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THE EFFECT OF WINDOW WIDTH AND WINDOW HEIGHT ON READING CONNECTED TEXT WITH A CCTV MAGNIFIER

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INTRODUCTION

Traditional measures of the visual functions, such as visual acuity, are poor predictor of low vision reading performance. As a consequence the selection of a low-vision reading-aid is often a difficult and tiring process. Over the past years several models were developed to make this process more efficient by defining the visual requirements for magnifier reading. The most extensive model in predicting the reading performance with a magnifier was developed by Whittaker and Lovie-Kitchin (1993). In the model four visual factors were distinguished: (i) acuity reserve (print size relative to acuity threshold), (ii) contrast reserve (print contrast relative to contrast threshold), (iii) field of view (number of characters visible), and central scotoma size (in case of macular degeneration).

For the factor field of view, Whittaker and Lovie-Kitchin (1993) argued that a window width of 1-6 characters would be optimal. This value is not self-evident, because the results of the several studies into magnifier reading differ with regard to the optimal window dimensions. Whittaker and Lovie-Kitchin based their value mainly on the results of experiments by Legge, Rubin, Pelle and Schleske (1985a, b), who found that a window width of 5 characters was optimal. Other studies revealed much larger viewing fields (Neve, 1989; Cohen & Waiss, 1991). Lowe and Drasdo (1991) found even a width of 24 characters as optimal. Such a value is of the same order as the viewing field for normal reading (McConkie & Rayner, 1975). To solve this dispute a more detailed study into the function and dimension of the visual field in the process of magnifier reading in necessary.

Funtion of the visual field

The way the visual system can be used for both normal and magnifier reading is constrained by the heterogeneous structure of the retina. The retina, with cones in the middle and rods in the periphery, affords a high visual acuity that is restricted to the central area of the retina.

The lack of a full retinal acuity is compensated for by an ingenious control system by means of which all parts of the surrounding area can be focused into the central region (Grind, 1994). This implies that only a small part (about 8 characters) of the page can be seen sharply enough to recognize the text. In normal reading the eyes jump from line segment to line segment. During an eye-jump (saccade) the retinal image is too blurred to allow information processing. Between two saccades, the fixation pause, the information is picked up from the stabilized image. After the recognition has taken place, the next point of fixation is selected from the adjacent (less sharp perceived) text. This holds for all situations, the selection of the next word, the selection of the beginning of the next line, or any other part of the page or display where the reader decides to continue reading. Therefore, the visual field can be broken down in two parts, a recognition and a localisation field (Den Brinker & Beek, 1996; Den Brinker & Bruggeman, 1996). The number of characters that can be recognized in one fixation pause (the recognition field) is determined by the size and contrast of the characters (Legge, Rubin and Luebker 1987; Bouwhuis, 1994). For the localisation field global word properties like word shape are important, which can be derived from the findings that reducing the field width decreases the reading rate (McConkie and Rayner, 1979), and that replacing the characters with a similar shape do not affect the reading rate (Rayner, Well, Polatsek and Bertera, 1982).

Reading with an optical magnifier is somewhat different. While reading the device has to be moved along the line and, at the same time, kept at a constant distance from the text to secure a sharp image. Usually the magnifier is moved smoothly to the right along the line, while the eyes fixate on the same location in the magnified image and thus move smoothly in the opposite direction. As soon as the recognition process is completed, the eyes jump rightwards to a new fixation point in the moving image (opto-kinetic nystagmus). This pattern has been found both in normal and low vision subjects (Legge et al., 1985b; Neve, 1989; Bowers & Ackerly, 1994; Fotonakis & Dickinson, 1994).

Except for the phenomena that hand and eye movements have to be synchronized to create a stable retinal image, reading with a magnifier is very similar to normal reading. In both tasks one can speak of a fixation pause to recognize the characters and a saccade to reach the next point of fixation. therefore, studying the visual field with regard to the size of the recognition field and the size of the localisation field is of equal importance for normal reading and reading with a magnifier.

Window dimension

For magnifier reading two kind of experimental set-ups were used to determine the visual field. Firstly, reading was simulated by the so-called «Drifting Text Technique» (Legge et al., 1985a): the magnified text was not moved by the subjects themselves, but by a device that regulated the smooth transportation of text on the screen. Applying this technique, both normal and partially sighted subjects were found to reach maximum reading rates with a window width of only 4 to 5 characters (Legge et al., 1985a,b). In the second kind of experiment, subjects had to move the text (Lowe & Drasdo, 1990) or the magnifier (Neve, 1989) themselves. Under these conditions the visual field was very similar to the field of 18 characters found in normal reading (Bertera & Rayner, 1979). So, a tentative conclusion may be drawn that Legge and co-workers (1985a,b) only measured the recognition field, whereas Neve (1989) and Lowe and Drasdo (1990) showed that wider windows are necessary to control the magnifier.

In the past, the discussion on the dimension of the visual field for magnifier reading was restricted to the width of the viewing field. Den Brinker and Beek (1996) proposed that the height of the viewing field is also important, especially in controlling the magnifier to reach the beginning of the next line (return sweep). When the reader starts the movement to place the magnifier from the end of a line to the begin of a next line, this begin can not be seen, so the movement starts as a non-visual search. Because the angle between the end of a line and the beginning of the next is about 2 degrees (Bouma, 1980), and larger errors are made in pointing with the hands (Graaf, Sittig, Denier and van der Gon, 1994), it is assumed that a higher window will help in correcting (with the eyes) misdirection caused by hand movements (Den Brinker & Beek, 1996).

In this research the following predictions will be tested. Within the limitations of the magnifier system in use, (i) there is a positive relation between width of the viewing field and reading rate, (ii) there is a positive relation between the height of the viewing field and the speed with which return-sweeps can be made.

METHOD

Subjects

To test the effect of window dimension (height and width), the reading performances were measured of 17 low-vision and 18 normal-vision subjects (male and female). The subjects were divided over three age-groups (young: 20-39 years, middle: 40-64 years, and old: 65 years and older). For the low vision, 5 young subjects (mean acuity = .06), 6 middle subjects (mean acuity .08) and 6 old subjects (mean acuity = .06) participated to the experiment. For the normal vision in each age group 6 subjects participated to the experiment. Male and female subjects were equally distributed over all groups. All low-vision subjects were people with macular degeneration, the category of partially sighted people that suffer the most from low reading rated (Legge et al., 1985b). The low vision subjects were experienced closed circuit television (CCTV) magnifier users. All subjects got the same instructions about the reading with a magnifier, and got ample opportunity to get acquainted to reading with the apparatus in use.

Apparatus

The CCTV magnifier used was a TeleSensory VersiColor XL with a CCD camera and a high contrast black and white screen with a diagonal of 46 cm. The text was, with a few exceptions, displayed black on white. The windowing was performed using the build-in functions for that purpose. To measure the position of the text relative to the camera, the pen of a graphical tablet (Penpad 300) was attached to the platform, enabling the recording at a rate of 100 Hz with an accuracy of .05 mm. In some conditions the gaze direction of the eyes was monitored with an IRIS system in the horizontal plane. This system recorded gaze direction by reflection of iris-sclera boundaries by means of infrared light (Reulen, Marcus, Koops, de Vries, Tiesinga, Boshuizen and Bos, 1988). The analogue output from the IRIS was digitized at a rate of 500 Hz. Both platform and eye recording were synchronized. The head was fixated at an eye-to-screen distance of 40 cm, using a jaw bone fixation method. The calibration of the eyes was based on 5 horizontal markers on the screen. Calibration of the horizontal positions of the eyes was performed at the beginning of each session.

Text materials

The text, derived from «Het Gounde Ei» by Tim Krabbé, was reprinted on A4 format pages with about 18-21 lines. The text was printed in font type «Helvetica» (12 point) in lines of 15 cm length, with an average of 80 characters per line, and an interline distance of 1.2 line height. For both low and normal vision subjects, the text was magnified 13.50 times resulting in characters (x-size) of 25 mm. width (3,6°) and 28 mm height (4.0°). This magnification was required to enable all our low vision subjects to read the text.

The smallest width of the window used, corresponded to the size proposed by Legge and co-workers as optimal for reading drifting text (Legge et al., 1985a, b). The largest width was 12 characters, with this magnification the maximum that could be applied on the screen. The three widths were respectively 4, 8 and 12 characters, corresponding with 132 mm (18,3°), 260 mm (33,0°) and 390 mm (44,3°). These widths were combined with a height of a single line (67,5 mm, 9,6°) or three lines (203 mm, 26,9°), creating 6 different conditions.

Procedure

At entrance, all subjects were offered ample opportunity to get acquainted with the experimental set-up, including the CCTV magnifier. Each subject started at another page in the book and read 7 pages, a page for each of the 6 conditions and 1 page for the control condition. In the control condition (window width 12 characters, window height 3 lines) the head was not fixated like in the other conditions. During the experimental conditions the IRIS system was attached to the head of the subject, although the gaze direction was only measured during the three conditions where the window height was one line. The order of the conditions was randomized for each subject. The experimental leader placed the text at the beginning of the first line and the subject started after a go signal that marked the digital sampling of eye and platform movements. Subjects had to read silently and were interviewed between trials about the story. The experimental leader explained the story of the book onto the page were the subject started. The subjects had 4 minutes to read a page. Between each trial the experimental leader saved the recorded signals on disk, adapted the window dimension for the next trial, and explained the lines that could not be read by the subjects. This inter-trial period lasted 150 seconds on average.

Statistics

The first line was not incorporated in the analysis because part of it could be read before the go signal. The calculation of the reading rate was based on the number of words in the lines that were completed during the reading. The other dependent variables like time to read a line or time to return the platform the beginning of the next line were determined on the basis of full lines, excluding the short lines that mark the end of paragraphs. The recordings of the eye movements were analysed as the amount of saccades per line. For 2 low vision subjects eye-data were not available, due to recording problems.

Differences in mean scores were tested using Analysis of Variance (ANOVA) with a four factor design (WIDTH, HEIGHT, AGE, and VISION).

RESULTS

Reading rate

With a grow of window dimension (both width and height) large increases in reading rate were found across all groups. For the smallest window condition (width-4/height-1) the average reading rate was 67 words per minute (wpm), whereas for the biggest window condition (width-12/height-3) the average reading rate was 108 wpm (see figure 1 and table 1). A more detailed analysis of the effect of window dimension revealed that an enlargement of both window width and window height significantly increased the reading rate, respectively (F (2, 28) = 222.8, $p < .001$) and (F (1,29) = 38.7, $p < .001$), that these factors, WIDTH and

HEIGHT, did not interact with one another. So, enlarging the window from 4 to 12 characters increased the reading rate from 77 to 102 wpm, and enlarging the window height from 1 to 3 lines increased the reading rate from 83 to 93 wpm. Furthermore, the old group read much more slowly than the young group ($F(2,29) = 83.6, p < .001$), and the subjects with a macular degeneration read slower than the normal-vision subjects ($F(1,29) = 15.4, p < .001$). Finally an interaction was found between AGE and WIDTH ($F(4,58) = 6.4, p < .001$), implying that the younger group benefited more in their absolute reading rate than the old group for wider windows. However if this advantage of a wider field of view was expressed as a percentage of the reading rate for the smallest window, the increments between the age groups were less different, namely 53% (young), 68% (middle) and 58% (old).

	height-1						height-3					
	width-4		width-8		width-12		width-4		width-8		width-12	
	wpm	s.d.	wpm	s.d.	wpm	s.d.	wpm	s.d.	wpm	s.d.	wpm	s.d.
nv-young	89,11	7,50	110,15	14,05	122,61	12,59	99,84	8,80	120,59	7,20	129,81	10,90
nv-middle	87,31	17,94	113,77	26,63	128,35	26,70	101,85	17,48	124,48	22,42	147,56	31,15
nv-old	53,05	8,45	63,07	11,83	78,72	11,61	59,20	15,28	72,16	14,27	85,02	17,38
lv-young	78,22	13,64	101,04	16,31	117,71	17,57	91,02	13,38	116,14	12,69	125,69	19,23
lv-middle	66,05	23,29	81,52	30,31	96,65	24,55	75,70	27,89	94,61	30,58	110,71	31,06
lv-old	32,13	11,76	36,59	7,35	41,46	9,03	34,95	6,92	44,01	8,90	50,26	1,61

Table 1. Mean reading rates (wpm) for the normal vision (nv) and low vision (lv) subjects in the three age groups reading with windows with a height of 1 or 3 lines and a width of 4, 8 or 12 characters.

These data showed that for magnifier reading the reading rate increases with a larger window dimension, and decreases with age and low vision. To supply insight in the origin of these effects, the subsequent analysis will be done on parameters of the reading process that are often mentioned in the literature: (i) time required for reading a line and returning the magnifier to the next line, (ii) velocity of transportation of the text, (iii) smoothness of transportation of the text, and (iv) length of the saccades.

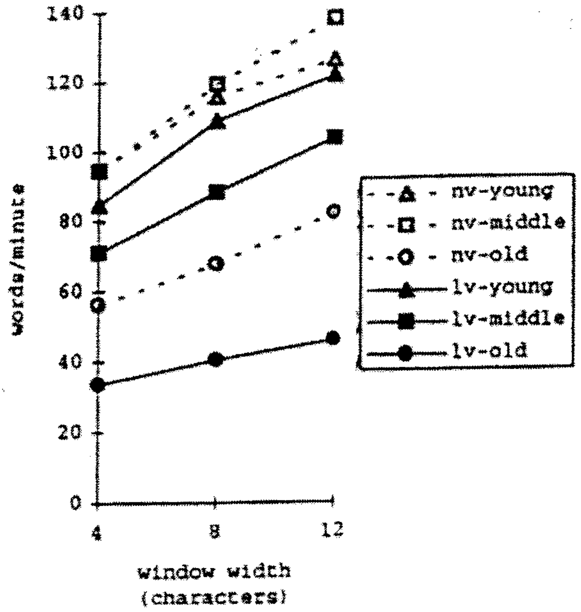

Figure 1. Mean reading rates (wpm) for normal vision (nv) and low vision (lv) subjects in the three groups for a window width of 4, 8 and 12 characters, averaged over the two windows heights.

Time to make a return sweep and to read a line

The difficulty of finding the beginning of the next line was often mentioned as the main problem in using magnifiers with small viewing fields (Pelli, Legge and Schleske, 1985; Neve, 1989). Our data allso showed that a smaller field indeed takes more time to find the beginning of the next line. Across all groups the smallest window took 3,1 s for a return sweep, whereas the largest window took 2,2 s (see table 2). Statistical analysis showed that enlarging WIDTH ($F(2,28) = 47.0$, $p < .001$) and HEIGHT ($F(1,29) = 33.7$, $p < .001$) significantly decreased the duration of the return sweep and were interacting with one other ($F(2,28) = 7.5$, $p < .002$). Furthermore, the old group took more time a return sweep than the young group, $F(2,29) = 18.0$, $p < .001$. Finally, there were no differences found between normal-vision and low-vision people in the time it took to find the next line, $F(1,29) = .01$, $p < .934$. Although the effects of window dimensions on the duration of return sweeps were significant, the size of the effect could not explain the large differences found in the reading rats. Therefore, larger effects are to be found during the reading phase itself.

	height-1						height-3					
	width-4		width-8		width-12		width-4		width-8		width-12	
	lrt	rst	lrt	rst	lrt	rst	lrt	rst	lrt	rst	lrt	rst
nv-young	7,88	2,02	6,33	1,91	5,51	1,70	7,04	1,82	5,61	1,60	5,15	1,60
nv-middle	7,69	2,71	5,55	2,24	5,04	2,13	7,06	1,94	5,50	1,80	4,64	1,64
nv-old	12,79	5,08	10,68	4,10	7,80	3,58	11,08	4,43	8,36	3,79	7,17	3,56
lv-young	8,97	2,60	6,68	2,07	5,70	1,71	7,88	1,96	5,99	1,77	5,62	1,54
lv-middle	13,26	2,99	10,79	2,42	7,85	2,15	11,42	2,55	8,52	2,18	7,11	1,85
lv-old	29,23	5,08	23,32	3,72	20,73	3,03	25,9	3,84	19,13	3,03	15,47	2,73

Table 2. Mean line reading time (lrt) and mean return sweep time (rst) for the normal vision (nv) and low vision (lv) subjects in the three age groups reading with windows with a height of 1 or 3 lines and a width of 4, 8 or 12 characters.

The mean line reading duration decreased with a grow of window dimension: across all groups the mean reading time for the smallest window was 13,43 s and for the largest window was 7.58 s (see figure 2, table 2). Statistical testing revealed main effects for: WIDTH ($F(2,28) = 27.1$, $p < .001$), HEIGHT ($F(1,29) = 8.8$, $p < .006$), AGE ($F(2,29) = 20.9$, $p < .001$) and VISION ($F(1,29) = 19.3$, $p < .001$), Furthermore, an interaction was found between AGE and VISION ($F(2,29) = 7.7$, $p = .002$) on the mean line reading duration, originating from a lower performance by the elderly low vision subjects.

To summarize, (i) a grow of window dimensions had a much larger effect on the line reading phase than on the duration of the return sweep, and (ii) the presence of a visual impairment interacted with age in increasing the time needed to read a line.

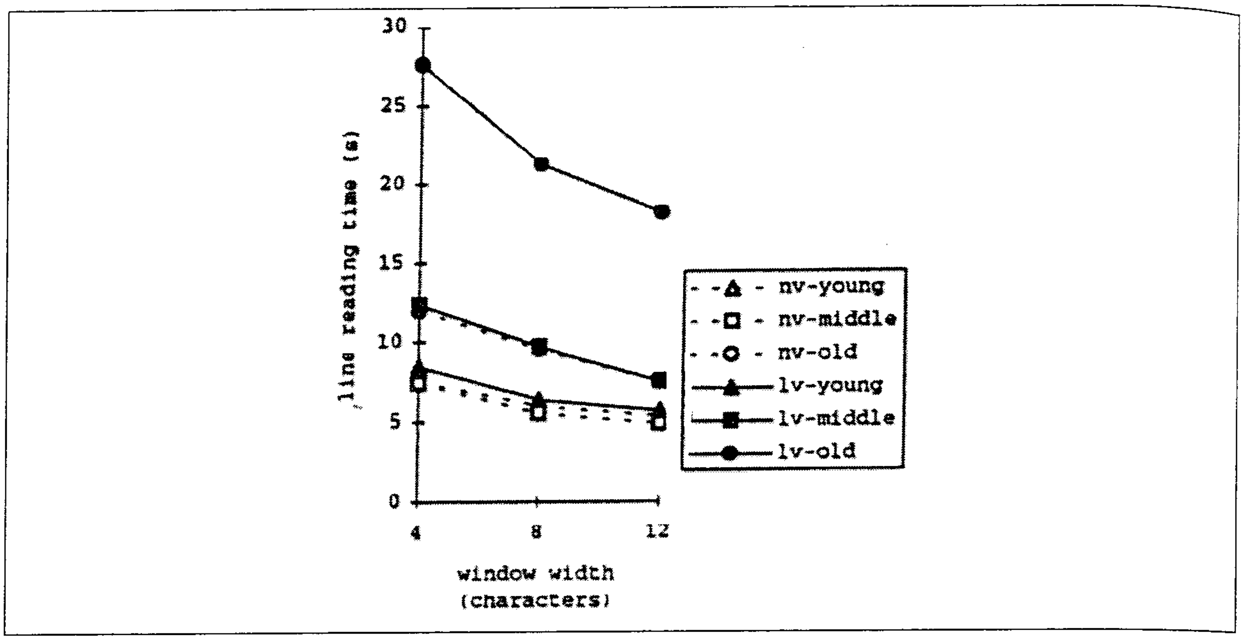

Figure 2. **Mean time (s) to read a line for the normal vision (nv) and low vision (lv) subjects in the three age groups for a window width of 4, 8 and 12 characters, averaged over the two window heights.**

The velocity of transportation of text

We now know that larger viewing fields afforded higher reading rates and that this effect was most prominent in the line reading phase, during which the old low vision sujects had a striking bad performance. The remaining results to be reported describe kinematic parameters that reflect the underlying (dynamic) processes in magnifier reading.

From the results reported so far it can not be derived how the text is transported during the reading phase. Therefore we analyse the mean velocity in this section and the variation of velocity in the following section. In the only one study available on this matter, Neve (1989) reported that the velocity with which the magnifier was moved forward to read a line and the velocity with which the magnifier was moved backward to the beginning of the next line, were not effected by the «loupe-width». This does not contradict his own finding on the reading rates, because a wider field of view allows less extended movements. However, we could not confirm the findings of Neve. The velocity of transportation the text increased with a grow of window dimension: across all groups from 16 mm/s for the smallest condition to 24 mm/s for the largest condition. Statistical testing showed main effects for WIDTH ($F(2,28) = 208.5$, $p < .001$), HEIGHT ($F(1,29) = 26.5$, ($p < .001$), AGE ($F(2,29) = 29.8$, $p < .001$) and VISION ($F(1,29) = 19.2$, $p < .001$), Two interactions were found, AGE by WIDTH ($F(4,58) = 5.0$, $p = .002$) and VISION by WIDTH ($F(2,28) = 5.2$, $p = .012$). However, when the data were expressed as a percentage of the smallest window these differences almost vanish (young opposite old: 35%-40%; normal-vision opposite low-vision: 37%-37%).

The smoothness of movement of the platform

The smoothness of transportation of the magnifier (or the text) is an important kinematic parameter. It is generally assumed that undisturbed magnifier reading is characterized by smooth movements of the platform during reading (Whittaker & Lovie-Kitchin, 1993; Legge et al., 1985a, b; Pelli et al., 1985; Neve, 1989), and that most disruptions for the fluency of the movements were related to the finding of the beginning of the next line (Neve, 1989). The variation of the velocity pattern of the platform was used as an indicator of smoothness of the movements. We used COV (coefficient of variance) to correct for differences in mean velocity. For this study, COV was the standard deviation of the values of the velocity during a line, expressed as a percentage of the mean velocity during the same period. COV values were calulated for each line and averaged for each page.

The results revealed large deviations from the ideal smooth movement pattern, across all groups and conditions the average value of COV was 88%. Statistical analysis showed main effects for WIDTH ($F(2,28) = 12.3$, $p < .001$), HEIGHT ($F(1,29) = 11.7$, $p < .002$), AGE ($F(2,29) = 40.2$, $p < .001$) and VISION ($F(1,29) = 57.1$, $p < .001$) (figure 3). A strong interaction was found between AGE and VISION ($F(2,29) = 30.2$, $p < .001$), implying that macular degeneration enhanced the effect of age in enlarging non-smooth movements with the loop: for the normal-vision subjects COV values ranged from about 55% in the youngest age group to about 66% in the oldest age group, whereas for subjects with a macular degeneration they ranged from about 64% in the youngest age group to about 196% in the oldest age group.

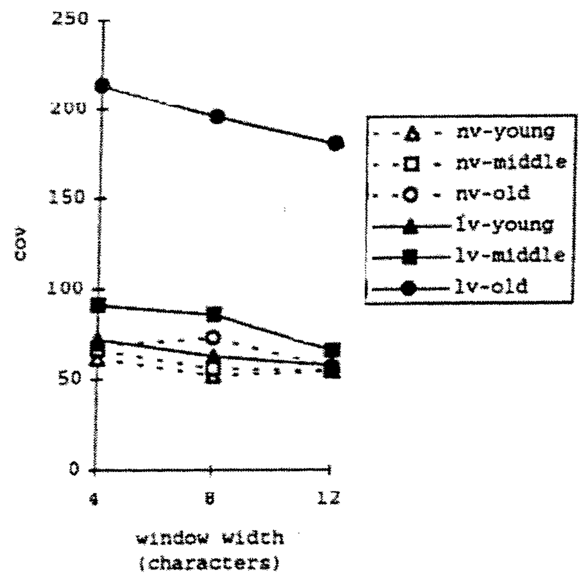

Figure 3. **Mean Coefficience of Variance of the velocity of the platform during the reading phase. Data are presented for the normal vision (nv) and low vision (lv) subjects in the three age groups for a window width of 4, 8 and 12 characters, averaged over the two window heights.**

Finally, these large variations in the velocity were not necessarily a sign of lack of control. Variability might be the result of a process that required flexibility. Such a flexibility was probably needed if the reading rate was disturbed by changs in the comprehension speed. Moreover, because systematic studies on the movement control are lacking, it is not clear wether or not a smooth pattern of transporting is optimal under all-circumstances (Lowe & Drasdo, 1990).

Eye movements

Eye movements could only be measured for the condition with the height of a single line. The number of saccades per line was calculated and average for each page. The mean number of saccades per line is displayed in figure 4. From this figure it is clear that enlarging the window width decreased the number of saccades. Statistical analysis revealed main effects for WIDTH

($F(2,26) = 37.2$, $p < .001$), AGE ($F(2,27) = 16.6$, $p < .001$) and VISION ($F(1,27) = 9.7$, $p < .004$), and a marginally significant interaction between AGE and VISION. ($F(2,27) = 3.2$, $p = .056$). So, the fewest saccades were made by the subjects in the youngest age group for the largest window (18.7) and the most saccades by the low vision subjects in the oldest age group for the smallest window (68.4), implying that the mean length of the saccades varied between 4.3 and 1.2 characters. However, one should be careful in interpreting these data because the counting was based on different time samples. When expressed as the number of saccades per second the differences between age group and width of visual field almost vanished.

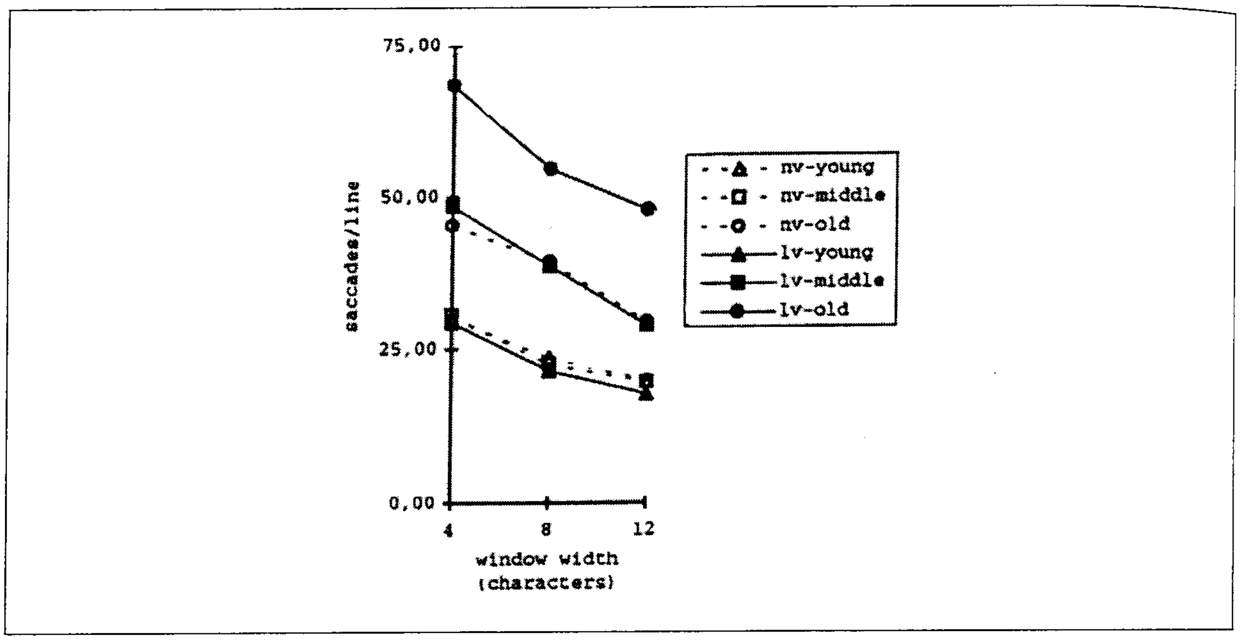

Figure 4. Mean number of saccades per line for the normal vision (nv) and low vision (lv) subjects in the three age groups for window width of 4, 8 and 12 characters and a height of 1 line.

DISCUSSION

The results from this experiment are clear, for magnifier reading large window dimensions enabling better reading performances of both normal and low vision subjects. Therefore, the value of 1-6 characters for the visual field in the model of Whittaker and Lovie-Kitchin (1990) is too low. However, the optimal visual field for magnifier reading cannot be derived from this study, because the required magnification of the text restricted the maximum number of visible characters to 12. The results, for enlarging the window width from 4 to 12 characters, showed a linear relation between reading rate and field of view. To find out whether the reading rate would continue to grow for wider windows, the experiment was return for the normal sighted subjects only, using a smaller magnification so a window width of 24 characters could be displayed on the screen. For these conditions, the reading rate still increased for windows larger than 12 characters, but almost levelled of at a rate of 156 wpm for the 24 character window. Such a wide field of view was also found by Lowe and Drasdo (1990), who argued that high skilled magnifier readers need a wide field of view to induce an optimal scanning technique. To supply more insight in these mechanisms, especially how textual information is processed from the visual field, the kinematic parameters will be discussed below.

For all conditions the mean saccade length was smaller than the available window width. For normal reading Bertera and Rayner (1979) did a similar experiment and also found that the saccade length was smaller than the available window width (table 3). Because the saccade length is an indicator for the extend of the recognition field they argued that the remainder of the textual information from the visual field was used for guiding the eyes to the next fixation. So, there is strong evidence that for both magnifier reading and normal reading the visual field can be broken down in two parts. One part is used to recognize the letters and words, the recognition field. The other part is used to locate an interesting segment of the text to place the next fixation, the localisation field.

	Saccade length					
	width-3	width-4	width-7	width-8	width-12	width-13
Bertera & Rayner	2.4	–	3.9	–	–	5.1
Bruggeman & Brinker	–	2.6	–	3.5	4.1	–

Table 3. Mean saccade length for different window widths for normal reading (Bertera & Rayner), and magnifier reading (Bruggeman & Den Brinker).

Furthermore, the mean saccade length varied with age and vision. In comparison to the old normal vision subjects, the old low vision subjects did have a tiny average saccade length and needed a very long time period to read a line (the interaction between age and vision was significant). It is very unlikely that the elderly low vision subjects had such a small recognition field, because in a study into the normal reading of large printed text, the elderly did not perform so poor (Aberson & Bouwhuis, 1992). A key to the explanation for their low magnifier reading performance may be the large variations found in the platform velocity during the reading phase. It is observed that the elderly low vision subjects often slowed down the platform during the reading phase. It is observed that the elderly low vision subjects often slowed down the platform during the recognition phase. It is observed that the elderly low vision subjects often slowed down the platform during the recognition phase. In some cases they made repetitive back and forward platform movements to, as they reported afterwards, improve the recognition of the text. This behaviour might be related to problems in successfull placing of text onto usable retinal locations peripheral to the central scotoma (Cummings, Whittaker, Watson and Budd, 1985; Baldasare, Watson, Whittaker and Miller-Shaffer, 1986). We assume that the elderly low vision people may have had more difficulty in saccade control, because they had to develop an extrafoveal fixation point at an older age than the younger subjects. In this task, one way to compensate for the inefficient saccadic control is to move the retinal image by platform or head movements. To test this assumption, the reading performance was compared in the two conditions that differed only with respect to the fixation of the head. Across all groups no diferences were found in reading rate. However, in contrast to the other subjects, the elderly low vision subjects were able to improve the smoothness of the platform movements from 161% to 138% ($F(2,13) = 4.2$ $p = .040$). These results suggest that head movements are preferred above platform movements to compensate for the inefficient saccadic control. In other words, part of the high COV values can be explained by platform movements that are were necessary to compensate for the inefficient saccadic control by the elderly low vision patients.

To summarize, we assume that the following mechanism are at work during reading with a CCTV magnifier. Firstly, the maximum extend of the recognition field is determined by the size and contrast of the characters and has a value that can be calculated on the basis of the contrast sensitivity function for spatial frequencies (Legge, Rubin and Luebker 1987; Bouwhuis, 1994). Secondly the recognition field is limited by the size of the window because space is required for the location field. Thirdly, the reading performance of people with a macular generation is related to their scotoma size and quality of saccadic control: the ability to consistently place successive words or text onto usable retinal locations peripheral to their central scotoma. Finally, some variation in velocity of the magnifier is normal, reflecting a flexibility that is required to adapt to fluctuations in the comprehension process.

Since it is shown that a wide field of view is important to attain high reading rates, manufacturers should reconsider their starting points for designing low vision aids, especially low vision aids for high magnifications. In a recent study it was shown that the present generation of optical magnifiers were optimally designe for image properties which were unaccessible for their users (Leat & Rumney, 1992). The authors compared the modulation transfer function for spatial frequencies of various optical magnifiers with the sensitivity for spatial frequencies of a group of partially sighted people with, as is usually the case, intact contrast sensitivity in the low frequency domain. They concluded that all devices tested had wasted transmission performance in the medium and high frequencies range, and recommended designers to sacrifice high resolution for a greater image diameter. Therefore we do not share the opinion of Whittaker and Lovie-Kitchin (1993) that the physical dimensions of low vision aids do «NOT significantly» offer limitations for low vision reading. It was even suggested previously by Den Brinker (1994) that slight distortions in the periphery of a low vision aid may be acceptable in cases were wide fields of view are required.

To close the discussion, we propose new elements for models on reading with magnifiers: (i) the eye-hand synchronization, (ii) the dimensions of viewing field, (iii) the magnifier type, and (iv) the typographical structure of the text to be read. Eye-hand synchronization is important in two ways. Firstly, when the magnifier is moved during the recognition phase, imperfections in the eye-hand coordination cause blurring of the visual image and thus require larger magnifications. Secondly, when saccadic control is short coming too much, the reader will switch to another strategy, and stop the magnifier during the recognition phase. Because such behaviour is especially found for the elderly low vision people, problems in saccadic control may be the cause of what Legge et al (1992) called a strange interaction between age and presence of visual impairment that depress the reading rate. This phenomena makes the elderly a special group, that deserve specific attention and training during reading with magnifiers. The factors «width and height» of viewing field are important because they determines the amount of visual information that is available to select new fixation points. Moreover, the finding that for normal and magnifier reading the ratio between the dimension of the visual field and the saccade length is about the same, is a strong evidence that the same textual information is needed to organize an optimal reading system. The next factors, the magnifier type and typographical structure, set the limits for the previous factors. They determine the quality of the visual image, the difficulty of control of the movements, and the limits of the viewing field. In our study the ratio between the duration of return sweeps and duration of line reading is much smaller than the one reported by Neve (1989), a difference that is mainly determined by mechanical properties of the devices used in the studies. Large differences in reading rate can also originate from the typographical properties of the text to be read (Den Brinker & Beek, 1996).

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