The necessary field of view to read with an optimal stand magnifier

Elisabeth M. Fine, Ph.D.[a]
Matthew P. Kirschen[b]
Eli Peli, M.Sc., O.D.[b, c, d]

A B S T R A C T

BACKGROUND

For most people with low vision, some form of magnification is necessary to read. Using a magnifier reduces the number of letters that can be seen simultaneously (field of view), which has been shown to decrease reading rates. This study sought to determine how many letters are necessary to attain maximal reading rates with a stand magnifier.

METHODS

Younger and older normally-sighted and visually-impaired observers read short passages using a fiber optic stand magnifier (taper). The optical properties of this magnifier allowed the field of view to be precisely varied. Each subject read using at least four field sizes (3, 5, 9. and 13 characters visible) while reading speed was measured.

RESULTS

Reading rates continued to increase with as many as 13 characters visible, regardless of age or vision status. In addition, reading with the taper was slower for all subject groups than reading without the magnifier.

This study confirms reports that reading rates increase as the field of view increases when reading from a page of text. The need for this large field of view relative to other low vision reading aids (i.e., computer-generated scroll displays) is likely the result of the readers' need to actively navigate across the page of text.

KEY WORDS

low vision, magnifier, field of view, reading rates, taper

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Reading is crucial to independence and self-sufficiency. For many older adults faced with the problems of visual impairment, reading has become a difficult or impossible task. Because magnification often permits reading and increases reading speed for most people with low vision,[1] magnification of some sort is common to almost all reading aids.Among the most frequently used reading aids are stand magnifiers.* Stand magnifiers are easy to use, transportable, and relatively inexpensive. One distinct disadvantage of stand magnifiers (as well as other optical magnifiers) is that the number of letters that can be seen through the device at any one time is limited.

There is considerable evidence that limiting the number of letters that can be seen simultaneously (often called the field of view or window size) slows reading rates. For example, Rayner and his colleagues showed that as the size of the field of view was reduced, reading rates decreased.3 In their studies, normally-sighted readers were asked to read relatively small print from a computer screen as varying amounts of the text surrounding fixation were masked.As many as 30 characters were needed for subjects to attain maximal reading rates.While these experiments have not been replicated using magnified text, other researchers have looked at the relationship between window size and reading rate for text viewed through different low vision reading aids.Two different types of reading aids have been used in this research: those that require the reader to navigate around a page of text and those that do not.

A scrolled text display continuously pans text (usually magnified) across a television screen from right to left. Using this display format, Legge et al.* showed that only about five letters visible at one time were necessary to read at maximal rates.This result was obtained for both normally sighted and low vision readers, but Fine and Peli[5] showed that visually impaired readers may require more. letters to read at maximal rates than normally sighted readers.A similar finding for well-trained CCTV users has also been reported.627 However, other studies have shown that a much larger field (up to 24 letters) is necessary for maximal reading rates with a CCTV.[8,9] Unlike reading from a scroll display, efficient use of a CCTV does require the reader to navigate around the page. The movement of the device is mechanically limited, however, to facilitate horizontal movements across the text. When moving across lines of text, the vertical position of the CCTV is constant. In addition, there is a stop at the left edge of the text platform that limits its movement, limiting the possible problems associated with fmding the beginning of the next line (the return sweep), which is often inaccurate and always time-consuming.[8,10]

Magnifiers that require navigation also require a much larger window size to attain optimal reading rates among young, normally-sighted observers. For example, Neve varied the window width of hand magnifiers and showed that reading rates increased as the width increased, until the window width and horizontal extent of each line of text were the same.[10] Neve used a light positioning diode to record the movements of the magnifier while subjects read. Using this technique, he found that the additional time required to read with the smaller window size was likely due to the increased time required to move the magnifier across the line of text, and the additional difficulty readers had making the return sweep with a smaller window.

Cohen and Waiss also reported that the field of view afforded by a magnifying device affected reading rates among young normally-sighted observers.[11] They asked their subjects to read using four different types of magnifying devices, each of which had a different field of view. They found that reading was fastest with the device that allowed the most characters to be visible at a given time. It is interesting to note, however, that unlike Neve,[10] they continued to see increases in reading rate even when the field of view of the different devices exceeded the column width. However, only head-mounted devices (i.e., spectacles and telemicroscopes) had fields of view larger than the column width. A similar finding was reported using a hand-held magnifier by McMahon and Spigelman.[12] They varied the column width while holding the field of view constant and showed that it had little effect on reading rates when text length (in cm or number of lines) was accounted for, because there is a one-to-one correspondence between the number of lines required to print a text and the number of return sweeps required to read it.

While the reports cited have concluded that expanding the field of view benefits reading for normally-sighted young observers when using different forms of magnifiers, the number of simultaneously visible letters necessary for optimal reading has not been reported. One likely reason for this is the imprecision with which field of view can be defined for the magnifiers tested. This imprecision is especially true for stand magnifiers because the field of view changes with eye-to-lens distance,[13,14] and depending on whether the viewer is using a monocular, binocular, or combined visual field.[10,14] Unlike other stand magnifiers, the field of view (defined in number of letters) of the fiber optic taper does not change with viewing distance.[15] The field is simply defmed as the linear extent of the bottom face of the taper. Unlike other magnifiers, tapers produce an almost distortion-free real image on their top face, and while the retinal size of the image changes with the viewers' distance, its physical size is easy to measure and define (Fig. 1). Specifically, the magnifying power of a taper is equal to the ratio of the size of the top face to the bottom face. Thus, a taper whose top face is twice as large as its bottom face will have a magnification of 2x, and the physical size of the image at the top face will be twice the size of the unmagnified image. For the purposes of reading, the field of view of the taper can be defined as the number of letters that can be printed in a line equal in length to the diameter of the bottom face.

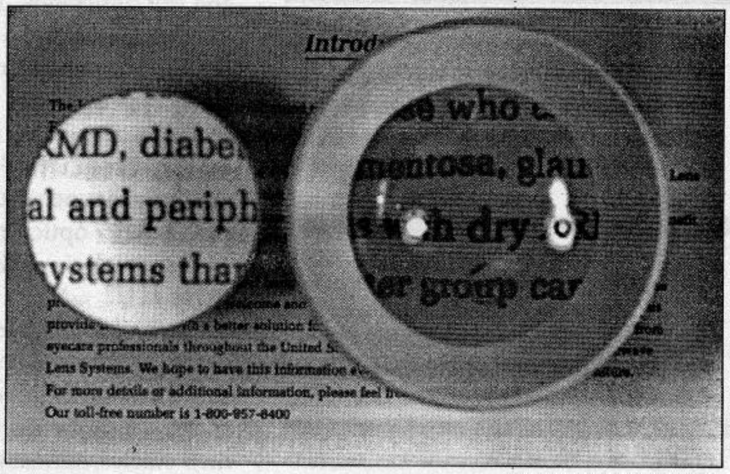

Figure 1

A taper (left) and a typical stand magnifier Note the distortions, especially at the edges of the stand magnifier, as well as the reflection of the light source from above. Both of these are absent in the taper.

An additional advantage of the taper for evaluating the effects of window size on reading rate is that the number of characters visible can be easily and accurately changed by attaching an opaque occluder to the top face of the taper (Fig. 2). While this eliminates from view the characters from the edges of the taper, it does not change any other optical or nonoptical properties of the magnifier, such as height, weight, or illumination. For these reasons, the taper was chosen to evaluate the number of characters necessary to attain maximal reading rates with a stand magnifier. Also, unlike previous reports,[10-12] which focused only on normaliy sighted young readers, reading performance was evaluated for both normally sighted and visually impaired observers.

Figure 2

A taper magnifier with occluder. Only the available field of view (defined in number of letter s visible) changes

In addition to comparing changes in reading rate with different fields of view for visually impaired and age-matched normally-sighted readers, reading behavior was also assessed for a younger group of observers. When using a magnifier, fine motor control is required. This controlmay serve to further reduce reading rates for elderly readers relative to younger readers. In addition, it has been recently reported that the difference in reading rates between older and younger observers changes depending on the display format used.[16] Thus, it is important to determine if changes in field of view also affect readers of varying ages differently.

Methods

Subjects

English-speaking adults with and without visual impairments were recruited to participate in this study. Normal vision was defined as visual acuity of 20/40 or better in the subject's better eye, with habitual distance correction. Normally sighted subjects were separated into two groups on the basis of age: 30 years or younger and 55 years or older. These groups will be referred to as the younger normal (YN; n = 14) and older normal (ON; n = 18) groups, respectively. Visually-impaired (VI; n = 16) readers of all ages were grouped together because all of them were over the age of 55 years. Only visually-impaired subjects who could read using the taper with no artificial field restriction were included in this study. Eight of these subjects had documented central field loss (CFL) in their better eye; thirteen had CFL in at least one eye. Average age and visual acuity of these three subject groups is shown in Table 1.

Stimuli

Forty-three short passages from fourth- and fifth-grade reading primers (***Multiple Skills Series*** *E3* and *D1*, respectively; Barnell Loft Ltd., Baldwin, NY) were used to test reading rates. Each primer contained 50 passages, each of which was accompanied by five multiple choice questions. Volunteers aged 55 years or older were asked to answer four of these multiple choice questions for each passage without having read the passage. (The fifth question was eliminated because it always required word 'definitions which should have been in the vocabulary of most adults.) Only those passages for which average performance on the questions was 60 percent or less (without reading the passage) were chosen as stimuli. These 43 passages had an average of 17 lines each, with about 7 words per line.The average word length was 4.2 characters.

Apparatus

A 2.5x taper was used for the reading task. This taper provided retinal image magnification that exceeded the magnification available with common stand magnifiers rated as 4x.15 This taper has a 2.1 cm bottom face and a 5.3 cm top face (5.3/2.1 = 2.5), and allowed for thirteen letter "e's", printed without spaces using a Times 10 point font, to be seen on the top face simultaneously. The contrast transfer through the taper was 79 percent of the contrast of the printed materials, which was 83 percent.15 The taper was 4.7 cm tall and weighed 9.5 oz. An additional 2.75x taper with similar properties was used for practice. The field of view through the tapers was limited using doughnut-shaped occluders cut from an adhesive white vinyl with a laser plotter. When these occluders were placed on the top face of the taper, they allowed for 11, 9, 7, 5, 3, 2, or 1 letter to be seen. As previously mentioned, the addition of these occluders changed no other properties of the taper. Only the field of view was changed. This apparatus is shown in figure 2.

The layout of the passages on the page was similar to a newspaper column. The passages were printed on white paper in 2-inch (5. I cm) wide columns, with 3.8 cm margins on the left and right. The top margin was 6.1 cm. The font was Times 10 point generated with a laser printer. Each passage was mounted on poster board measuring 14.9 cm x 2 1.6 cm, and backed with hook-and-loop tape. The reading surface was covered with poster board of the same thickness with a cut-out to fit the passages. This modification was performed to provide a smooth surface over which to navigate with the magnifier and hand.

The reading surface was 81 cm high. Subjects were seated in a height-adjustable chair and encouraged to fmd a comfortable reading position. Fluorescent ceiling lights and a 60 Watt incandescent goose-neck lamp lit the reading area. The lamp was positioned over the reader's left shoulder so that no reflection of the bulb was seen in the magnifier.15

Design and Procedure

During all phases of testing except acuity measurements, subjects used their habitual reading glasses. All subjects were asked to read three paragraphs with no occluder (13 characters) and with occluders that left 9, 5, and 3 characters visible. In addition, nine of the 14 observers in the YN group read with 11, 7, and 1 character visible. The 11 and 7 character window sizes were eliminated for the remaining subjects because there was no difference in reading rate between the 11 and 9 character conditions (178 and 175 wpm, respectively), nor between the 7 and 5 character conditions (147 and 148 wpm, respectively). The 1 character condition was eliminated because the initial subjects in the ON group (n = 4) found the task too difficult. It was replaced with a 2 character condition. All subjects who were able (all YN, 15 ON, and 12 VI) also read three passages without the taper. Because the no-taper condition was always last for the Vl subjects (described below), it is unclear whether those subjects who did not read in the no-taper condition were unable to read due to visual difficulties or simply because they were tired or out of time. However, at least on the basis of their acuity relative to the remaining VI group, there is no reason to believe that they would have been unable to read without the taper.

Characteristics of subject groups

group	n	age (years)	visual acuity (snellen)
younger normal vision	14	18 16-27	20/17 20/15-20/20
older normal vision	18	68 56-85	20/22 20/15-20/40
visually impaired	16	75 59-88	20/81 20/50-20/1 60

Table 1

Mean and range of the data for the age and visual acuity of subjects by group. Acuity for all subjects was measured using their habitual distance correction.

The order of occluder size (including no occluder) and passages was randomly determined for each subject. Normally-sighted younger readers were presented with all of the conditions in random order (including reading without the taper and the 1 or 2 character condition). Normally sighted older subjects and visually-impaired subjects read with 13, 9, 5, and 3 characters visible in random order, and then, if they were able, read three passages without the taper. Normally sighted older subjects then read with 2 characters visible. None of the VI subjects were able to read in this condition. A short break was given after every six passages (2 occluder sizes), and more frequently if requested by the subject.

Each trial began with the experimenter placing the passage on the reading surface with an opaque cover. Timing began when the cover was removed and continued until the subject indicated that the passage had been read.The passage was then removed.After the passage was removed, subjects were read the four multiple choice questions and responded to each verbally. If the subject was

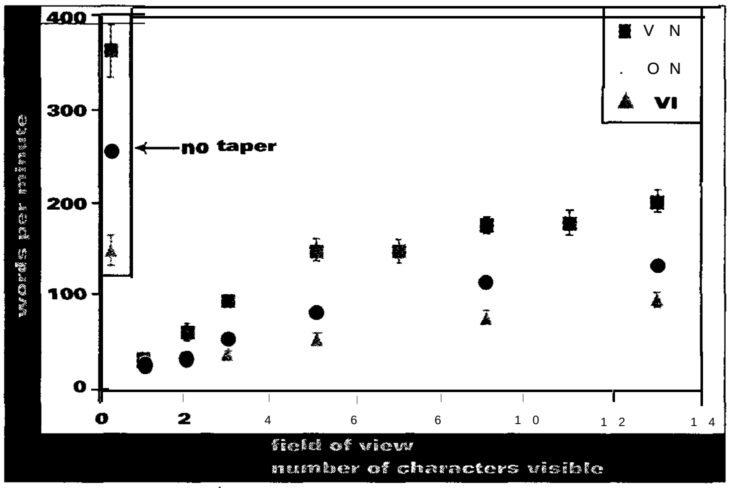

Figure 3

Reading rate in wpm by field of view in characters. Error bars are SEM. for all groups, reading rates continue to increase with increasing field of view up to and including at least 13 characters, although for the YN group the data are beginning to level off. The three data points on the far left of the graph are reading rates without the taper. Reading was faster without the taper, even for the visually impaired group.

unable to answer at least three of the four questions, that trial was eliminated. Reading rate in words per minute (wpm) was calculated on the basis of the total time required to read the passage and the number of words it contained.

Before testing began, each subject read at least one passage using a different taper (7.0 cm top face; 2.75x magnification). The primary purpose of this practice passage was to tram readers to navigate with the taper, and to familiarize them with the level of difficulty of the questions. McMahon and Spigelman showed that reading with stand magnifiers improves (reading rates are faster) with long-term practice (two weeks).[12] Five subjects who did not participate in the primary study each read 10 passages with the taper. There was no change in reading rate between the first (165±31 wpm) and the tenth (180±42 wpm) passages. Thus, while long-term practice may have increased reading rates, it is unlikely that practice would have had an effect over the small number of trials in this experiment (no more than 24).

Acuity was measured monocularly, with habitual distance correction, using a Mentor B-VAT II™ (Mentor O&O, Inc., Not-well, MA). Using this system, randomly chosen letters can be presented at various sizes. Subjects were asked to name letters, presented individually, and the size was reduced until fewer than four of five were correctly named. A more detailed description of this procedure can be found in Fine and Peli.[17]

Results

Average reading rate across the three passages for each subject in each condition was calculated. If fewer than three of the comprehension questions were answered correctly, the data from that passage were eliminated and the average calculated from the remaining two pas sages, If performance on fewer than two passages reached criterion, the data for that sub ject in that condition was replaced by the mean of the subject's group (YN, ON, or VI). (Replacing missing data by the group mean does not change the mean performance of the group and allows the remaining data from that subject to be included in the analysis. It also reduces the within group-or condition-variability, thereby reducing the likelihood of finding an effect.) This occurred for five different subjects (one YN, two ON, two VI) and four different conditions (no taper, 7, 5, and 3 characters visible). In addition, the datum from one VI subject was replaced by the group mean in the three-character condition because she was unable to complete the task due to time constraints. Therefore, six data points were replaced with the group mean.

The mean of the data for each group in each condition are shown in figure 3. Using these data, simple regression analyses were performed within each subject group. Because field size cannot be accurately defined for the no-taper condition, those data were not included in the analyses.The regression coefficients for each group were as follows:

$$Y' = 80.70 + 9.82N \quad YN$$
$$Y' = 36.02 + 7.76N \quad ON$$
$$Y' = 21.40 + 5.82N \quad VI$$

where N = field of view in number of characters and Y' is the predicted reading rate in wpm.These models accounted for 49, 49, and 43 percent of the variance in the data, respectively, all of which were statistically significant.[c] Comparisons of the slopes and the intercepts showed that they were all signifi-candy different from each other (all $t > 4.14$

for the slopes and 19.39 for the intercepts; all $p < 0.01$), indicating that, overall, the younger subjects read faster than the older subjects, who read faster than the visually impaired subjects, and that the increase in reading rate with increased field of view was greatest for the YN group, followed by the ON and VI groups.The difference in intercept for the YN and ON groups reflects the expected change in overall reading rate with age.The steeper slope for the YN group indicates that younger readers are more sensitive to changes in the field of view than older readers. The difference between the YN and ON groups, however, was similar to the difference between the ON and VI groups (2.06 and 11.94, respectively).The YN group overall had better acuity than the ON group.This difference may result in a larger useful field of view (the portion of the visual field from which usable information can be extracted).[18] Restricting the window size of the taper would have eliminated a larger proportion of the YN subjects' field than for the ON readers.The decrease in slope for the VI readers can be explained in a similar manner.

In addition to comparing reading rates across fields of view, reading rates with the taper were compared to reading rates without it. In order to decrease the effects of baseline reading rate on this analysis, the ratio of reading rates for the full-face (13 character) taper condition to the no-taper condition was calculated, and this ratio was averaged across subjects.The YN group read 42 percent slower with the taper, the ON group was 44 percent slower, and the VI group was 36 percent slower. None of these values differed from each other [$F(2,38) < 1.0$, n.s.] .This result was surprising. One would have expected the VI group to read faster with the taper, which provided magnification, than without it. However, they were allowed to move as close to the reading material as they desired in the no-taper condition, thus increasing the retinal size of the print. This may have provided sufficient magnification for optimal reading, and whatever factors served to slow the remaining subjects affected the visually-impaired group about equally.The average reading rate of 150 wpm without the taper for this subject group supports this idea.While it could be argued that this subsample of the Vl group is biased toward the better readers (four of the original group did not read without the taper), the reading rates for two of those subjects when reading in the 13 character condition (using the taper with no occluder) were more than one standard deviation (SD) above the mean for the same condition for the VI subjects who did read without the taper (mean = 88 wpm, SD = 2 l).The reading rates for the other two subjects in the no occluder condition were within two SD below that mean. For all groups, the relative decrease in reading rates when using the taper was about the same as McMahon and Spigelman reported for their normally-sighted subjects (28 to 61 percent decrease).[12]

Discussion

The data from this experiment show that reading rates continue to increase at least up to a field of view of 13 characters.This result was found regardless of age group or the presence of visual impairment.This window size is substantially larger than what Legge and his colleagues have shown to be sufficient for reading both scrolled text and with a CCTV,[1,4,6,7] although some studies indicate the need for larger fields with CCTVs (up to 24 characters).[8,9] The most likely reason for the difference in findings between the current study and Legge et al.'s is the need for unrestricted navigation using the tapers.When reading from the scroll display, there is no need for hand-eye coordination.The text is presented to the reader, who has no control over its display. With the CCTV, the reader must navigate around the page of text, scanning across the lines and finding the next line. Unlike a stand magnifier, however, the movement of the CCTV table is limited such that moving the table quickly to the farthest position to the left will align the viewer with the left edge of the text and keep it at the same vertical alignment.The same is not true of reading with a stand magnifier.

When reading with a stand magnifier, there are no limits on where the device can be moved. Subjects in the present study were shown how to limit the movement of the taper by placing a finger at the left edge of the text. However, they were only given practice with this technique using a taper without an occluder.When a portion of the taper was occluded, aligning the edge of the taper with the edge of the text would result in the reader missing the first several letters on a line.Thus, adjustments would need to be made to align a usable portion of the taper with the beginning of the line. This off-set between the edge of the taper and the edge of the usable field could help to explain why informal observations of the subjects indicated that almost 50 percent of their reading time was needed to move from the end of one line of text to the beginning of the next when using an occluded taper. This is far greater than the 20 percent of reading time that is used to make the return sweep with one's eyes.19 It is also far greater than one would predict given Neve's finding that the velocity of stand magnifiers was greater on the return sweep than when reading across the line.10 He also noted that finding the beginning of the next line was often inaccurate and did consume a fairly large proportion of the reader's time. This problem would be exacerbated when the taper was occluded. While the effects of reducing the field of view on navigation time and reading time (decoding the visual stimulus) cannot be separately assessed, it is evident from the current study that at least some of the wider field is necessary to navigate around the text.

Of the 16 visually impaired subjects, five habitually used microscopic spectacles to read. It could be argued that the field of view available through these glasses further limits the field of view available through the taper. The data provide some support for this. Those readers who used microscopic spectacles read about 30 wpm more slowly than the other visually impaired readers with the taper. However, the use of more than one device (i.e., glasses in addition to other magnifiers) is not atypical, and more closely represents the reading practices of the target population.

Five subjects used hand magnifiers in their normal reading, and this practice may have reduced their reading time with the taper. (They were not allowed to use these during this study.) With the exception of one subject, who read at 202 wpm in the no-occluder condition, this group of readers were no faster than the group who did not use magnifiers at home (mean difference = 8.7 wpm; $t(13) < 1.0$, n.s.).

Conclusions

Using a 2.5x taper magnifier, at least 13 characters are needed for optimal reading. Although data were not collected for all the intermediary points in the ON and VI groups, the data from the YN group indicate that the benefit of a wider field of view begins to decrease when about nine characters are visible. There are only two ways to increase the number of characters visible with a taper: reduce the size of the print or increase the size of the magnifier. The first option would be counter-productive for the target population of users. The second option is also untenable because both the weight of the taper and its cost increase as the cube of the increase in diameter. It remains to be seen whether a similarly large field of view will be necessary with greater magnification. For readers with more severe visual impairments than those who participated in this study, their useful field of view may be far smaller,[18] and thus eliminate the need for the larger magnifier field of view. It is clear from this study that for moderately impaired readers a fairly large field of view is necessary for optimal reading with a stand magnifier.

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Footnotes

a. Wilmer Eye Institute. Johns Hopkins University, Baltimore, MD

b. Schepens Eye Research Institute. Harvard Medical School, Boston, MA

c. Taper Vision. Inc., Newton, MA

d. New England Eye Center, Tufts University School of Medicine, Boston, MA

e. Inclusion of the remaining conditions (11. 9, 2. 1 characters) for the YN group does not substantially change the pattern of the data. Across all conditions: $Y' = 52.22 + 12.51 N; R^2 = 0.63$ The increase in the amount of variance accounted for is expected given the extended range of the independent variable (window size). There was also little change for the ON group when the additional conditions (1 and 2 characters) were included' $Y' = 29.24 + 8.44N; R^2 = 0.58$

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Elisabeth M. Fine, Ph.D.
Wilmer Eye Institute
Johns Hopkins University
550 N. Broadway, 6th Floor
Baltimore, MD 21205