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Determining magnification for reading with low vision

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Background: In the past, practitioners have used distance and/or near visual acuity (VA) to calculate required magnification for low vision aids. Magnification was usually under-estimated when compared with the final magnification prescribed. Recent studies have emphasised the importance of acuity reserve in determining the required magnification for optimum reading rate. Two different approaches have been proposed for the appropriate acuity reserve to use in calculating magnification. These are a fixed acuity reserve of 0.3 log unit or an individual determination of optimum acuity reserve. The aim of this study was to investigate the magnification and reading rates with low vision aids selected by the two methods.
Methods: Nineteen low vision subjects with age-related macular degeneration (AMD) who were experienced magnifier-users were recruited. Reading rates and near VA with low vision aids determined by the fixed and individual acuity reserve methods were compared with the same measures made with the subjects' own magnifiers.
Results: There were no significant differences in reading rate and near VA measured with low vision aids selected by either the fixed or individual acuity reserve methods or the subjects' own magnifiers. Reading rate with low vision aids was not significantly different from reading rate for large print with conventional near additions. Thus, for experienced users, magnifiers do not cause reduced reading rate.
Conclusions: The fixed acuity reserve method is simple to apply as only near VA and print size of the target reading task are required. For the individual acuity reserve method, reading rates at different print sizes need to be measured. We recommend the use of a fixed acuity reserve (0.3 log unit) for the calculation of required magnification for low vision patients. If near VA or reading rate are not satisfactory with the magnification calculated by this method, individual assessment of required acuity reserve is necessary.

Key words: age-related macular degeneration, magnification, magnifiers, reading

Low vision is defined as permanent vision loss that is not correctable with spectacles, contact lenses or surgical intervention and that interferes with normal daily life.[1-3] Reading is one of the most highly-valued activities in human society. Any ocular disorder that deprives people of the ability to read causes severe restriction of daily activities. This disability may be improved by various low vision aids (LVA) such as hand-held, stand and spectacle-mounted magnifiers, telescopes or electronic reading aids.[4,5] To provide the appropriate LVA to assist people with low vision to retain their reading ability, accurate and efficient calculation of the required magnification is necessary as part of low vision rehabilitation. Magnification for reading is most often prescribed in the form of simple plus lenses.[6]

Previous calculations of required magnification

In the past, low vision rehabilitation practitioners measured patients' distance and/or near visual acuity (VA) to calculate the required magnification for LVA by using simplified equations. These methods were Kestenbaum's rule and the Lighthouse Method.[5,7] Kestenbaum's formula assumes that: distance VA and near reading can be equated, the reference addition is +2.50 D and the desired acuity level is 6/15 Snellen equivalent (0.4 logMAR) at near.[8] Kestenbaum's formula for calculating magnification is the reciprocal of distance VA divided by four. However, the Lighthouse Method considers near VA instead of distance VA. The desired acuity is assumed to be 1 M (6/15 Snellen equivalent at 40 cm) or 8 point print (N8) with a reference addition of +2.50 D. The equation for calculating magnification by the Lighthouse Method is 2.5 times near VA (M unit) divided by four. Cole[6] found that magnification levels determined by these methods were usually under-estimated when compared with the final prescription. These equations consider only patients' VA and ignore their desired reading material or assume that it is always 1 M (N8) print size. By taking patients' target reading materials into account, for example, newspapers, magazines or large print books, appropriate magnification can be determined to meet patients' reading requirements.

To improve the accuracy of the calculation of magnification, Cole[6] introduced another equation: 'reciprocal of vision'. This method predicts the magnification based on the patients' distance VA and the required near VA, which can be predicted from the patients' target reading materials. It assumes that the patients' distance and near VA are equivalent and the reference distance is 40 cm. Cole's reciprocal of vision equation for calculating magnification is 2.5 times distance VA divided by four times the required near VA. However, magnification was still under-estimated by this method, when compared with the final magnification prescribed.[6,9,10] This under-estimation may be due to a number of factors, which affect reading with magnification. The introduction of magnifiers can result in restricted field of view, reduced illumination and aberrations and patients may have difficulty in manipulating the magnifiers.[11-15] The calculation of magnification needs to include some acuity reserve to help offset these difficulties in using magnifiers.[16]

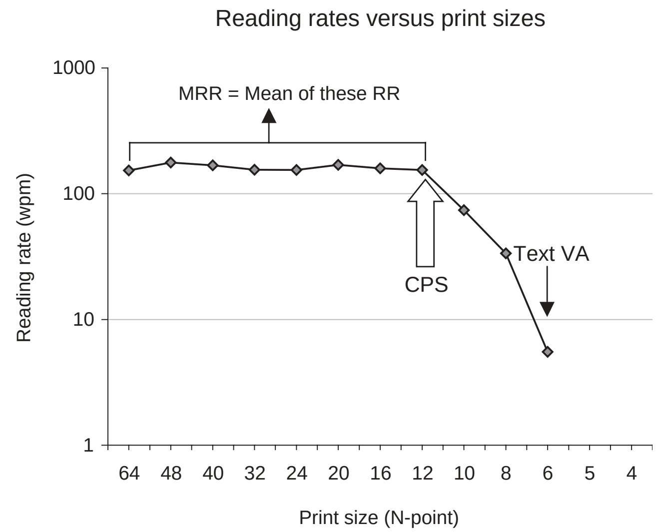

Figure 1. Example of the determination of text visual acuity (text VA), critical print size (CPS) and maximum reading rate (MRR). Text visual acuity (VA): threshold print size, critical print size (CPS): the smallest print size that gives maximum reading rate, maximum reading rate (MRR): the mean of the reading rates for print sizes at and above CPS

Importance of acuity reserve

A number of studies has demonstrated that reading rates of normally sighted and low vision subjects increase as print size increases from threshold.[11,13,17] Regardless of the level of vision, it is not possible to read fluently if the print size is at or close to threshold.[11,16,18,19] This implies that the print size of a reading task must be larger than threshold to achieve a fluent reading rate. For this reason, Whittaker and Lovie-Kitchin[16] introduced the term 'acuity reserve'. Acuity reserve was defined as the ratio of print size that the patient intends to read to threshold print size. For example, a person with 0.5 M (N4) threshold print size reads 1.0 M (N8) newspaper print at 40 cm, with an acuity reserve of 2:1. Watson[20] suggested that one of the reasons that closed-circuit television (CCTV) or video magnifiers give better reading performance than optical magnifiers is the greater acuity reserve provided.

In the past, guidelines for prescribing magnification for reading with low vision suggested that minimum magnification should be prescribed to maximise the field of view available.[2,21] However, Whittaker and Lovie-Kitchin[16] showed that inadequate acuity reserve was one of the main impediments to reading with low vision. They have shown that field of view is not the limiting factor affecting reading rate if sufficient acuity reserve is given.[22]

In the literature, there appear to be two different approaches for the provision of acuity reserve in determining required magnification to achieve fluent reading rate.[16,18,23,24] Whittaker and Lovie-Kitchin[16] suggested that print size that was two times larger than threshold was sufficient to

Subject number		Age (years)	Years since onset of vision impairment	LVA *	Target print size		Reading frequency †	Distance VA (logMAR)	Near VA (word) with +4 D (logMAR)
					N-point	M units			
1	§	79	3	3	8	1.0	4	1.10	1.20
2		83	6	2	8	1.0	1	0.70	0.62
3	§	89	3	2	8	1.0	1	0.38	0.46
4		89	2	2	10	1.3	2	1.12	1.1
5		75	3	3	8	1.0	1	0.52	0.60
6	§	83	4	2	8	1.0	1	1.26	1.10
7	§	68	5	1	8	1.0	1	0.74	0.88
8		80	9	2	10	1.3	2	1.04	1.04
9	§	80	3	2	8	1.0	1	1.04	0.98
10	§	80	3.5	3	8	1.0	1	1.08	1.08
11		79	3	3	8	1.0	1	0.94	1.00
12		90	3	2	12	1.6	2	1.14	1.40
13	§	76	1	3	16	2.0	4	1.26	1.30
14		50	1	1	10	1.3	1	0.84	1.20
15		82	3	1	8	1.0	1	0.62	0.60
16	§	81	4	3	8	1.0	2	1.02	1.10
17		72	1	2	10	1.3	3	1.30	1.43
18	§	79	4	3	8	1.0	1	0.60	0.84
19		80	1	1	8	1.0	1	0.72	0.70

* Code for low vision aids (LVA) used at near: 1. High addition spectacles (+4 D addition or greater); 2. Hand-held magnifiers; 3. Stand magnifier
† Reading frequency: 1. Read daily; 2. 2–3 times per week; 3. Once per week; 4. Rarely
§ Subjects who participated in both the first and second visits

Table 1. Subject details

achieve fluent reading rate for normal and low vision subjects. They recommended using this fixed acuity reserve in the calculation of magnification for reading.[25] For example, if a person's target is to read the newspaper (N8 or 1 M print) fluently, a fixed acuity reserve of two times (0.3 log unit) means that the required threshold size will be N4 (0.5 M) so that the person can read N8 (1 M) fluently.

The fixed acuity reserve suggested by Whittaker and Lovie-Kitchin[16] was generalised from data from groups of subjects with low vision. Some individuals might need more or less acuity reserve for fluent reading. Legge and colleagues[18,24] suggested that acuity reserve (and therefore magnification) required for fluent reading should be determined on an individual basis. From the measurement of reading rates at different print sizes, an individual's required acuity reserve for maximum reading rate is calculated as the ratio between critical print size (CPS)—the smallest print size that gives maximum reading rate—and the person's threshold print size (Figure 1).

The fixed and individual acuity reserve methods each have their advantages and disadvantages. The fixed method can simplify the clinical procedures of calculating the required magnification, as only near visual acuity and the target print size of the person's reading materials are required. However, this method may over- or under-estimate the required acuity reserve for different individuals. The individual assessment overcomes this disadvantage of the fixed acuity reserve method but it requires measurement of the patients' reading rates at a number of different print sizes, which makes the clinical assessment more complicated. Lovie-Kitchin and Whittaker[23] discussed the two methods of using acuity reserve to prescribe magnification for reading and suggested a combination of the two methods. However, there have been no studies comparing the two prescribing methods to support the suggestion of Lovie-Kitchin and Whittaker.[23]

The aim of this study was to investigate if there is a significant difference between the fixed and individual acuity reserve methods for determining the required magnification for optimum reading performance.

Visit	Reading	Measures	Instrument used	Working distance	Results
First	Large print reading rate without LVAs	Reading rate on sentences	Bailey-Lovie text chart	Working distance of near addition	Maximum reading rate (wpm) Critical print size (CPS)
	Reading rate with LVAs	Reading rate with LVAs • Fixed method • Individual method • Own LVAs	Passages of texts with LVAs used in random order across subjects	Habitual working distance with magnifiers; EVD calculated.	Reading rate for passages at target print size
Second	Large print reading rate without LVAs	Reading rate on sentences Reading rate on passages	Bailey-Lovie text chart Passages of text at CPS	Working distance of near addition	Maximum reading rate (wpm) for sentences Critical print size (CPS) Maximum reading rate (wpm) for passage
	Reading rate with LVAs	Reading rate with LVAs • Fixed method • Individual method • Own LVAs	Bailey-Lovie text chart Passages of text at CPS Passages of text at target print size	Habitual working distance with magnifiers; EVD calculated.	Maximum reading rate with LVAs (wpm) for sentences Critical print size (CPS) Reading rate with LVAs (wpm) at CPS for passage Reading rate for passages at target print size

Table 2. Reading rate measures for first (n = 19) and second visits (n = 9)

METHODS

Subjects

Nineteen subjects with low vision aged between 50 and 90 years (mean age 78.7 ± 8.83 years) were selected from the Queensland University of Technology (QUT) Vision Rehabilitation Centre (VRC). Distance VA in the better eye ranged from 0.38 logMAR ($6/15^{+1}$) to 1.3 logMAR (6/120) (Table 1). All subjects were diagnosed by ophthalmologists to have age-related macular degeneration (AMD) and had been prescribed optical LVAs such as high additions, hand-held magnifiers or stand magnifiers (Table 1). The subjects had received a comprehensive vision examination or follow-up assessment of low vision aids during the 12 months preceding their recruitment. They were selected to have less than one line (0.1 log-unit) change in near VA since their last assessment. Subjects had used their low vision aids for three months or longer, had no known cognitive problem (as indicated from the clinical record) and all were fluent in English. Previous studies have stated that reading rate could be reduced due to difficulties with comprehension among people with normal[26] or low vision.[27] Therefore, it was important to ensure that subjects would have no difficulties understanding the reading materials.

A simplified Neale Analysis of Reading Ability[28] was used to confirm that all recruited subjects had Grade 6 or above reading ability. A short Grade 6 story was read to each subject and then four questions were asked to assess comprehension. Any subject who could not answer three of the four questions correctly was excluded from this study. All subjects gave signed informed consent to their participation in the study, which was approved by the QUT Human Research Ethics Committee. Vision and reading performance were assessed at one visit for 19 of the subjects and at a second visit for nine of the subjects (see below).

Vision assessment

Vision and reading were assessed monocularly with the eye used for reading or with the eye with better near VA, if the subject usually read binocularly. Distance VA was measured using the subjects' current spectacle prescriptions with the Bailey-Lovie distance visual acuity chart at 2.4 metres scored to the nearest letter and recorded in logMAR.[29] Average chart illuminance was 356 lux. Near word VA was measured using the Bailey-Lovie word chart[30] at a working distance determined by the subjects' near prescriptions. In addition, near word VA was measured at 25 cm with a +4 D addition for all subjects (Table 1). Chart illuminance ranged from 320 to 380 lux (depending on the subject's working distance).

Reading rate assessment

Reading rates were measured for single sentences on the Bailey-Lovie text reading chart and for short passages of text (see below). The level of text difficulty in both tests was well below the reading ability of the subjects to ensure that reading performance was not limited by text difficulty.[31]

The Bailey-Lovie text charts were modified MNRead charts[32,33] suitable for measuring reading acuity and reading rate of people with normal or low vision at 25 cm. Print sizes ranged from 1.5 logMAR (8 M/N64) to 0.2 logMAR (0.4 M/N3) in 0.1 logarithmic steps with one sentence at

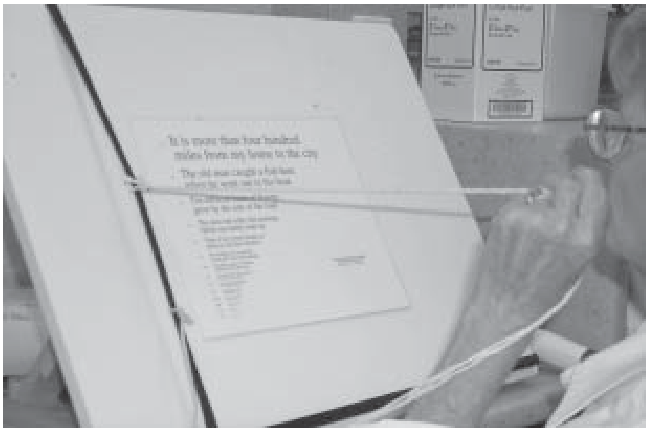

Figure 2. Measurement of large print reading rate using a Bailey-Lovie text reading chart

each print size. Each sentence contained 60 characters (10 standard words[a]) including a space between each word and at the end of each line. All sentences used in this chart were selected from the MNRead Corpus[b] with each sentence printed over two lines at each print size and left justified. Six charts were produced with Times New Roman font in black on white print and three charts were randomly selected for each subject.

Nine reading passages of approximately sixth grade reading level (263 ± 5.56 characters or 43.85 ± 0.93 standard words), selected from other reading tests (Sloan Reading Cards for low vision patients; University of Waterloo near vision test card; Maclure bar reading book for children—Clement Clarke International Ltd), were produced in various print sizes. These passages were used in a different order for each subject.

Reading rates were measured with the subjects' habitual near additions (referred to as 'without LVA') and with LVA (Table 2). For all reading trials, subjects were instructed to read each sentence aloud at their normal reading rate to enable good understanding of the sentence or passage, that is, to read for understanding.[31] Time to read each sentence was recorded with a Micronta LCD Stopwatch to ± 0.5 second and any words missed or incorrectly read were recorded. Errors, in number of characters, were taken into account in calculating reading rate.

Oral reading rate (standard words per minute [wpm]) was calculated as follows:

Reading rate = (number of characters read - errors) x 60/reading time (secs) x 6.

Reading rate for each sentence on the Bailey-Lovie text chart was plotted against print size. A smooth curve was fitted to the data and CPS was selected by eye (at N12 [1.6 M] in Figure 1). Text VA was the smallest print size the subject could read (N6 [0.8 M] in Figure 1).

Maximum reading rate (MRR) was taken as the mean of the reading rates for print sizes at and above CPS. For example, from Figure 1, MRR is the mean of reading rates at N12 and all print sizes larger. MRR and CPS without LVA were determined three times with different Bailey-Lovie text charts. The mean of the three measures of MRR was used for analyses, while mean CPS was selected to the nearest whole line.

Illumination and working distance were controlled by placing the reading charts on a reading stand in a constant position. The working distances were controlled by a measuring string held by the subject during the experiment (Figure 2). The charts were illuminated by overhead fluorescent tubes and the illuminance ranged from 320 to 380 lux.

Magnification calculation

Magnification was calculated from the reading measures without LVA using the two methods described above—the first, using a fixed 2:1 (0.3 log unit) acuity reserve for all subjects[16,23] and the second using the acuity reserve determined individually for each subject from the CPS.[18,24] Magnification was determined for a target print size selected according to each subject's preferred reading material. For example, if the subjects indicated that they wanted to read newspaper print, the target print size was N8 (1 M), but if they wanted to read books, the target print size was N12 (1.6 M).

Magnification was calculated in terms of equivalent viewing distance (EVD).[22,34] Using the fixed acuity reserve method:[23,25]

Required EVD (cm) = (Target print size/ 2) x (Current viewing distance/Current threshold print size)

Using the individual acuity reserve method:[18,24]

Required EVD (cm) = (Target print size/ CPS) x Current viewing distance.

Based on the magnification calculated by the two methods, optical LVAs of the same type as the subjects' own magnifiers (that is, high addition spectacles, hand-held or stand magnifier) were chosen. In selecting an appropriate hand-held or stand magnifier of the required EVD, the eye-lens distance, image distance and the subject's near spectacle addition were taken into account.[25,34]

First visit

Reading rates with two optical LVAs determined as described above were measured by asking the subjects to read passages of their target print size three times. In addition, reading rate with each subject's own optical aid was measured. The

a. A standard word is six characters[31]
b. http://vision.psych.umn.edu/www/people/stevem/mnr/sentences.htmlb. http://vision.psych.umn.edu/www/people/stevem/mnr/sentences.html

three magnifiers were used in random order (Table 2). When measuring reading performance with the magnifiers selected by the fixed and individual acuity reserve methods, the subjects were instructed on the appropriate eye-lens distance to give the required EVD. They were allowed to adopt their own eye-lens distance when reading performance with their own magnifiers was measured; this eye-lens distance was measured to calculate the EVD of the subjects' own magnifiers.[34]

As described above, MRR was calculated as the mean of the reading rates for print sizes at and above CPS (Figure 1). However, reading rate with LVA in some cases was reduced for large print sizes, because few characters were visible in the field of view (Figure 3). Therefore, when reading rates on large print sizes were less than 90 per cent of the reading rate at CPS, they were excluded from the calculation. For example, in Figure 3, MRR was the mean of reading rates at print sizes from N20 (2.5 M) to N8 (1.0 M).

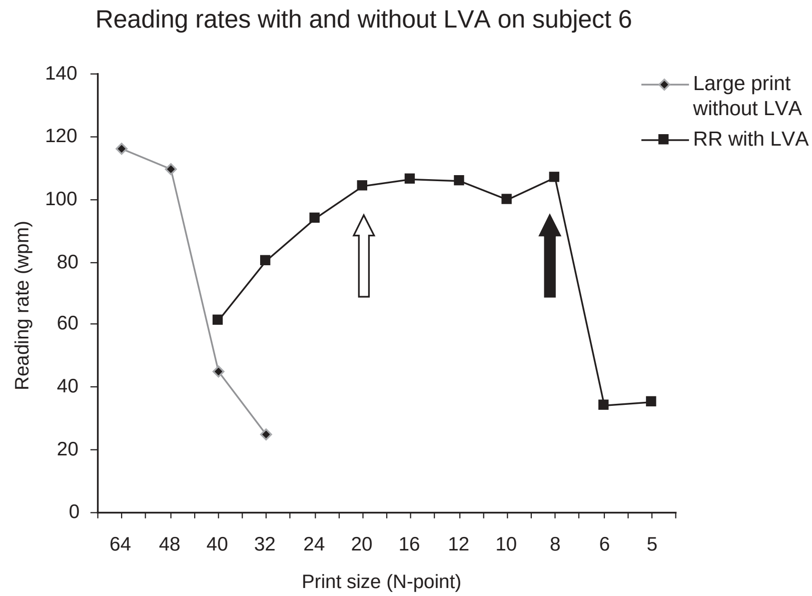

Figure 3. Example of reduced reading rate with low vision aids (LVA) when reading large print sentences. (Note that a linear scale rather than a logarithmic scale, as used in the other figures, has been used to show more clearly the changes in reading rate for subject A6.) Reading rate with LVA was reduced for print sizes larger than N20 (unfilled arrow). For calculation of maximum reading rate, these reading rates (RR) which were below 90% of the reading rate at CPS (N8 - filled arrow) were excluded.

Second visit

To assess repeatability of reading rate measurements over a period of time, nine of the 19 subjects returned for further reading rate measures approximately two months after the first measurement. These subjects reported that their vision had not changed during this time and this was confirmed from repeated vision measurements. There were no statistically significant differences in VA for distance or near (word and text) between the two visits (repeated measures ANOVA; $F_{1,8} = 2.86$, $p = 0.13$; $F_{1,8} = 0.29$, $p = 0.61$; $F_{1,8} = 2.29$; $p = 0.17$ respectively). At this second visit, reading rates for sentences (Bailey-Lovie text charts) and passages were measured with and without LVAs (one trial each) as described in Table 2.

Maximum reading rate without LVAs (sentences)	100.35 ± 45.2 wpm
Reading rate with LVAs (by fixed acuity reserve method) – passage	53.68 ± 29.8 wpm
Reading rate with LVAs (by individual acuity reserve method) – passage	53.49 ± 29.2 wpm
Reading rate with own LVAs – passage	56.11 ± 28.12 wpm

Table 3. Mean reading performance measures at the first visit (n = 19)

Data analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS)—version 10. As vision measures and reading rates were not significantly different from a normal distribution (Kolmogorov-Smirnov Goodness of Fit test, $p > 0.1$), parametric statistics were used—Pearson's correlation, analysis of variance (ANOVA), repeated measures ANOVA and paired t-tests. Repeated measures ANOVA were used to test subjects' distance and near visual acuities to ensure that there were no significant changes in vision between experimental visits. To compare the three reading rates with LVA and the maximum reading rate without LVA, one-way ANOVAs were performed. A probability of less than 0.05 was taken to indicate statistical significance for all analyses. However, the probability of finding a significant difference by chance alone increases rapidly with the number of statistical tests. Because the number of tests equalled the degrees

		First visit (n = 9)	Second visit (n = 9)
Sentence	Maximum reading rate without LVAs	104.35 ± 53.25 wpm	111.97 ± 55.78 wpm
	Reading rate with LVAs (by fixed method)	*	98.33 ± 47.5 wpm
	Reading rate with LVAs (by individual method)	*	103.19 ± 48.84 wpm
	Reading rate with own LVAs	*	102.07 ± 50.81 wpm
Passage	Maximum reading rate without LVAs	*	67.37 ± 34.25 wpm
	Reading rate with LVAs at target print size (by fixed method)	58.42 ± 30.2 wpm	58.84 ± 31.81 wpm
	Reading rate with LVAs at target print size (by individual method)	50.13 ± 31.3 wpm	57.14 ± 30.9 wpm
	Reading rate with own LVAs at target print size	53.2 ± 24.67 wpm	55.99 ± 28.1 wpm

* The measurements were made at second visit only

Table 4. Comparison of the reading performance of (nine) subjects at two visits.

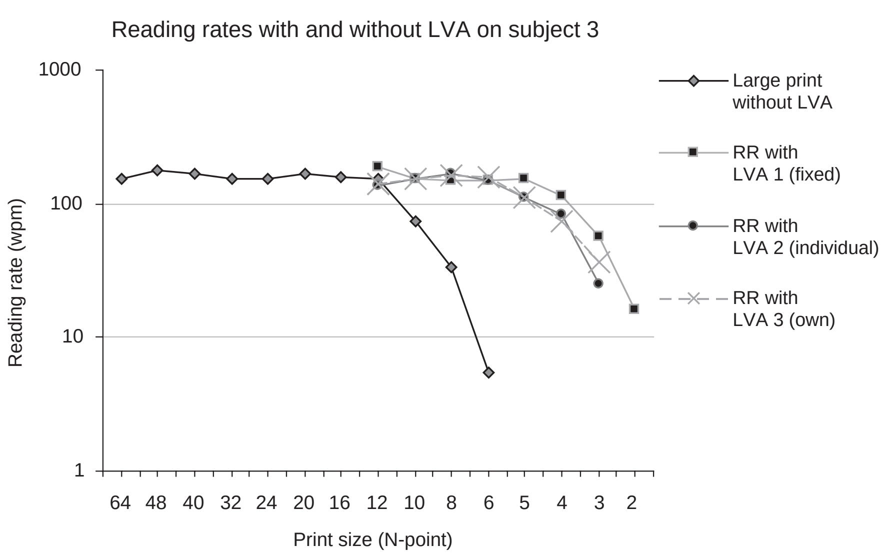

Figure 4. Examples of reading rates as a function of print size with and without LVAs for sentences using the Bailey-Lovie text reading. Maximum reading rates were not significantly different with or without LVAs.

of freedom, a Bonferroni correction was applied to the probability associated with each test by dividing it by the number of tests executed.[35,36] The adjusted probability was 0.006 as there were eight repeated measures at the second visit.

RESULTS

Method of determining magnification

There were no significant differences between the reading rates on passages with LVA determined by the two methods (the fixed or individual acuity reserve method) or with the subjects' own-magnifier (Table 3). This was true at the initial visit and at the repeat visit ($F_{2,54}$ = 0.05, p = 0.95; $F_{2,24}$ = 0.24, p = 0.79 respectively) (Tables 3 and 4). Similarly, there were no significant differences in the required EVD calculated by the two different methods or the EVD of the subjects' own magnifiers ($F_{2,54}$ = 0.69, p = 0.51). The magnification of the LVAs prescribed for QUT VRC patients are determined initially on the basis of a fixed acuity reserve of 0.3 log unit. Reading performance is then assessed and the magnification may be modified. For this reason, it was not surprising to find no significant differences in EVD between that of the subjects' own LVA and that calculated by the two different methods.

The method of using a fixed acuity reserve (prescribing for print size that was two times [0.3 log unit] smaller than target print size)[16] satisfactorily determined the required magnification for almost all subjects. There was one exception in this sample—subject 8 was unable to read with the hand-held magnifier selected using the fixed acuity reserve method. Subject 8 had had AMD for the longest period of all the subjects and was well adapted to her own magnifier, which provided an acuity reserve of 0.5 log unit. While fluent reading was still possible with 0.4 log acuity reserve, it was not with 0.3 log acuity reserve. The fixed acuity reserve method in this case under-estimated her required acuity reserve. She needed at least 0.4 log acuity reserve to achieve fluent reading with magnification.

Repeatability of measurements

Reading rates were repeatable when measured in one session. At the first assessment, reading rate without LVA was highly repeatable with no statistically significant differences between the three trials ($F_{2,54} = 2.23$, $p = 0.12$). Ahn, Legge and Luebker[24] similarly found reading rates without LVA to be very repeatable across six measurements. This suggests that one measurement of reading rate on large print is sufficient to estimate a low vision subject's MRR without a low vision aid.

Reading rates between visits were also repeatable (Table 4). Maximum reading rate on large print without LVA at the second visit (112 ± 55.8 wpm) was not significantly different from the first trial of maximum reading rate at the first visit (104 ± 53.25 wpm) ($F_{1,8} = 2.76$; $p = 0.14$). Mean reading rates with LVA for passages at the subject's target print size were not significantly different between the two visits for the magnifiers determined by the fixed acuity reserve method or individual method ($t = -1.24$; df = 8; $p = 0.25$; $t = -3.36$; df = 8; $p = 0.01$ [not significant with Bonferroni correction] respectively) or using subject's own LVA ($t = 0.56$; df = 8; $p = 0.59$).

Comparison of reading performance with and without magnifiers

At the first visit, MRR without LVA was significantly faster than the reading rate with LVA at subject's target print size ($F_{3,72} = 0.89$, $p < 0.001$). This difference probably occurred because single sentences were used to measure MRR without LVA, but longer passages were used to measure reading rates with LVA. Carver[31] has suggested that reading rate for longer passages is lower than reading rate for short sentences. To confirm that the significant reduction in reading rate with magnifiers compared with large print was due to the different reading tasks, reading rate measures were made for similar tasks, both sentences and passages, with and without LVA at the second visit.

At the second visit, there were no significant differences between MRR for sentences ($F_{3,32} = 0.12$, $p = 0.95$) and passages at critical print size ($F_{3,32} = 0.08$, $p = 0.97$) with or without LVA (Table 4 and Figure 4). This result agrees with the findings of Bowers, Lovie-Kitchin and Woods,[37] who also reported no significant differences in reading rates with and without LVA for paragraph reading at critical print size. In addition, our results confirm that reading rate without magnifiers is a good predictor of reading rate with magnifiers ($r = 0.96$; $p < 0.0001$) as previously reported by Lovie-Kitchin, Bowers and Woods[38] and Ahn and Legge.[39]

DISCUSSION

Our results and those of previous studies[37,39] indicate that, provided there is ample acuity reserve, LVAs do not reduce reading rate for experienced users. From the measurement of reading rate on large print without LVA, an estimation of the potential reading performance with LVA can be determined before optical aids are prescribed.[39]

Numerous previous studies have found that reading rate is reduced by the use of magnifiers.[40-44] These studies recruited subjects who had normal vision, were highly educated and who had higher maximum reading rates without LVA than those achieved by people with low vision. These subjects were not experienced in using low vision aids and in some studies the retinal image sizes with and without LVA were different for the two conditions. Passages of the same print size were used to measure the reading rates with and without LVAs, giving different image sizes.

The results of our study showed that there was no significant difference between reading rate with and without LVAs for experienced subjects when performing similar reading tasks. However, these findings were for experienced magnifier users only. For inexperienced users, based on previous studies,[40-44] it is reasonable to expect a reduction in reading rate when the LVA is first prescribed. There are at least two possible reasons for this: they lack the experience to use the LVAs or they have given up reading for a long time because of their poor vision. Perhaps giving these low vision patients large print reading practice before prescribing the LVAs would enhance their reading performance with magnifiers. The results of this study suggest that reading rates with LVAs will reach large print reading rates, once the low vision subjects adapt to their LVAs. Previous studies have mainly concentrated on providing extensive training programs for the use of optical low vision aids.[45,46] However, there has been no study to evaluate subjects' adaptation to LVAs by monitoring reading performance over time. Therefore, further research to determine the effects of reading practice and/or training with magnifiers is needed.

CONCLUSION

Determining the appropriate magnification of low vision aids to assist people for reading is an important task in low vision rehabilitation. For clinical purposes, a method that is easy, efficient and accurate would be most useful. For the AMD subjects in this study, using the fixed acuity reserve method to determine magnification gave results similar to those of the individual acuity reserve method. The fixed acuity reserve method as described by Lovie-Kitchin and Whittaker[23,25] requires only the identification of the patient's target reading material and the assessment of near visual acuity; an acuity reserve of 2:1 (0.3 log-unit) is then used to determine magnification. This study indicates that for most patients with AMD, this method gives magnification that meets their reading goals and is not significantly different from that which had been prescribed. Our clinical experience suggests that these results probably apply to patients with other causes of low vision. However, occasionally the reading rate achieved with the magnification calculated in this way was not satisfactory. In such cases, individual assessment of reading rates for different print sizes is needed to determine the acuity reserve required for fluent reading rate and calculate appropriate magnification.[39]

We have confirmed Lovie-Kitchin and Whittaker's[23] suggestion that for clinical purposes the practitioner should determine the required magnification based on a required acuity reserve of three lines for fluency. If the reading performance is not satisfactory with this magnification, individual assessment of required acuity reserve for fluent reading rate is necessary.

By this prescribing regime, reading rates versus different print sizes do not need to be measured as a routine procedure in determining magnification. The patient's near visual acuity and target print size are the only required information for calculating magnification.

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REFERENCES

1. Leat SJ, Legge GE, Bullimore MA. What is low vision? A re-evaluation of definitions. *Optom Vis Sci* 1999; 76: 198-211
2. Lovie-Kitchin JE, Bowman KJ. Senile Macular Degeneration—Management and Rehabilitation. Boston: Butterworths, 1985.
3. Brown B. The Low Vision Handbook. Thorofare, NJ: SLACK Inc, 1997.
4. Brilliant R. Magnification in low vision aids made simple. *J Vis Impair Blindness* 1983; 77: 169-171.
5. Dickinson C. Low vision: Principles and Practice. Boston: Butterworth-Heinemann, 1998.
6. Cole RG. Predicting the low vision reading add. *J Am Optom Assoc* 1993; 64: 19-27.
7. Cole RG. Visual acuity and predicted reading add. In: Rosenthal BP, Cole RG, eds. Functional Assessment of Low Vision. St. Louis: CV Mosby, 1996: 27-39.
8. Kestenbaum A, Sturman RM. Reading glasses for patients with very poor vision. *Arch Ophthalmol* 1956; 56: 451-470.
9. Flom RE, Raasch TW, Braudway SM, Rubin GS, Massof RW. A test of Kestenbaum's rule for prescribing low vision reading devices. *Optom Vis Sci* 1993; 70: 128.
10. Elam JH. Analysis of methods for predicting near-magnification power. *J Am Optom Assoc* 1997; 68: 31-36.
11. Legge GE, Rubin GS, Pelli DG, Schleske MM. Psychophysics of reading—II. Low vision. *Vision Res* 1985; 25: 253-265.
12. Lowe JB, Drasdo N. Efficiency in reading with closed-circuit television for low vision. *Ophthal Physiol Opt* 1990; 10: 225-233.
13. Lovie-Kitchin JE, Woo GC. Effect of magnification and field of view on reading speed using a CCTV. In: Woo GC, ed. Low Vision: Principles and Application. New York: Springer-Verlag, 1987: 308-322.
14. Ortiz A, Chung ST, Legge GE, Jobling JT. Reading with a head-mounted video magnifier. *Optom Vis Sci* 1999; 76: 755-763.
15. Beckmann PJ, Legge GE. Psychophysics of reading—XIV. The page navigation problem in using magnifiers. *Vision Res* 1996; 36: 3723-3733.
16. Whittaker SG, Lovie-Kitchin JE. Visual requirements for reading. *Optom Vis Sci* 1993; 70: 54-65.
17. Legge GE, Pelli DG, Rubin GS, Schleske MM. Psychophysics of reading—I. Normal vision. *Vision Res* 1985; 25: 239-252.
18. Legge GE, Ross JA, Isenberg LM, LaMay JM. Psychophysics of reading. Clinical predictors of low-vision reading speed. *Invest Ophthalmol Vis Sci* 1992; 33: 677-687.
19. Bullimore MA, Bailey IL. Reading and eye movements in age-related maculopathy. *Optom Vis Sci* 1995; 72: 125-138.
20. Watson GR, De l'Aune W, Long S, Maino J, Stelmack J. Veterans' use of low vision devices for reading. *Optom Vis Sci* 1997; 74: 260-265.
21. Mehr EB, Freid AN. Low Vision Care. Chicago: Professional Press, 1975.
22. Lovie-Kitchin JE, Whittaker SG. Interaction between acuity reserve and window size for scrolled reading rates in adults with normal and low vision. *Invest Ophthalmol Vis Sci* 1999; 40: S34.
23. Lovie-Kitchin JE, Whittaker SG. Prescribing magnification for reading with low vision: what are the criteria? In: Stuen C, Arditi A, Horowitz A, Lang MA, Rosenthal B, Seidman K, eds. Vision Rehabilitation—Assessment, Intervention and Outcomes. Tokyo: Swets & Zeitlinger, 2000: 314-318.
24. Ahn SJ, Legge GE, Luebker A. Printed cards for measuring low-vision reading speed. *Vision Res* 1995; 35: 1939-1944.
25. Lovie-Kitchin JE, Whittaker SG. Prescribing near magnification for low vision patients. *Clin Exp Optom* 1999; 82: 214-224.
26. Shankweiler D, Liberman I. Mis-reading: A search for causes. In: Cavanagh J, Mattingly I, eds. Language by Ear and Eye. Cambridge: MIT Press, 1972.
27. Baldasare J, Watson GR, Whittaker SG, Miller-Shaffer H. The development and evaluation of a reading test for low vision individuals with macular loss. *J Vis Impair Blindness* 1986; 80: 785-789.
28. Neale MD, McKay MF, Barnard J. Neale Analysis of Reading Ability. 3rd Australian standardisation / ed. Camberwell, VIC: Australian Council for Educational Research, 1999.
29. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. *Am J Optom Physiol Opt* 1976; 53: 740-745.
30. Bailey IL, Lovie JE. The design and use of a new near-vision chart. *Am J Optom Physiol Opt* 1980; 57: 378-387.
31. Carver RP. Reading rate: A Review of Research and Theory. San Diego: Academic Press, 1990.
32. Mansfield JS, Legge GE, Leubker A, Cunningham K. MNRead acuity charts. New York: Lighhouse Low Vision Products, 1994.
33. Legge GE, Ross JA, Luebker A, LaMay JM. Psychophysics of reading. VIII. The Minnesota Low-Vision Reading Test. *Optom Vis Sci* 1989; 66: 843-853.
34. Bailey IL, Bullimore MA, Greer RB, Mattingly WB. Low vision magnifiers—their optical parameters and methods for prescribing. *Optom Vis Sci* 1994; 71: 689-698.
35. Green SB, Salkind NJ, Akey TM. Using SPSS for Windows: Analyzing and Understanding Data, 2nd ed. London: Prentice Hall, 2000.
36. Pallant J. SPSS Survival Manual: a Step-by-Step Guide to Data Anlysis Using SPSS for Windows (Version 10). Buckingham: Open University Press, 2001.
37. Bowers AR, Lovie-Kitchin J, Woods RL. Eye movements and reading with large print and optical magnifiers in macular disease. *Optom Vis Sci* 2001; 78: 325-334.
38. Lovie-Kitchin J, Bowers AR, Woods RL. Oral and silent reading performance with macular degeneration. *Ophthal Physiol Opt* 2000; 20: 360-370.
39. Ahn SJ, Legge GE. Psychophysics of reading—XIII. Predictors of magnifier-aided reading speed in low vision. *Vision Res* 1995; 35: 1931-1938.
40. Mancil GL, Nowakowski R. Evaluation of reading speed with four low vision aids. *Am J Optom Physiol Opt* 1986; 63: 708-713.
41. Cohen JM, Waiss B. Comparison of reading speed in normal observers through different forms of equivalent power low vision devices. *Optom Vis Sci* 1991; 68: 127-131.
42. McMahon TT, Spigelman V. Reading with a stand magnifier: 1. Effect of text configuration and experience on normal subjects. *J Vis Rehab* 1989; 3: 19-23.
43. Bowers AR. Eye movements and reading with plus-lens magnifiers. *Optom Vis Sci* 2000; 77: 25-33.
44. Dickinson CM, Fotinakis V. The limitations imposed on reading by low vision aids. *Optom Vis Sci* 2000; 77: 364-372.
45. Watson GR, Wright V, De l'Aune W. The efficacy of comprehension training and reading practice for print readers with macular loss. *J Vis Impair Blindness* 1992; 86: 37-43.
46. Goodrich GL, Kirby J, Keswick C, Donald B, Oros T, Wagstaff P et al. Low vision reading: effects of field loss, training and device. *Optom Vis Sci (Suppl)* 1998; 75: 25.

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