Abstract

One of the most important, and most studied, aspects of human perception is the act of reading. Reading has received much attention from researchers, both from a human information processing (HIP) approach and as a common, practical act that needs to be optimized, especially in the realm of human-computer interaction (HCI). One of the text variables that has been studied for over 100 years is line length, at times referred as line width. Psychologists, typographers and others working in the field of reading and advertising have demonstrated the effects of line length on readability of text. Two of the questions addressed in past studies include, How long should a column of text be, to optimize readability of the text?, and Which view is more preferred by readers ñ multiple narrow columns or one wide column with the same amount of information content?

Optimal Line Length in Reading –

A Literature Review

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Research has led to recommendations that line length should not exceed about 70 characters per line. The reason behind this finding is that both very short and very long lines slow down reading by interrupting the normal pattern of eye movements and movements throughout the text. In a world of personal digital devices (PDAs), one-inch cell phone displays and of wide-screen TVs and full-wall computer displays, the question of line length has renewed timeliness. Studies reviewed here show that different aspects of reading performance such as comprehension, reading speed, method of movement (e.g., paging and scrolling) and eye movements are affected by changes in line length. In addition to that, various typographic factors such as font type and size, line and character spacing as well as different screen structures such as varying number of columns and screen sizes also affect readability. These factors have an effect on optimal line length for the text read from printed or on-screen material.

Introduction

One of the most important, and most studied, aspects of human perception is the act of reading. Reading has received much attention from researchers, both from a human information processing (HIP) approach (see Gough, 1972) and as a common, practical act that needs to be optimized, especially in the realm of human-computer interaction (HCI) (see Gould et al., 1987).

From both the HIP approach and the HCI-optimization approach, it has been interesting to examine what variables in the reading act lead to enhanced or inhibited reading performance. These variables can be divided into the following types:

• Variables within the reader (e.g., visual acuity, education level, reading experience, familiarity with the reading material).

• Typographic variables in the text itself, such as font type and size, line and character spacing, line length and column structure.

• Variables within the environment (e.g., ambient lighting, visual angle, tailorability of the reading material and medium of the text, i.e., printed or on-screen reading material).

• And within the on-screen text, display characteristics such as contrast, flicker, aspect ratio and image polarity (Gould et al., 1987; Dillon, 1992).

The advent and evolution of computer technology, including computer terminals, the personal computer, selectable fonts and variable-width fonts, has spawned a wealth of studies design to identify the settings—controllable through typographic and environment variables—that will optimize reading performance and enjoyment.

One of the text variables that has been studied for over 100 years is line length, at times referred as line width. The effects of line length upon readability of text have been demonstrated by psychologists, typographers and others working in the field of reading and advertising. Two of the questions addressed in past studies include, How long should a column of text be, to optimize readability of the text? and Which view is more preferred by readers—multiple narrow columns or one wide column with the same amount of information content? Research has led to recommendations that line length should not exceed about 70 characters per line (Spencer, 1968). The reason behind this finding is that both very short and very long lines slow down reading by interrupting the normal pattern of eye movements throughout the text. In a world of personal digital devices (PDAs), one-inch cell phone displays and of wide-screen TVs and full-wall computer displays, the question of line length has renewed timeliness.

Studies reviewed here show that aspects of reading performance such as comprehension, reading speed, method of movement (e.g., paging and scrolling) and eye movements are affected by changes in line length. In addition to that, various typographic factors such as font type and size, line and character spacing as well as different screen structures such as varying number of columns and screen sizes also affect readability. These factors have an effect on optimal line length of the text read from printed or on-screen material.

A fundamental finding

"Line lengths that are recommended as optimal for print are not the most legible on screen, when reading rate is used as a measure of legibility" (Dyson and Kipping, 1998). The differences between reading hard copy and reading a computer display—differences such as lighting source, glare potential, whether the text can be moved, ability (or lack of it) to dynamically reflow the text, potential for color change or text motion and visual angle, mean that a century of research data on optimal line lengths in print may or may not be applicable to the on-line reading situation.

Measuring line length

Early studies in the field of reading measured line lengths in terms of picas. One pica is one sixth of an inch. Some of the studies measured line length in the units of inch, centimeter or millimeter. More recent studies tend to measure line length as total number of characters in a line or characters per line (cpl). Units like picas and millimeters can be interpreted in cpl for better comparison of line lengths. Bringhurst (1992) presented a method for determining the number of characters in a line for any font face and size: measure the length of the lowercase alphabet and use a copyfitting table (abbreviated version shown in *table I*) that shows for a given alphabet length, the average number of characters in that line.

Another approach to measuring line length is based on the size of the text and the distance at which the text is read or visual angle of a line. As called out in Gould et al. (1987), visual angle of a line of characters is the angle formed by the width of the line as it relates to the reading distance of that line from the reader's eye. This is useful in the sense that printed text and text on screen are normally viewed at different distances from the reader, with printed text viewed at a shorter distance than the text on screens.

POINTS	LINE LENGTH IN PICAS							
	10	14	18	22	26	30	35	40
80	40	56	72	88	104			
85	38	53	68	83	98	113		
90	36	50	64	79	86	107		
95	34	48	62	75	89	103		
100	33	46	59	73	86	99	116	
105	32	44	57	70	82	95	111	
115	29	41	53	64	76	88	103	
120	28	39	50	62	73	84	98	112
125	27	38	48	59	70	81	94	108
130	26	36	47	57	67	78	91	104
135	25	35	45	55	65	75	88	100
140	24	34	44	53	63	73	85	97
145	23	33	42	51	61	70	82	94
150	23	32	41	51	60	69	81	92
155	22	31	39	49	58	67	79	90
160	22	30	39	48	56	65	76	87
165	21	30	38	46	55	63	74	84
170	21	29	37	45	53	62	72	82
175	20	28	36	44	52	60	70	80
180	20	27	35	43	51	59	68	78
185	19	27	34	42	49	57	67	76
190	19	26	33	41	48	56	65	74
195	18	25	32	40	47	54	63	72
200	18	25	32	39	46	53	62	70
220	16	22	29	35	41	48	56	64
240	15	20	26	32	38	44	51	58
260	14	19	24	30	35	41	48	54
280	13	18	23	28	33	38	44	50
300	12	17	21	26	31	35	41	47
320	11	16	20	25	29	34	39	45
340	10	15	19	23	27	32	37	42

Table I: Copyfitting table—average character count per line (Reproduced by author permission, Bringhurst, 1992.)

Read down, in the left column: lowercase alphabet length in points. *Read across,* in the top row: line length in picas.

Early findings

Early research into the effects of line lengths on read-ability concluded that moderate line lengths are optimal for efficient reading compared to very short or very long lines. A number of early studies conducted by Tinker and Paterson (1940) (summarized in Tinker, 1963) had shown that optimal line length of text read from printed material was 13 picas or somewhere in between 59 to 97 mm or 52 cpl, (as interpreted by Rayner and Pollatsek, 1989), which was moderate in between very long lines of 36 picas and very short lines of 5 picas. The explanation given for the legibility of moderate line length was that, if the lines are too long, it is difficult to make an accurate return sweep to the beginning of the next line and if they are too short, readers cannot make maximum use of horizontal cues and other more peripheral information in each fixation.

Burt, Cooper and Martin (1955) also found better reading speeds and ease of reading at medium line lengths between 3.5 to 5.5 inches (approximately 89 to 140 mm). The reason given for this was similar to Tinker and Paterson's findings (1940).

Summary of Studies

This section of the paper reviews literature relevant to the factors affected by line length and factors affecting line length of printed or on-screen text.

Factors affected by line length

User responses from various studies concerning the readability of text from computer screens as well as printed material address subjective and objective attributes of reading affected by line length of the text. Subjective aspects of reading are attitudinal responses of test participants while reading text during the experiment and objective factors are the behavioral and cognitive aspects of readability.

Subjective factors

These factors include readers' attitudes toward line lengths while reading. People's subjective preferences like reported ease of reading and satisfaction, affected by line lengths, usually did not correlate with their performance in range of experiments conducted to explore the effects of line length on readability (see Dyson and Kipping, 1998). This means that what people reported as easy to read was not objectively measured faster to read nor did it yield better comprehension in the experiment. Some of these subjective factors were studied based on various objective measures. For instance Luckiesh and Moss (1941) measured the subjective factor of ease of reading shorter lines (13 to 17 picas) based on objective measure—number of blinks that occurred during reading.

Ease of reading

In 1998, Dyson and Kipping conducted two experiments to explore the effects of line length and paging versus scrolling on reading from computer screens. In the first experiment each participant, out of 24, was asked to read six documents with different line lengths of approximately 25, 40, 55, 70, 85, 100 cpl. The time taken to read each document was recorded to evaluate reading speed at various line lengths. Participants were asked to compare documents at each line length with every other line length and say which they thought was easier to read. Ease of reading was not explicitly defined so participants could take any aspect of reading such as reading speed or effective comprehension as a measure for ease of reading. As a result of the experiment, Dyson and Kipping found that moderate lines of 55 cpl were reported easier to read than very short lines of 25 cpl or very long lines of 100 cpl using scrolled or paged movements to navigate through the document. The experiment reported that participants did not base their judgments on feedback from their speed of reading or degree of understanding; instead they monitored their level of comfort or discomfort when reading particular line length. Dyson and Kipping also noted that perception of ease of reading from computer screen at 55 cpl might be influenced by experience in reading certain types of printed material with line length in between 50 to 70 cpl. Burt, Cooper and Martin (1955) also found reports of ease of reading at medium line length of 55 cpl in printed text. The reason given behind this was difficulty in picking up the beginning of the next line (return sweeps) in long lines and inability to take in large phrases of text with single fixation and make maximum use of peripheral vision in short lines. On the other hand based on a judgment of faster readers Dyson and Kipping (1997b) found that a three column format with shorter lines was easier to read.

In the second experiment by Dyson and Kipping (1998), relatively bright white areas in the test document were replaced with a light gray background color to test whether or not the amount of glare might have factored into their findings. Results of this experiment remained consistent with the previous one in concluding ease of reading among different line lengths read. As a result of these two experiments Dyson and Kipping concluded that line length should be considered a significant factor as a criterion for judging ease of reading.

User preference and satisfaction

Shaikh and Chaparro (2004) considered user preference, satisfaction and reading efficiency as dependent variables of interest in their experiment investigating the effects of four different line lengths (35, 55, 75, and 95 cpl) on reading speed and comprehension. In their study user preference for line length was found to be inconclusive. Users either loved or hated the extreme line lengths (35 and 95 cpl) and judged the medium line length as optimal. Shaikh and Chaparro found no effects of line length or passage type (short news stories or long narrative) on the overall user satisfaction. No direct effects of line length were found on reading efficiency.

Objective factors

Various factors associated with reading such as reading speed, comprehension, eye movements, method of movements for navigation and peripheral vision are affected by line length of text read. These aspects of reading acted as a base for various studies carried out on the effects of line length on readability.

Comprehension

Out of many variables identified as possible influence on comprehension, one is the amount of text that can be viewed simultaneously on-screen (Dyson and Kipping, 1997a). The amount of text displayed on screen can be manipulated by varying line lengths. A number of studies have been conducted to identify the effects of line lengths on comprehension. Dyson and Kipping (1997b) studied the effects of one wide column (about 80 cpl) against three narrow columns (about 25 cpl each) of text documents on various comprehension tasks. Eighteen subjects were asked to silently read three documents displayed on screen. Comprehension was assessed by how successfully participants were able to answer questions about whether or not a series of questions was answerable or not based on what they had read. Researchers found no overall difference in comprehension. However, based on a judgment of a group of subjects they noted that the three column format with short line length, similar to those found in printed magazines, improved comprehension for fast readers. As a possible explanation for this, Dyson and Kipping stated that different types of readers may adopt different reading patterns that affect their comprehension. For example faster readers might have benefited from three narrow columns with short lines due to their ability to easily scan through narrow columns and extract meaning.

In another comprehensive study conducted by Dyson and Kipping in 1998, they found similar results with no significant effect of line length on comprehension. As reported above, they had 24 participants read six documents with different line lengths of approximately 25, 40, 55, 70, 85 and 100 cpl. There was no evidence of speed-accuracy trade-off between speed of reading and comprehension in the study. They reported that faster reading rates did not appear to be at the expense of comprehension. As a second experiment of the same study, relatively bright white areas in the test documents were replaced with a light gray background color, but results for comprehension remained the same. On the other hand Dyson and Haselgrove (2001) had 36 participants read documents edited to a total length of approximately 1000 words with varying line lengths of 25, 55 and 100 cpl at fast and normal reading speeds. They hypothesized that readers may vary their reading rate to maintain a relatively constant level of comprehension across different line lengths (i.e., speed-accuracy trade-off). They attributed the reason behind this contrast to the requirement for participants to recall details and make inferences in their study which was missing in Duchnicky & Kolers (1983) and Dyson & Kipping (1998). Dyson and Haselgrove (2001) concluded that overall

comprehension was reduced when reading fast, but that the type of information recalled was not dependent on the speed of reading. They explained the effects of line length on comprehension in terms of mechanics of reading (nature of eye-movements), mechanics of scrolling and consolidation of what is read. Both very short and very long line lengths can slow down reading by disrupting the normal pattern of eye-movements. They recommended a medium line length of 55 cpl compared with long lines of 100 cpl for better comprehension due to the interruptions that occurred with long line lengths because of locating the beginning of a line, following a return sweep and disrupted concentration.

McMullin et al. (2002) measured the effects of surrounding information and line length on text comprehension. They found that participants got distracted by the additional column or paragraph of information and performed slightly less well on comprehension questions than when information was surrounded by white space. They favored the use of white spaces over multiple columns, as white spaces helped prevent the influence of distracting and unimportant information and decreased the need to scan across the entire screen, which could be tiring for the viewer's eye span. Results from this study supported the research by Dyson and Haselgrove (2001) showing that very small line lengths (25 cpl) lead to less comprehension than line lengths of 55 and 100 cpl. Shaikh and Chaparro (2004) noted a speed-accuracy trade-off while participants read faster at the longest line length of 95 cpl and they actually comprehended less.

Reading rate

Numerous studies have been conducted to explore the effects of line length on reading rate on printed as well as on-screen material. Early research on legibility of different line lengths in print has been measured by reading rate with only a check on comprehension (Tinker, 1963). Past studies have shown that other factors like method of movement (scrolling and paging) and eye movements with fixation frequency, pause duration, regression frequency, and saccade duration also affect reading rate as a function of line length (Paterson & Tinker, 1940; Luckiesh & Moss, 1941). Using reading performance test results Tinker and Paterson (1940) found that very short line widths (seven picas) and excessively long line widths (36 picas) for six point type size, produced delayed reading rates in comparison with moderate line widths of about 14 picas. They summarized the reasons behind delaying rates in reading long lines as an inaccurate return sweep, from the end of one line to the beginning of the next, causing the reader to re-read the same line or omit the next, and in reading short lines as inability to make maximum use of horizontal cues. Another study

conducted by Tinker and Paterson in 1940, compared reading performances on speed of reading for 80 mm lines (form A) with varying line lengths of 59, 97, 114, 136, 152, 168 or 186 mm (form B), both at 10 point type size. They found 80 mm lines yielded faster reading than any of the other line lengths and concluded that optimum line length lies somewhere in between 59 to 97 mm. They also suggested that line lengths should be kept within the limits of 75 to 90 mm if speedy reading is desired. They showed the relation between speed of reading and the ability of the reader to establish and maintain regular rhythmic eye movements. They claimed that less efficient reading with very short lines is due to inability to establish rhythmical eye movements.

An experiment comparing form A and form B (see Tinker and Paterson, 1940) also revealed that negative or positive change in optimum line length affects fast readers in terms of retardation in speed of reading and improves speed of reading for slow readers. On the other hand Luckiesh and Moss (1941), who studied the influence of line-length on readability by measuring the rate of involuntary blinking of the eyes, patterns of eye movements in reading and rate of normal reading on 10-point text type with line lengths of 13, 17, 21, 25, 29 picas, found no influence of line-length on speed of reading. Yet they considered shortest line length of 13 picas superior to lines of longer lengths for increased readability, attributed to fewest blinks during reading shortest lines. However, rate of blinking as an appropriate criterion of readability is questionable and produces unreliable data (Tinker, 1963; Perera, 2004). Tinker (1963) considered rate of blinking as a measure of legibility questionable, if no experimenter other than Luckiesh and his colleagues can duplicate the results in Luckiesh and Moss (1941).

Duchnicky and Kolers (1983) found that 80-character lines were read faster than 40-character lines based on their experiment on readability of text scrolled on visual display terminals as a function of three different variables: line lengths with respect to window size, number of characters in each line and window heights. They had subjects read 30 noncontiguous passages of about 300 words with two character densities (40 or 80 cpl), five window heights of 1, 2, 3, 4 or 20, lines and three different line lengths as approximately full, two-thirds and one-third the screen width. They found that text in 80-character lines were read 30% faster than text in 40-character lines, lines of two-thirds or full-screen widths were read 25% faster than lines of one-third screen widths and text in one-line or two-line windows was read 9% slower than text in 20-line windows. These findings led to the conclusion that speed of reading scrolled text is increased with increase in line length, character density and window height, with window height having less effect than the other two.

Dyson and Kipping (1998) conducted two experiments to explore the effects of line length on reading from a screen. Participants were asked to silently read a series of documents displayed on the screen with line lengths of 25, 40, 55, 70, 85, 100 cpl and scrolling and paging as methods of movement. As participants read and moved through the document with the down and up keys, the time taken to read each document was recorded. The total reading time per document was used as a measure of reading rate. They found that 100 cpl was read significantly faster than 25 cpl in both scrolled and paged conditions. In the scrolled condition they argued that less time had to be spent on scrolling through the documents, as there were fewer lines of text (also Dyson and Haselgrove, 2001). This pattern of scrolling exploited the full size of the window, as more lines of text were read before moving further down in the document allowing for processing of larger chunks of text without interruption from scrolling movement. In the paged condition, the shorter time could be attributed to fewer key presses at 100 cpl than at 25 cpl while navigating through the document. Another possible explanation given for faster reading at 100 cpl was that this line length reduces some glare from the screen, as text was covering most of the screen. Line lengths that did not fill the screen had an area of white to the right of the text which might have proved distracting. This glare is increased when lines are short, but can be reduced by having multiple columns of short lines. Glare had also been reported as a problem in a comparison of different CRT displays by Gould et al. (1987). As a follow up experiment of the same study Dyson and Kipping (1998) had hypothesized that by reducing the glare from the screen using a gray background, shorter lines were read at similar rates to longer lines. This study had revealed that participants may adjust their reading patterns according to the line length they are reading and the amount of scrolling required, thus achieving better reading rates. In 1997, Dyson and Kipping (1997a) concluded that text displayed in a single wide column (80 cpl) was read faster than a three column (25 cpl each) format, when both used paged movement to advance through the document. In contradiction to Dyson and Kipping (1997a), they further concluded that long lines, when read at fast speeds, facilitated skim reading as more information displayed at a time could aid readers to skim through it easily. In their experiment on the effects of line length on reading speed and comprehension, Shaikh and Chaparro (2004) found that while reading rate was fastest in 95 cpl, reading efficiency did not differ based on line length. This implies a speed-accuracy trade-off as participants read faster at 95 cpl but actually comprehended less.

Method of movement

Method of movement refers to how a reader navigates through the text on screen. Studies have been conducted to analyze the effects of line length on comprehension and reading rate influenced by method of movement like scrolling and paging. However, research that has investigated methods of moving through the text on screen has not produced any clear findings. Readers use various scrolling patterns measured by the time spent in pauses, time in scrolling, the length of the first pause and the number of scrolling movements (Dyson and Haselgrove, 2001). Dyson and Kipping (1997a) found that paging was faster than scrolling, as time spent in the physical action of scrolling accounted for the slower reading rate. In 1998, Dyson and Kipping studied the effects of paging versus scrolling on reading from the screen. They noted no significant difference in reading rate in scrolled or paged conditions as well as no interaction between line length and method of movement in their findings. They concluded that reading from a screen permits a number of ways of scrolling through text which may result in a range of reading patterns. These patterns may be influenced by line length and result in varying degree of efficiency of reading. Dyson and Haselgrove (2001) had believed that scrolling time may be longer with short lines as they require more time to bring up an equivalent amount of new text than with longer lines. They reported the influence of line length on time spent in pauses, with the longest pauses at the longest lines resulting in slower reading rate. Participants might have felt that they can allocate more time in pauses as they did not need to spend much time in scrolling long lines. More detailed explanation of the effects of line length on comprehension and reading rate with scrolling and paging from these studies can be found in the previous two sections of this paper.

Eye movements

Measuring eye movements has been an important part of determining readability of text from print as well as screen media. While reading, the eye does not continuously scan a line. Rather, it stops (fixates) for about one-quarter of a second and then rapidly jumps to another place on the line; these stops and jumps are known as fixations and saccades (Gould et al., 1987) and information is perceived during the fixations. When the end of the line is reached readers traverse back to read the beginning of the new line. These return movements are referred to as return sweeps. Backward moves within a line to re-examine material not clearly perceived or understood are know as regressions (Tinker, 1963). Various studies have measured the effects of eye movements on readability of text in terms of fixation frequency, fixation duration, perception time, regression frequency and saccade duration. Eye-movement records from different studies (summarized in Tinker, 1963) show that more fixation pauses of greater duration occur while reading very short lines (Tinker, 1963). Further, reading very long lines is less efficient due to regression following the return sweep to the beginning of the new line. Early research conducted by Tinker and Paterson (1940) reported that while reading excessively short lines, fixation frequency was increased with fewer words per fixation, pause duration was lengthened

and perception time (combination of fixation frequency with pause duration) was greatly increased. Luckiesh and Moss (1941) noted that eye muscle mechanisms would become less capable of making small and precisely controlled steps in each fixation as lines get longer, making reading more difficult due to erratic eye movements.

Kolers et al. (1981) measured the readability of CRT displays based on eye movements. Their results show that increasing the number of characters per line (from 40 to 80) by halving their widths increased the number of fixations but the total number of fixations per passage was decreased. In addition, the number of words extracted per fixation was larger, the duration of each fixation was longer and the total reading time was shorter. Duchnicky and Kolers (1983), replicating findings from Kolers et al. (1981), supported this conclusion that very short lines elicit more and longer fixation pauses. With short line length readers may not be able to make use of much information in each fixation and may decrease their saccade length which could slow down the reading (Rayner and Pollatsek, 1989). Luckiesh and Moss (1941) observed the unique characteristic of eye movements during the reading of lines of different lengths. Data from their study revealed that the average number of fixations as well as average fixation-span was increased as the line-length was increased, which was contradictory to Duchnicky and Kolers (1983). Lynch and Horton (1999) showed that wider lines of text require readers to move their heads slightly or strain their eye muscles to track over the long text, so readability suffers because readers may lose track of the next line on the long trip back to the left margin. On the other hand, Kolers et al. (1981) favored long line lengths of 80 cpl as more information was extracted from the text with each fixation, for more efficient reading. They achieved this by halving letter widths, so they didn't increase the actual line width here.

Peripheral vision

Readability of text read from screen or print material is also affected by how readers make use of horizontal or vertical peripheral cues generated by reading end of lines. Readability is decreased due to inability of readers to make maximum use of these cues. Tinker and Paterson (1940) observed retardation in the rate of reading an excessively short line, due to inability to make maximum use of horizontal peripheral cues in reading printed text. They found that efficient use of peripheral vision during the first fixation of a line yielded premonitions of coming word, phrase positions, sentence breaks and meanings with an optimum line length (i.e., moderate line length of 13 picas), which could guide and shorten future fixations. They also noted that peripheral vision in a vertical as well as a horizontal direction provides visual cues of words in the line succeeding the one in direct fixation to facilitate reading. Furthermore, peripheral vision accompanying the first fixation in a line is less effective with long lines than with short lines. (For printed text Burt, Cooper and Martin, in 1955 concluded that short lines prevent the eye of the trained reader from taking in large phrases with a single fixation and making optimal use of peripheral vision.

Factors affecting line length

A number of studies have been conducted assessing the factors that affect line length of material read from screen as well as print media. The studies so far in this field discuss the structure of the screen including number of columns, vertical or horizontal screen organization, screen size and typographical factors like font type and size, line leading, visual angle, spacing and justification.

Print versus screen media

Variation in optimal line length between print media and on-screen text may be due to a range of reading patterns generated with a number of different ways of scrolling and paging to navigate through the document (Dyson and Kipping, 1998). Kruk and Muter (1984) found that the text was read significantly slower from screen than from book when both had a comparable amount of information at 39 cpl. Various experiments were conducted by Gould et al. (1987) in an attempt to answer why reading is slower from CRT displays than from paper. They reported that lines of characters on CRT displays are often wider than the same lines printed on paper. They found that at optimum conditions reading performance from a display could get to within 90% of reading print. They also noted significantly slower proofreading speed with computer display compared with paper. On the other hand, Kahn and Lenk (1998) recommended that optimal line length should not vary between print and screen media. Results from print research do not address specific characteristics of computer display such as monitor refresh rate, screen resolution, gamma rate (non-proportional rate at which a monitor screen "gets brighter" as the electrical signal applied to it increases) and reflected vs. emitted light. The consensus is that print results should not be applied to Web sites or other computer-based platforms without consideration of the unique aspects of computer monitors (McMullin et al., 2002).

Screen structure

Readability of text is also affected by the way information is organized onto the screen. Number of columns (one wide vs. multiple narrow columns), large or small screen sizes, vertical or horizontal screen organizations and window height are some of the driving factors affecting line length. In a number of studies, rate of reading and comprehension were studied based on changes in line lengths depending upon these factors.

Number of columns

Line length measures can be confounded with the amount of information on the screen. So experiments studying the effects of number of columns on line lengths should compare one wide column with multiple narrow columns where each page has the same amount of information and therefore the same amount of potential glare. As stated earlier, Dyson and Kipping (1997) tested the ease of reading specific formats used for on-line publications. A single column format with relatively long line length of 80 cpl was compared with a three column format with a line length of 25 cpl. They found that a single wide column was read faster with no overall difference in comprehension than three narrow columns when both used paged movement to advance through the document (also (Dyson and Kipping, 1998). In contrast to reading performance in this study, subjective judgments of ease of reading rated the three-column format easier to read for fast readers, reportedly due to their ability to easily scan through narrow columns and extract meaning. Efficient reading with three column format for speedy readers was also supported by Brown (1970), who explained that the three-column format reduces the need for lateral eye movements and thereby allows the readers to scan vertically down the text. On the other hand Duchnicky and Kolers (1983) indicated that text in narrow columns was read significantly more slowly than text in wider columns on CRT displays.

There are several other contradicting recommendations made regarding the effects of line length in single or multicolumn display. Kahn and Lenk (1998) recommended a line length of 66 to 75 cpl for a single column layout and 30 to 40 cpl per column for a multiple column layout for on-screen reading. Lynch and Horton (1999) offered a psychological reason behind narrow columns: at normal reading distance the eye's span of acute focus is only about 3 inches wide. Bringhurst (1992) in his book *Elements of typographic style* proposed an optimal line length for a single column page between 45 to 75 cpl (with 66 cpl being ideal) and for a multiple column page between 40 to 50 cpl per column. Reynolds (1980) recommended a single column of text on the screen while Mourant, Lakshman and Chantadisai (1981) preferred three-column layout attributable to reduced visual fatigue. Luckiesh and Moss (1941) stated that lines of 13 picas in length are superior to greater line lengths for print, but it should not be assumed that two 13-pica columns on the same page would be superior to a single column of 26 picas, due to a possibility that the second column might be a distraction in reading of the first, and vice versa. This argument was also supported by visual masking data (Turvey, 1973), that when a visual stimulus is too near to other stimuli, the ability to perceive each is diminished. This collection of apparently contradictory studies seems to point towards readers' preference for relatively narrow columns of text, but performance superiority, at least for fast readers, on single,

Screen size

Dyson and Kipping (1998) concluded that shorter reading time occurred for on screen material at 100 cpl. As a possible reason for this they cited de Bruijn et al. (1992) who investigated the effects of screen size (12 versus 15 inch) on learning of text presented on the monitor of a personal computer. De Bruijn et al. (1992) found that subjects using a 15 inch screen needed less learning time than subjects using a 12 inch screen, with no difference in learning performance. Learning was assessed by summarization and a multiple choice test after the reading task to measure the amount of information retained. They interpreted this advantage in terms of an efficient integration process in constructing the semantic representation of text from a single page. Dyson and Kipping (1998) also noted that lines that did not fill the screen had an area of white to the right of the text that could distract readers resulting in slower reading. Hansen and Haas (1988) considered page size as one of the primary factors that influence the behavior of users as they read and write with computers. In their experiments they utilized small (personal computer screen holding 24 lines of 80 characters each) and large (workstation screen holding 46 lines of about 80 characters each) page sizes. Their various reading experiments showed reading from workstation superior to reading from personal computers. They further noted that page size could affect reading tasks by limiting the context for the visible text, thus burdening short term memory. If the page size is small, it takes time to scroll through the document and that interferes with concentration. Still, optimum display size remains an issue that requires further empirical attention (Dillon et al., 1990).

In all these studies it is important to note the effects of screen resolution on length of line for onscreen reading. Bridgeman et al., (2003) in their study on effects of screen size, screen resolution and display rate on computer based test performance, noted that screen resolution is critical because it impacts both the size of text on the screen and the amount of information that can be displayed. Also, a higher resolution allows more words per line and more lines per screen than can be displayed in a lower resolution.

Typographical factors

The literature reviewed so far in this paper addressed psychological aspects of reading from screen and print media. Studies cited showed how these factors relate with line length and readability of text. This section of the paper describes typographical factors like font size and type, line leading, spacing and visual angle and their effects on readability with a stress on line length.

Font type and size
Early research conducted by Tinker and Paterson (1940) (summarized in Tinker, 1963) showed a strong relation between line width and font type sizes. They recommended line widths ranging between 17 and 37 picas for 12-point type size, between 17 and 27 picas for 10 points, between 13 and 25 picas for 8 points, and 9 to 25 picas for 6 points. Of course if amount of information is held constant, line length increases with increase in font type sizes. They also noted that 6- and 8-point type sizes were read slower than the larger type sizes (9, 10, 11, 12 points) due to the increased number of fixations, fewer words per fixations, longer pause duration and longer perception time with more regression. (Especially the 'fewer words per fixation' for smaller fonts is counterintuitive, and, we would guess, wrong. But that is what they reported.) Bringhurst (1992) recommended that length of line (in point unit) should be around 30 (between 20 to 40) times the point size of a font type in a conventional book page. For example for 12-point font size line length should be 360-point.

Line leading
The amount of space between lines of text, line leading, is closely related to line length effects. These effects were studied for both print as well as on-screen reading. For on-screen reading, Grabinger and Osman-Jouchoux (1996), in their recommendation for basic typography, noted that space between the lines helps readers maintain vertical position in the text. Readers prefer short lines of about eight to ten words or 45 to 60 characters long that are single spaced. The longer the line, the harder it is to maintain position on that line, therefore more leading is needed. Hedrick (2002) also recommended more leading as the line gets longer. But he strongly disagreed with the use of double line spacing. Kolers et al. (1981) studied the effects of space between lines on reading performance. Their results showed that single spacing produced more fixations per line, that is fewer words per fixation. Therefore total reading time was longer with single spacing than with double spacing. Lynch and Horton (1999) presented a line spacing rule: make line spacing at least 1/30 of the line length to give a two-degree downward angle for finding the next line (HFS, 1988). Though additional line leading allows longer line length without sacrificing leg-

ibility (Lynch and Horton, 1999), line length of more than 75 to 80 cpl with proper leading is too long for continuous reading (Bringhurst, 1992). For printed text, Tinker (1963) presented limits of variation in line width and leading ('safety zones') that may be used for a given type size without loss of legibility from various experiments and surveys in printing practice.

Visual angle

The visual angle of line of characters is the angle formed by the width of the line of characters as it relates to the reading distance of that line from the reader's eye. More precisely, the visual angle of a line of characters is twice the arc tangent of the ratio of one-half the width of that line to its distance from the reader's lens (Gould et al., 1987). Experiments conducted by Gould and Grischkowsky (1984) had a line on a CRT display 1.52 times the width of the same line printed on paper in 10-point type size. In these experiments the visual angle subtended at viewer's eye by a 69-character line on CRT display was greater than the visual angle subtended by a 69-character line on paper with equal reading distance from both the media. Thereafter Gould et al. (1987) conducted a number of experiments in an attempt to explore multiple variables, with reading distance (visual angle) as one of them, for why reading is slower from CRT displays than from paper. Their reading distance experiment concluded that people sit farther away from a CRT screen than from paper which led to smaller visual angle by CRT display than by paper. From the visual angle experiment they noted that speed and accuracy of proofreading were reduced at extreme visual angles. At small visual angles, characters were hard to discriminate and at large visual angles more eye fixations were required due to fewer characters perceived peripherally. From various experiments conducted by Gould et al. (1984; 1987) it is not clear whether people are sitting farther from the screen because lines are longer or lines are kept longer on screens because people sit farther from the screen. McMullin et al. (2002) noted that line length subtended by visual angle increases with the distance from the viewer's eyes to the reading material. Since computer monitors are viewed at greater distance than most of the printed material, eyes can transverse greater line lengths with motions that are equivalent to the recommended line lengths in print.

Word spacing and text justification

One of the early psychological studies in typography was conducted by Burt, Cooper and Martin in 1955. They concluded that short lines require widely varying spaces between words and increase the number of broken words at the end of lines. Bringhurst (1992) also supported this by stating that line length less than 38 or 40 cpl will lead to uneven spaces and more hyphenation at the end of the line which is hard to read. Hedrick (2002) recommended that no more than three lines in a row should be hyphenated. He also found difficulties encountered in reading lines of text with uneven spaces and hyphenation.

Campbell (1981) studied the effects on reading speed of two different types of right justification in computer printed text, one with fixed character spacing and the other with variable character spacing, where extra space is distributed proportionally between and within the words of the line. He noticed that right justification with variable character spacing produced faster reading than fixed character spacing or unjustified text. On the other hand Gregory and Hartley (1987) recommended the use of left-justified text on the screens when line lengths are approximately 20 cpl.

Length and complexity of passages

Surber (1992) had 52 college students read a long or a short passage and then take a multiple choice test containing main point and detail questions to investigate the effects of length of the passage on retention of information, reading speed and highlighting patterns. He found that subjects took almost twice the amount of time per word to read short passages compared with long passages. He hypothesized the reason behind this was engagement in a greater depth of processing for more elaboration. The conclusion of efficient reading with narrative passages compared to short news articles was also supported by Shaikh and Chaparro (2004). They found that test participants read faster and comprehended more while reading narrative passages compared with reading short news articles. We believe these findings had more to do with the participants' motivation and their understanding of the task, than with lower-level reading processes.

Design Guidelines

Here we distill the studies reviewed in this paper and derive recommended design guidelines for printed and on-screen text considering line length as a major factor affecting readability of the text.

Design guidelines for printed text

• Medium line lengths are optimal for efficient reading of printed text compared to very short lines of 5 picas and very long lines of 36 picas: for example 13 picas or 59 to 97 mm or 52 cpl (Tinker, 1963) and 3.5 to 5.5 in. (Burt, Cooper and Martin, 1955).

• As line length is decreased, the angular deviation of the return sweeps is increased, and thus the relative separation between the lines appears to increase and so readability is decreased (Luckiesh and Moss, 1941).

• Line width between 17 to 18 picas for double column printing in magazines, between 21 to 22 picas for a single column printing in scientific journals and between 21 to 22 picas for a single column printing in text books is considered to be optimal (Tinker, 1963).

• For 8- and 10-point font type sizes, line widths can be extended without the loss of legibility with two-point line leading (Tinker, 1963).

• Optimal line length for 10-point type size is about 80 mm, laying somewhere in between 59 and 97 mm (Tinker and Paterson, 1941).

• Line widths for multiple columns, 30 to 40 cpl (Lynch and Horton, 1999).

Design guidelines for on-screen text

• Medium line length of 55 cpl for ease of reading, better comprehension and better reading rates for on-screen text compared to very short lines of 25 cpl and very long lines of 100cpl (Dyson and Kipping, 1998).

• Readers prefer short lines of about 8 to 10 words or 45 to 60 characters long (Grabinger and Osman-Jouchoux, 1996).

• Single spacing produces more fixations per line resulting in fewer words per fixation and so total reading time is longer than with double spacing (Duchnicky and Kolers, 1981).

• Additional line spacing allows longer line length without sacrificing legibility (Lynch and Horton, 1999).

• Lines more than 9 or 10 words on an average must be leaded proportionately to the length of line. Lines with more words should have additional space between them (Hill, 2001).

• Make line spacing at least 1/30 of the line length to give a 2-degree downward angle for finding the next line (HFS, 1988).

• Line length should be around 30 times (between 20 to 40) the size of the font type (Bringhurst, 1992).

• Line widths for single columns, 65 to 75 cpl (Kahn and Lenk, 1998) or 45 to 75 (66 cpl ideal) (Bringhurst, 1992) or 100 cpl (Dyson and Kipping, 1997a).

• Line widths for multiple columns, 30 to 45 cpl (Galitz, 1993) or 30 to 40 cpl (Kahn and Lenk, 1998) or 40 to 50 cpl (Bringhurst, 1992).

• Fully justified text is hard to read because of hyphenation, uneven breaks in phrases and words and variable spacing. So left-justified text is considered easier to read with constant spacing (Grabinger and Osman-Jouchoux, 1996).

Conclusion and directions for future research

Line length of text read from printed and on-screen material affects various aspects of reading such as comprehension, reading rate, method of movement to navigate through the page (scrolling and paging) and eye movements. On the other hand different screen structures with different number of columns and screen size and various typographical factors like font type and size, line spacing, distance from the media, character spacing, length and complexity of passage affect what is considered to be an optimal line length. This is a very complex interaction, occurring on multiple levels. For instance, it seems as though line length affects method of movement, and method of movement affects reading speed.

Studies concluded that moderate line length in between 50 to 70 cpl are the easiest to read and users do not prefer extreme line lengths (very short or very long) while reading from screen. There was no significant effect of line length found on comprehension, though fast readers benefit from narrow columns with short lines due to specific reading patterns (with one contradictory finding). It seems as though good readers can, with columns that are almost exactly as long as their spans of apprehension, simply make downward saccades, down the middle of the column, apprehending all the line, left and right.

And so, let us conclude with the following set of recommendations.

1. Ensure that the width of the column, for running text, is at least as long as the span of apprehension for good readers, to maximize the use of their peripheral vision. The length of this span will vary with the easiness of the material being read, but a reasonable guideline would be 55 to 75 cpl.

2. Keep length of line moderate for ease of reading. It is difficult to make accurate return sweeps in longer lines, and shorter lines decrease the saccade length and don't let the reader make maximum use of their peripheral vision.

3. Longer lines are OK, especially for non familiar or otherwise difficult material and if speedy reading is desired. But again they increase the difficulty in making return sweeps.

4. Use the whole screen, regardless of the screen size. Leaving too much white space allows too much glare and distracts the reader. Consider a grayed background, to reduce glare, while still maintaining high levels of contrast with the text.

5. In using the whole screen, consider multiple (optimal width) columns, rather than one long column.

6. If using multiple columns, ensure that the columns are divided by enough white space to minimize the effects of visual masking.

7. Left-justify the text. If you wish to right-justify the text also, only do so with proportionately-spaced fonts.

8. Have the longer lines spaced (leading) proportionally to the line length to easily identify the beginning of the new line. No less than one-thirtieth of the line length.

9. Increase the line length with increase in distance from which the text is read.

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