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Developing Visual and Reading Efficiency in Older Adults

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ABSTRACT

The authors hypothesized that adults, ages 62 to 75 years, who are in good health for their age can be trained to read more efficiently using approaches similar to those reported for younger individuals. Recruited successively from the State College of Optometry's primary care clinic, the subjects were 20 volunteers who had minimum corrected Snellen visual acuity of at least 6/9 (20/30) at distance and near, no oculomotor anomalies, and no significant ocular diseases such as diabetic retinitis. After a reading efficiency pretest using the Eye-trac, an infrared eye-movement recording device, the subjects were assigned to either a control group or a reading efficiency training group. Those in the control group were tested again after the control period. All subjects were retested after experimental intervention that consisted of rapid visual processing, oculomotor, and Guided Reading training. The results revealed a statistically significant and clinically meaningful improvement in all aspects of reading efficiency, including reduced number of fixations and regressions per 100 words, increased average span of recognition, and improved reading rate without loss of comprehension, only in those who received training. Our recommendation is that training in reading efficiency should be stressed to a greater extent in reading, educational, and vision therapy programs at all age levels.

Key Words: reading efficiency, Eye-trac, visual processing, fixations, regressions, span of recognition, older adults

Although the professional literature does not dwell upon it, most people between 60 and 80 years of age are healthy individuals.[1] They live independently, drive a car or use public transportation, shop in supermarkets, go to the movies and sporting events, play cards, and read books. They are capable of compensating for the anatomic and physiologic changes associated with "normal" aging. This article focuses on those older individuals who are healthy despite the usual cardiovascular limitations, hearing impairment resulting from presbycusis, and musculoskeletal changes. We are not, however, dismissing the fact that other maladies such as acute cardiovascular diseases, diabetes, neurologic disorders, advanced osteoarthritis, and immunologic diseases seriously affect other adults, and that the prevalence and seriousness of these conditions increase with age.

Normal anatomical/physiological visual system aging, such as reduced retinal luminance, slower dark adaptation, and incipient cataracts, encourages the development of compensatory and adaptive strategies. In the absence of overt ocular pathology, such as macular degeneration, diabetic retinopathy, glaucoma, and cataracts, most senior citizens develop suitable adaptive strategies for seeing. For example, a common reading adaptation is to increase luminance while, at the same time, avoiding glare. Sensitivity to glare, also evident during other daily activities, i.e., when driving, is a common complaint that is often exacerbated by the normal reduction in dark adaptation that is associated with aging. A decrease in contrast sensitivity may also impact on reading. This change, especially at intermediate and high spatial frequencies, may be precipitated by the concurrent reduction in retinal luminance that is characteristic of older adults.[2] Senior citizens also readily adapt to other age-related changes such as floaters (muscae volitantes), tearing, dry eyes, and small reductions in visual acuity.

In this investigation, we are concerned with the centrally mediated visual skills necessary to read efficiently, namely, visual information and cognitive processing and oculomotor efficiency. Morgan,[2] in an autobiographical assessment of his visual status recounted from the point of view of an octogenarian, stated:[3]

> The most aggravating aspect of my vision is the feeling I have that it doesn't work as effortlessly or as quickly as it did when I was younger. It seems to me that I must now concentrate more than I did before to have the same perceptual results. Just plain seeing in simplified situa-

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tions, as in vision testing, seems as good and as quick as ever, but perceiving the meaning of a complex, ever changing scene is definitely more difficult. (p. 280)

Efficient reading presupposes that the individual sees the print in a book clearly, is able to sustain effort comfortably for extended periods of time, and comprehends what is read. These criteria imply that the person has been examined and provided with glasses that yield a binocular visual acuity of at least 6/9 (20/30) at distance and near. Other binocular vision measurements should approximate the clinically expected values. When a visual analysis reveals a binocular dysfunction in an older adult, i.e., convergence insufficiency, the prognosis for improvement with vision training is usually favorable.[4]

A number of studies have investigated oculomotor dynamics with nonreading targets in younger and older adults. Spooner et al.[5] reported that when measures of visually controlled saccadic and smooth pursuit movements were compared for velocity and latency in younger (42 years) and older adults (65 years), the younger subjects were consistently and significantly superior to the older group. The older group showed more variability in their responses than the younger group. These data do not, however, indicate whether the decline was linearly related to age. Another more recent investigation did not reveal an age-related decline in saccadic velocity, although there was a significant age-related decline in latency.[6] This latter result may indicate that although the brainstem saccadic generator is not affected by age, the higher cortical centers involved in programming saccades (latency effect) deteriorate with age. It is also of interest that in this study the saccades of the younger subjects were more accurate, although not faster, than those of the older group. On the other hand, Warabi et al.[7] found that although a longer time was necessary for older individuals to locate a visual target, the accuracy of the saccades was no different from that of young subjects. He also found that the older subjects showed an increase in saccadic latency along with a decrease in saccadic velocity, the same finding reported by Spooner et al.[5] Although the data from these experiments are suggestive, they do not necessarily relate to saccadic eye movements under reading conditions.

A series of investigations by Walsh and his colleagues confirmed a significant age-related slowing in the speed of central and peripheral visual processing.[8,9] They reported that studies of age differences in central visual perceptual processes have consistently found that older adults (60 to 70 years) require processing times about 25% longer than young adults (20 to 30 years). Although both younger and older adults improved after visual processing training, the age *difference* was not altered. In two of these studies, the speed of processing of an older group after training approached the scores of a younger group before training, but a significant difference between the two groups persisted.[10,11] Sekular and Ball[12] also found that older adults showed a significant practice effect in a selective attention visual search task (useful field of view), even in the presence of distractors. It appears that although visual and cognitive processing resources may change with age, older individuals can continue to be adaptable information processors throughout life.[13] Furthermore, it has been found that verbal ability and education are even better predictors of recall than age.[14,15] In addition, although new skills may take longer for elderly subjects to acquire, once learned, they can be retained quite well.

With aging, extracting the structural organization, selecting the salient features, and seeing patterns in a text appear to become more difficult, thereby impeding comprehension.[16] Rice and Meyer[14] reported that people who can identify and use the structural organization of a text will recall more of it. Holland and Rabbitt[13] noted that when asked to recall the theme of a text, older adults tended to recall details rather than automatically processing the main points.

There is considerable evidence that practice can improve certain perceptual-motor skills in older individuals.[11,17] On the other hand, although Solan[18,19] has shown the salutary effect of visual processing and oculomotor training on the improvement of reading efficiency in high school and college students, it has not been demonstrated on older adults. Whether the techniques that improve reading efficiency by developing central processing and oculomotor skills in younger individuals can be applied successfully to senior citizens still remains unanswered. The purpose of this study is to test the hypothesis that reading efficiency can be improved with the appropriate visual training procedures in a group of healthy older adults, ages 62 to 75 years.

METHODS

Subjects

The 20 subjects were nonpaid volunteers, 62 to 75 years of age, from the New York Metropolitan area. They had a complete eye examination at the University Optometric Center/SUNY and responded to an announcement about a research study in reading and aging. They had corrected monocular Snellen visual acuity of at least 6/9 (20/30), no oculomotor anomalies known to impede reading efficiency (i.e., convergence insufficiency), and no ocular disease condition that would alter their acuity. All subsequent testing was done through the lens correction best suited for the task. Participants were selected without regard to gender, after each was verbally informed about the nature of the experiment and written consent was obtained.

Testing

Pre- and post-training measures of reading efficiency for all 20 subjects were obtained from eye movement recordings made with the Eye-trac (model 106, G & W Applied Science Laboratories, Waltham, MA). Subjects read a 6th grade level, 100 word selection while an infrared light system recorded their eye movements. A minimum comprehension of 80% on 10 true/false questions was required to validate the eye movement recordings. As the subject viewed a word or part of a word, a trace of the subject's binocular eye movements was inscribed on the recording tape. Four measures of reading efficiency were assessed. These were mean number of fixations per 100 words, mean number of regressions per 100 words, mean span of recognition (words per fixation), and mean reading rate with comprehension (words per minute).

The 20 subjects were recruited successively for the study in 2 phases. The Training Group was recruited first. The second group was the Control/Training Group. A pretest was given to each group. The Training Group (N=8) was given 8 weeks (16 sessions) of training followed by a post-training test. The Control/Training Group (N=12) was given an 8 week nonintervention control period, followed by a postcontrol period test. Eight of the 12 subjects from the Control/Training Group were then randomly selected and given exactly the same experimental intervention as the Training Group, followed by a post-training test.

Training

The experimental sessions lasted 1 h and included Guided Reading,[a] tachistoscope,[b] React,[c] and PAVE training (Perceptual Accuracy Visual Efficiency).[a] Each training program was conducted with a computer. The subjects viewed the screen at a distance of 50 cm. The room was dimly lit to reduce glare.

The purpose of tachistoscopic training was to develop rapid visual processing and enhance visual recognition and memory. In this study, the subject was instructed to look at briefly presented digits, about 5 cm in height, remember the numbers in sequential order, and enter them on the computer keyboard. As training progressed, the number of digits was increased and/or the exposure time was decreased gradually and progressively. The subjects spent about 10 min of each training session on 2 trials of 20 tachistoscopic exposures. The instructions to the subjects were to watch the screen for the numbers, rehearse them silently, and then type them. All training was initiated with 3 digits at 0.25 s. When a performance level of 90% was reached, the exposure time was decreased to 0.10 s. When that level was mastered at 90% correct, an additional digit was added and the exposure time reverted to 0.25 s.

The intent of the PAVE program, usually administered second, was to improve oculomotor efficiency as the subject observed a series of three letters or numbers presented left to right across the computer screen. The subject was asked to count the number of times one specific number or letter was seen, usually 6 to 9 times in 15 lines. Each correct response automatically advanced the rate of presentation 5 lines a minute faster. After 2 consecutive incorrect responses, the rate decreased by 5 lines a minute. Each training session included 12 trials.

The main purpose of the Guided Reading training was to improve reading efficiency. Improved reading efficiency consists of good left to right directionality, a reduction in the number of fixations and regressions (right to left fixations), and increased reading rate without loss of comprehension. These components can be seen in Fig. 1. From these primary measurements of eye movements, the average span of recognition and duration of fixation can be calculated. The reader extracts information from the text during fixational pauses of the eyes that consume about 90% of the reading time. Each fixation is separated by a rapid saccade or interfixation movement that brings a new region of the text into foveal vision for detailed analysis. Regressions are right to left eye movements made while reading. The return sweep from the end one line to the beginning of the next is not considered a regression. Among normal readers, regressions account for 10 to 20% of the total eye movements.[19]

The Guided Reading training sequentially exposes three words at a time in a left to right presentation on a computer screen at a predetermined rate. The moving slot trains directional attack inherently and, in addition, results in a decreased number of fixations and regressions. Each subject read two selections per session, which required about 30 min. Based on the initial testing, all subjects started with a grade 7 selection and progressed to grade 9 level. The first selection was unfamiliar to the subjects and was preceded by contextual examples of 10 words from the article. Part A of the selection was presented in paragraph form; Part B as Guided Reading. The instructions for Part A were to read as quickly as possible without sacrificing comprehension. The rate for Guided Reading in Part B was similar to the free reading in Part A. Comprehension was tested with 10 multiple choice questions based on information contained in the

[a] Taylor Associates, 200–2 East 2nd St., Huntington Station, NY 11746.

[b] American Vision Training, Inc., P.O. Box 197, Cicero, IN 46034.

[c] Life Science Associates, Bayport, NY 11705.

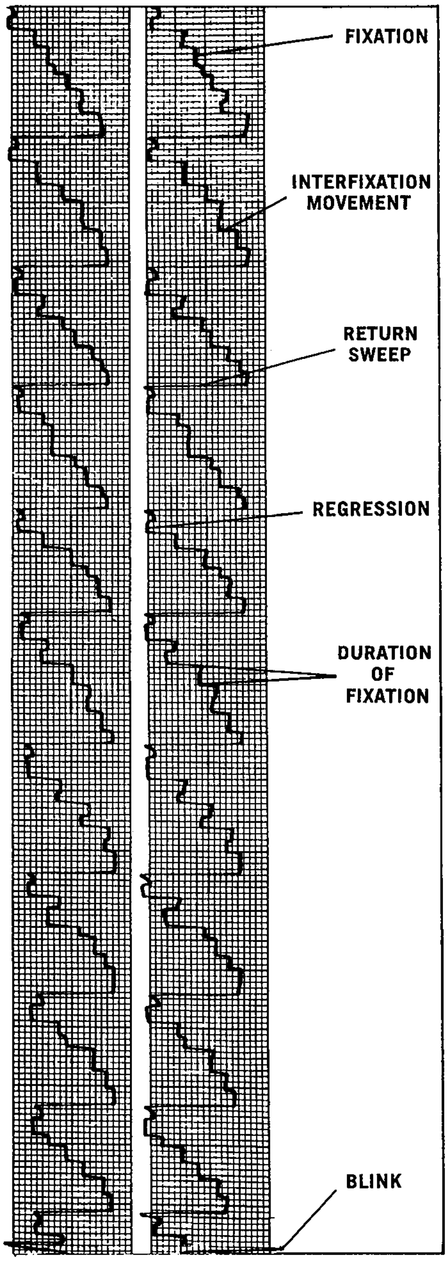

Figure 1. Diagram depicting how eye movement characteristics are represented in an Eye-trac recording. From *Eye-movement Analysis with the Reading Eye II*, by Helen Frackenpohl Morris, New York: McGraw-Hill, 1973.

reading. If a question was answered incorrectly, the relevant portion of the passage reappeared on the screen with the words "Please read carefully." The question was then repeated, but no credit was awarded. The second reading selection in each session was the previous week's first passage. The purpose was to read as quickly as possible because comprehension was not tested and the selection was already familiar. The whole selection was presented as Guided Reading, and the rate increased incrementally to about 50 words a minute faster than for the first selection.

React training was designed to develop a high level of visual attention, central and peripheral awareness, and a rapid visual reaction time. The subject, unaware of where the stimulus would appear on the screen, was instructed to view the center of the computer screen and to push the response button as soon as the stimulus was seen. The stimulus consisted of rapidly advancing numbers that would freeze when the subject responded. The visible number represented the fraction of a second required for the subject to respond. Two trials of 20 central and peripheral stimuli were presented for about 10 min each session.

After all the training was completed, the before and after eye movement measurements from the Eye-trac were transformed to Grade Equivalent scores.

RESULTS

The pretest and post-training test performance of the Training Group was assessed with a repeated measures t-test using a two-tailed test of significance (Table 1). The performance of the Control/Training Group was assessed with a one-way repeated measures analysis of variance (ANOVA) using a two-tailed test of significance (Table 2). The ANOVA compared differences in mean performance between the pretest, postcontrol test, and the post-training test. The ANOVA was used to control for experiment-wise error-rate, which would be violated if multiple t-tests were used. If a significant ANOVA was found for any measure, a Tukey paired comparisons *post hoc* analysis was then used to identify the source of the differences between each pair of the three means.

Table 1 depicts the change in mean number of fixations for the Training Group before and after training. A t-test revealed a significant 20% decrease in fixations, from a mean of 97.5 before training to 78.1 fixations after training, $t = 3.34$, $df = 7$, $p = 0.012$. Table 2 portrays the performance of the Control/Training Group. These subjects showed a 5% decrease in mean number of fixations after the control period, from 108.0 to 102.3. However, after training the mean number of fixations decreased about 16% further, to 86.0. An ANOVA revealed an overall significant difference among the three test means (pretest, post-control, and post-training), $F(2/18) = 7.94$, $p < 0.003$. A Tukey paired comparison test showed that the mean number of fixations was not significantly different between the pretest and the post-control period performances. However, the mean number of fixations for each of these tests was significantly higher than that after the post-training period ($p < 0.01$ and $p < 0.05$, respectively). Thus, the mean number of fixations decreased only after the training period.

TABLE 1. Means, SD's, and grade equivalents are shown for each measure of reading efficiency in each phase of testing[a]

	Training Group		
	Pretest (N = 8)	Post-Training (N = 8)	p
Fixations (per 100 words)	97.5	78.1	
SD	(19.1)	(12.1)	0.012
Grade Equivalent	Junior High School	College	
Regressions (per 100 words)	14.4	8.6	
SD	(5.0)	(3.8)	0.004
Grade Equivalent	High School	College	
Average Span of Recognition (words per fixation)	1.06	1.30	
SD	(0.2)	(0.2)	0.012
Grade Equivalent	Junior High School	College	
Rate of Reading (words per minute)	207.4	243.5	
SD	(42.1)	(48.6)	0.075
Grade Equivalent	5th Grade	6th Grade	

[a] p values are two-tailed repeated measures t-test.

TABLE 2. Means, SD's, and grade equivalents are shown for each measure of reading efficiency in each phase of testing[a]

	Control/Training Group			
	Pretest (N = 12)	Postcontrol (N = 12)	Post-Training (N = 8)	p
Fixations (per 100 words)	108.0	102.3	86.0	0.003
SD	(24.7)	(23.6)	(13.4)	
Grade Equivalent	6th Grade	6th Grade	High School	
Regressions (per 100 words)	21.2	18.5	12.4	0.008
SD	(9.2)	(9.8)	(6.2)	
Grade Equivalent	6th Grade	Junior High School	College	
Average Span of Recognition (words per fixation)	0.96	1.00	1.17	0.002
SD	(0.19)	(0.25)	(0.16)	
Grade Equivalent	6th Grade	6th Grade	High School	
Rate of Reading (words per minute)	202.2	209.8	252.1	0.001
SD	(55.2)	(54.8)	(55.5)	
Grade Equivalent	5th Grade	5th Grade	Junior High School	

[a] p values represent overall ANOVA significance. For each reading measure, the Tukey test was used to compare each pair of means. No significant differences were noted between any pretest and postcontrol test. Post-training test scores were significantly better ($p > 0.01 < 0.05$) than either the pretests or postcontrol tests for all measures.

Tables 1 and 2 show the changes in the mean number of regressions for the Training Group and the Control/Training Group, respectively. The Training Group showed a 40% decrease in mean number of regressions (from 14.4 to 8.6) after training, which was significant, $t = 4.31$, $df = 7$, $p = 0.004$. The subjects in the Control/Training Group showed about a 13% decrease in mean number of regressions between the pretest and the postcontrol test (from 21.2 to 18.5), and about a 33% decrease in mean number of regressions, to 12.4, in the post-training test. The ANOVA revealed statistical significance for differences among the three test periods, $F(2/18) = 6.33$, $p < 0.008$. A subsequent Tukey paired comparisons test confirmed a significant decrease in the mean number of regressions between the pretest and the post-training test ($p < 0.05$) and between the postcontrol test and the post-training test ($p < 0.05$).

Significant changes in average span of recognition for the Training Group are noted in Table 1. As shown, for the Training Group there was a significant 23% increase in average span of recognition after training, from 1.06 to 1.30 ($t = 4.31$, $df = 7$, $p = 0.012$). The results of the Control/Training Group are shown in Table 2. These subjects achieved a 4% increase in average span of recognition after the control period, from 0.96 to 1.00. After training, the average span of recognition increased about 17%, from 1.00 to 1.17. An ANOVA revealed a statistically significant difference among the three tests, i.e., the pretest, postcontrol test, and the post-training test [$F(2/18) = 8.54$, $p < 0.002$]. Tukey *post hoc* paired comparisons revealed significant increases in average span of recognition only between the pretest and the post-training test ($p < 0.01$) and between the postcontrol test and the post-training test ($p < 0.05$). In general, training produced a significant increase in average span of recognition.

In Table 1, the mean rate of reading with comprehension for the Training Group increased 17%, from 207.4 to 243.5 wpm. This improvement was in the predicted direction, but did not attain significance ($t = 2.09$, $df = 7$, $p = 0.075$). The Control/Training Group, seen in Table 2, shows a 2% decrease in mean rate of reading, from 202.6 to 198.6 wpm after the control intervention. After training, however, the mean rate of reading increased to 245.1 wpm, about 23%. An ANOVA revealed overall significant differences in reading rate among the three test periods [(2/18) = 10.53, $p < 0.001$]. As was generally the case in other experiments the fixations, regressions, and span of recognition, Tukey *post hoc* paired comparisons showed significant increases in reading rate after training compared to the initial pretest, $p < 0.01$, or compared to the postcontrol period test, $p < 0.01$. All of the results are summarized in Tables 1 and 2.

DISCUSSION

The outcome of the reading efficiency training was statistically significant with each of the four measures of reading efficiency in the predicted direction. The magnitude of the improvement was considered clinically meaningful because most measures improved by several years. Training significantly decreased the number of fixations and regressions and increased the span of recognition and the reading rate without loss of comprehension. These findings are consistent with our initial hypothesis that a specific program of training can improve reading efficiency in older adults. Although prior research[11,17] indicating that cognitive processing can be improved in a geriatric population through the use of remediation and/or training has been cited, this study is the first example of applying the techniques to measures of reading efficiency for subjects over the age of 62 years.

Because fixations and regressions while reading are not usually under conscious control, they reflect a high degree of automaticity. Provided that the reading selection is not difficult to comprehend, previous research has shown that the reading pattern of teenagers and younger adults can be improved with training so that the reader will *automatically* make fewer eye stops.[18,19] The current study broadens this finding to older adults and also shows that improvement in reading efficiency results in a larger span of recognition for each fixation in this population.

When compared to fixations and regressions, the rate of reading in older adults does not have the same degree of automaticity. There are a number of other factors that tend to limit improvement in reading rate, especially when the older subject knows that comprehension is being measured. First, oculomotor responses affect reading rate. For example, either an increase in saccadic latency or a decrease in saccadic velocity with aging could impede the rate of reading.[5–7] Second, the slower rate of central visual processing in older adults[8,9] would normally limit the improvement in reading rate. However, it is possible that the tachistoscopic training in our study tended to compensate for any deficit in speed of visual processing that may have been present. A third factor related to reading speed of older adults appears to be psychological in nature. Evidence of reluctance to read the selections rapidly was often observed during the course of training. This overly cautious behavior seemed to emanate from a combination of an underlying state of anxiety associated with not being able to answer the questions correctly at the end of the passage, plus a sense that missing a question was unacceptable. Although each subject was reassured, this concern was especially apparent, according to subjects' verbalizations, at the time of the final testing on the Eye-trac.

Nevertheless, the results of the training support the initial hypothesis that, with the appropriate program, reading efficiency can be improved significantly in a population of healthy older adults, ages 62 to 75 years.

CONCLUSION

We have discussed just one aspect of reading improvement: reading efficiency in older adults. Reading disorders, however, can take many forms. For example, individuals with specific reading disabilities often show poor word attack skills, poor sight recognition of words, and deficits in a myriad of comprehension skills such as understanding main ideas, drawing conclusions, and reasoning. The standardized reading tests that appraise reading performance frequently reveal a combination of these problems that require a number of remedial strategies. Rarely does the question of reading efficiency arise.

This study quantifies the level of reading efficiency in older individuals who present with average or better reading comprehension skills, but whose reading pattern is slow and laborious. Our subjects frequently showed slow visual processing, inefficient oculomotor skills, poor directional attack, and a slow reading rate. All of these visual functions improved significantly with the appropriate training intervention described previously. In general the subjects were satisfied that their reading after the training was more comfortable and efficient than before. They could read for a longer period of time with improved concentration. The statistical analysis of the results justifies this conclusion in this population of older adults. Prior studies cited earlier noted that similar improvements were attainable in adolescents and young adults. There appears to be sufficient evidence that reading efficiency should be stressed to a greater extent in reading, educational, and vision therapy programs in all age groups and at all reading levels. The outcome of this study supports the role of the optometrist in improving the quality of life of older individuals through enhanced visual functioning.

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