ARTICLE

# Vision rehabilitation for patients with age-related macular degeneration

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## Epidemiology of low vision

The epidemiology of vision impairment is dealt with in detail elsewhere.[1] However, there is one particularly salient factor that bears emphasis. The prevalence of vision impairment increases dramatically with advancing age. Statistics compiled in the UK by the Royal National Institute for the Blind[2] indicate that there were approximately 1.1 million blind or partially sighted persons in 1996, of whom 82% were 65 years of age or older. Thus it is not surprising to learn that the major causes of vision impairment are age-related eye diseases. Fig. 1 illustrates the distribution of causes of vision impairment from three recent studies.[3–5] Approximately equal percentages are attributed to macular degeneration and cataract, with smaller percentages for glaucoma, diabetic retinopathy and optic neuropathies. However, the primary cause of vision impairment among patients referred for low-vision services is markedly different. As shown in Fig. 2, over half the low vision patients referred to three large practices in the US,[6] UK[7] and Canada[8] had macular degeneration and fewer than 10% were referred with each of the other conditions.

Why is macular degeneration so over-represented in the low-vision clinic compared with its prevalence in the population? There are several possible reasons. First, cataract, the other leading cause of vision impairment, is treatable. Although half of those with vision-limiting cataract elect not to have surgery in the 2 years following diagnosis,[9] few are referred for vision rehabilitation. A second reason may be that macular degeneration affects central vision while some of the other conditions, such as glaucoma, initially affect peripheral vision. A drop in central vision is more quickly noticed by the patient and may be more detrimental to everyday visual activities. Third, many of those who refer patients for low-vision services view vision rehabilitation as the mere dispensing of optical magnifiers. Magnification is effective for problems with poor resolution in central vision, but has little value for addressing peripheral vision problems caused by restricted fields.

The over-representation of macular degeneration patients in the low-vision clinic is reflected in the chief complaints of those referred for rehabilitation. A study of 1000 consecutive patients seen at the Wilmer Low Vision clinic indicated that 64% listed 'reading' as their chief complaint, while other activities were identified by fewer than 8% of patients. Undoubtedly the bias towards reading problems results partly from the nature of the low-vision services offered. Those served by a community-based programme that includes home visits might be more likely to report problems with activities of daily living, while a blind rehabilitation centre would be more likely to address mobility issues. Nevertheless, most macular degeneration patients are referred to hospital or optometry clinic services, and as their overwhelming concern is with reading, that will be the emphasis of this paper.

## Reading rehabilitation in age-related macular degeneration

### *Magnification*

Most low-vision patients require magnification in order to read. When reading speed is measured as a function of character size, those with normal vision read the fastest with a broad range of letter sizes between 0.5° and 2.0°. Not surprisingly, this range of letter sizes encompasses the range of ordinary print from newspaper text to small headlines. Most low-vision patients read best with enlarged print and the amount of magnification is fairly closely related to their acuity.[10] On average, the optimum letter size is about 4 times the acuity limit. Patients with central scotomas, including those with advanced macular degeneration, typically require more magnification than those with intact central fields, and the magnification required is usually a greater multiple of their acuity. Even when provided with optimal magnification, patients with central scotomas usually read more slowly than those with intact central fields. In a study of low-vision patients reading with optimal magnification, the median reading rate was less than 50 words/min for

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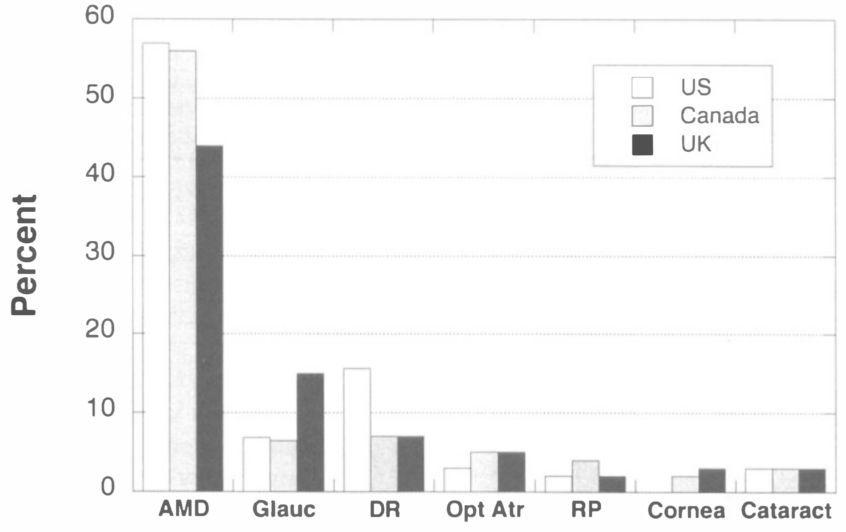


**Fig. 1.** *Leading causes of visual impairment (acuity worse than 6/12 in better eye) are shown for three recent population-based studies. Data for rural US are adapted from a study of 1136 subjects over age 40 years in rural Kentucky.*[3] *Data for urban US are from a study of 5300 adults 40 years of age and older in Baltimore, Maryland.*[4] *Data for Australia are from a study of 3647 adults aged 46 years and over from the Blue Mountains Eye Study.*[5] *AMD, age-related macular degeneration; DR, diabetic retinopathy; Opt Atr, optic atrophy.*

patients with scotomas in the central 5°, but over 150 words/min for those with intact central fields.[10]

It is not completely understood why patients with macular degeneration or other central field defects have so much difficulty reading. One factor is probably related to the high magnification requirement. In order to read efficiently, one needs to be able to see and recognise at least a minimum number of characters. This minimum 'window width' may be as low as 4 or 5 letters for text that is passively scrolled past the reader,[11] but extends to 15–30 letters for text that must be actively scanned.[12] All optical magnifiers, be they high-plus spectacles, hand or stand magnifiers, or telescopes, restrict the field of view more as the magnification increases. It is difficult to obtain the magnification required to recognise letters without restricting the field to less than the minimum required window width.

Electronic magnification aids, such as closed circuit televisions, provide high magnification with a large field of view. Nevertheless, experienced CCTV users with macular degeneration still read slower than other types of low-vision patients. This suggests that reading speed is limited not only by the field of view of the magnifier, but also the visual span of the reader.[13] To a first approximation, the visual span is the number of letters that can be recognised in a single fixation. In normally

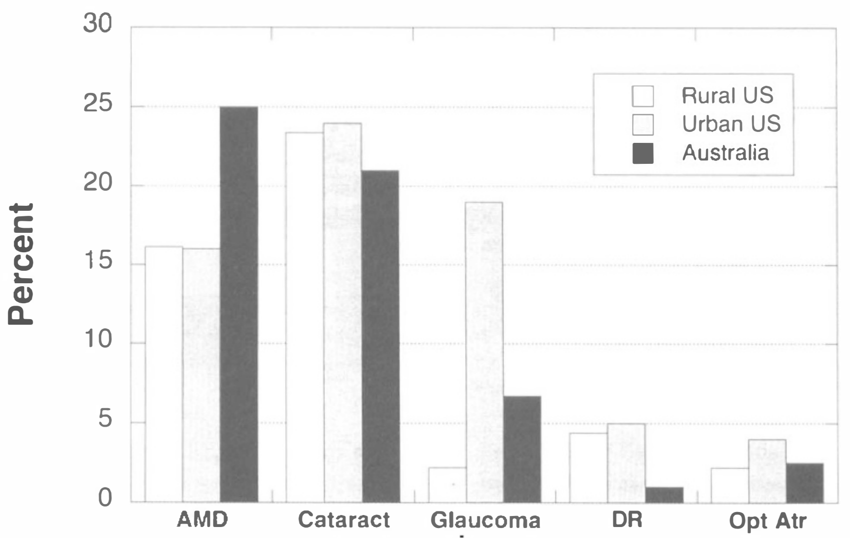


**Fig. 2.** *Leading causes of visual impairment in patients referred for low-vision rehabilitation are shown for three low-vision services. Data for the US are from an unpublished study of 1000 consecutive patients seen at the Johns Hopkins Wilmer Eye Institute low-vision service.*[6] *Data for Canada are from a study of 1398 individuals in an assistive devices program in Ontario.*[8] *Data for the UK are from a study of 218 patients seen at the University of Wales College of Cardiff low-vision service.*[7] *AMD, age-related macular degeneration; Glauc, glaucoma; DR, diabetic retinopathy; Opt Atr, optic atrophy; RP, retinitis pigmentosa.*

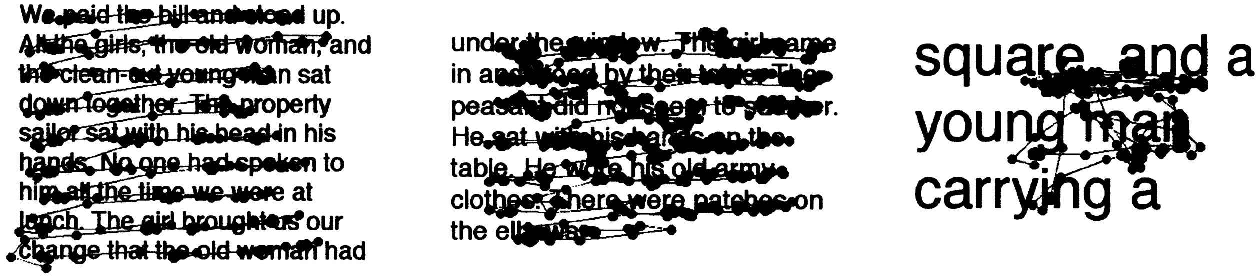

**Fig. 3.** *Eye movement records are shown for three reading trials. Gaze position was sampled at 250 Hz and each black dot is the gaze position for one sample. Clusters of dots indicate fixations, and dots separated by straight lines indicate saccades. In the left panel, the subject was reading with a full visual field. In the middle panel, the subject was reading with a 3.5° diameter simulated scotoma placed one letter space to the right of fixation. The right panel shows data for a 3.5° simulated scotoma centred on fixation.*

sighted observers the visual span is limited by the drop-off in acuity and contrast sensitivity away from the fovea. In patients with macular disease, even if the peripheral retina is normal,[14] visual span is constrained by the presence of a scotoma at the centre of the visual field, by distortions just outside the scotoma,[15] and by the drop-off in acuity and contrast sensitivity in peripheral vision.

### *Eye movements*

Static pictures that attempt to simulate the appearance of the world through a central scotoma fail to depict the full extent of the difficulty. As we inspect such simulations our eyes are free to roam to and fro over the representation. But for the person with a macular scotoma, the scotoma is fixed on the retina and moves with the direction of gaze. There is no looking around it. To gain a better understanding of problems confronted by patients with macular degeneration, we undertook a series of studies of eye movements and reading performance in normally sighted observers in whom a central scotoma was simulated by means of an eyetracker.[16–18] Unlike static simulations, these simulations created dynamic 'scotomas' that moved as the eye moved. An SRI Generation VI eyetracker was fitted with a stimulus deflector[19] containing two mirror galvanometers. Analogue eye position signals from the eyetracker were used to rotate the mirrors about the vertical and horizontal axes and thus cancel eye movements over a range of about $\pm 20°$. The stimulus deflector was modified as described by Crane and Kelly[20] so that a stabilised mask could be superimposed on an unstabilised view of the world. The world in this case was a computer monitor containing text.

The eye movement signals from the eyetracker were sampled at 250 Hz with an analogue-to-digital converter and stored for later analyses. Fig. 3 shows examples of the eye movement records obtained under three conditions. The left panel shows eye movements when reading text without a scotoma. Each dot represents a sampled eye position. Clusters of dots indicate fixations, while individual dots connected by straight lines represent saccades. In the absence of a scotoma, this reader followed the lines of text in a regular and predictable fashion, with one fixation for most of the words and a rapid sweep to return to the beginning of a new line. The middle panel shows data for a fairly small 3.5° scotoma located one letter to the right of fixation.

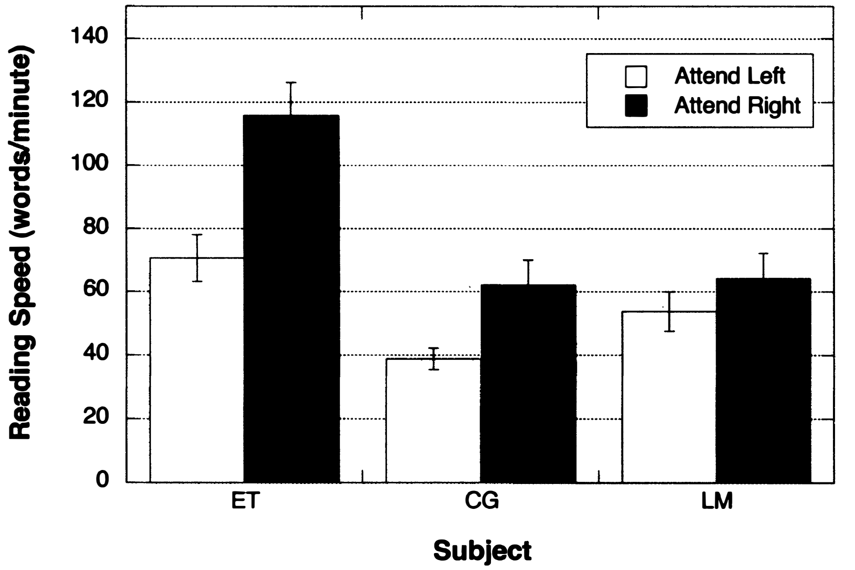


**Fig. 4.** *Reading speeds are plotted for three subjects with normal vision. The open bars show data when the subjects were forced to attend to the left of fixation by a retinally stabilised mask that blocked all information from the right of fixation. The black bars show data when the subjects were forced to attend to the right of fixation by a mask to the left. Vertical bars are ±SE of the mean.*

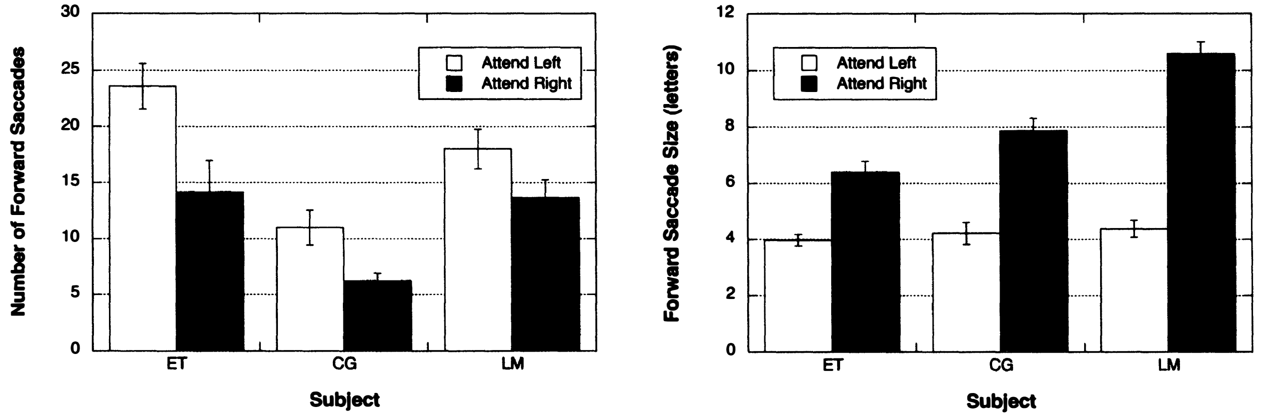


**Fig. 5.** *Eye movement data are plotted for the same reading conditions as in Fig. 4. The left panel shows the number of forward saccades when the subjects were forced to attend to the left or right of fixation. The right panel shows the average saccade size when subjects were forced to attend to the left, or right. Vertical bars are ±1 SE of the mean.*

The eye position samples are displaced to the right compared with the no scotoma condition. This indicates that the observer had deviated the eyes slightly to the right and was presumably using an area in the left visual field to read. In this condition the reader often made multiple fixations per word, and the return sweep was interrupted by multiple fixations. The right panel shows the eye movement record for a 3.5° scotoma centred at the fovea. The text had to be enlarged for the observer to resolve the letters with peripheral vision. However, even with the magnfied text the eye movement pattern was quite disorganised with multiple fixations and small saccades within words.

### *Eccentric fixation*

The eye movement patterns in Fig. 3 were obtained with a normally sighted observer who had only a few hours of practice reading with a scotoma. Macular degeneration patients adapt to their scotomas slowly and typically make a transition from conscious use of eccentric retinal areas to the automatic substitution of a single eccentric locus which behaves as a pseudo-fovea. This 'preferred retinal locus' or PRL[21] can behave as the anatomical reference for fixation eye movements, much as the real fovea serves those with normal vision.[22] Nevertheless, even in patients with long-standing scotomas and well-established PRLs, there is tendency towards multiple fixations within words and shorter saccades between fixations.[23]

Most patients with age-related macular degeneration adopt a PRL that is to the left of a central scotoma (in visual field space).[24,25] However, research on reading and eye movements in subjects with normal vision indicates that more information about word identity is obtained from letters to the right of fixation. According to one estimate, the normal reader acquires letter shape information from 12–15 letters in the right half of the field, but only 4–5 letters in the left half.[12] Thus, it would seem better to use a PRL to the right of a scotoma instead of to the left.

We measured reading speed and eye movements in normally sighted subjects who viewed text through a stabilised mask that limited information to the left or right visual fields.[17] The results are shown in Fig. 4. Consistent with our predictions, reading speeds were up to 50% faster when attending to the right field instead of to the left. The right field advantage was reflected in the eye movement data shown in Fig. 5. There were significantly fewer saccades (left panel) and the saccades were correspondingly larger (right panel) when attending to the right. Fixation duration did not differ according to the direction of attention (not shown). The fastest reading rates and most efficient eye movements were obtained when all the textual information was presented in the lower visual field. Indeed, patients with Stargardt disease, a juvenile form of macular degeneration, were more likely to use a PRL below their scotoma.[25] Another important difference between the age-related macular degeneration and Stargardt disease patients was that those with age-related macular degeneration were more likely to use a PRL that was very close to the scotoma boundary. Whether the more remote placement of the PRL increases the efficiency of visual processing is a question for future research.

One of the goals of vision rehabilitation is to help the patient establish an appropriate PRL and to use that PRL efficiently. Various procedures have been promoted for training the PRL,[26] but it remains controversial whether these training procedures work any better than simple practice. One of the major problems confronting the clinician is to know where the PRL is located on the retina. Without this information it is difficult to evaluate whether the location is appropriate, how it changes as the patient adapts to the eye condition, and how the PRL location responds to rehabilitation and training. The scanning laser ophthalmoscope[27] can provide this much-needed information, but its potential uses in the field of vision rehabilitation have only begun to be recognised (see e.g. Fletcher *et al.*[28]).

As an alternative to training eccentric fixation and reading eye movements, we have investigated whether it may be possible to change the reading task in order to make it simpler for patients with macular degeneration.

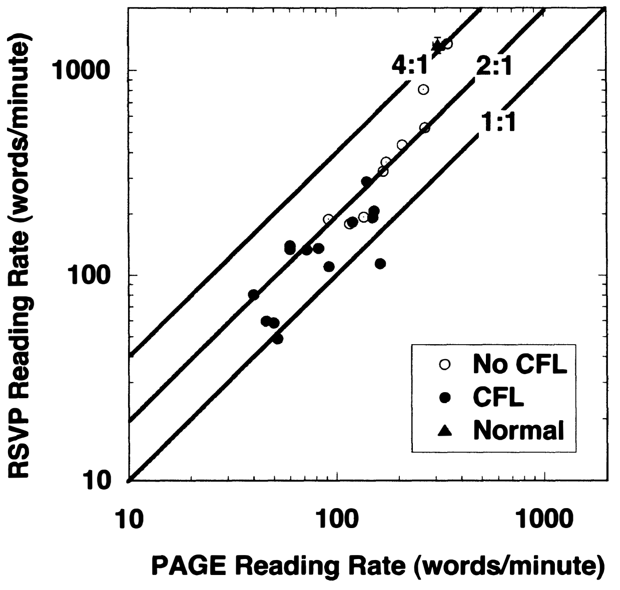


**Fig. 6.** *Maximum reading speeds are compared for conventional PAGE reading, on the x-axis, and sequential RSVP reading, on the y-axis. The filled triangle is average data for four observers with normal vision. Open circles are data for low-vision subjects without scotomas in the central 5 °, and filled circles are data for subjects with central scotomas. The diagonal lines indicate the relative advantage of RSVP over PAGE reading. Data falling along the 1:1 line indicate that RSVP was read no faster than PAGE text, while data falling along the 4:1 line indicate that RSVP reading was 4 times faster than PAGE reading.*

A text presentation technique developed around 1970[29] provided the key. Rapid serial visual presentation (RSVP) was first used to study cognitive processing during normal reading. Instead of presenting a full page of text that is scanned with a series of eye movements, RSVP presents words one at a time in a fixed location. Provided the entire word fits within the visual span, no eye movements are necessary. Our work[30] demonstrated that normally sighted observers could read RSVP text with good comprehension even faster than a normal page of static text. Some were able to read RSVP text at speeds in excess of 1000 words/min, compared with 250–300 words/min for static text.

But what about low-vision patients? Fig. 6 compares RSVP and static reading speeds for 23 subjects with various ocular pathologies.[31] The filled circles present data for 14 subjects with central scotomas, most due to macular degeneration, and the open circles present data for the 9 subjects with low vision but who had intact central fields. The open triangle represents average data for a group of normally sighted subjects. The normally sighted subjects read about 4 times faster with RSVP compared with static text. Low-vision patients with intact central fields read approximately twice as fast with RSVP. Unfortunately, the low-vision patients with macular scotomas showed the least improvement, reading an average of 40% faster with RSVP. A detailed analysis of eye movements using a scanning laser ophthalmoscope indicated that RSVP reduced but did not eliminate intra-word saccades in patients with macular scotomas. Some of these subjects indicated that with the high level of magnification needed to resolve the letters it was impossible to recognise an entire word in a single fixation. This suggests that restrictions in visual span combine with eye movement inefficiencies to limit reading performance in patients with macular degeneration. Nevertheless, some patients were able to increase their reading speeds enough with RSVP that it might provide a useful alternative to conventional static text.

## Future developments in reading rehabilitation

This brief review of some recent developments in reading rehabilitation research indicates that many of the problems confronted by patients with age-related macular degeneration cannot be solved with magnification alone. One key to improving reading efficiency may be better training in the use of eccentric fixation. Another approach is to improve access to the written word by increasing text legibility, making better use of the limited visual span, and reducing the need for accurate saccadic eye movements. This approach will benefit from recent technological advances in computer imaging and video displays. The development of a commercial market for 'virtual reality' displays has made it economically feasible to produce portable, light-weight, head-mounted TV systems that deliver bright images with high contrast. Several commercial head-mounted reading devices have been put on the market in the past few years and we anxiously await the results of current studies to evaluate their effectiveness as low-vision aids. The Internet has had both positive and negative effects on visual rehabilitation. While the growing dependence on graphical interfaces, icons and windows may make it difficult for the visually impaired reader to acquire information from the World Wide Web, there is a vast increase in the amount of information that is available in digital format. When RSVP was first suggested as a low-vision reading technique, there was very little text that was directly accessible via computer. We envisioned having to scan pages of text one at a time and convert them to a digital format that could be played back a word at a time. Now, books, magazines and newspapers are all being created and stored in computer files, many of which are available free or by subscription on the Web. Thus far, too little effort has been devoted to developing the software to access those files and present them in an optimal fashion for visually impaired readers. We must hope that as we become more dependent on computerised sources of information, the accessibility needs of those with visual impairments, and particularly the growing population of those with age-related macular degeneration, will not be ignored.

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