibility variance. Thus, once the Acuity/Legibility relationship was specified, Mean Sensitivity and Peak Sensitivity added little information. R-to-T transformations for dependent measures were conducted to determine if far acuity was a better predictor of legibility than the other visual measures. Far Acuity was the best predictor of Legibility, however, it was only marginally superior to Near Acuity (see Table 17).

Table 17

R-to-T Transformations to Examine Differences Between Far Acuity and Far Contrast Sensitivity Measures and Near Acuity as Predictors of Legibility

Measure	T Value	Measure	T Value
CSF 3 c/deg	1.7334*	Peak Frequency	6.6391*
CSF 6 c/deg	2.1559*	Peak Sensitivity	3.1695*
CSF 12 c/deg	3.9430*	Mean Sensitivity	2.1284*
CSF 24 c/deg	4.5326*	Near Acuity	0.9468

* = Significant at $p < .05$

The different measures of readability were not related to one another; Reading Distance and Reading Time $r(22) = 0.039, p > .05$; Reading Distance and the Composite Subjective Ratings $r(22) = 0.159, p > .05$; and Reading Time and the Composite Subjective Rating $r(22) = 0.139, p > .05$). Only Reading Time was associated with Legibility (Reading Time Beta = 0.473, $p < .05$, Reading Distance Beta = -0.102, $p > .05$, Composite Subjective Rating Beta = -0.010, $p > .05$). The correlation between Legibility and Reading Time was significant ($r(22) = 0.470, p < .05$). Thus, this model was reduced to a very simple one in which acuity predicted Legibility Size, and thus in turn related to Reading Time (see Figure 13).



Figure 13. Reduced theoretical model of the relationship between vision, legibility and reading performance.

Discussion

Age and Vision

Consistent with the findings of previous research (e.g., Kline & Scialfa, 1996; Owsley & Sloane, 1990) and as hypothesized (Hypothesis 1) Spatial vision of older people in this study was generally inferior to that of their younger counterparts. As in prior studies, the acuity of the elderly observers was worse than that of the young observers for both the near and far test distances (e.g., Gittings & Fozard, 1986; Pits 1982) and an age deficit was observed on both near and far measures of contrast sensitivity at intermediate and high spatial frequencies (e.g., Elliott, 1987; Scialfa et al., 1992). The only exception to this general trend was the absence of significance for the large mean age difference on the far contrast sensitivity measure at 24 c/deg. This reflects the high variability in the measure at this spatial frequency, in conjunction with the relatively low number of observers used in this study (24). Composite measures of contrast sensitivity extracted from the CSF also showed an age-related decline. The Mean Contrast Sensitivity and the Mean Peak Contrast Sensitivity were significantly higher for young observers for both the near and far measures. Although not significantly different, the spatial frequency at which peak sensitivity occurred on the near CSF, was somewhat lower for the older participants. These findings are generally consistent with previous studies (e.g., Owsley et al., 1983). On the far measure, however, the spatial frequency at which peak sensitivity occurred was not different for the two age groups.

As might be expected, older participants more frequently reported general visual as well as health symptoms than did young participants. Elderly people were more likely to need corrective lenses (12 vs. 5 participants), particularly of the multifocal type (7 vs. 0 participants). Consistent with this and the normal age-related loss of accommodation

(i.e., presbyopia) most of the older participants (10 of 12) used corrective lenses for reading. None of the younger participants reported using a reading correction. No serious chronic visual diseases were reported by the participants in either age group.

As has been observed in prior studies (e.g., Kosnik et al., 1988; Kline et al., 1992), elderly participants appear to have considerable knowledge regarding some of their visual limitations. For example, older people rated both their near vision and the ease of reading near materials more poorly and reported having more problems with their near vision than did young participants (see Table 3), an insight validated by significant relationships with the objective measures of their near peak and mean contrast sensitivity, as well near mean acuity.

Age and Self-Reports on Reading

Although the difference was not significant, the elderly participants reported reading more hours per day than did the younger participants. This was somewhat surprising, considering that the young observers were primarily university students in excellent visual health. In addition the older people, as noted above, were more likely to report difficulty in reading close material, a problem that correlated strongly with their near acuity and contrast sensitivity. The unexpected parity between the age groups on the reading measures may have been attributable to non-visual factors. The older participants were as well educated as the young group, and their measured vocabulary scores were just as high. They were also in good general and visual health, and most of them being retired, had more leisure time available to them. They also were as likely to be motivated as their younger counterparts to read in that they rated the importance of both near and far reading at about the same level as younger readers.

Age and Reading Performance

Legibility. Consistent with Hypothesis 2, the elderly participants required larger letters than the young to achieve legibility. This was not surprising given the clear support as hypothesized (Hypothesis 7), for a robust relationship between Acuity and Legibility. Far Mean Contrast Sensitivity across the two age groups was also related to Mean Legibility Size, although, significantly less so than acuity (see Table 17). Some of the composite measures of contrast sensitivity approached a significant relation with Legibility Size for younger participants, but none did so for older participants. In fact,

once Mean Acuity had been considered, these other visual measures added little to the predictability of legibility (see Figure 12). The importance of acuity in affecting legibility, and legibility in turn, determining reading speed was also seen in the description of the findings of this study using structural modeling. Acuity explained 80% of the Legibility variance, which in turn accounted for 22% of the Reading Time variance. The practical implications of this for older readers concerned about their reading speed is to optimize their acuity for the reading distance (e.g., through good optical correction) and to select or adjust font sizes, font type, and reading distance to maximize print legibility.

Readability. No age differences were found in the time taken to read prose passages, nor were any of the visual measures related to reading time either within an age group or across them. The relative independence of this task from acuity may reflect that participants were allowed to hold the material at their most comfortable reading distance. Although longer reading times were expected from the elderly readers (Hypothesis 2), this hypothesis was not confirmed. The experimental conditions used in this study may have minimized the likelihood of such an age difference suggested by the absence of any age differences in overall subjective ratings (i.e., across font) of Reading Ease, Reading Discomfort, Clarity of Type, or Font Preference. These relationships may have been significant if smaller print sizes and/or more adverse viewing conditions had been employed. That at least is implied by the strong performance of older readers despite their visual disadvantages. Other factors may also have minimized age differences in reading. Among them, reading was purposefully self-paced, and participants knowing that their comprehension would be evaluated at the completion of each passage, may have emphasized accuracy rather than reading speed.

As hypothesized (hypothesis 8), the time taken to read a passage was affected positively by high legibility. The two measures were positively correlated overall, and approached significance for the two groups separately, again highlighting the fundamental importance of legibility to reading performance.

Contrary to Hypothesis 3, no age differences were found regarding the distance at which fonts were held for reading, nor were any visual measures related to reading distance overall. Within age groups, non-significant, moderately high correlations (about

.5) occurred between Reading Distance and Acuity in both the young and elderly groups. As might be expected, readers with better acuity generally held their material further away from them.

There was little evidence in this study that readers, young or old, discriminated between the various subjective dimensions used to assess fonts in this study. Reading Ease, Reading Discomfort, and Clarity of Type were all strongly associated with each other, both across and within age groups (see Tables 12-15). The only minor exception to this pattern was that the Reading Discomfort/Clarity of Type did not quite reach significance in the young group. The Complexity of fonts was related to Reading Ease, Reading Difficulty and approached a significant relationship with Clarity of Type for elderly readers, but not young ones, or the two groups combined.

Although not significant, Reading Time tended to be inversely related with the subjective rating measures for the two age groups (see Table 13). The younger readers who read passages more quickly tended to rate the fonts as easier to read, causing less discomfort, clearer and simpler. Perhaps attributing speed of reading to subjective ratings of fonts. Conversely, older readers with shorter reading times were more likely to rate the fonts as less easy to read, causing more discomfort, less clear, and more complex. Whatever the cause for the reversal, it appears to have been a purely subjective effect as it did not occur on the objective reading measures (i.e., Legibility, Reading Distance).

Do Fonts Make a Difference?

The findings of this study provide an affirmative answer to this question. Specifically, on both objective and subjective measures Times New Roman, Bell Gothic and Sabon fonts consistently facilitated reading relative to other fonts and appeared to be particularly suitable for small print applications. Times New Roman Sans was an effective small-print font and, except for reader preference, belonged among the better fonts.

Contrary to the Hypotheses regarding the superiority of sans serif fonts (i.e., Hypothesis 4, 5 and 6), the presence or absence of serifs did not distinguish the better fonts from the worse ones. Two of the best fonts were serif types and two were sans serif fonts. This was particularly evident when comparing Times New Roman and Times New Roman Sans fonts, which differed only on the presence or absence of serifs, yet were

comparable in regards to legibility, readability and reader ratings. These findings suggest, that characteristics other than the presence or absence of serifs are the fundamental determinants of font effectiveness. In accord with Hypothesis 9, two aspects of the fonts in particular, condensation and complexity, appeared to determine font effectiveness in small-print applications. Two condensed fonts (Univers Condensed and Garamond Condensed), and one highly complex font (Century Old Style) were consistently low on the performance measures. In addition to being condensed, Univers Condensed was also rated as an extremely simple font. It may be that extremes of simplicity/complexity also make fonts less usable. The effects of The Sans on reading was highly inconsistent. It was rated as a fairly simple font, high on Legibility, low on Reading Distance, Reading Ease, and Preference and intermediate on Reading Discomfort and Clarity of Print.

To determine what other characteristics of fonts might affect their utility, the relationships between percentage x-height (the percent of a font's x-height to its cap-height), font contrast (the percentage of a font's thin stroke width to its thickest stroke width), the length of a standard sentence printed in the same x-height (see Appendix G and H), vulnerability to low-pass spatial-frequency filtering (i.e., the amount of high frequency information that can be removed from a display and still be legible) and reading were examined. The outcome of these analysis are presented in Table 18. For all of the participants, fonts with greater difference between x-height and cap-height tended to be held further away to be read, but took the younger readers longer to read. Neither effect was significant. Percentage x-height was not related to any other measures, nor did the difference between thick and thin strokes (i.e., contrast) predict the performance of the fonts on any of the reading measures evaluated. Fonts that produced long sentences length were positively related to subjective ratings. They were rated as being easier to read, causing less discomfort, having better clarity of letters and were generally preferred. These same fonts also tended to be more legible, could be held farther away to be read, and could be read more quickly. This factor reflected greater "openness" of font (i.e., a combination of greater letter width, and increased spacing between letters and words). The low-pass filter thresholds of fonts related strongly to several of the reading measures. Consistent with previous research (Dewar, Kline, Schieber, & Swanson, 1994), low-pass filter threshold was highly related to Legibility. Fonts with greater resistance to such

Table 18

Overall Person Correlations Between Reading Measures and Objective Font Measures for all Participants

	% x-height	Contrast	Sentence Length	Low-pass Filter
Legibility	0.27	-0.31	-0.40**	.88*
Reading Distance	-0.58**	0.00	0.70**	-.43
Reading Time Young	-0.64**	-0.05	0.56**	-.58
Reading Time Elderly	0.26	0.12	-0.49**	.38
Reading Ease	0.20	-0.02	-.75*	.54
Reading Discomfort	0.28	-0.09	-.79*	.83*
Letter Clarity	0.19	-0.22	-.75*	.75*
Preference	0.35	0.18	-.92*	.65

* = Significant at $p < .05$

** = Approaches significance

filtering (i.e., blurring) were rated as causing less discomfort, having clearer letters, and easier to read. They were also preferred, and tended to have a greater comfortable reading distance. Surprisingly, however, while fonts that were resistant to blurring were read faster by elderly readers, they were read more slowly by young readers. Possible explanations for this reversal of results may be attributable to visual limitations of the elderly participants and motivational differences between the age groups and are discussed later in this section. Presumably resistance to low-pass filtering also reflects the openness of a font (i.e., a combination of stroke width, inter letter spacing and openness of the counters (white space within letters) and is reflective of fonts that are not condensed. This again lends support to the recommendation that condensed fonts should be avoided.

Contrary to expectation, age differences in reading were little affected by font characteristics. Age interacted with font on only two measures, Simplicity/Complexity and Reading Time. The significant age by font interaction on Simplicity/Complexity reflected the fact that younger readers rated serif fonts as more complex than sans serif fonts, while elderly readers did not distinguish font complexity based on serifs. Shorter

reading times for younger people tended to be associated with fonts that yielded longer Reading Times for older readers. This effect was not significant after Geisser-Greenhouse correction. The absence of a font effect on reading rate in this study was in accord with some of the previous literature (e.g., Mansfield, Legge & Bane, 1996; Moriarty and Scheiner, 1984; Paterson & Tinker, 1932; Poulton, 1965; Smither and Braun, 1994). These findings disagree with studies that have found serif fonts to be either superior (Nolan, 1959; Prince, 1966; Vanderplas and Vanderplas, 1980) or inferior (Shaw, 1969; Sorg, 1985) to sans serif fonts. The reasons for such inconsistencies in font effect on reading speed are not clear. Perhaps the serif effects observed in earlier research were produced by other features of the particular fonts used, such as condensation or complexity. Such an interpretation at least is consistent with the impact of these variables in the present study.

Overall, preferred fonts were read from farther away, were rated as easier to read, causing less discomfort and having greater clarity (see Table 14). Fonts that were also more legible, were associated with less rated discomfort while reading. The positive relationship found earlier among subjective reading measures across participants (i.e., Reading Ease, Reading Discomfort and Clarity of Letters) were also seen when examined across fonts, and all three of these variables were inversely related to Reading Distance. The relationship between Reading Time and Legibility that was seen across participants, however, did not occur when analyzed across fonts.

When possible age differences in the relationships between fonts and measures of reading were considered on a font-by-font basis, font characteristics were generally more important for elderly readers than younger ones. While 19 of the correlations, indicative of these relationships (see Table 15), were significant for elderly participants, only 14 were significant for young participants. Inspection of these correlations reveals a reversal in the relation between reading time and other dependent measures between young and elderly participants. Although this apparent reversal is without obvious explanation, possible explanations relate to possible age differences in visual comfort, emphasis on comprehension, and visual problems experienced in reading. As expected, among older readers, fonts that took less time to read, were more legible, read from further away, rated as being easier to read, causing less discomfort, having clearer, simpler letters, and were

preferred. This relationship might have been mediated by the greater visual limitations of older readers (e.g. reduced acuity, presbyopia). In other words the visual limitations of older people's visual functioning may be important determinants of their reading performance and reading preferences. The stronger acuity/legibility relationship for elderly readers ($r=0.83$) than younger ones ($r=0.59$) is at least consistent with this suggestion. Surprisingly, among the younger readers more time was spent reading fonts that they judged as being superior. A possible explanation for this is that being students the young participants are assessed by examinations on a regular basis, and may have been motivated to optimize their comprehension 'score' on the passages. While the general comprehension questions were designed only to encourage participants to read the passages carefully, they may have been perceived as an examination deserving of careful preparation. That is, the young participants may have been optimizing comprehension by spending more time on fonts that facilitated such an effort (i.e., the "easier" fonts). This is reflected in the drop out rate (only one young but five elderly participants dropped out). There was little evidence that elderly participants were less motivated overall than their younger counterparts. Previous research (e.g., Furchgott & Busemeyer, 1976; Powell, Eisdorfer & Bogdonoff, 1964) indicated that the elderly were just as well, if not more motivated than younger people based on objective physiological measures. Whatever its basis, when the Ranked Reading Time for the two groups were compared across the eight fonts, they were inversely related ($r = -0.57$). Certainly this effect cannot be related to the content of the materials since it was randomized with font and matched across each age/sex groups.

Differential effects of font on young and elderly readers were also seen in the relationships between the Simplicity/Complexity rating and the other subjective measures. While Simplicity/Complexity was robustly and positively related to Reading Ease, Reading Discomfort, and Clarity of Type (correlations $>.85$) for older participants, none of these relationships were significant among the young. Again, their visual limitations may have made these discriminations more salient for older readers.

Study Limitations and Future Research

Although some legibility differences were found between the fonts tested, they may have been more robust had this study used smaller size steps between lines on the

legibility charts. The 0.1 minarc step in critical detail between adjacent lines (i.e., 1/5 x-height) and corresponding 0.5 minarc change in x-height, may have been inadequate to reveal small differences in font legibility. Future research dedicated to evaluating font differences in legibility might be well-advised to use smaller size steps between print lines.

Although an evaluation of the effectiveness of small print size was the purpose of this study, the relative absence of age differences may also indicate that the print tested was not small enough to “push” the readers who participated in this study. Mean Reading Ease was low (3.38/7.0) overall as well as for the young (3.45/7.0) and elderly groups (3.32/7.0) separately. It may be useful in future research to set print size for readers based upon an initial assessment of individual legibility threshold rather than at the same level for all participants, as was done in this study.

Although the effect only approached significance, the fact that fonts that were read quicker by young people required longer times for older readers was nonetheless surprising. So too were the inverse relationships between Reading Time and most other reading measures for the two groups. It seems that the best fonts for the young readers are not always the best for older readers in all regards. A structural modeling study that tests a large number of readers of different age over a wide range of reading measures might help to define the degree to which different factors contribute to effective reading in the young and elderly.

Another limit on the generalization of the results of this study is that it examined the effects of fonts only on the reading of prose passages. Many important information, such as instruction on medicine bottles involve short passages that contain numbers (e.g., “Take 2 tablets 3 times daily”). Future research should examine the effects of fonts on short passages that contain numbers as well as text.

Another limitation of the present study was that reading was evaluated under viewing conditions that were near ideal. In the “real world”, small print is often read under sub-optimal conditions such as reduced lighting, low luminance or colour contrast, poor print and relative motion between reader and material. The high luminance, and contrast (black print on a white background), in combination with high resolution print (600 dpi) used in this study may have minimized age differences. Future research in this

area should consider possible interaction between viewing conditions, and font characteristics. Given the visual losses normal in old age, this work would be particularly informative if it included participants with widely varying visual abilities.

Finally, the high correlations among Reading Ease, Reading Discomfort, and Clarity of Type may have been artificially high due to method variance. These three measures were always assessed in immediate sequence, and participants may not have differentiated sufficiently between them. If these measures are to be used in the future, it may be best to assess them separately, and also to provide participants with “well-anchored” operational definitions/explanations of each rating dimension prior to their use of it.

Conclusions and Recommendations

In the printing industry, fonts are usually selected for specific applications for the “feeling” they portray, and based on the assumption that commonly-used fonts are more or less equally effective. The results of this study question the validity of this assumption. Fonts vary significantly in their legibility and readability and they appear to do so somewhat differently for young and elderly readers, perhaps partly reflective of the different visual capacities of the two groups. It is important that fonts be selected based on empirical data for specific reading task(s), the content of the written material, the visual characteristics of the “target” audience, the criticality of the message, and the viewing conditions in which the print might be read.

Based on the findings of this study, what general recommendations can be offered regarding font selection? First, small print should not use condensed or complex fonts. It should be printed with the highest possible spatial resolution with high letter-to-background contrast (i.e., black on white). The fonts used in this research that appear to best fit these recommendations for small print are Times New Roman, Bell Gothic and Sabon and avoid the use of condensed or complex fonts. Finally, if the information is truly important, it probably should not be conveyed with small print unless there is no alternative.

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Appendix A: Self-Report Survey 1

Research Participant

Name: _____ Birth Date: _____
(Last) (First) (Month)(Day)(Year)

Sex: _____ Single: _____ Married: _____ Education: _____
(M) (F) (Years)

Address: _____

Postal Code: _____ Phone #: _____ Source: _____

First Driver's License: _____ Current Driver's License _____
(Date) (Yes) (No)

Current Health Problems: _____

Vision Problems: _____

Have you ever had any visual problems (i.e., cataracts, glaucoma, retinal diseases)?

Things you have particular problems reading: _____

Appendix B: Self-Report Survey 2

1a. English is my first language? Yes No

1b If not what is? _____

2. Do you use corrective lenses (e.g., glasses, contacts)? Yes No

If yes, what types of corrective lenses do you use and what % of each waking day do you use them:

SINGLE VISION GLASSES (E.G., DISTANCE OR READING GLASSES)	_____%
CONTACT LENSES	_____%
MULTIFOCAL GLASSES (E.G., BIFOCALS OR TRIFOCALS)	_____%

3. Do you use corrective lenses to read or see near objects? Yes No

4. Do you use corrective lenses to drive or watch TV or movies? Yes No

5. If you wear lenses or glasses, when did you obtain your most recent prescription? 19_____

6. How would you rate your near vision with your near-vision correction (if required)?

EXCELLENT VERY GOOD GOOD FAIR POOR VERY POOR

7. Do you have visual problems like blurry vision or eye strain when reading or doing close work?

NEVER RARELY SOMETIMES MOST OF THE TIME ALWAYS

8. How would you rate your distance vision with your distance-vision correction (if required)?

EXCELLENT VERY GOOD GOOD FAIR POOR VERY POOR

Near Vision:

9a. How many hours a day do you spend reading? _____Hours

9b. If different how many hours a day do you spend reading English text? _____Hours

10. Do you have difficulty reading small print (e.g., medicine bottle labels, newsprint, telephone books, product labels) in good lighting conditions with your near-vision correction (if required)?

NEVER RARELY OFTEN MOST OF THE TIME ALL OF THE TIME

11. How often do you read a newspaper or magazine?

_____DAILY
 _____THREE TO FOUR TIMES A WEEK

- ABOUT ONE TO TWO TIMES A WEEK
 ONE TO TWO TIMES A MONTH
 LESS THAN ONCE A MONTH
 TASK IMPOSSIBLE DUE TO MY VISION
 TASK NOT APPLICABLE TO ME FOR NON-VISUAL REASONS

12. How important is your ability to read a newspaper or magazine?
 NOT IMPORTANT SOMEWHAT IMPORTANT QUITE IMPORTANT VERY IMPORTANT

Distance Vision:

13. Do you have difficulty reading distant print (e.g., a house numbers, store signs in a mall) in good lighting conditions with your distance-vision correction (if required)?

NEVER RARELY OFTEN MOST OF THE TIME ALL OF THE TIME

14. How often do you engage in activities or hobbies that require you to read printed material that is far away (e.g., reading store signs, LRT schedules)?

- DAILY
 THREE TO FOUR TIMES A WEEK
 ABOUT ONE TO TWO TIMES A WEEK
 ONE TO TWO TIMES A MONTH
 LESS THAN ONCE A MONTH
 TASK IMPOSSIBLE DUE TO MY VISION
 TASK NOT APPLICABLE TO ME FOR NON-VISUAL REASONS

15. How important is your ability to engage in activities or hobbies that require you to read printed material that is far away (e.g., reading store signs, LRT schedules) is?

NOT IMPORTANT SOMEWHAT IMPORTANT QUITE IMPORTANT VERY IMPORTANT

- 1 6a. In the last 2 to 3 years have you changed the amount of time spent reading?

INCREASED DECREASED STAYED THE SAME

- 1 6b. If your reading patterns have changed, Why? _____

Appendix C: Examples of Fonts

Practice Font

Palatino abcdefghijklmnopqrstuvwxyz

Serif Fonts

Century Old Style abcdefghijklmnopqrstuvwxyz

Times New Roman abcdefghijklmnopqrstuvwxyz

Garamond condensed abcdefghijklmnopqrstuvwxyz

Sabon abcdefghijklmnopqrstuvwxyz

Sans Serif Fonts

Times New Roman Sans abcdefghijklmnopqrstuvwxyz

Univers Condensed abcdefghijklmnopqrstuvwxyz

Bell Gothic abcdefghijklmnopqrstuvwxyz

The Sans abcdefghijklmnopqrstuvwxyz

These fonts were printed at 14 point size.

Appendix D: Letters used in Legibility Charts

Visual Angle (Minarc)	Letters Used
2.5	cefjlmopqstvwxy
2.4	abcehijklmqsuvwx
2.3	cdefgijkmquvwxyz
2.2	aehjklmopstuvwyz
2.1	bcefhijklmnosvwy
2.0	abcefjkloprsuwxy
1.9	bcfghijmnoqrtvwx
1.8	acdehjkmoqstuvwyz
1.7	abdeilnqrstuvwxyz
1.6	abceghijklorvwxy
1.5	adefghkmoqrsvwxyz
1.4	cfghijlnopqsuvxz
1.3	acefghijklmopquvx
1.2	abegijklmnopqruvw
1.1	adghijkmpstvwxyz
1.0	adfhijnopqtuvwxy
0.9	befhijmnoqrtvwxz
0.8	acghklmnrstuvwyz
0.7	abcefhjlnoprsvwy
0.6	abcdefgjkmorvwxy
0.5	cdeghijkmnoptuvy

Appendix E: Passages used to assess Reading Time

Sans Serif Fonts

The Sans 6 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Univers Condensed 6 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

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Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Bell Gothic 7 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

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Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Times New Roman Sans 7 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Serif Fonts

Sabon 7 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she

couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Century Old Style 6 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Gramond Book 7 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Times New Roman 7 points

A woman in a dark red car pulls up to a toll booth. "I'm paying for myself and the six cars behind me," she says with a smile, handing over seven commuter tickets.

One after another, the next six drivers arrive at the booth. "Some lady up ahead already paid your fare," says the collector. "Have a nice day."

The lady had read a note taped to a friend's refrigerator: Practice random kindness and senseless acts of beauty. The words leaped out at her, and she wrote them down.

Brenda Foster spotted the same phrase on a warehouse wall 120 kilometers from her home in San Francisco. When she couldn't get it out of her mind, she finally drove all the way back to copy it down. "I thought it was incredibly beautiful," she said, explaining why she writes it at the bottom of all her letters. "It's like a message from above."

Her husband, Frank, a teacher, liked the saying so much he posted it on the wall for his seventh graders, one of whom was my daughter. A local columnist, I put it in the paper, admitting I liked it but didn't know its source or real meaning.

Appendix F: Subjective Ratings (Reading Ease, Reading Discomfort and Clarity of Type)

Looking again at the print in the preceding passage, could you please rate it regarding the ease with which you can read it on the scale below where 1 = Very Easy, and 7 = Very Difficult. Please rate this font by circling the best answer below.

Very Easy							Very Difficult
1	2	3	4	5	6	7	

Looking again at the print in the preceding passage, could you please rate it regarding the amount of discomfort you experienced reading the passage on the scale below where 1 = Very Little Discomfort, and 7 = Very Much Discomfort). Please rate this font by circling the best answer below.

Very Little Discomfort							Very Much Discomfort
1	2	3	4	5	6	7	

Looking again at the print in the preceding passage, could you please rate it regarding the clarity with which you can read it on the scale below where 1 = Very Clear, and 7 = Very Unclear. Please rate this font by circling the best answer below.

Very Clear							Very Unclear
1	2	3	4	5	6	7	

Appendix G: Simplicity/Complexity Rating

The same sentence is printed repeatedly in the same fonts as the passages that you read. They vary in their simplicity or complexity (i.e., the amount of small detail on the ends of individual letters). Please look at all of the passages. Please rate the fonts below in terms of their simplicity or complexity on a scale of 1 to 7 where 1 is a simple "clean" font (the letters have clean straight edges) and 7 is very complex "ornate" font (the letters have lots of fancy edges). Please look the sentences over and then begin with font number 1 and rate each font based on your initial impression of its simplicity or complexity. This should only take you a few minutes to complete.

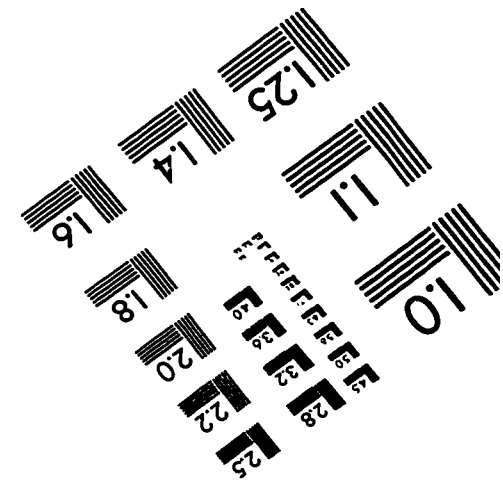
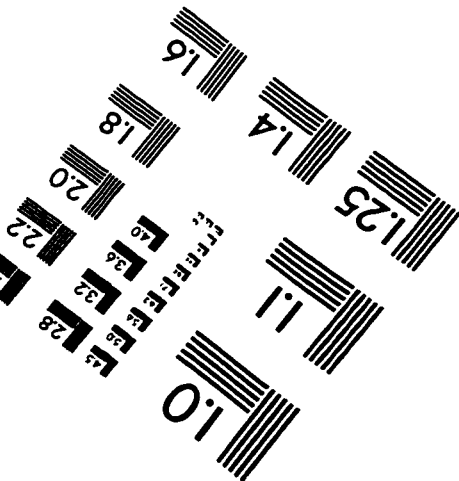
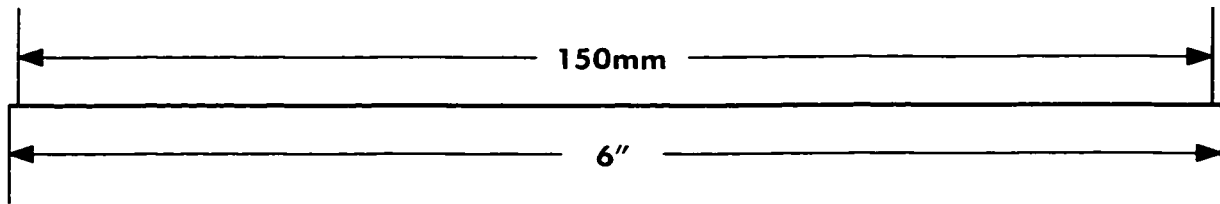
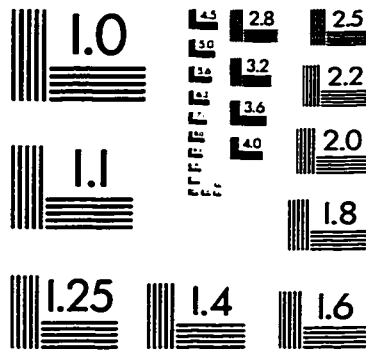
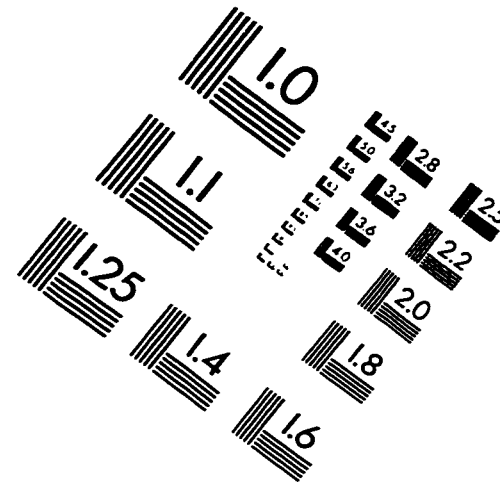
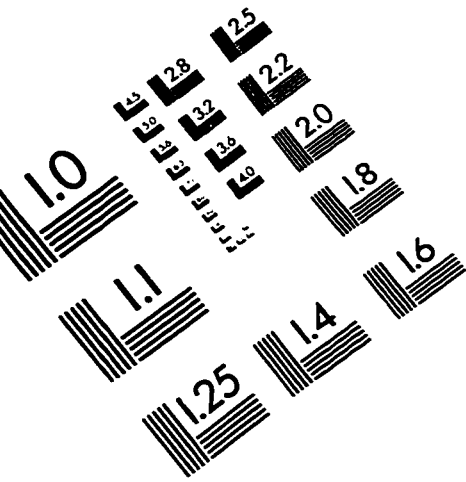
Font	Please Rate these Fonts		Simplicity/complexity						
			Simple	Complex					
Univers Condensed	1	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Times New Roman Sans	2	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Garamond Condensed	3	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Sabon	4	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Times New Roman	5	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Bell Gothic	6	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
The Sans	7	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7
Century Old Style	8	The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7

Appendix H: Preference Rating

The same sentence is printed repeatedly in the same fonts as the passages that you read. I would like you to rank all fonts from "1" most preferred to "8" least preferred based on the fonts you would like to see used in small print applications (e.g., newspapers, magazines, phone books). Please use each number only once and use all 8 numbers. This should only take you a few minutes to complete.

Font	Please Rate these Fonts	Preference							
		Most							Least
Times New Roman Sans	1 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Sabon	2 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Garamond Condensed	3 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Century Old Style	4 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Univers Condensed	5 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Times New Roman	6 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
Bell Gothic	7 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8
The Sans	8 The quick brown fox jumped over the lazy dog.	1	2	3	4	5	6	7	8

IMAGE EVALUATION TEST TARGET (QA-3)



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