DOCUMENT RESUME

ED 111 116 EC 073 352

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| AUTHOR | Ross, Alan O. |
| TITLE | The Relationship of Saccadic Eye Movements to Reading Disabilities. Final Report. |
| INSTITUTION | State Univ. of New York, Stony Brook. |
| SPONS AGENCY | National Inst. of Education (DHEW), Washington, D.C. Office of Research Grants. |
| PUB DATE | Dec 73 |
| GRANT | OEG-2-2-2B024 |
| NOTE | 26p. |
| EDRS PRICE | MF-$0.76 HC-$1.95 Plus Postage |
| DESCRIPTORS | Childhood; Exceptional Child Research; *Eye Movements; *Eyes; Learning Disabilities; Program Effectiveness; *Reading Difficulty; *Remedial Reading; Tutoring; *Visual Perception |
| IDENTIFIERS | *Saccadic Eye Movements |


ABSTRACT

Saccadic (small, rapid, and apparently involuntary) eye movements of 14 children (7- to 12-years-old) with reading difficulties and of 14 normal readers were compared before and after the problem readers underwent a 7-month individual tutoring program. At pretesting the problem readers showed a rate of eye movements that was markedly lower than that of the normal readers whose rate they attained and surpassed or surpassed at completion of the remedial reading program. Results suggested that saccadic eye movements are not involuntary and are susceptible to training for improved reading, attention, and information gathering. (Author/DB)

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Final Report

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# THE RELATIONSHIP OF SACCADIC EYE MOVEMENTS TO READING DISABILITIES

December 1973

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
National Institute of Education
(Regional Research Program)



EC073352

Abstract

Saccadic eye movements of 14 children with reading difficulties and of 14 normal readers were compared before and after the problem readers underwent a 7-month individual tutoring program. At pretesting the problem readers showed a rate of eye movements that was markedly lower than that of the normal readers whose rate they attained and surpassed at completion of the remedial reading program. Results are discussed in terms of the presumed function of saccadic eye movements and their relation to reading, attention, and information gathering.

FINAL REPORT

Grant No. OEG-2-2-2B024

# Saccadic Eye Movements and Reading Difficulties

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15 December 1973

The research reported herein was performed pursuant to a grant from the National Institute of Education, U. S. Department of Health, Education, and Welfare. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official National Institute of Education position or policy.

U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

National Institute of Education

Office of Research Grants

While it seems reasonable to assume that there is a relationship between reading and eye movements and that children who manifest deficient reading skills should therefore have atypical eye movements, the research literature on this relationship is equivocal. Tinker (1958) reported that improved reading is reflected in changed occulomotor patterns, but stated that the study of eye movements in reading had reached the stage of diminishing returns. He therefore suggested that "The future study of eye movements in reading does not appear to be too promising [p. 229]." In a similar vein, Taylor (1965), addressing himself to the "facts and fallacies" regarding eye movements in reading, concluded that, "Eye movements are neither the cause nor the effect of good or poor reading [p. 199]." The interest in this relationship had nonetheless persisted. Some (e.g. Schmidt, 1966) report that eye movements undergo significant change during a reading course, and others (e.g., Gilbert, 1959) find

that certain eye movements interfere with reading efficiency.

Goldberg and Arnott (1970) have pointed out that conflicting research results may be a function of the different methods used in recording eye movements. A perusal of the literature further suggests that there is little agreement among investigators as to which of several aspects of eye movements should be examined in connection with reading or on how to analyze a record of these movements once it has been obtained. Goldberg and Arnott (1970), for example, examined the overall pattern of the gross, sweeping movements of the eyes as they follow a line of print, while Gilbert (1959) was interested in the miniature eye movements called saccades. These, as Dodge (1903) defined them long ago, are rapid small movements of the eyes which occur one to three times each second. The person is not ordinarily aware of making these movements, they have, in fact, been considered involuntary. Their function has recently become the object of renewed interest and research (Steinman et al., 1973). Some have suggested that saccadic eye movements (SEM) are related to attention (Amadeo and Shagass, 1963; Antrobus, Antrobus, & Singer, 1964; Weitzenhoffer &

Brockmeier, 1970) but these investigators differ on whether the two variables are positively or negatively correlated.

We became interested in SEM when we observed that deaf children emit them at a higher rate than hearing children. We later found that SEM rate can be changed by operant conditioning procedures, with low SEM rates associated with poor performance on a memory task[2]. These observations led us to the tentative conclusion that SEM may have an information gathering function. Preliminary work, comparing children with reading problems with normal readers confirmed this impression inasmuch as the problem readers emitted a much lower SEM rate than the normals even when the visual stimuli were random polygons, which were quite unlike printed material. Encouraged by these early findings, we decided to investigate the relationship between SEM and reading difficulties by making relevant comparisons before and after a seven-month program of individual reading tutoring.

Method

Subjects. Thirteen males and one female, ages 7 to 12 (Median age 9), who had been referred by their teachers

and/or parents to a University reading program as problem readers participated in the study and were assigned to the experimental group. The children were from middle class backgrounds and they were neither severely deficient in academic areas other than reading nor were they significant behavior problems. The Spache Diagnostic Reading test and the Gilmore Oral Reading test were used to assess their reading level. All scored below their grade reading level and, according to their school records, all were at least six months retarded in reading. Two of the children were repeating a grade, having been held back because of their reading difficulty.

Fourteen children, matched with the problem readers by age and sex, were selected for the control group. These children were attending a public school and had no academic or other relevant difficulties. The Spache and Gilmore reading tests showed all of them to score at or slightly above their grade reading level.

Apparatus. S reclined in a lounge chair (Barcalounger) which had been modified by the addition of a cushioned headreast that restricted head movements. Room dividers

were positioned on either side of the chair. Located 6 feet behind and above the S was a Kodak Carousel slide projector, so positioned that it could project images on a 50 x 50 inch screen which was centered approximately 84 inches from the eyes of the S. This allowed each S to view the screen at a comfortable 30 degree angle. Also behind and to one side of S were the recording and timing devices. These consisted of a Beckman Type RB Dynograph, equipped with a Beckman 9853 Strain Gage Coupler, and a Hunter 100-C timer which controlled the slide projector. Beckman skin electrodes, mounted with adhesive collars and electrode paste, were placed near the outer canthi of the eyes with an ear-clip reference electrode on the left earlobe.

The stimulus slides consisted of 10 color photographs of panoramic natural scenery, 15 black and white vertically arranged pairs of 4- or 5-letter words, and 10 colored objects taken from commercially available flash cards. (Also presented, but not included in the data analysis, were 5 additional object slides and 5 slides of black and white random polygons.) The order of presentation was the same for all Ss: photographs, words, and objects.

Magnification was such that the image would occupy all of the screen except 10 inches at each side. Exposure time for each slide was 10 seconds.

Measurements. The Dynograph with the electrode placement described permits one to obtain a graphic analogue of lateral eye movements, by a method known as electro-oculography (Shackel, 1967). This method is based on the fact that there is a difference in standing potential between the front and the back of the eyeball. This potential field moves as the eye rotates so that electrodes placed on the skin near the eye will detect resulting changes in direct potential. The Dynograph was so adjusted that 1 degree of lateral eye movement was shown as a 1 mm deflection of the recording pen on the tape which moved at 10cm/sec.

In analyzing the polygraph record we scored any pen deflection of 2mm or more; that is, any movement of 2 degree or more was considered a scorable scan. In scoring records of this nature

it is necessary to set an arbitrary criterion because the saccadic movements with which we were concerned are superimposed on miniature movements which occur at all times, even when the eye is supposedly stationary and when no visual stimuli are being presented. It is thus necessary to differentiate this "physiological nystagmus" (Steinman et al., 1973) from saccadic movements. Investigators in this field have yet to agree on a convention for scoring saccadic eye movements (Weitzenhoffer & Brockmeier, 1970). We expressed our data as total scans per second (TSS) by counting eye movements as defined and obtaining an average over time. For each S we calculated a TSS score for photographs (10 stimuli averaged for each S), for words (average for 15 stimuli), and for objects (average for 10 stimuli). These individual averages for each category were then summed across the 12 Ss in each group and these are the data reported below.[3]

Procedures. The children were told that the "buttons" would not hurt, that we needed them

to find out what their eye muscles were doing while they were watching some pictures on the screen. They were instructed to look at the screen and to watch each slide carefully because they would be asked some questions about the slides at the end. If any words appeared they were to read them out loud. After seating the child, affixing the electrodes, and giving the instructions, the E withdrew to a position behind the S to operate the equipment.

Each S was shown all 45 slides on two occasions, separated by 7 months for the pre- and post-test. A session lasted about 15 minutes and after the presentation of the slides the children were asked some irrelevant questions such as which they had liked best.

The children in the control group were not contacted between the pre- and the post-testing sessions. In that seven-months interval, the children in the experimental group participated in a remedial reading program with individual tutoring. As described elsewhere (Heiman, Fischer

& Ross, in press), seven of these children also participated in a supplementary program which involved a point system to reinforce attention to and identification of letter and word combinations. While the reading performance of all of the children in the remedial program improved by an average of 1.2 years, the seven who had also been in the supplementary program showed a significantly greater gain than the other seven who, as yoked controls, had been shown the same materials but without a specific task and reinforcement, The supplementary program took place during the last seven weeks of the seven months remedial program and used the same room and equipment described earlier. While there was no specific reinforcement for eye movements, the children did wear the electrodes and looked at written material projected on the screen.

## Results

The mean total scans per second for the three stimulus conditions, taken before and after

the seven months interval for the tutored deficient readers (experimental group) and the normal readers (control group) are shown in Figure 1. For both groups at both pre-test and post-test the word stimuli elicited

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Insert Figure 1 about here

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more eye movements than either the photographs of scenery or the pictures of common objects. This difference was less pronounced for the control group during pre-testing but emerges clearly on post-testing. Before the start of the remedial reading program, the children in the experimental group show a rate of eye movements that is markedly lower than that of the normal readers whose rate the retarded readers attained (and surpassed) at the completion of the remedial reading program.

Summing and avaraging across the three categories of stimuli, the total scans per second for the experimental (problem reader) group increased significantly from pre- to post-test ($t = 2.34$, 22, $p < .05$). For these children the increase in total scans per second for the word stimuli from 1.41 to 1.69 is significant ($t = 3.28$, 22, $p < .02$) while for the control group neither of these differences reaches the conventionally accepted

significance level.

While other comparisons between means failed to reveal significant differences, there was a significant ($p < .002$) change in the variances of scores for the control Ss from pre- to post-test (see Table 1).

Insert Table 1 about here

## Discussion

Our work has demonstrated a significant increase in the rate of lateral eye movements (saccades) to word stimuli for reading disabled children who had participated in a remedial reading program. It is obvious that a great many things took place during the seven-month interval between pre- and post-testing so that it is impossible to attribute this change in eye movements to any specific variable. Since no comparable change in mean scan rate was found for the normal readers who were the control group, the conclusion suggests itself that some aspects of the remedial reading program probably were responsible for the change. A report by Steinman, Haddad, Skavenski and Wyman (1973) which appeared since our work was completed permits one a speculation about

the implications of that change. Steinman et al. conducted a series of studies on miniature eye movements which led them to conclude that saccades take place both during maintained fixation and normal reading. They further suggest that these eye movement patterns represent a learned motor skill, used to maintain fixation and reduce visual error and that they are probably acquired early in life. They suggest that, "each individual originally learned to pattern the direction, size, and timing of fixation saccades to best serve his visual search of small parts of his visual field [p. 817]" and point to the "expectation of large individual differences [ibid.]." In the light of these conclusions we view our own findings to suggest that one of the consequences of learning to read is a change in the size and timing of fixation saccades so as to make these more functional for the task of reading. Normal readers have a relatively high scan rate, particularly when presented with words as stimuli; retarded readers have a much lower scan rate but as their reading improves, concurrent with a remedial reading program, their overall scan rate becomes quite similar to that of the normal readers. Again, this is particularly true when the stimuli are words; for other visual stimuli

the scan rate is lower for both normal and treated retarded readers. The "learned motor skill" of which Steinman and his colleagues speak (1973) thus may be quite specific to the particular situation in which it is performed.

With respect to the point raised by Taylor (1965), quoted at the beginning of this paper, eye movements seem indeed neither the cause nor the effect of good or poor reading but eye movements are an aspect of reading and as reading skills improve the eye movements here under discussion increase in rate. It is unlikely that a child's reading will improve if one limits one's intervention to increasing his saccadic rate but it is a question worth investigating whether the effect of a remedial reading program can be enhanced by giving the child concurrent training designed to increase the rate of his saccadic eye movements in relation to improved reading accuracy and comprehension.

Our data also permit a comment on the expectation of individual differences expressed by Steinman et al., (1973). As pointed out, the variance for our control group was almost ten times greater than that for the

experimental group during the pre-test session. During the post-test session the variances for the two groups were of the same order of magnitude, the variance for the control Ss having decreased by 20 to 25 per cent of the pretest value. Since variance around a mean is a reflection of the range of differences among individuals' scores, it would appear that the normal Ss were, in terms of visual patterns, a more heterogeneous group than the disabled readers. If this is not merely a statistical regression effect, this change from pre- to post-test might be tentatively explained if one recalls that the first testing took place early in the school year (shortly after the summer vacation) while the second testing was conducted close to the end of the school year. Could it be that the learned motor response represented by saccadic eye movements is, in elementary school children, not yet so well established that it remains stable over the summer vacation during which children's activities have a wide variation (e.g., from no reading at all to a great deal of reading)? By the end of summer saccadic eye movements might then be "all over the place", with relatively little differentiation in response to reading (words) and

non-reading (photos and objects) stimuli. These movements may then be brought back to a narrow (and reading relevant) range around the group mean by the far more uniform visual experiences demanded by school attendance. Seasonal variations in saccadic eye movements of young school children might be an interesting area to investigate.

Our work encourages us to view the eye movements we have studied as a response, modifiable through learning, which serves an information gathering function and varies with the nature of the visual stimulus presented. Like other operant responses it is, in other words, under stimulus control. This formulation clarifies for us why Weitzenhoffer and Brockmeier (1970) could not agree with Amadeo and Shagass (1963) on whether increased attention results in an increase or a reduction of SEM: they did not control for the nature of the visual stimulus. Attention is an aspect of information gathering but eye movements do not seem to provide a "pure" measure of attention, unrelated to the stimulus to which the S is attending. Contrary to Tinker (1958) we believe that further research on the relation of eye movements to reading is warranted. A logical step in this direction

might be to assess the saccadic eye movements of a reading readiness population and to follow them as they develop reading skills. It could be that children with an initially higher saccadic rate have an easier time becoming proficient at reading then those whose rate was lower. Research of this nature may eventually prove clinically useful but until more studies are carried out one can agree with Bond and Tinker (1967) that the routine study of eye movements in the reading clinic contributes no information that is essential for the reading teacher.

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## Footnotes

1 This study was supported by grant OEG-2-2-2B024 from the National Institute of Education.

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The valuable assistance of Mark J. Fischer and the help of Sandra Armel, Steven Rayack, and Betty White are gratefully acknowledged. Dr. Lowey, of the Three Village School District and particularly Mr. Hanrahan, Principal of Main Street School, greatly facilitated our work and we are most grateful.

2 Unpublished studies by M. Sobel and M. J. Fischer.

3 Two records were incomplete or defective due to mechanical difficulties and had to be discarded, and two children were not available for post testing.

Table 1

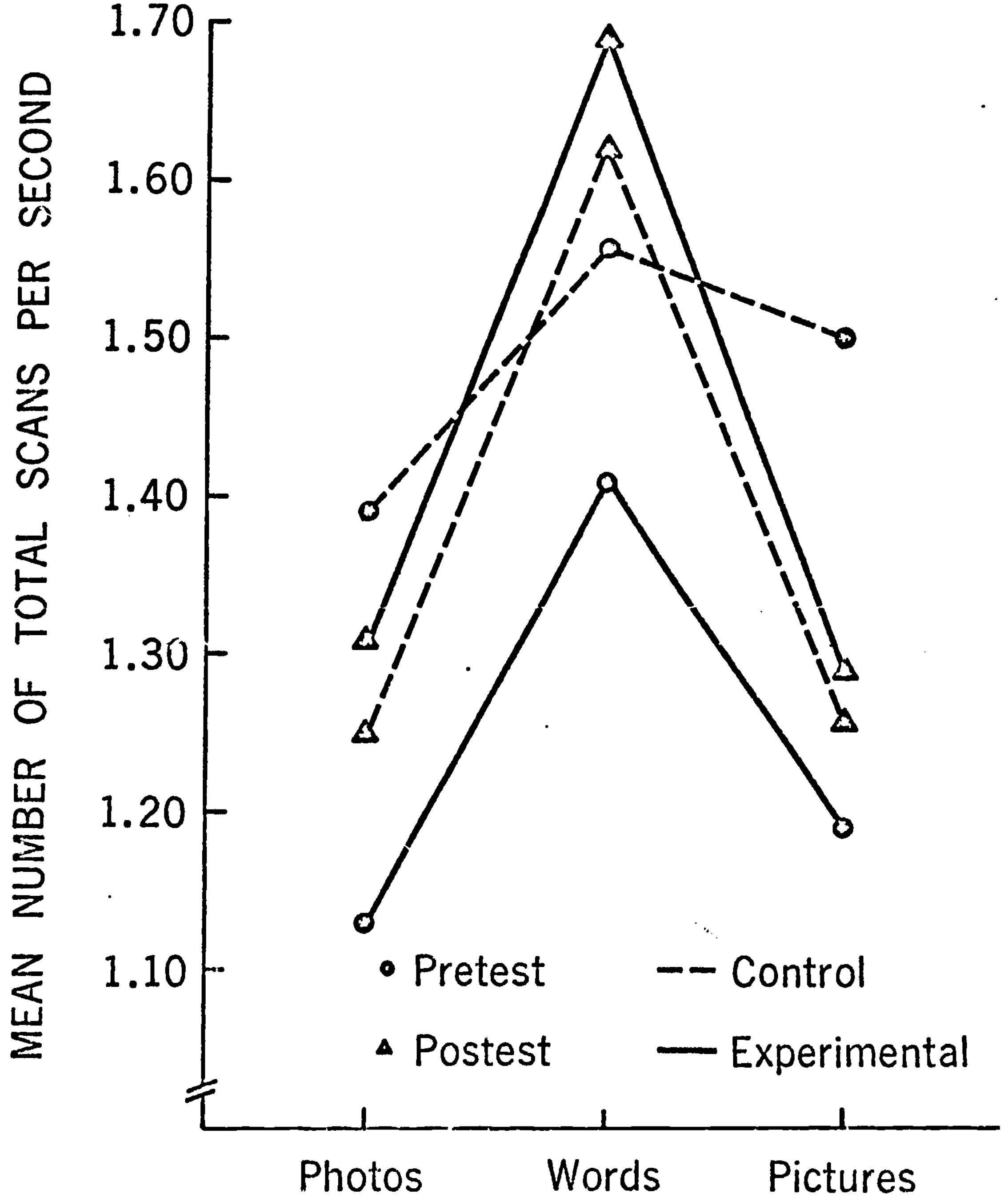
Total Scans per Second

| Group | Photos | | Words | | Objects | | PWO Combined | |
|---|---|---|---|---|---|---|---|---|
| Experimental | M | $s^2$ | M | $s^2$ | M | $s^2$ | M | $s^2$ |
| pretest | 1.13 | .025 | 1.41 | .027 | 1.19 | .032 | 1.24 | .028 |
| posttest | 1.31 | .035 | 1.69 | .053 | 1.27 | .026 | 1.42 | .038 |
| p | | | $<.02$ | | | | $<.05$ | |
| Control | | | | | | | | |
| pretest | 1.39 | .302 | 1.56 | .325 | 1.50 | .325 | 1.48 | .317 |
| posttest | 1.25 | .017 | 1.62 | .020 | 1.26 | .028 | 1.37 | .021 |
| p | | | | $<.002$ | | | | $<.002$ |

Note: Where p is blank, differences did not reach conventionally accepted level of statistical significance.

Figure Caption

<u>Figure 1</u> Mean total scans per second


MEAN NUMBER OF TOTAL SCANS PER SECOND
1.70
1.60
1.50
1.40
1.30
1.20
1.10
Pretest
Postest
Control
Experimental
Photos
Words
Pictures