

# Visual requirements for reading: The importance of a large field of view in reading with a magnifier

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## **Abstract**

It is assumed that too low values for optimal field of view in magnifier reading were obtained in the past by applying the 'Drifting Text' Technique [1,3,4] in which the subjects had no control of the movements of the magnified image. On the basis of the view that reading involves alternating sequences of locating and recognizing textual information [9], it is argued that part of the magnified image is required for the movement control of the visual display. Higher values are predicted than the 1-6 characters proposed in the model of Whittaker and Lovie-Kitchin [1]. 14 Male and female subjects with a macular degeneration ranging in age from 20 to 82 years of age participated in an experiment to determine the optimal field of view in CCTV-magnifier reading. Large effects of width and height are found on reading rate and the data suggest that the optimal values are even higher than the maximum value of 12 characters that could be technically realized in the present experiment. Large age effects are found in both reading rate and smoothness of control of the platform. The data on the movements of the platform and the eyes are discussed. It is concluded that the elderly subject applied another strategy to move the platform than the other subjects. In all subjects large variations are observed in the velocity of transportation of the platform. It is assumed that these variations signal the flexibility of the motor control process that is required to adapt the reading process as a whole to fluctuations in the comprehension process.

*Keywords:* low vision aids; visual fields; macular degeneration. CCTV magnifier.

## 1 Introduction

### 1.1 The problem of predicting reading rates

By defining the visual requirements for reading tasks, psychophysical models on reading may improve the efficiency of the selection process of low vision aids. Whittaker and Lovie-Kitchin [1] recently proposed such a model to predict reading rate with a diverse set of devices under varying reading conditions. In their model four visual factors were distinguished: (i) acuity reserve (that is print size relative to acuity threshold), (ii) contrast reserve (print contrast relative to contrast threshold), (iii) field of view (number of characters visible), and (iv) central scotoma size (in case of maculopathy). It is a promising model, allowing better predictions of reading rate than were possible in the past [2].

However, we have some doubts about the value of one of the parameters in the model. According to the model an optimal field of view could be obtained with a 'window' of only 1 to 6 characters. These values were derived mainly from the studies of Legge and co-workers [3,4] in which reading with a CCTV magnifier was simulated by having a device move the text in stead of the subject. It deserves to be mentioned that reading with a fiberscope, a magnifier with a field of view of 4-5 characters, turned out to be very difficult [5], and later studies [6,7] found that much wider viewing fields were required for optimal reading rates. In the study of Lowe and Drasdo [6] the values for optimal window width were very similar to those found in normal reading [8]. These findings suggest that higher reading rates with magnifiers can be achieved than predicted by Whittaker and Lovie-Kitchin, a matter of particular importance for those with low reading rates who have to decide to use magnifiers for reading or to switch to another modality (tape or Braille). Therefore an explanation should be sought for the conflicting results on the role played by the width of viewing field in magnifier reading.

An explanation for the conflicting results can be found in the heterogeneous structure of the retina and the consequence of this for the reading process. The retina with cones in the middle and rods in the other parts of the retina, affording high central acuity and high peripheral sensitivity, sets limits to the way the visual system can be used for reading. The lack of full retinal acuity is compensated for by an ingenious control system by means of which all parts of the surrounding world can be focused into the central region [9,10]. For reading this implies that only a very tiny part of a page can be seen sharply enough to identify characters. By moving the eyes line segments can be brought into the foveal area, one by one, making it possible to recognize the characters and the words and hence comprehend the message. Reading can therefore be considered as a complex system, in which the control of the eye movements, word recognition, and language comprehension are integrated subsystems.

With this knowledge in mind we will introduce new elements for a model on magnifier reading and offer data to question the remarks by Whittaker and Lovie-Kitchin [1] on the limited contribution of very wide viewing fields to improve reading rates. In the remainder of this paper we briefly summarize the literature on normal reading and reading with magnifiers to discover the differences and similarities in both ways of reading. On the basis of this analysis we formulate one single working model for the role of window dimensions in both types of reading and test a hypothesis derived from that model.

### **1.2 A working model for reading connected text**

During normal reading the eyes make rapid horizontal jumps along the lines of the text, called saccades. Between the saccades, the eyes are more or less fixated at the same point and during this period, called the fixation pause, information is extracted from the visual reading field through character and word recognition. The saccades are ballistic causing a blurred retinal image from which no information can be picked up. The length of the jumps is 7-8 characters, independent (within certain limits) of character size and reading distance. The fixation pauses vary between 100 and 500 ms with an average of about 250 ms. Long backward movements, line saccades or return sweeps, occur at the end of a line when reading has to continue on the next line. Return sweeps are complex because they are accompanied by a blurred retinal projection of the target at the moment of their onset. As a result, return sweeps are often misdirected, and because most of them are too short, they are followed by an extra backward saccade before reading proceeds [11].

Since extraction of information only occurs during the fixation pause, one of the major topics in reading research should be the study of the perceptual span, i.e. the size of the text area from which information is picked up. McConkie and Rayner developed the so-called Moving Window Technique [12] to study perceptual span. Subjects had to read from a display while their gaze direction was monitored. The text was partially manipulated by substituting display characters by Xs at some distance of the fixation point. Increasing the undisturbed part of the window symmetrically from one to seven characters did result in an increase of both saccade length and reading rate. A further increment of the window did not affect the saccade length but did increase the reading rate up to a width of 29 characters [12]. The experimenters [13] reran the experiment with an asymmetrical window. They found that, while reading English, subjects did not use the area to the left hand side of the fixation point. In subsequent research it was found that information from the right hand side could be partially distorted by replacing the characters with a similar shape without significant effects on reading rate [14].

The fact that a blurred image of (partially distorted) text still supports reading performance may be explained by the existence of two parallel processes: 1) the parafoveal information supports the word-recognition by pre-processing the visual image, and 2) the parafoveal information supports the eye movement control system by supplying the targets for the subsequent fixation point[9]. As will be shown below, similar processes may operate during magnifier reading.

While reading with an optical or electronic magnifier, 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 rightward to a next fixation point in the moving image (opto-kinetic nystagmus). This pattern has been found both in normal and partially sighted subjects [3,4,7,15,16].

Except for the phenomena that hands 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. In other words, studying perceptual span in magnifier reading is of the same importance as it is for normal reading.

Two kind of experimental setups were used to determine the perceptual span in magnifier reading. Firstly, reading was simulated by the so-called 'Drifting Text Technique' [3]: the magnified text was not moved by the subjects themselves, but by a device that regulated the smooth transportation of text on the monitor. Applying this technique, both normal and partially sighted subjects were found to reach maximum reading rates with a window of only four to five characters [3,4]. In the second kind of experiment, subjects had to move the text [6] or the magnifier [7] themselves. Under such conditions the perceptual span was very similar to the span found in normal reading. A tentative conclusion may be drawn that wide windows are necessary for the control of the position of the magnifier, a conclusion that could also be drawn from the experiments with the fiberscope [5].

We therefore assume that the factor 'dimension' (width and height) of viewing field is important because it determines the amount of visual information that is available to select a fixation point for the next word or line. As has become clear from the research of Rayner and co-workers, the quality of the visual image outside the 'recognition field' (the area within which recognition takes place) need not be of a high quality, as long as general properties of the words (their shape, length) are visible. Furthermore, there are reasons to believe that the height of the viewing field is also important, especially in the case of the return

sweep. It is known from the literature that the angle between the end of a line and the beginning of the next is about 2 degrees [11], while it is also known that larger errors are made in pointing with the hands [17]. Therefore, it is assumed that a higher window will help in correcting (with the eyes) misdirection caused by hand movements [9].

In this study 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. To understand the underlying processes, the movements of the magnifier and the eyes are recorded.

## 2 Methods

### 2.1 Subjects

To test the effects of window height and width, reading rates were measured of subjects with macular degeneration, the category of partially sighted people that suffer most from low reading rates. An overview of the patients participating in the experiment is given in table 1. For the analysis the subjects are divided in three age groups: 20-39, 40-64 and 65 and older. All subjects are experienced CCTV magnifier users.

Table 1. Subject data.

Age-group	Subject	Sexe	Age	Acuity: Left Eye	Acuity: Right Eye
Young	60-MR	F	26	0.02	0.03
	61-IS	F	20	0.10	0.10
	62-NR	F	26	0.02	0.04
	64-RK	M	29	0.06	0.08
			mean 25		
Middle	59-HK	M	47	0.08	0.08
	63-SS	M	43	0.10	blindfolded
	65-MB	F	56	0.02	0.03
	67-IJ	F	49	0.10	0.10
	68-MK	F	47	0.10	<0.01
			mean 48		
Old	51-MB	F	80	0.045	0.045
	53-MB	F	82	0.07	0.03
	54-JN	M	75	0.06	0.05
	57-HJ	M	77	0.10	< 0.01
	58-NL	F	70	0.07	0.03
			mean 76		

## **2.2 Apparatus**

The closed circuit television (CCTV) magnifier used was a TeleSensory VersiColor XL with a CCD camera and a high contrast black and white monitor with a diagonal of 46 cm. The text was, with a few exceptions, presented black on white. The windowing was performed using the functions built in 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 .05mm.

Positions of subjects' eyes were monitored with an IRIS system. This system records eye position by reflection of iris-sclera boundaries by means of infrared light [18]. The analog output from the IRIS was digitized at a rate of 500 Hz. Both platform and eye recordings were synchronized.

The head was fixated at an eye-to-monitor 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.

## **2.3 Text materials**

The text, derived from 'Het Gouden Ei' by Tim Krabbe, was reprinted on A4 format pages with about 18-21 lines. The text was printed in font type 'Helvetica' (11 point) in lines of 15 cm length, with an average of 80 characters per line, and an interline distance of 1.2 line height. The text was magnified 13.5 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 subjects to read the text.

The smallest size of the window used, corresponded to the size proposed by Legge and co-workers as optimal for reading drifting text [3,4]. The largest width was 12 characters, the maximum that could be applied on the monitor. 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.

## **2.4 Procedure**

At entrance, all subjects were offered ample opportunity to get acquainted with the experimental setup, including the CCTV magnifier. Each subject started at another page in the book and read 7 pages, one page for each of the 6 conditions and one page for the control condition. In the control condition, with a window of 12 characters width and 3 lines height, the head was not fixated as it had been for the other conditions. The order of the conditions was randomized for each subject. The leader of the experiment placed the text at the beginning of the first

line and the subject started after the 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 leader of the experiment explained the story of the book up to the page where the subject started. The subjects had 4 minutes to read a page. Between each trial the leader of the experiment 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 an average of 150 seconds.

## **2.5 Statistical analysis**

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 reading. The other dependent variables, like 'time to read a line' or 'time to return the platform to the beginning of the next line', are determined on the basis of full lines, excluding the short lines that mark the end of paragraphs. Differences in mean scores were tested using Analysis of Variance (ANOVA) with a three factor design (WIDTH, HEIGHT, and AGE).

## **3 Results**

### **3.1 Reading rate**

Large increases in reading rate are found with an increase in the width and height of the window and this holds for all age groups (see figure 1 and table 2). The factors WIDTH and HEIGHT are both significant (respectively  $p < 0.001$  and  $p \leq 0.001$ ) and are not interacting with one another. Reading rates decrease with age and this effect is also significant ( $p \leq 0.001$ ). Finally there is an interaction between the factors AGE and WIDTH ( $p \leq 0.001$ ) implying that the effect of an increase in width is greater for the younger groups. However if we express the advantage of wider windows as a percentage of the mean reading rate in the narrowest windows the increments are less different for the age groups, namely 44%, 39% and 34% in the widest windows.

While it is clear now that large dimensions of the view of field facilitate reading, the subsequent analysis will supply insight in the origin of the beneficial effects of large windows. The effects of the window dimension are presented 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) the mean length of the saccades.

### 3.2 Time to read a line and make a return sweep

The difficulty of finding the beginning of the next line is often mentioned as the main problem in using magnifiers with small viewing fields [5,7]. Our data also show that a smaller window takes more time to find the beginning of the next line. It is found that the return sweeps are faster when the height and the width of the reading window are increased, effects that are found in all age groups (see table 3). Both factors WIDTH and HEIGHT have a significant effect on the duration of the return sweep ( $p < 0.001$ ;  $P \leq 0.005$ ). Furthermore the return sweep duration increases with age: averaged over all window conditions the durations are respectively 1.94, 2.52 and 3.53 seconds. However, the factor AGE is significant at a moderate level ( $p \leq 0.036$ ), reflecting relative large variations in return sweep duration.

Although the effects of window dimensions on the duration of return sweeps are significant, the size of the effect cannot explain the large differences found in the reading rates. In other words larger effects are to be found during the reading phase itself. The mean 'line reading' duration is shown in figure 2 for the three age groups under the three window widths averaged over window height. Statistical testing revealed main effects without interactions for the factors AGE ( $p \leq 0.001$ ), WIDTH ( $p \leq 0.004$ ) and HEIGHT ( $p \leq 0.034$ ).

Table 2. Mean reading rates (WPM) for the 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.

Age-group		Width-4		Width-8		Width-12	
		WPM	s.d.	WPM	s.d.	WPM	s.d.
Young	Height-1	78.2	13.6	101.0	16.3	117.7	17.6
	Height-3	91.0	13.4	116.1	12.7	125.7	19.2
Middle	Height-1	69.5	24.3	84.3	33.0	97.8	27.3
	Height-3	78.9	29.9	94.4	34.2	108.3	34.1
Old	Height-1	34.8	10.9	38.7	5.7	44.6	5.3
	Height-3	36.2	7.0	46.8	6.2	50.3	1.8

Table 3. Mean duration (s) of return sweeps (RS) for all age groups reading with windows with a height of 1 and 3 lines and a width of 4,8 and 12 characters.

Age-group		Width-4		Width-8		Width-12	
		RS	s.d.	RS	s.d.	RS	s.d.
Young	Height-1	2.60	0.94	2.07	0.77	1.71	0.67
	Height-3	1.96	0.67	1.77	0.57	1.54	0.55
Middle	Height-1	3.13	1.12	2.59	0.65	2.37	0.81
	Height-3	2.61	1.02	2.42	0.70	2.01	0.69
Old	Height-1	5.14	1.19	3.61	1.13	2.84	0.81
	Height-3	3.92	1.51	2.91	1.37	2.73	0.90

To summarize, it is clear that the window dimensions have a larger effect on the line reading phase than on the duration of the return sweep. For example, in the oldest age group the mean time required for reading a line decreases from 23.8 in the smallest window condition (WIDTH-4, HEIGHT-1) to 15.4 second in the largest window condition (WIDTH-12, HEIGHT-3), while the return sweeps decreased from 5.1 to 2.7 second in the same window conditions.

### 3.3 The velocity of transportation of text

We now know that larger viewing fields afford higher reading rates and that this effect is most prominent in the reading phase. The remaining results to be presented describe kinematic parameters that reflect the underlying (dynamic) processes in magnifier reading.

From the results presented so far it cannot 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 study available on this matter, Neve [7] reported that the velocity with which the loupe was moved forward to read a line and the velocity with which the loupe was moved backward to the beginning of the next line, were not effected by the 'loupe- width'. This does not contradict his own findings on the reading rates" since a wider field of view allows less extended movements. However, we cannot confirm the findings of Neve. The velocity increased with the width and height of the window and this was the case in all age groups (see also Figure 3). Statistical testing showed main effects without interactions for the factors AGE ( $p \leq 0.001$ ), WIDTH ( $p < 0.001$ ) and HEIGHT ( $p \leq 0.009$ ). In the youngest age group

the velocity increased from the smallest (WIDTH-4, HEIGHT-1) to the largest window (WIDTH-12, HEIGHT-3) from 18.4 to 27.2 mm per second. The increase in the oldest age group in the same window conditions is from 7.5 to 10.0 mm per second.

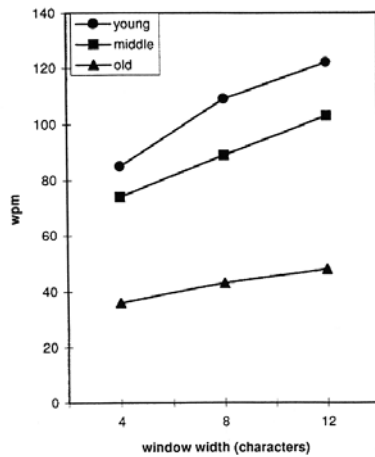


Figure 1. Mean reading rates (words per minute) for MD patients in three age groups with window widths of 4, 8 and 12 characters, averaged over the two window heights.

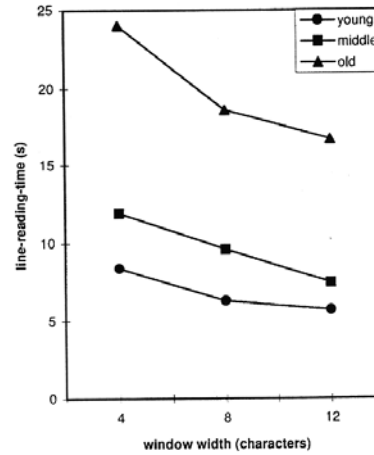


Figure 2. Mean time (in seconds) to read a line for three age groups with a window width of 4, 8 and 12 characters, averaged over window height.

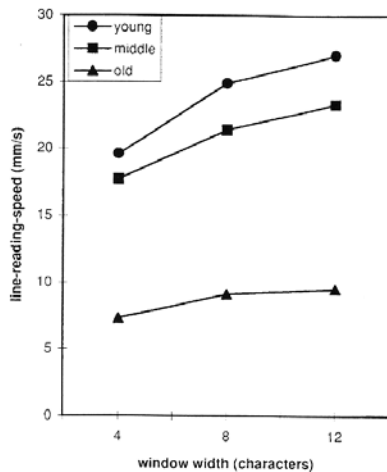


Figure 3. Mean velocity with which the text is transported with the platform of the CCTV magnifier for three age groups reading with windows of 4, 8 and 12 characters, averaged over window height.

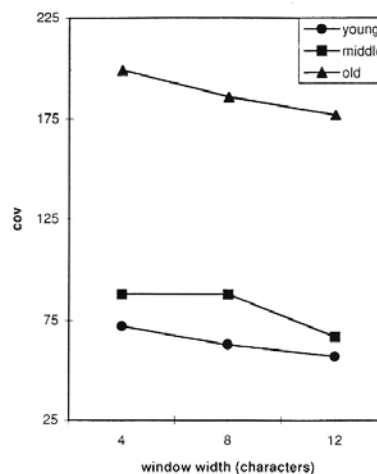


Figure 4. Mean Coefficients of Variance (COV) of the velocity of the platform during the reading phase. Data are presented for the three age groups reading with windows of 4, 8 and 12 characters, averaged over window height.

### 3.4 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 [1,3,4,5,7], and that most disruptions of the fluency of the movements are related to the finding of the beginning of the next line [7].

In our study we use the variation of the velocity pattern of the platform as an indicator of smoothness of the movements. We use COV (coefficient of variance) to correct for differences in mean velocity. In our case a COV is 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's are calculated for each line and averaged for each page.

The results reveal large deviations from the ideal smooth movement pattern: the mean COV for all window conditions range from about 64% in the youngest age group to about 187% in the oldest age group (see also figure 4).

Statistical analysis shows a large effect for the factor AGE ( $p < 0.001$ ) and a moderate effect for the factor WIDTH ( $p \leq 0.039$ ). These large variations in the velocity are not necessarily a sign of lack of control. Variability may be the result of a process that requires flexibility. Such flexibility is needed if the reading rate is disturbed by changes in the comprehension speed. Moreover, since systematic studies on the movement control are lacking, it is not clear whether or not a smooth pattern of transporting is optimal under all circumstances [6].

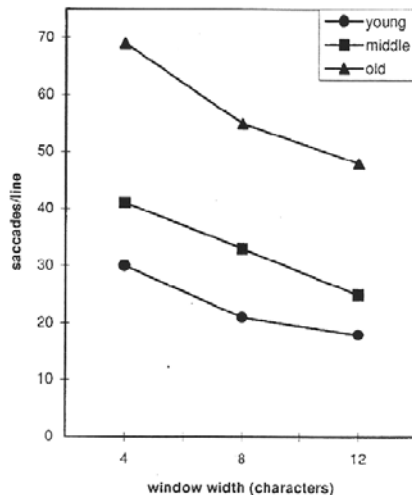


Figure 5. Mean number of saccades per line for the three age groups while reading with windows of 4, 8 and 12 characters, and a window height of 1.

### **3.5 Eye movements**

Eye movements were only recorded in the window conditions with HEIGHT-I. The number of saccades per line are calculated and averaged for each page. The mean number of saccades per line are presented in figure 5. From this figure it is clear that the number of saccades decreases with the increase of the window width and increase with age. Statistical analysis reveals a main effect for the factor AGE ( $p \leq 0.008$ ) and a main effect for the factor WIDTH ( $p \leq 0.005$ ). The least number of saccades were made by the subjects in the youngest age group in the largest window (17.6) and the highest number by the elderly in the smallest window (68.4), implying that the mean length of the saccades varied between 4.5 and 1.2 characters. However, one should be careful in interpreting these data because the counting is based on different time samples. When expressed as the number of saccades per second the differences between age groups and width of field almost vanish (see table 4).

### **4 Discussion**

From our study it is clear that larger windows are to be preferred above smaller ones and that the parameter values in the model of Whittaker and Lovie-Kitchin are too low, at least for people with a macular degeneration. However, the perceptual span in magnifier reading for these partially sighted people cannot be derived from this study, since the size of the monitor prevented us from applying larger windows. Our finding that the relation between reading rate and window width is almost linear, suggests that reading rates will continue to grow with wider windows. To find support for this idea, we repeated the experiment with normal sighted subjects, using a smaller magnification affording a 'larger' window (24 characters). Under this condition the reading rate still increased with windows larger than 12 characters, but almost leveled off at the 24 character window. There is strong evidence, therefore, that the perceptual span in magnifier reading is of the same order as the perceptual span in normal reading. We will now interpret the kinematic parameters to understand how the visual information in the perceptual span is used during magnifier reading.

Table 4. Mean number of saccades per second (SACC's) for the subjects in the three age groups reading with windows with a height of 1 and a width of either 4, 8 or 12 characters.

Age-group	Width-4		Width-8		Width-12	
	SACC/s	s.d.	SACC/s	s.d.	SACC/s	s.d.
Young	3.39	0.53	3.24	0.52	3.15	0.48
Middle	3.46	0.46	3.34	0.57	3.35	0.35
Old	2.90	0.26	2.76	0.33	2.65	0.30

Assuming that reading involves alternating sequences of locating and recognizing textual information [9], the perceptual span can be divided in two areas: a recognition field and a location field. Since the frequency of saccades is more or less stable (in this study about 3.2 hertz), the size of the recognition field is completely dependent upon the number of characters that can be recognized in the fixation pause. As a consequence, the maximum extent of the recognition field is determined by the size and contrast of the characters [19,20]. However, in our study the mean saccade length, an indicator of the extend of the recognition field, varied with width and age. In the youngest age group the mean saccade length ranges between 2.7 characters for the narrowest window and 4.5 characters for the widest window. In the oldest age group these values were respectively 1.2 and 1.7. These data imply that the recognition field is always smaller than the available window width. However, it is very unlikely that the elderly subjects had such small recognition fields since in other studies with large printed text, elderly people do not behave differently from younger subjects in this respect [20]. The key to the explanation of these short saccade lengths are the large variations found in the platform velocity during the reading phase (see the COV values in figure 4). It is observed that the elderly subjects more often slowed down the platform during the recognition phase, causing larger variations in velocity as reflected in higher COV values. In other words, instead of transporting the platform during the recognition phase, elderly subjects seem to transport the platform after the recognition has taken place.

To summarize, we assume that the following mechanisms are at work during reading with a CCTV magnifier. Firstly, the maximum extent 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 [19,20]. Secondly, the recognition field is limited by the size of the window since space is required for the location field. Thirdly, while most of the younger subjects prefer to transport the platform during the recognition phase, many elderly subjects prefer, at least during part of the reading phase, to transport the platform after the recognition has been completed. Finally, even for those who are able to transport the platform smoothly, a lot of variation in velocity is to be observed. We believe that this variation reflects 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, [21] it was shown that the present generation of optical magnifiers were optimally designed for image properties which were inaccessible for their users. 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 frequency 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 [1] that the physical dimensions of low vision aids do 'NOT significantly' offer limitations for low vision reading. It was even suggested previously by us that slight distortions in the periphery of a low vision aid may be acceptable in cases where wide fields of view are required [22].

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 enforce larger magnifications. Secondly, when eye-hand coordination is not satisfactory the reader will switch to another strategy, stopping the magnifier during the recognition phase. The factors 'width and height' of viewing field are important since they determine the amount of visual information that is available to select new fixation points. 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. For example in our study the ratio between the duration of return sweeps and the duration of line reading is much smaller than the one reported by Neve [7], a difference that is mainly determined by mechanical properties of the devices used in the studies. Future research should focus on these new factors to incorporate them in models on reading with magnifiers.

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