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Adults' prior exposure to print as a predictor of the legibility of text on paper and laptop computer

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Abstract. This study investigated the effects of variations in graphic elements that account for differences in speed and accuracy between reading text aloud from paper versus laptop computer. Variations in accurate reading-aloud performance are attributable to individual differences in the visual accessibility of information due to (1) the experimental manipulations of the independent variables, (2) the subjects' prior exposure to print within the culture, and (3) the educational attainment of the subject. A non-representative sample of 48 female survey interviewers (ages 38–72) were employed in the conduct of this study. Survey interviewers were selected because they gather information using laptop computers; the quality of the survey information collected may be directly associated with the legibility of computerized text on reader performance. Subjects completed a prior exposure to print questionnaire (Stanovich & West 1989) and a demographic data form (IDIQ). Repeated-measures analyses of variance were employed to examine individual differences in the speed and accuracy of reading-aloud performance for twenty-four conditions varying the levels of independent variables including: (1) Font (Times Roman, Helvetica, and Courier), (2) Justification (fully-justified versus left-justified), (3) Leading (single-spaced versus double-spaced), and (4) Mode of Presentation (paper versus laptop computer). Linear regression analyses found subjects' prior exposure to print significantly and positively related to predicting speed and miscue performance. The subjects' educational attainment significantly predicted miscue performance. Subjects' ages were not significantly related to performance. Results of this study inform computer programmers and designers who are responsible for developing standards and guidelines for legible computerized text for the effective access of accurate information.

Key words: Fluent reading, Fonts, Legibility, Text accessibility, Typefaces

Introduction

Recent research efforts which measure or assess readers' decoding and cognitive processing may have overlooked, or taken for granted, one area of the encoding process which may facilitate and predict decoding variables. While readers' prior exposure to print on paper has been correlated with measures such as comprehension, verbal literacy, declarative and cultural knowledge, and increased vocabulary (Cunningham & Stanovich 1990, 1991), no mention has been made of the graphic elements and features of the targeted text. Researchers have *not* considered the role of standardized textual formats apparent in most cultural paper documents in the USA – specifically, daily broadsheet newspapers, trade books, magazines, legal papers and academic manuscripts. Because exposure to documents of this nature are defined as proxy reports of readers' prior exposure to print, predicting performance on so many areas of cognitive processing (Stanovich & Cunningham 1992, 1993; Stanovich & West 1979, 1989; Stanovich, West & Harrison 1995; West, Stanovich & Mitchell 1993), it may be of some worth to examine the physical form the text takes to see if readers differentially encode graphic features which, in turn, may account for individual variability in text accessibility. Therefore, for this study, the readers' prior exposure to print is defined as the subject's prior exposure to media which are formatted within specific graphic parameters in cultural paper documents. Cultural paper documents are *anything* that has been produced in order to convey information of any kind which may be found within a cultural context (e.g., bumper stickers, billboards, newspapers, magazines, textbooks, and novels). Furthermore, the readers' prior exposure to standardized cultural paper documents may be a possible contributing factor to the accessibility of text when readers use the computer mode. The graphic elements used in standardized paper publications may indicate how easily the reader perceives (encodes) the text and comprehends (decodes) the message on paper as well as laptop computer.

Few prior exposure to print studies are grounded in theory – either that of perception science or that of psychosocial constructs (Hartley 1982). Contemporary researchers have little or no theoretical basis on which to construct hypotheses concerning the role of graphic elements in text and their contribution to text accessibility. While the fields of perception psychology and neuroscience map areas of the brain responsible for processing letters and words looking for the architecture responsible for reading and understanding text, reading researchers are developing theory concerning cognitive processing investigating performance outcomes. The collaboration of these disciplines may bring us closer, faster, to begin to understand reading and to intervene sooner and more effectively when performance fails. Therefore, identifying which features are differentially encoded during the reading process may lead to identifying which perceptual variables mediate cognitive function.

Study purpose

The purpose of this study was to investigate differential graphic elements and identify significant interactions that would account for variations in speed and accuracy between reading text aloud from paper versus laptop computer. The study design was chosen to examine reading-aloud performance when the following independent variables are manipulated:

1. *Font* – presence or absence of features due to the typeface;
2. *Leading* – variation in the vertical spacing between lines of text (single versus double spaced text);
3. *Justification* – variation in the of horizontal spacing between words (fully justified versus left justified) in the text; and
4. *Mode* – variation in the presentation of text (paper versus laptop computer).

The dependent variables were defined as (1) speed – the rate of verbal articulation of the text of the experimental passage, and (2) accuracy – the number of miscues or mistakes read aloud per passage. Factors that are thought to predict individual reading performance include the individual's: (1) prior exposure to print, (2) level of educational attainment, and (3) age. The subjects' prior exposure to print in the culture may be a function of the subjects' educational attainment and/or chronological age.

Implications of this study's findings: (1) can be used by computer software developers to enhance information accessibility to a wider range of audiences, (2) will help describe individual differences in the perception of text using serif and sans-serif typefaces for information presentation, and the influence of prior visual knowledge and exposure to material available in the culture (i.e., newspaper, magazines, etc.), and (3) should identify more accessible information presentation in terms of typeface and text spacing on laptop computer so this knowledge may be applied to enhance computer-assisted interviewing in survey research and educational reading programs.

Review of the literature

Prior exposure to print. A review of the literature indicates that individuals perceive (defined as the imposition of meaning upon sensory information) and encode text at highly variable rates depending on the purpose for reading the information, the individual's familiarity with the content, the complexity of the syntactic structure of the text, the background knowledge the reader possesses, and the manner in which the information is presented graphically (Black & Watts 1993; Just & Carpenter 1987; Rayner 1978; Tufte 1990). Fluent reading, therefore, may depend not only upon the configuration of the object or text, but also the individual's prior exposure to print – prior knowledge concerning the literacy experience. Rosenblatt (1994) beautifully describes this relationship:

> Reading is, to use James's phrase, a 'choosing activity.' From the very beginning, and often even before, some expectation, some tentative feeling, idea, or purpose, no matter how vague at first, starts the reading

> process and develops into the constantly self-revising impulse that guides selection, synthesis, and organization. The linguistic-experiential reservoir reflects the reader's cultural, social, and personal history. Past experience with language provides expectations (p. 1064).

Goodman's (1994) research on miscues or reading errors suggests that visual perception depends on a transactive process between the reader's knowledge of language and how 'text features influence reading' (p. 1100). Goodman suggests the more typical the reading material is, relative to general language events within the culture, the easier it is for the reader to process information because language is both 'personal invention and social convention' (p. 1101). Smith (1975) explains:

> Readers utilize two different sources of information when reading. One source is the author (or the printer) who provides visual information which is the ink marks available on the page. The second source of information is non-visual information which the reader provides and which is available even when the visual information is not. This information is in the mind of the reader. These two forms of information account for the view that 'reading is only incidentally visual' (p. 8).

Prior exposure to print has been shown to predict word recognition, spelling ability in both children and adults, vocabulary knowledge, cultural knowledge and general cognitive ability (Stanovich & West 1989; Stanovich & Cunningham 1993; West, Stanovich & Mitchell 1993). Beck and McKeown (1986) state that meaning is constructed by the reader through the use of many differing kinds of prior and immediate knowledge; 'the sources interact to compile information about the textual input, identify it, and integrate it with what has come before' (p. 115).

Discussions about prior knowledge that individuals bring to the reading experience may reflect the researcher's point of view about perceptual process variables and their sources. Researchers differ, however, on the importance and source of this knowledge; while some believe prior knowledge is mostly learned, others hold there is a vast knowledge base intrinsically inherent and individual in nature (Stanovich & Cunningham 1993).

Dole, Duffy, Roehler and Pearson (1991) believe there may be at least three types of prior knowledge which can be interactive in nature, specifically: (1) context or topic specific knowledge, (2) knowledge generalized from social and causal relationships, and (3) structural knowledge pertaining to how text is organized (p. 241). Smith and Holmes (1971) believe readers may also use implicit knowledge in the form of syntactic and semantic constraints (p. 397).

What presently confounds the issue, with respect to reading, is how much of this prior knowledge is embedded within the visual perception process and how much is influenced by the domain of cognition. For example, some images may be encoded easily because these images are familiar or common within the culture. Readers learn to process these familiar images (using, perhaps, a specific encoding algorithm) such that readers' knowledge of the image appears to be automatic (Samuels 1994). Other images, however, which rarely appear in the culture are ambiguous and extremely complex, and take much longer to process or may not be recognizable to the reader at all. These images may take more time and psychological resources to encode and understand (Frisby 1978). It may take longer, therefore, to visually process text produced in an unfamiliar font which may *not* be read on a regular basis, than one used in many familiar cultural documents such as newspapers and magazines.

Standardized text. Studies concerning the legibility of text (i.e., typeface on paper) find that serif typefaces are more legible than sans-serif. Researchers (Hoffman 1987; Tinker 1927; Tinker 1963) have found that Roman typefaces – those typefaces with serifs that have 'sharp angles and straight lines' (Hoffman 1987, p. 14) are more legible than sans-serif typefaces. Poulton (1969), however, found that sans-serif type is easier to read.

Barnhurst (1992) concluded that legible type is a function of cultural preference, such that experimental conclusions coincide with visual preferences of research participants. Barnhurst further recognized the fact that legibility studies and controlled experiments 'ignore the social interaction and ordinary distractions that may impinge on the reader's commitment . . . at best, the rules indicate what is common, popular, and familiar at any given moment in the sweep of stylistic change' (p. 38). Implications of this research on studies on legibility suggest that documents in the culture, and the reader's familiarity with those documents, may influence reading performance.

Additionally, prior knowledge and experience in reading text on paper may not necessarily transfer to a new medium such as reading text from a computer screen (Hofstadter 1995; Muter 1997). More importantly, the reader's experience with the way information is arrayed (the general layout of the printed page) and the perceptual load that it presumes may not transfer when the mode of presentation changes. No process has yet been described that delineates the basic role of the most elementary graphic elements (e.g., typeface serifs and other visual cues such as spaces between words or lines of type) in the perception of language structure and in facilitating attention and encoding of information.

In summary, prior exposure to print has been identified as predictive of several domains of declarative knowledge (word recognition, spelling, comprehension, cultural knowledge, etc.) (Stanovich & Cunningham 1993; Stanovich, West & Harrison 1995). What has not been identified is the individual's prior exposure to print as visual literacy, per se. Prior print exposure, especially regarding books, newspapers and magazines, is based on strict industry standards of paper size, font selection, line length, point size and leading (Tinker 1963). The more one reads culturally standardized documents, the more likely it *may* be that one has more automatic visual access to similarly formatted visual information or text features.

Springer (1995) asserts this cultural dependence on readers' prior exposure to print:

> Many Europeans see sans-serif typesetting on a regular basis, and show little preference for serif typefaces. North Americans, on the other hand, are more used to serif typefaces. Research shows that the actual difference in readability is negligible. Poor type size, and problems with the spacing or tracking are more likely to affect the ease of legibility (p. 3).

Although Springer (1995) does not cite research to support his statements, he does suggest that readers' preferences and their previous reading experience (especially for spacing and type size) may be more influenced by one's perceptual abilities and less by their cultural environment. Measuring prior cultural exposure to print information, therefore, may not fully explain exactly what specific text features (typeface, point-size, etc.) are most salient for readers (Alexander & Kulikowich 1991; Anderson & Pearson 1984; Langer & Nicolich 1981; Stahl, Hare, Sinatra & Gregory 1991).

Age-related differences. Few researchers acknowledge the diverse nature of vision (with its own micro- and macro-processes) and tend to concentrate on changes in the perceptual process due to age, disease or trauma (Bagnoli & Hodos 1991; Marr 1982). Changes that occur to the physical visual system as the result of aging include decreases in acuity, dark adaptation, perception of targets at low contrast, peripheral vision, and accommodation (Muter 1997). Meyer, Marsiske and Willis (1993) report that 'older persons read at a 20 percent slower rate and remember 10 percent fewer critical main ideas than young adults' (p. 235). These changes to the visual system and one's reading rate, however, are rarely instantaneous, but take place over years, and often go unacknowledged or measured by legibility researchers and those interested in human-computer interactions (Muter 1997). Although these visual changes may not significantly impede the reading of text in one mode (paper), they may be critical for encoding text in another mode (computer).

Furthermore, what may, heretofore, have been considered to be age-related reading performance may, in fact, be due to the influence of a combination of the evolution of cultural print, or the medium delivering the print, and the aging process. For example, Rosenstein and Glickman (1994) found that older people (ages 48–84) scored lower on the Wonderlic Personnel Test than their younger counterparts. Even though researchers enlarged the typeface to accommodate fading visual acuity with age, the size difference in type was not significant. They did not, however, report the typeface used or any other variables associated with the experience of reading text.

The reader's physical ability to see and discern is important in any reading environment, but it is also of interest to measure the contribution of the reader's environment. The reader's prior exposure to print may influence the reading process with respect to the availability and type of texts familiar to the reader. Certain available textual materials may affect how fast and accurately text is read on certain occasions. Readers' prior exposure to print may influence the visual process, change it, and as a consequence, alter the nature of the way other kinds of text are read (Cunningham & Stanovich 1990, 1991).

In summary, reading performance may be influenced and, perhaps, remediated by print and spacing changes. For example, Hartley, Davies and Burnhill (1977) suggest standardizing such things as page size, consistent vertical spacing, and horizontal spacing to denote complexity of text. Samuels (1982) reported that:

> In general, physical characteristics of a text can influence speed, comprehension, eye movements, and the reading strategy implemented, but these effects are more noticeable with experienced readers who can adopt reading strategies which match design (p. 231).

Implications of this research suggest that printed documents in the culture may affect readers' performance. Reading performance, however, may be affected by previous visual and reading experiences. For example, the use of computer technology in the schools may promote the use of different reading strategies by young students not normally available to even their parents.

Developmental consequences of information media that promote subtle changes in visual perception are important to consider. Reading is a dynamic process (Rosenblatt 1994) and the legibility of images may need to be reviewed and up-dated as cohorts of readers mature. Research on legibility may also find that what is legible for one cohort is not necessarily the case for another.

The difficulty with understanding this process, and all that is involved in the perception and comprehension of text, is exemplified by the research findings of Eleanor Gibson (1975). Gibson found that ‘the reader processes the largest structural unit that he is capable of perceiving and that is adaptive (has utility) for the task he is engaged in’ (p. 23). Gibson’s proposed theory of perceptual learning of letter-forms was derived from an ‘intuitive’ matrix of distinctive features of uppercase English letter-forms. She found that the perception of complex distinctive features were developmentally associated (i.e., straight-curved, round letters without intersection, and curved letters with intersection). These features could be readily identified by both children and adult readers. Diagonal features, however, appeared to have a higher priority for children than adults. Gibson states that, ‘we shall arrive at that [a list of definitive distinctive features] only by research which will eventually provide an objectively obtained set of features which are really used in distinguishing one letter from another’ (p. 16).

With respect to the present study, three basic considerations emerge that are not presently addressed in the legibility literature. The first concept is the issue of individual differences associated with reading, specifically, reading rate differences associated with variations in adults: (1) chronological age, and (2) prior exposure to print. The second concept is that of graphic elements and their interactive nature. The third factor is the concern for modal differences in the legibility of text on paper versus laptop computer.

It is necessary to acknowledge age differences reported by Rosenstein and Glickman (1994) and possible deficits in readers’ visual systems. This study addresses those differences by: (1) noting corrective eye-wear and self reports of difficulty in seeing, and (2) considering each individual reader’s performance across different treatments as features of text change with each new textual presentation.

With respect to prior exposure to print, accessing information on a computer may be a particular type of visual literacy. Prior knowledge with text may inform readers and covertly teach the relationships between graphic elements of type and space. This relationship may include both the positive characters and the negative spatial surround (i.e., paper, computer screen, etc.) on which these characters are placed. Furthermore, text formats in one mode (computer), which are significantly different from normal text configuration on paper are unusual to readers’ cultural perception and may increase the potential ambiguity and confusion associated with reading. This study will address the relationship between prior knowledge (defined as visual literacy in terms of readers’ prior exposure to typefaces within cultural documents – newspapers, magazines, textbooks, novels, etc.) and the legibility of typeface and spacing.

Text accessibility may not only be a function of the exposure to written documents, but its antecedent – educational attainment. In order to understand the relationship between what is primarily temporal (for example, day-to-day reading of the local newspaper) versus more foundational (educational attainment), both questions are asked and treated separately in this study and their individual predictive contributions are reported.

In conclusion, Goodman (1994) states, ‘people tolerate and comprehend texts that are visually highly variable. All language employs orthographies that include alternate writing forms: there are upper- and lower-case forms, cursive and print forms, and varied type fonts; some orthographies use different letter forms in initial, medial or final positions . . . if people were intolerant of such variation, written language would be a less useful means of communication.’ (pp. 1107–1108). It may be true that people are tolerant of text presentation that is currently ill-suited and less efficient for the mode due to (1) readers’ lack of prior exposure to the medium, or (2) poor eye sight. This illegibility, however, may also be due to inappropriate typeface and poor horizontal or vertical-line spacing. Goodman’s quote encapsulates the very spirit of this study.

Results

Subjects

The non-representative sample comprised forty-eight (n = 48) survey interviewers employed at an employee-owned private research firm located in Rockville, Maryland. Survey interviewers were selected because they gather information using laptop computers; the quality of survey information collected may be directly associated with the legibility of computerized text on reader performance.

All 48 subjects were female, between the ages of 38–72 (Mean age = 50.08, sd = 8.233, Median = 49.5) and had worked as survey interviewers between 0.2 and 13 years (Mean = 4.446, sd = 3.746). Essentially, data in Table 1 indicate that the subjects may be characterized as a homogeneous group of middle-aged females, rather well educated although not currently enrolled in school, primarily white, right handed, and who use glasses or contact lenses for reading.

Data about prior computer use by subjects was collected, indicating that only 10 subjects used e-mail (25%), but that 22 subjects (45.8%) used personal computers outside of work and 36 (75%) used a desktop computer at work. Only four subjects (8.4%) used a laptop computer prior to this study. Thus, prior computer experience varied only slightly for the survey interviewers who participated in this study.

Table 1. Study subjects: Demographic data (n = 48)

Criteria	Levels	Number of interviewers	Percent
Education	1. Completed high school or GED	4	8.3
	2. Voc-tech training after high school	2	4.2
	3. Some college or an AA degree	12	25
	4. Completed four-year college	21	43.8
	5. Completed Master’s Degree or more	7	14.6
	6. Other degree or school	2	4.2
Currently enrolled in school	1. Yes	3	6.3
	2. No	45	93.8
Ethnicity	1. African-American/Black	6	12.5
	2. White	40	83.3
	3. Other	2	4.2
Wear glasses/ contacts for reading	1. Wear glasses to read	32	66.7
	2. Wear contact lenses to read	5	10.4
	3. Do not wear glasses or contacts	11	22.9
Handedness	1. Left handed	3	6.3
	2. Right handed	45	93.8
Native speaker of English	1. No (emigrated at 3 years old)	1	2.1
	2. Yes	47	97.9

During an initial telephone contact, subjects were screened for chronic vision impairments, and advised to bring glasses to the scheduled appointment, as needed. Subjects were seated at a table with the experimenter to ensure that both could see the computer screen. The first task oriented subjects to the context of the experiment. For subjects reading text from a laptop computer first, the computer was turned on and pre-programmed software was used. Subjects adjusted the screen so they could see it without a glare from ambient lighting, and were asked to read aloud a ‘test’ passage. Subjects were tested individually, one at a time, and paid $10 as remuneration for their time.

General reading habits and television watching behavior of subjects were self-reported. Data in Table 2 depict subjects who are generally well read, watch some (but not a great deal) of television, and are aware of printed materials within the culture.

Subjects reported the type of reading materials and the amount of reading for each type they generally read during the three months prior to the study. These data are reported in Table 3.

Table 2. Study subjects: Data describing print literate behaviors (n = 48)

Behavior	Measure	Number of interviewers	Percent
Watch TV	1. Almost never	10	20.8
	2. 0–1 hour a day	15	31.3
	3. 1–3 hours a day	23	47.9
Visit bookstores	1. Never	1	2.1
	2. Once or twice a year	9	18.8
	3. Once or twice a month	30	62.5
	4. Once or more a week	8	16.7
Read for pleasure	1. Almost never	0	
	2. A couple of times a year	0	
	3. A couple of times a month	4	8.3
	4. At least once a week	17	35.4
	5. Once or more a day	27	56.3
Number of books read in a year	1. None	1	2.1
	2. One or two	4	8.3
	3. 3–10	16	33.3
	4. 11–40	14	29.2
	5. More than 40	13	27.1
Library card holder	1. Holds card to community library	36	75
	2. Holds cards to more than one community library	8	16.7
	3. Holds no library card	4	8.3
Personally subscribes to magazines	1. None	6	12.5
	2. One	4	8.3
	3. 2–5	31	64.6
	4. 6–10	6	12.5
	5. More than 10	1	2.1

Research design. A *randomized block design*, designated as a *repeated measures design*, was employed in this study (Neter & Wasserman 1974). This design entailed the administration of 24 treatments, all of which were administered to all 48 subjects. Treatments were given during a single session with balanced presentations of independent variables; treatments were administered randomly to minimize order effects.

Table 3. Study subjects: Specific type and frequency of material read (n = 48)

Type of material read	How often read	Number of interviewers	Percent
Daily newspapers	1. Never read	4	8.3
	2. Read 'cover to cover' once or twice a week	5	10.4
	3. Read over highlights/or special section (sports, comics, etc.) almost everyday	24	50
	4. Read thoroughly everyday	15	31.3
Weekly newspapers	1. Never read	6	12.5
	2. Read over highlights/or special section (sports, comics, etc.)	27	56.3
	3. Read thoroughly	15	31.3
Devotional material (bible, etc.)	1. Never read	18	37.5
	2. Read occasionally	23	47.9
	3. Read a selection everyday	6	12.5
		1 missing	2.1
Work-related materials	1. Never read	0	
	2. Read occasionally	13	27.1
	3. Read as required by my job	35	72.9
Magazines	1. Never read	0	
	2. Read occasionally	13	27.1
	3. Read only when I'm waiting, like at the dentist or doctors	0	
	4. Read frequently	35	72.9
Books	1. Never read	1	2.1
	2. Read occasionally	11	22.9
	3. Read frequently	36	75
Textbooks or school-related materials	1. Never read	22	45.8
	2. Read occasionally	21	43.8
	3. Read frequently	5	10.4
Other (such as TV guide, children's homework, recipes, mail circulars, bus/train schedules and advertisements)	1. Never read	2	4.2
	2. Read occasionally	19	39.6
	3. Read frequently	27	56.3

Instrumentation. Two instruments were administered in this study:

1. *Prior Exposure to Print Questionnaire(s)* (PEP) is an instrument originally developed by Stanovich and West (1989). It is made up of three recognition checklists and a reading habits composite questionnaire. The three recognition checklists were constructed to ‘circumvent the problem of questionnaire contamination by tendencies to produce socially desirable responses’ (Stanovich & West 1989). The checklists are measures of literacy which cover both direct and proxy behaviors of subjects. Stanovich, West and Harrison (1995) state that ‘in summary, knowledge of that author’s name was a proxy for reading activities even though the particular author had not been read. Although there are clearly ways of gaining familiarity with the [author’s] names that could reduce validity (TV, radio, etc.), many behaviors leading to familiarity with author names are themselves proxies for reading experience’ (p. 813). Because the printing industry is standardized, it can be assumed that familiarity with print media assumes familiarity with specific print formats used primarily in newspapers, magazine and book printing.

Scoring for the PEP is as follows: The proportion of foils endorsed (incorrect responses) is subtracted from the proportion of target items (correct responses) endorsed to derive a discrimination index.

The checklists are used to collect the following information:

a. Author Recognition Test (ART) assesses the subject’s familiarity with the names of popular authors and contains 40 names of writers and 40 foils – all 80 were alphabetically listed *en toto* – used in prior studies by Stanovich and colleagues (Stanovich & Cunningham 1992, 1993; Stanovich & West 1989). Split-half reliability of the number of correct items endorsed by subjects was reported to be 0.89 for Spearman-Brown corrected (Stanovich, West & Harrison 1995).
b. Magazine Recognition Test (MRT) taps the subject’s familiarity with magazine titles and contains 40 magazines which appeared in the Standard Periodical Directory of 1988 that had a circulation of over 1 million copies (Stanovich, West & Harrison 1995). For this study, 40 foils were selected from a list of 50 provided by Stanovich and West (1989). Split-half reliability for the number of correct magazines endorsed by subjects was 0.85 using a corrected Spearman-Brown formula (Stanovich, West & Harrison 1995).
c. Newspaper Recognition Test (NRT) evaluates subjects’ familiarity with newspaper titles and contains 15 nationally recognized newspapers combined with 15 foils. Stanovich, West and Harrison (1995) report a corrected Spearman-Brown coefficient of 0.71 for this subtest.

2. *The Interviewer Demographic Information Questionnaire* (IDIQ) is an instrument developed by the investigators to collect information about criti-

cal demographic variables and typical reading behaviors. The reading habits composite questionnaire was embedded within the IDIQ, which was designed to collect information about subjects' demographic attributes and typical reading behaviors. This instrument combines Stanovich and West's 1989 'Reading and Media Habits Questionnaire' with demographic questions. Subjects' observed scores ranged from 13 to 26 with 50% (24 subjects) scoring 21 or better. As a group profile, subjects appeared to be very familiar with the print media within their cultural context.

Study stimuli

Twenty-four treatment protocols were administered to 48 subjects. Protocols consisted of 30 random words at the eighth-grade reading level. A total of 700 words comprised the pool of words. Some words were used more than once, but the tense or class of the word was changed. Therefore, the 24 protocols consisted of 30-word passages which randomly assigned and ordered the words; the experimental passages were explicitly designed to have little or no context.

Twelve protocols were designated as paper mode stimuli and computer-mode stimuli, respectively. Twelve protocols were printed, one to a page, on white paper and served as paper-mode protocols. The remaining twelve protocols served as the computer-mode protocols. All 24 protocols had a line length of four inches and presented typed words in 12-point font in one of three typefaces, either Times Roman, Helvetica, or Courier. The order of words for the protocols on laptop computer contained the identical set of words as the paper protocols, with *only* the word order reversed. This was done to minimize the likelihood that subjects' recall effects would cause them to adjust their performance accordingly.

Protocols were formatted so that subjects saw the entire line of type on the screen at one time. This prevented problems associated with reading text that 'runs off ' the viewing area and forces the reader to use 'cursor arrows' (←), and (→) to read the entire line of type. Type was also presented in positive video, or black type on a white background which simulated the look of type on paper. It should be noted, however, that some fonts on the liquid crystal display (laptop screen) looked larger than the paper representation (i.e., Helvetica and Courier) while Times Roman font looked smaller than its corresponding point size on paper.

Data collection procedures. Subjects were instructed to read each passage as quickly and accurately as they could. If they did not know any of the stimuli words, they were permitted to try to pronounce them. Subjects read aloud six protocols on either computer screen or paper, and then completed the next six protocols using the alternative mode (i.e., computer first, paper second *or* paper first, computer second). Subjects rested for ten minutes between both sets of twelve protocols. The task was completed when the subject read aloud all twenty-four protocols.

Subjects were individually audio-taped. Audio-tapes were used to time individual treatments yielding a speed operationalized as ‘rate of verbal articulation of the text of the experimental passage’. The audio-tape was used to count the number of miscues (accuracy score) elicited for each treatment. Data were analyzed using the Statistical Package for the Social Sciences (SPSS), version ‘SPSS 7.0 and 7.5 for Windows’ General Linear Model (GLM) repeated-measures MANOVA procedure.

Data analysis procedures

Transformation of variables

Unit of analysis for this study

This section describes the unit of analysis for this study. Verbal protocols were timed in seconds to the tenths of a second using a standard stopwatch. Protocols were timed from the subject’s first utterance to the last utterance including the time for subjects’ miscues. Preliminary examination of the reaction-time data indicated that a common unit of analysis – the syllable – was required to be calculated, in order to standardize the existing dataset across subjects and treatments (Dorfman, personal communication, 1996). Although each passage consisted of 30 words, the number of syllables per passage varied from 65 to 84. In order to obtain the unit of analysis for data analysis purposes, the following standardized ratio was calculated:

$$\frac{\text{Number of syllables per passage}}{\text{Respondent's time to read passage aloud}} = \text{Ratio}$$

Upon inspection of the original ratio-dataset, it was apparent that there was a violation of the assumption of singularity. In order to correct for the violation of the assumption of singularity, the inverse of the ratio was derived. The inverse of this ratio (1/Ratio) provided the transformed variable to conduct the statistical procedures for this study (Czarnolewski, personal communication, 1996).

Poisson distribution of the miscue dataset

Cohen and Cohen (1983) describe a Poisson distribution as one which is highly positively skewed (characterized by a long right-handed tail). Poisson distributions, common in perceptual task datasets, are likely when ‘the number

Table 4. Study covariates: Descriptive statistics

Variable	Mean	SD	Range	Minimum	Maximum
MEANPEP	50.003	8.099	34.72	34.17	66.89
AGE	50.083	8.233	34	38	72
EDUC	4.656	1.176	5	2	7

of times per sample in which a rare event occurs within either a restricted period of time or space (or both), are independent of each other' (p. 263). Subjects' miscues were comparatively rare; 75% of subjects committed one or fewer miscues (Mean = 0.88) per treatment. There were 30 words for each of 24 treatments for 48 subjects (30 words $\times$ 24 treatments $\times$ 48 subjects) for a possible total of 34,560 miscues for the entire experiment. However, subjects actually committed only 1014 mistakes or 3% of the total number of possible miscues. A square root transformation was performed on the miscue dataset. The corrected miscue mean was equal to 1.9390, and the corrected standard error was 0.108.

Prior exposure to print variables

Three independent variables in this study served as predictors for the regression analyses conducted in this study: (1) Age, (2) Educational attainment (EDUC), and (3) Prior Exposure to Print (PEP). The Prior Exposure to Print (PEP) instrument yielded three sets of raw scores which were transformed into standardized Z scores and then transformed a second time to a T-score distribution to eliminate negative values and facilitate analysis (West, personal communication, 1996). A mean score (MEANPEP) was then computed and used in the final regression analysis. The descriptive statistics reported above represent a homogeneous group of subjects. This homogeneous group, however, yielded significant individual differences in their responses to the twenty-four treatments.

Analysis of speeded (reaction time) data

Descriptive statistics (speeded/reaction time)

For this procedure, a *lower* inverse-ratio mean score indicates *faster* reading-aloud behavior, and a *higher* inverse-ratio mean score indicates a *slower* reading-aloud behavior. Sample statistics indicate little variation among obtained scores. Means for each treatment ranged from 0.21 to 0.25; similarly, the standard deviations of the obtained score distribution ranged from 0.03 to 0.05.

ANOVA (speeded/reaction time)

The Grand Mean for the overall within-subjects design for speeded results equals 0.2261, standard error = 0.004. A repeated-measures analysis of variance (ANOVA) employed to test for significant main and interaction effects of the dependent variable (speed), yielded a significant overall main effect ($F_{(47,1)} = 2926.00$, $p = 0.000$). This procedure yielded a significant ($\alpha = 0.05$) main effect for three of the four independent variables: (1) Font, (2) Justification, and (3) Leading. No significant effect was obtained for Mode. Significant two-way interaction effects include: (1) Font by Justification, (2) Justification by Mode, and (3) Leading by Mode. Significant three-way interactions included all possible combinations between the four independent variables, Font, Justification, Leading and Mode. The four-way interaction, however, was not significant.

Because speed was timed with both correct and incorrect responses included, the amount of variance associated with the production of miscues and the relationship between miscues and the speed of reading aloud was investigated using a hierarchical regression followed by a simultaneous regression. Miscues were found to be non-linearly (cubically) related to the speed of reading aloud. The overall findings suggest that 3–45% (depending on the treatment condition) of the overall variance in reaction time (speed) is attributable to miscues.

Analysis of miscue data

Descriptive statistics (miscue results)

Descriptive statistics for the second dependent variable – number of miscues – were computed for each level in the 24 treatments. Miscue means ranged from 1.64 to 2.40; standard deviations ranged from 0.90 to 1.34. A *higher* mean score indicates *more* miscues committed during the reading aloud tasks, and a *lower* mean score indicates *fewer* miscues committed during the reading-aloud tasks. Sample statistics indicate little variation within obtained scores for miscues, with a mean number of miscues committed across all treatments of 1.9390 and a standard error of 0.108.

Analysis of number of miscues per level of independent variable indicates that 75% of the subjects committed less than the mean number of miscues per treatment (corrected miscue mean = 1.9390, sd = 0.108). Times Roman, left-justified, single-spaced text produces the fewest number of miscues for readers on paper. Cell totals indicate, however, that for laptop computer, Helvetica and Courier fonts were the most visually accessible because subjects made fewest miscues under these conditions. Fewer errors were committed on laptop computer when fully-justified, single-spaced text was presented.

Table 5. Speed and miscue results: Regression of independent variables

Variable	R	R^2	SEE	Beta	F	*p*
Mean Speed (DV)						
MEANPEP (IV)	0.409	0.167	0.0027	−0.409	9.245**	0.004
AGE (IV)	0.138	0.019	0.0029	0.138	0.893	0.350
EDUC (IV)	0.200	0.040	0.0029	−0.200	1.914	0.173
Mean Miscues (DV)						
MEANPEP (IV)	0.574	0.329	0.6217	−0.574	22.583**	0.000
AGE (IV)	0.095	0.009	0.7557	0.095	0.423	0.519
EDUC (IV)	0.541	0.292	0.6386	−0.541	19.009**	0.000

** $p < 0.01$.

ANOVA (miscue results)

The Grand Mean for the overall within-subjects design for miscues equals 1.9390, and the standard error equals 0.108. A repeated-measures ANOVA using subjects' miscue data yielded an overall unique sums of squares statistic $F_{(47,1)} = 319.97$ ($p = 0.000$). The only significant main effect is that of Leading, where subjects produced significantly different numbers of miscues. Examination of the ANOVA results indicated significant two-way and three-way interactions for miscue results.

Multiple regression analyses

Six standard linear multiple regression analyses were performed with the dependent variables, speed and miscues (respectively). The first two regressions used subjects' age to predict separate outcome performance for paper and laptop computer. The second set of regressions used subjects' level of educational attainment to separately predict outcome performance for paper and laptop computer. The third and last set of regressions used the subjects' MEANPEP to predict performance outcomes for paper and laptop computer, respectively.

The Speeded Results (Grand Mean = 0.2261, sd = 0.0029) were significantly predicted by scores on the Prior Exposure to Print questionnaire (MEANPEP = 50.003, sd = 8.099; $F_{(46,1)} = 9.245$, $p = 0.004$); however, speed of reading was not significantly predicted by subjects' age or educational attainment. The number of errors made by subjects was reliably predicted by both subjects' educational attainment (EDUC) and Prior Exposure to Print (MEANPEP). Age did not predict the number of errors committed by subjects in this study. Table 5 shows results of these analyses.

Specifically, univariate analysis of variance (ANOVA) output showed that subjects' speed of reading on paper ($F_{(46,1)}$ = 6.798, p = 0.012) and speed on computer ($F_{(46,1)}$ = 11.466, p = 0.001) were predicted by the subjects' mean scores on their prior exposure to print checklists. Miscues were also predicted by subjects' MEANPEP scores. Univariate output showed that miscue performance for both paper ($F_{(46,1)}$ = 959.988, p = 0.000) and computer ($F_{(46,1)}$ = 902.784, p = 0.000) was predicted by MEANPEP.

While educational attainment did not predict the dependent speed performance measure ($F_{(46,1)}$ = 1.914, p = 0.173), the level of educational attainment did predict miscue performance ($F_{(46,1)}$ = 19.009, p = 0.000). Univariate analysis found that both paper ($F_{(46,1)}$ = 16.142, p = 0.000) and computer performance ($F_{(46,1)}$ = 19.599, p = 0.000) were predicted by subjects' educational attainment. Lastly, univariate analysis found that age did not predict speed or miscue performance for either paper or laptop computer. The subjects' prior exposure to standardized print media in the USA predicted performance outcomes for both paper and laptop computer.

Reading speed on paper was predicted by subjects' prior exposure to print scores on the Stanovich and West (1989) checklists. The number of miscues subjects made during the experimental conditions was also predicted by their prior exposure to print scores. Subjects with greater prior exposure to print on paper read faster and more accurately on paper conditions than did their counterparts who had less prior exposure to print on paper.

Reading speed was predicted by subjects' prior exposure to print scores on the Stanovich and West (1989) checklists. The number of miscues subjects made during the experimental conditions was also predicted by their prior exposure to print scores. Subjects with *greater* prior exposure to print on paper read faster and more accurately on laptop computer than did their counterparts who had less prior exposure to print on paper.

These important findings suggests that graphic elements – how text is configured with respect to its micro-variables – *cannot* be artificially separated from its macro-variables. Those graphic features of text (micro-variables) such as typeface, point size, and line length that determine the actual image on the page (Hartley 1984) can either facilitate or inhibit the speed and accuracy with which text is encoded, read and presumably comprehended. How information is structured on the page (macro-variables such as the use of headings, amount and use of space between paragraphs, and paragraph indentation) is dependent on the micro-variables that define that structure (Hartley 1984).

An additional multiple regression analysis was performed with the mean value for Prior Exposure to Print (represented as MEANPEP) as dependent variable. A stepwise regression analysis was performed using 17 independent variables extracted from the IDIQ instrument used to collect information about subjects' reading and television viewing habits, watching computers, use of eyeglasses, and current educational attendance, library card ownership, and native language, as predictor variables. Each of the variables was entered in the order of the magnitude of their correlations with the dependent variable, using the F-to-enter criteria. Each of the variables that was not correlated with the dependent variable significantly dropped out of the equation at the second step. Two variables from the larger set significantly predicted the dependent variable, MEANPEP: (1) the amount of time spent reading for pleasure everyday (READ), and (2) the number of books read in a year (Numbooks).

Table 6. Speed and miscue results: Regression of independent variables

Variable	R	R^2	SEE	Beta	F	*p*
MEANPEP (DV)						
READ (IV)	0.598	0.358	6.5617	0.429	25.599**	0.000
NUMBOOKS (IV)	0.667	0.444	6.1692	0.340	32.639**	0.011

** $p < 0.01$.

The results of this regression analysis allows a model to be developed that helps explain the variables that more completely predict subjects' speed and accuracy of oral reading. As may be seen in Figure 1, the two independent variables, Number of Hours Spent Reading Every Day and Number of Books Read per Year, predict the subject's performance on prior exposure to print. Embedded within this variable are the graphic elements that were essential components of this study: Font, Justification, and Leading of Standardized Text. These last three variables, in concert with the subjects' reading behaviors (hours spent reading for pleasure everyday and the number of books read in a year), have a significant impact on Speed and Accuracy of Oral Reading, and, in effect, account for the variance within this variable.

Interpretation of the findings

Relationship of graphic elements to standardized cultural paper documents

This study essentially replicated most of the findings of Tinker & Paterson's legibility studies *on paper* conducted 60 years ago that resulted in the standardization of the print industry in the USA (Tinker 1963). Subjects who participated in the current study read faster *on paper* when presented with

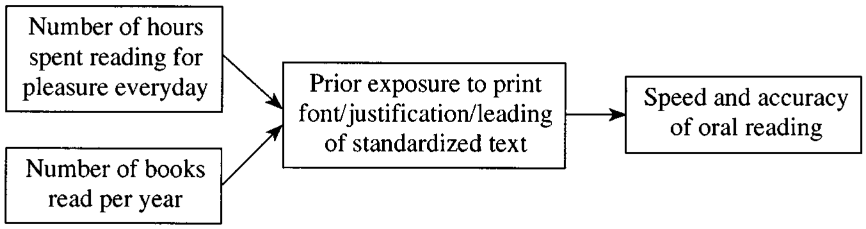

Figure 1. Predictive model of prior exposure to print and reading performance using the variable set.

serif fonts (Times Roman or Courier). Accuracy results indicated, however, that readers made fewest errors reading text *on paper* with Times Roman, left-justified, single-spaced text *or* with Courier, left-justified, double-spaced text. Furthermore, since reader performance is also predicted by subjects' prior exposure to print in the culture, the results of the speed and accuracy data indicate that readers in this study have a visual preference for familiar formats used in cultural paper documents. However, the most familiar formats, accessed by the prior exposure to print instruments, should have matched the following documents:

1. All daily newspapers, and most magazines and paperback books printed in the USA are formatted in Times Roman, fully-justified, single-spaced text.
2. Most legal and academic documents are formatted in Courier, left-justified, double-spaced text.

Discrepancies emerged between this study's findings and standardized text in cultural paper documents. The results indicate that subjects read faster and more accurately when Times Roman font is left-justified text on paper, while most cultural paper documents use Times Roman font which has been fully-justified. This discrepancy may be explained as follows:

1. Fully-justified text in this study had *very* irregular inter-word spacing.
2. Cultural paper documents (such as newspapers, magazines and paperback books) are fully-justified. However, these documents use fully-justified text where inter-word spacing is very specific and regular. This regularized inter-word spacing is achieved by word-processing and/or typesetting software which designates an inter-word space (specific to the font) and further compensates for irregular spacing by the use of discretionary hyphenation.
3. Subjects read fastest when inter-word spacing was regular (i.e., when spaces between words were the same throughout the passage). When inter-word spacing was irregular, even the most fluent readers in this study read slower using a different reading strategy.

4. Speed of text accessibility, therefore, is a function of consistent inter-word spacing, rather than justification of the text. Subjects performed better when using left-justified rather than fully-justified text because these readers were more familiar with regularized inter-word spacing used in paper cultural documents. This finding suggests that readers in this study may have used at least two different reading strategies:
   a. For regular inter-word spacing, readers used a faster strategy whereby they quickly encoded text.
   b. For irregular inter-word spacing, readers used a slower strategy whereby they read and encoded text very accurately, word-by-word.

Graphic elements and their interactions have a decided effect on subjects' reading speed, accuracy and the type of reading strategy they use. The most fluent reading on paper and laptop computer occurred for text that was left-justified, single-spaced, using serif fonts. Subjects in this study read fully-justified text using a word-by-word strategy which was slower but slightly more accurate (for Times Roman and Helvetica fonts) than reading left-justified text. Therefore, regularized inter-word spacing may speed up reading of text, but may also encourage miscues in reading aloud performance. Irregular inter-word spacing may slow up reading speed, but may also encourage fewer miscues to be made by readers.

Therefore, this study provides empirical support for research which demonstrates that:

1. Serif fonts are most legible (Hartley 1987; Tinker 1963; Worden 1991);
2. Regular spacing between words that is proportional to the font (as is used in left-justified text) is the most legible (McConkie & Rayner 1975; O'Regan, Levy-Schoen & Jacobs 1983; Pollatsek & Rayner 1982; Reynolds 1984); and
3. Single-spaced text for Times Roman font is the most legible for paper (Tinker 1963).

Furthermore, this study confirms Hartley's (1984) observation that 'legibility is a function of clearly defined structural relations, and that this is most easily achieved by the consistent manipulation of space' (p. 504). The structural relationships between Font, Justification, Leading, and Mode are *not all* clearly defined in the results of this study. The lack of a significant four-way interaction indicates that other variables may need to be considered when developing legible text in a paper or laptop computer environment. For example, subjects read equally as fast using single- or double-spaced text for Times Roman or Courier fonts on laptop computer regardless of whether text was fully- or left-justified. Therefore, future research of possible additional variables are considered in the next section which may clarify structural relationships.

Implications of research outcomes: Individual differences

The results of this study indicate the more exposure one has to cultural documents, the more likely it is that the format of the text will become transparent to the reader. This transparency is critical to communication because it is the very vehicle that carries the message to the reader and to others who listen to the reader (Samuels 1982). Standardization, on paper and laptop computer, encourages textual transparency.

Transparency of the format allows the reader to tackle the more difficult areas of the reading process, such as unfamiliar vocabulary and lack of context. The very form the text takes, for *any* mode, allows the reader to adjust what they know about reading (from prior exposure to print formats) to produce fluent communication.

Furthermore, the generalized visual preference for the experimental conditions which used serif fonts was predicted by the subjects' prior exposure to those fonts. Findings that subjects' educational attainment predicted miscue elicitation reinforces this assertion. The more education one presumably has, the more exposure to standardized print media one is likely to experience. It is experience with standardized print rather than age, *per se*, that is the predictor of this study's outcomes. This study does *not* suggest that educational attainment *alone* makes for more accurate readers.

Directions for future research

Data collected for this study was essentially quantitative in nature. Furthermore, all quantitative information gathered has not been analyzed to yield as much information as possible about the process of reading text on a laptop computer. Further model-building is necessary to depict which reading strategy interacts with the independent variables – Font, Justification, Leading, and Mode.

Additional analyses would also clarify the kinds of miscues readers made and what circumstances led to these mistakes. Semantic and syntactic language confounds within the protocols need to be identified and noted. Some readers may be especially sensitive to semantic variations and may slow their reading rate or read the passage in a less fluent manner, underestimating the influence of the text format on reading ability.

Qualitative data collection would enhance understanding of readers' strategies and styles as well as the kind of burden certain type formats impose on readers. For example, taking note of spontaneous recognition of certain changes in the experimental setting, such as changes in posture, may flag to researchers the kinds of effort that readers make to adhere to the experimental setting. Complaints about ambient lighting, noise levels, and format changes signal the amount of effort and concentration the reader must use to focus on the text format and adequately perform. Since field conditions vary widely, systematic changes in lighting, noise levels and posture changes would identify the most robust test formats.

The use of context-free passages facilitated research of graphic elements (independent variables) for this study. Two conclusions arise from this practice. The first addresses the role of context in reading from alternative-mode text presentations. The readers' use of contextual information to aid in the fluent reading of text and possibly avoid the kinds of miscues generated by this study is certainly worthy of a future research endeavor. Secondly, the independent variables investigated in this study are only a sampling of the possible ways that text may vary. Line length, type size, and further study of leading would identify additional guidelines which would aid in the production of text on a laptop computer. Furthermore, changes in font characteristics (graphic emphasis) such as italic, boldface and all upper-case letter-forms would inform reading researchers.

Moreover, what this study did *not confirm* was a speed discrepancy between reading on paper versus a laptop computer (Gould & Grischkowsky 1984). In fact, in some cases, subjects read faster and more accurately from computerized text versus paper text. This automatic processing of [computerized] text indicates that subjects perceive and process text *differentially* (Reynolds 1984; Samuels 1982). Graphic elements which were transparent to the reader on laptop computer, but not on paper, are an indication that mode differences were present. However, the most fluent readers in this study read fast and accurately, despite the mode (Samuels 1982); readers who were less fluent had accuracy and speed problems with text on both paper and laptop computer (Reynolds 1984).

Lastly, the adult subjects who participated in this study were not representative of the adult population in general. Survey interviewers are a highly specialized group of readers who must fluently access information from many modes and are usually skilled readers. Other populations should be considered for future studies, such as a representative adult and/or student sample.

What is especially interesting about this future research endeavor is the possibility of examining the effects prior exposure to print in alternative media may have on reading, per se. Students who are extremely familiar with cybernetic environments and spend a great deal of time on computers may have a quantitatively different ability to access text in alternative modes. The prospect of developing a questionnaire assessing the effect of prior exposure to computerized media may be daunting, however. Identifying independent variables in a computerized textual field may not be obvious. However, samples comprised of younger subjects who are differentially exposed to computer text *may* predict reader performance on laptop computer independent of their prior exposure to print on paper.

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Appendix: Definitions

Cultural documents: Anything that has been produced in order to convey information of any kind which may be found within a cultural context, *regardless* of its mode of presentation.

Fluent reading: The ability to select and use varying reading strategies to accommodate varying conditions for encoding or accessing text.

Fonts, letter-images, and typefaces: The letter-image is defined as the 26-letter English alphabetic array. Within this array there are many possible variations, among them: (1) characteristics of the three typeface families (serif, non-serif, and script or cursive); (2) the characteristics of the letter-image employed (monospaced versus variable spaced letter forms); and (3) the spacing between word-forms.

Legibility: The 'ease, accuracy and efficiency of perceiving printed symbols while reading (of continuous text material) with understanding' (Tinker 1963, p. 7).

Prior exposure to print: Operationally defined as the reader's exposure to any print media which are formatted within specific graphic parameters in cultural documents, i.e., newspapers, magazines, textbooks, novels, etc.

Reading: Defined for purposes of this study as the perception and comprehension of text.

Text accessibility: Operationally defined as the facility with which words are encoded as measured by the reading speed (the reaction time) and accuracy of the number of words per minute read aloud.

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