Reading Rehabilitation of Individuals with AMD: Relative Effectiveness of Training Approaches

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Purpose. To quantify the effects of three vision rehabilitation training approaches on improvements in reading performance.

Methods. Thirty subjects with AMD participated in the training portion of the study. The median age of the subjects was 79 years (range, 54–89 years). The three training modules were: Visual Awareness and Eccentric Viewing (module 1), Control of Reading Eye Movements (module 2), and Reading Practice with Sequential Presentation of Lexical Information (module 3). Subjects were trained for 6 weekly sessions on each module, and the order of training was counterbalanced. All subjects underwent four assessments: at baseline and at three 6-week intervals. Reading performance was measured before and after each training module. A separate group of 6 subjects was randomly assigned to a control condition in which there was no training. These subjects underwent repeated assessments separated by 6 weeks.

Results. Reading speeds decreased by an average of 8.4 words per minute (wpm) after training on module 1, increased by 27.3 wpm after module 2, and decreased by 9.8 wpm after module 3. Only the increase in reading speed after module 2 was significantly different from zero. Sentence reading speeds for the control group, who had no reading rehabilitation intervention, was essentially unchanged over the 18 weeks (0.96 ± 1.3 wpm).

Conclusions. A training curriculum that concentrates on eye movement control increased reading speed in subjects with AMD. This finding does not suggest that the other rehabilitation modules have no value; it suggests that they are simply not the most effective for reading rehabilitation. (ClinicalTrials.gov number, NCT00125632.) (*Invest Ophthalmol Vis Sci.* 2011;52:2938–2944) DOI:10.1167/iovs.10-6137

Loss of central vision caused by macular degeneration affects more than 1.5 million Americans, with many thousands of new cases diagnosed each year (www.amd.org). Age-related macular degeneration (AMD) is the leading cause of visual loss in white Americans, affecting approximately 30% of those 75 years of age and older.[1] For many affected persons, a loss of photoreceptors resulting from dysfunction at the level of the RPE results in central scotomas. These individuals frequently adopt a pseudofovea, a locus in the peripheral retinal for eccentric fixation (preferred retinal locus [PRL]).[2–4] The sensory and perceptual consequences of using peripheral retina are well documented.[5–8] Oculomotor consequences of eccentric viewing have also been described.[9–12]

For persons with central scotomas, PRLs must be used for reading. However, reading performance using a PRL is considerably slower than in normally sighted subjects.[13–17] In a census of low-vision rehabilitation services, Owsley et al.[18] reported that reading difficulty was the most common motivation for AMD patients to seek rehabilitation (85.9% of patients). Although there are numerous reports of the effectiveness of low-vision rehabilitation assessed using patient-reported outcomes, there have been only a few studies that have directly quantified improvements in reading performance as a result of low-vision rehabilitation interventions.[19] Because of the extensive time commitment required for vision rehabilitation, it is critical to identify the methods that are the most effective. In the study presented here, we separated training methods according to the visual skills that were targeted and assessed the changes in reading performance directly attributable to the training of those skills. The results of our research provide a quantitative basis for selecting exercises to be included in an effective reading rehabilitation training program.

Patients and Methods

Individuals

Subjects with a diagnosis of dry nonexudative AMD and visual acuity greater than 20/400 in the better eye were included in the study. It is our experience that as acuity decreases beyond 20/400, the patient's ability and interest in prolonged reading drop off precipitously. Potential subjects were screened to exclude those with other major ophthalmologic or neurologic disease, choroidal neovascularization as a result of wet AMD, moderate to severe media opacities, and cognitive impairment.

This study complied fully with the Declaration of Helsinki, and written informed consent was obtained from all subjects involved in the study. This study was approved by the University of Illinois Institutional Review Board.

Clinical Vision Tests

Visual acuity and letter contrast sensitivity were measured using EDTRS acuity charts and the Pelli-Robson contrast sensitivity chart, respectively. Each patient's cognitive status was assessed with the Mini-Mental Status Examination. Subjects with scores below 25, which indicates cognitive impairment that could affect learning, were excluded.[20]

PRL Identification

All subjects had an eccentric PRL, confirmed with a micro perimeter (MP1; Nidek, Tokyo, Japan). For 10 subjects with normal vision, we

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measured the distance between the optic disc and the center of fixation (presumed fovea).[11,16,21] Based on this average, the distances and angles of the subjects' PRLs were calculated.

Training Protocols

We partitioned reading rehabilitation training exercises derived from the literature and from our laboratory's curriculum into three modules.[22] These modules were labeled Visual Awareness and Eccentric Viewing (module 1), Control of Reading Eye Movements (module 2), and Reading Practice with Sequential Presentation of Lexical Information (module 3). Each of these modules concentrated on training a different skill. We wanted to determine which training resulted in an improvement in our outcome measure of reading.

Module 1: Visual Awareness and Eccentric Viewing

In this module, awareness of the PRL location and eccentric viewing were trained. Exercises based on published sources were administered.[23–25] One example of these exercises is the clock face display adapted from Holcomb and Goodrich[26] and Maplesden.[24] On a monitor screen, a clock was drawn with hour markings at its periphery and a star at the center. The size of the clock numbers was 1.7°. Subjects were asked to place their fixation along the meridian of each hour location. The clarity of the center star when looking straight at it was compared with its clarity when viewing eccentrically. For example, if best vision was in the superior retina, the patient was asked to look up to cover the 12 o'clock number with his/her scotoma. Thereby, the PRL viewed the star at the center of the clock face.

This module also focused on awareness of the perceptual consequences of using a PRL. Subjects were instructed that, because of the undersampling of the peripheral visual system, visual targets presented to the peripheral visual system are perceived differently than in the central retina. The purpose of these training exercises was to allow the subjects to appreciate perceptual alterations that occur when using a PRL and to practice making perceptual discriminations with the peripheral retina. Previously published work has demonstrated that perception in the peripheral retina can be affected by practice.[27,28]

Module 2: Control of Reading Eye Movements

For these training exercises, the subjects were seated in a comfortable position with their foreheads supported and stabilized by an adjustable rest positioned 40 cm from the monitor. Eye movements were monitored using a CCD camera focused on the pupils of the tested eyes. During all sessions, the experimenter monitored pupil movements, provided feedback to the subjects, and verbally documented information relevant to the task. All training stimuli were presented on a standard 19-inch computer monitor. All sessions began by measuring the subject's smallest identifiable letter size. All stimuli presented during training were then displayed at 0.3 log units larger than the subject's threshold.[15]

In this module, control of eye movements was trained. These exercises began with a series of saccade tasks to nonalphabetical stimuli and then progressed to single letter, letter pairs, and word stimuli. For example, saccadic training began with a two-dot task, in which the dots were shown alternately on the screen at one of two horizontally separated locations. The distance between dots was one-, two-, or three-character spaces. Subjects were instructed to make a saccade between the dots. The experimenter provided feedback concerning the appropriateness of the saccades, and the alternation rate of the dots was increased as performance improved. In the next series of exercises, the dots were replaced with a letter. The same letter (e.g., E) was shown alternately at one of the two locations. On random alternations, the letter changed (e.g., from E to D), and the subjects were required to report only the change, not identify the letter. The same procedure was then repeated with pairs of letters and with two- or three-letter words. The rate of alternation and the distance were altered according to performance. To avoid contamination of our outcome measure, subjects did not practice using eye movements to read sentences.

Module 3: Reading Practice with Sequential Presentation of Lexical Information

A number of studies have shown improvements in reading performance after patients are prescribed a magnifier and provided with practice reading text.[29] The training exercises used in these previous studies implicitly combined oculomotor, perceptual, attention, and cognitive aspects of reading practice. In module 2, we examined the effects of oculomotor training alone. In module 3, we wanted to assess only the higher-level effects of reading practice. The targets were presented in the center of the computer monitor at a size that was 0.3 log units above each subjects' letter acuity thresholds so that they were able to read with sufficient acuity reserve.[15] Subjects practiced reading using stimuli that did not require reading eye movements. An example of these exercises is short sentences that were presented one word at a time at a single location on a monitor screen (Rapid Serial Visual Presentation [RSVP]).[30] Subjects controlled the rate of presentation of each word in the sentence with a click of the computer mouse button. At the end of the sentence, subjects reported whether the sentence made sense or not. We also had our subjects practice reading scrolled text. Subjects were instructed to fixate the center of the screen, and the position of fixation was marked by large arrows displayed above and below the point of fixation. Subjects were instructed to fixate between the arrows as the text scrolled from left to right past the point of fixation. Although, eye movements and saccades may spontaneously occur under the text presentation conditions of this module, they are not the efficient saccades necessary for reading. To avoid contamination of our outcome measure subjects did not practice using eye movements to read sentences in any of the modules.

Procedure

The subjects were trained and tested monocularly, using the eye with better visual acuity. If visual acuity was equivalent in both eyes, the subjects' dominant eye was used. A pair of eyeglasses with near-vision refraction (at 40 cm) was provided to the subjects to be used in training and testing.

The subjects' reading performances were initially assessed on day 1, before training began, with the outcome measure described below. After the baseline assessments, the subjects were split into 6 groups and trained on 1 of the 3 modules (assigned according to a table of counterbalanced module orders, shown in Table 1). The subjects were trained in 6 weekly sessions of approximately 2 hours each, plus time for rest. This was followed by second assessments. The subjects were then trained on a second module for another 6 weeks, followed by third assessments. Finally, the subjects were trained on a third module for 6 weeks, followed by final assessments.

The design was a randomized, repeated-measures, counterbalanced, crossover design. With this design, all subjects received all training modules, with the module order counterbalanced between subjects. The major advantage of this design is subject homogeneity because all subjects received all treatments. Because the same subjects are in every training module, factors such as visual status, age, education, mental status, motivation, disease severity, and PRL locations are

TABLE 1. Order of Training

Subgroup	First Training Session	Second Training Session	Third Training Session
1	Module 1	Module 2	Module 3
2	Module 2	Module 3	Module 1
3	Module 3	Module 1	Module 2
4	Module 1	Module 3	Module 2
5	Module 2	Module 1	Module 3
6	Module 3	Module 2	Module 1

completely matched and therefore do not contribute to the main effects of training module. Matching is always very difficult in older subjects with eye disease; this design eliminates this confound. We used a counterbalanced design so that each treatment followed every other treatment equally across subjects (Table 1) to average order effects. There were five subjects in each order.

Control Condition

We used a control condition to account for changes in performance as a result of repeated testing or spontaneous adaptation to vision loss. Subjects randomly assigned to this group had their training delayed for 18 weeks. These subjects underwent four assessments: baseline and at three 6-week intervals; but, they were not given any training during this time. After this data collection period, these control subjects were given training on the three modules. However, their performance after each period of training was not assessed.

Outcome Measures

Sentence Reading. The primary outcome measure for the study was sentence reading performance. We assessed reading performance using sentences displayed on a computer monitor.[22] Two lines of text were presented at the center of the monitor. Each subject was seated with his or her forehead on a head rest and at a viewing distance of 40 cm. The subject read each sentence aloud and indicated whether it made sense by responding true or false. Reading speed was calculated using an algorithm similar to that used for the MNRead test. The number of words read correctly was divided by the time required to read the sentence to yield a measure of reading speed in words per minute (wpm). Sentences were displayed at sizes of 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 log units above the subject's letter acuity threshold. Five sentences were presented at each font size. The sentences were adapted, in part, from the Woodcock Johnson III Tests of Achievement, Reading Fluency Test.[31] We used 105 different sentences so that no sentence was repeated for any subject during the entire study. Average speed of reading sentences (log wpm) was plotted as a function of font size (logMAR). These data were fitted with a sigmoid equation of the form: $y = a/1 + \exp(-(x - b)/c)$, where a quantifies the horizontal position of the curve, b is the maximum reading speed, and c is the slope of the function.[22] A research associate, masked to the training module order, administered the reading assessment battery.

Veterans Affairs Low-Vision Visual Functioning Questionnaire. We also measured perceived changes in visual function using the VA LV VFQ 48 self-report questionnaire.[32,33] The questionnaire was administered as part of the baseline and final assessments.

Statistical Analysis of Reading Outcomes Measure

Outcome measurements were obtained four times for each patient, at baseline and after each module. To assess the unique contribution of each module to reading, we computed a difference score between the reading score immediately after training on a module and the reading score immediately preceding that training. Thus, regardless of the order for the modules, the difference scores reflected how much each training module affected reading performance for each patient. Data were analyzed using repeated-measures statistics.

Results

Subjects

We recruited 30 individuals (15 women, 15 men) with AMD to participate in the training portion of the study (Table 2). The median age of the subjects was 79 years, mean acuity was 0.8 logMAR, mean baseline reading speed was 58.9 (wpm), and mean PRL eccentricity was 6.0°. Nineteen right eyes and 11 left eyes were trained. The mean duration of disease was 10.6 years

Table 2. Subjects' Baseline Characteristics

Subject	Age (years)	Sex	Acuity (logMAR)	Contrast Sensitivity	Reading Speed (wpm)	PRL Eccentricity (°)	Fixation Angle (°)	Stability within 2° (%)
1	54	F	1.0	1.2	85	7.3	75	46
2	60	M	0.1	1.3	87	2.9	315	81
3	62	M	1.0	1.2	8	14.5	190	29
4	64	F	1.3	0.6	42	13.1	315	14
5	65	F	0.9	1.2	80	8.7	245	40
6	66	M	0.8	1.3	26	11.6	175	33
7	71	M	0.8	0.6	88	4.4	80	16
8	73	M	0.4	0.5	75	2.9	160	96
9	73	F	0.8	1.3	58	6.3	120	39
10	74	F	0.9	1.3	47	5.8	60	75
11	74	M	0.5	1.3	80	3.8	155	63
12	74	F	0.5	0.5	72	1.5	340	86
13	74	M	1.0	0.9	3	1.5	320	16
14	77	F	0.9	0.5	35	3.2	270	22
15	77	F	1.3	1.0	−99	7.3	70	50
16	78	M	1.0	0.7	72	2.9	110	31
17	78	M	1.1	1.0	59	9.3	140	17
18	79	F	1.0	0.6	98	2.0	270	83
19	79	M	0.3	1.6	135	4.4	220	89
20	79	F	0.9	1.2	8	7.5	170	47
21	81	M	0.9	1.3	119	3.8	220	71
22	81	M	1.1	1.1	10	7.0	180	21
23	82	F	0.8	1.0	80	2.0	180	65
24	83	M	0.2	1.4	115	1.0	270	59
25	84	M	0.5	1.4	108	8.7	165	87
26	84	F	0.9	1.0	80	2.9	45	45
27	85	F	0.9	1.1	78	8.7	220	56
28	85	M	1.0	0.6	8	10.2	240	7
29	86	F	0.9	0.9	69	13.1	120	43
30	89	F	0.9	1.0	42	2.9	130	26

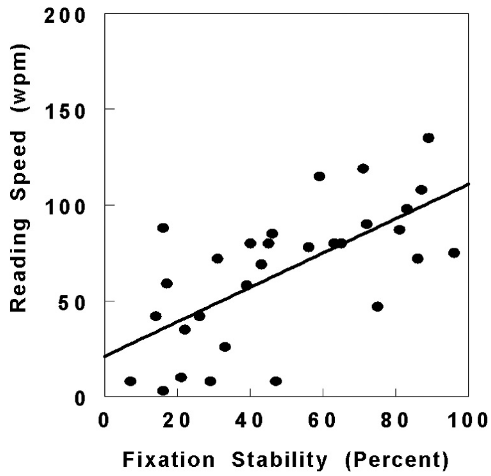

FIGURE 1. Reading speed at baseline is plotted against visual acuity at baseline.

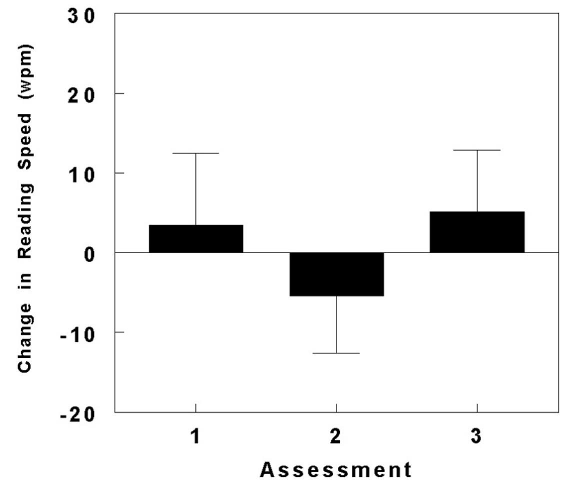

FIGURE 3. Average (+SD) change in reading speed as a function of training order collapsed across all training modules.

(range, 2–25 years). Fixation stability, as measured with a micro perimeter (MP1; Nidek), averaged 48.4% within 2°.

Relationship among Baseline Measures

We examine the correlation among baseline measures. Significant correlations were found between acuity and PRL eccentricity ($P = 0.05$) and acuity and fixation stability ($P < 0.001$). Reading speed was significantly correlated with acuity (Fig. 1; $P < 0.001$) and fixation stability (Fig. 2; $P = 0.005$).

Changes in Reading Performance

Training Time Effects. We initially examined the data to determine whether there was an order effect. That is, did reading speed vary as a function of time over the course of training? Collapsed across all training modules, the mean difference in maximum reading speed between the baseline assessment and the assessment after the first 6 weeks of training was 3.1 wpm (Fig. 3). After the second 6-week training period, average reading speed decreased by an average of 5.4 wpm, and after the third training period, average reading speed increased by 5.1 wpm (one-way repeated-measures ANOVA, $P = 0.34$). These results suggest that reading speeds did change simply as a function of time.

We examined whether the change in reading speed for each module was influenced by the module immediately preceding it (carryover effect). For example, it might have been that training PRL awareness before eye movement training increased the efficacy of that training. For each module, we separately calculated the change in reading speed as a function of the module immediately preceding it. For each of the three training modules, there was no significant effect of preceding module (one-way ANOVA; $P =$ NS).

Training Module Effects. We assessed the changes in maximum reading speed on the outcome reading test as a function of training module collapsed across all orders. The mean change in reading speed for each module is shown in Figure 4. There was an average decrease of 8.4 ± 7.2 wpm for the PRL awareness training (module 1), an increase of 27.3 ± 6.8 wpm for eye movement training (module 2), and a decrease of 9.8 ± 7.2 wpm for RSVP reading training (module 3) (one-way repeated-measures ANOVA, $P < 0.001$). Post hoc Tukey test analyses showed significant differences ($P \leq 0.05$) between eye movement control (module 2) and both PRL awareness (module 1) and RSVP reading (module 3).

We tested the hypothesis that the mean of each module's training effect was greater than zero. For modules 1 and 3, *t*-test results were not significant, demonstrating that the changes in reading speed were statistically not different from a

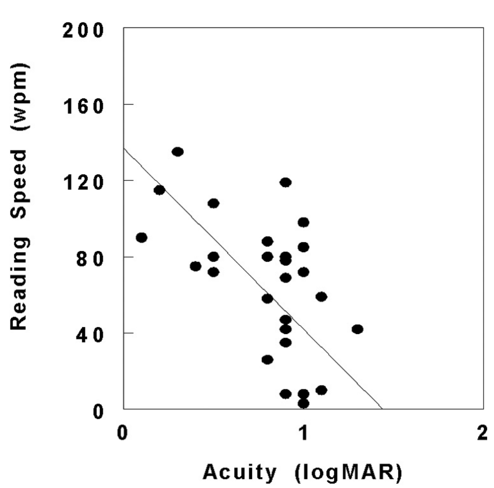

FIGURE 2. Reading speed at baseline is plotted against fixation stability at baseline.

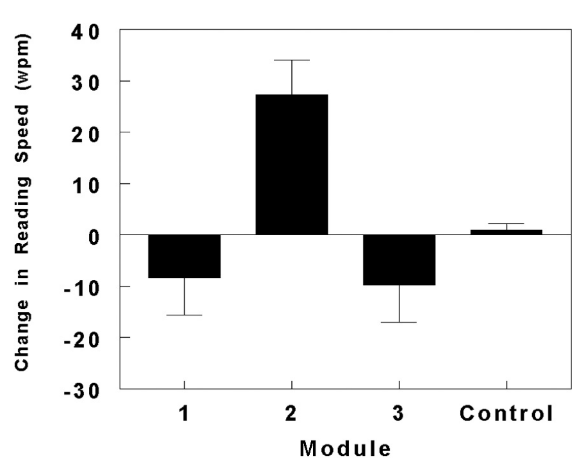

FIGURE 4. Average (+SD) change in reading speed as a function of training module collapsed across all training orders.

zero change. For module 2, we were not able to reject this hypothesis, demonstrating a significant improvement in reading speed ($P = 0.0002$).

After training with module 2, there was a significant, but low, correlation between baseline acuity and change in reading speed (Fig. 5; $r^2 = 0.19$; $P = 0.02$) and between age and change in reading speed (Fig. 6; $r^2 = 0.22$; $P = 0.02$). Reading speed change was not correlated with baseline contrast sensitivity, duration of disease, or baseline fixation stability ($P > 0.05$).

Control Group

We compared these findings for the training modules with the data from a control group ($n = 6$) who had no training. For the control group, the mean age was 78.4 years, the mean acuity was 0.9 logMAR, the mean baseline reading speed was 49.3 wpm, and the mean PRL eccentricity was 8.7°. There was no systematic increase in reading speed over the course of repeated testing. For the control group, average reading speed increased 3.8 wpm between the baseline assessment and assessment 1; between assessment 1 and assessment 2, the average reading speed decreased 9.6 wpm; and between assessment 2 and assessment 3, the average reading speed increased 11.7 wpm. The average difference between the reading speeds at baseline and those recorded after the entire 16 weeks of the control condition (assessment 4) was 0.96 (± 1.3 wpm) (Fig. 4).

Changes in Perceived Function

Differences between the pre-training and post-training questionnaire responses were analyzed. All subjects answered all questions on each visit, and the data were analyzed by sorting based on perceived item difficulty. The pre-training ranking of item difficulty is shown in Table 3 from rank 1 (least difficulty) to rank 48 (most difficulty).

Among the items with which the subjects reported the most difficulty were questions about reading performance and recognition of small text. For these items, the median change in score after training was −5 per item, whereas the median change in response scores for all the other items was −2 per item (rank sum, $P = 0.028$). There was no significant correlation between change in reading speed on module 2 and change in response scores across all questions (Spearman rank order $\rho = -0.148$; $P = 0.56$). There was also no significant correlation between change in reading speed on module 2 and change in response scores for only the reading questions (Spearman rank order $\rho = 0.004$; $P = 0.98$).

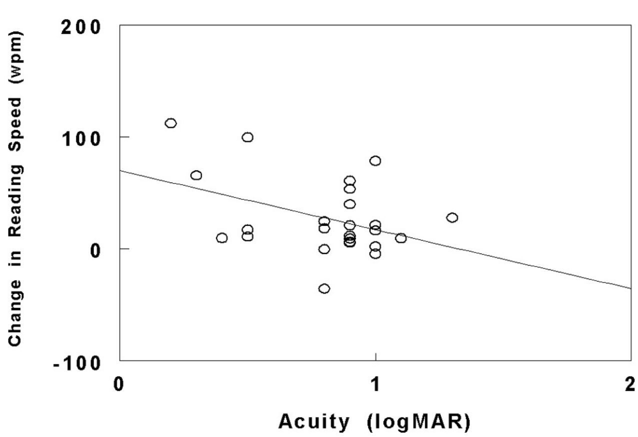

FIGURE 5. Scatterplot of changes in reading speed as a function of acuity, after training in module 2.

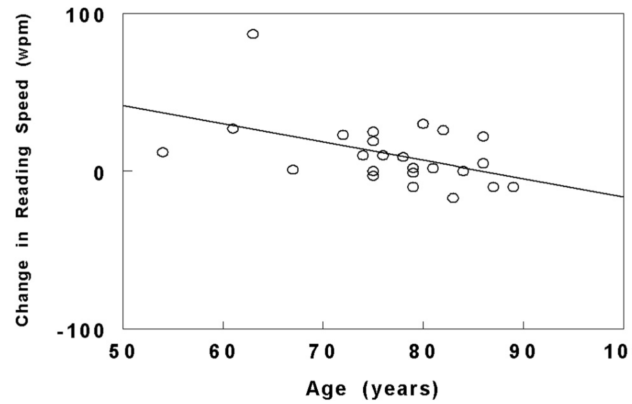

FIGURE 6. Scatterplot of changes in reading speed as a function of age, after training in module 2.

Discussion

Our results demonstrate that eye movement control training, even without direct reading practice, increased reading speed in our sample of individuals with AMD. The magnitude of the reading speed improvements we observed in the present study was in agreement with our previous work[22] and was of the same order of magnitude as those effects previously reported in the literature. For example, Nilsson[29] reported an increase of 50 wpm and Frennesson et al.[19] reported an improvement of 46 wpm after being given low-vision devices and training.

Reading, Aging, and Age-Related Macular Degeneration

Reading rates decrease with increasing age in normally sighted subjects.[34,35] The causes of decreased reading performance include decreased clarity of the ocular media, decreased accuracy and latency of eye movements, and decreased performance on divided attention tasks.[36–38] More general cognitive losses may also play a secondary role in decreased reading speed.[39] Combining these effects of aging with macular disease further decreases reading performance.[13–15,17,40] Legge et al.[34,41] found that reading rates in older persons with central vision loss range from one-fifth to one-third the rate in visually healthy older subjects.

Although sensory losses, such as decreased acuity and contrast sensitivity,[8,42] may be compensated for by altering the physical text size or by using magnification devices, failure to properly place the PRL on the text to be read, coupled with the inaccuracy of saccades to the next position, must also play an important role in decreased reading speed.[2,4,10,16,43–49] The present results suggest that oculomotor deficits may play a large role in slowed reading speed. There is support in the literature that the oculomotor skills needed for reading with a PRL are trainable. Hall and Ciuffreda[50] reported a 21% increase in reading speed after auditory feedback to the training of reading eye movements, and Solan et al.[51] reported an average 17% (36 wpm) increase in reading speed. We previously reported an average increase of 27.5% in reading speed after training eye movement control.[22]

Effectiveness of Low-Vision Rehabilitation Training

Persons with central vision loss typically undergo vision rehabilitation consisting of the prescription of magnification optical aids, PRL awareness training, or both.[23–26,52,53] There are few performance-based data in the literature on which to evaluate the effectiveness of such rehabilitation. Some insight may be

Table 3. Ranking of Item Difficulty

Rank	Item	Rank	Item
1	KEEP CLEAN?	25	FIND SOMETHING ON A CROWDED SHELF?
2	GET AROUND INDOORS IN PLACES YOU KNOW?	26	GET DOWN STEPS IN DIM LIGHT?
3	PHYSICALLY GET DRESSED?	27	RECOGNIZE PERSONS UP CLOSE?
4	EAT AND DRINK NEATLY?	28	HANDLE FINANCES?
5	GET AROUND OUTDOORS IN PLACES YOU KNOW?	29	GO TO MOVIES?
6	GROOM YOURSELF?	30	CLEAN THE HOUSE?
7	AVOID BUMPING INTO THINGS?	31	USE PUBLIC TRANSPORTATION?
8	SIGN YOUR NAME?	32	WATCH TV?
9	FIX A SNACK?	33	READ MAIL?
10	TELL TIME?	34	SEE PHOTOS?
11	IDENTIFY FOOD ON A PLATE?	35	READ SIGNS?
12	TAKE A MESSAGE?	36	READ NEWSPAPER OR MAGAZINE ARTICLES?
13	GET AROUND IN A CROWD?	37	KEEP YOUR PLACE WHILE READING?
14	FIND PUBLIC RESTROOMS?	38	GO TO SPECTATOR EVENTS?
15	MATCH CLOTHES?	39	PLAY TABLE AND CARD GAMES?
16	ADJUST TO BRIGHT LIGHT?	40	GO OUT AT NIGHT?
17	IDENTIFY MEDICINE?	41	RECOGNIZE PERSONS FROM ACROSS THE ROOM?
18	IDENTIFY MONEY?	42	READ MENUS?
19	READ HEADLINES?	43	READ SMALL PRINT ON PACKAGE LABELS?
20	MAKE OUT A CHECK?	44	READ STREET SIGNS AND STORE NAMES?
21	CROSS STREETS AT TRAFFIC LIGHT?	45	WORK ON YOUR FAVORITE HOBBY?
22	GET AROUND IN UNFAMILIAR PLACES?	46	DO YARD WORK?
23	PREPARE MEALS?	47	READ PRINT ON TV?
24	USE APPLIANCE DIALS?	48	PLAY SPORTS?

garnered from a publication by Nilsson,[29] in which he described the results of a vision rehabilitation study of 40 patients with AMD. In the design of this study, the behavioral outcomes were compared for two groups: a trained group who received education by a low-vision therapist in the use of low-vision devices and the use of residual vision through eccentric viewing training and an untrained group who received low-vision devices and instruction on using them but no training. After training, 70% of the subjects were able to read television titles, 100% could read newspaper text, and 85% could write letters, compared with the untrained group's percentages of 0%, 25%, and 20%, respectively. Reading speeds increased from 0 to 75.7 wpm in the trained group versus 0 to 22.6 wpm in the untrained group. Watson et al.[54] examined the effect of training on reading speed, accuracy, and comprehension. Subjects with macular disease were divided into three groups: those who received no training, those who practiced at home with no training, and those who received training. The trained group received biweekly training in comprehension strategies, making use of Gestalt principles of closure to fill in missing words. This study reported a significant effect of training on comprehension, with statistically significant differences between training and no training. These findings further emphasize that rehabilitation training is an essential part of an intervention strategy for individuals with low vision.

Numerous studies have evaluated the efficacy of low-vision rehabilitation based on patients' reports of perceived outcomes.[55–58] However, few studies have directly compared different approaches to reading rehabilitation using performance-based outcome measures. In the present study, we compared changes in reading performance as a function of rehabilitation approach. We compared traditional PRL training, oculomotor training, and reading practice without reading eye movement methods in individuals with central scotomas. Eye movement control training significantly improved reading speed. In contrast, we found that exercises designed to improve PRL awareness did not result in increased reading speed. Similarly, exercises in which the subjects practiced reading without eye movement did not improve reading performance. This does not mean that these later training exercises have no value; it suggests that they are not effective for reading rehabilitation. This finding is potentially important because many individuals seek rehabilitation based on their inability to read,[18] and most of the sites surveyed by Stelmack et al.[59] used reading exercises as a major part of their training curricula. The functional value of these increases in reading speed can be appreciated in the following example. The average baseline reading speed of our subjects was 73.3 wpm. After training on module 2, the average reading speed increased to 93.1 wpm. Assuming that a typical paperback book contains 350 words per page, reading 10 pages at the average baseline reading speed of our subjects would require 47.7 minutes. At the post-training speed, the same text could be read in 37.6 minutes, translating to a saving of approximately 1 minute per page.

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