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PSYCHOLOGICAL REVIEW PUBLICATIONS

Psychological Monographs

EDITED BY
JOHN F. DASHIELL
UNIVERSITY OF NORTH CAROLINA

STUDIES IN PSYCHOLOGY OF READING

Volume I

EDITED BY
JOSEPH TIFFIN

UNIVERSITY OF IOWA STUDIES IN PSYCHOLOGY

CHRISTIAN A. RUCKMICK, EDITOR
No. XXI

PUBLISHED FOR THE AMERICAN PSYCHOLOGICAL ASSOCIATION BY
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These studies clearly demonstrate that the psychology of reading has not been reduced merely to such physiological factors as eye-movement and functions of the vocal cords. More and more in the offing from the systematic point of view lie the mental components of attention, comprehension, and meaning. Many advantages appear when the technical applications of psychology to experiences of everyday life can be made to redound to the credit of pure experimental psychology. Always new problems are suggested when the facts of science are utilized in a practical way.

The Editor's obligations should be acknowledged. To Dr. Tiffin belongs the credit of formulating the program of research in this area; to Mr. Buxton thanks are due for the efficient preliminary editing of the manuscripts; and to the authors appreciation should be expressed for their willingness to rewrite theses in order to bring them within the scope and style of the Iowa Studies in Psychology.

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Iowa City, Iowa
15 April, 1936

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INTRODUCTION

The studies reported in this volume are part of a program of researches being carried on in the Reading Clinic at the State University of Iowa. Two papers deal with the rôle of eye-movements in reading deficiency. The article by Dr. Anderson demonstrates that eye-movements are determined by difficulty of the material, comprehension requirements, and reading attitude. Dr. Fairbanks' article presents the first experimental evidence that in oral reading many irregularities in eye-movements are related to errors and that the majority of such irregularities follow the errors temporally. These two studies offer considerable evidence that so-called ' poor ' eye-movements are determined by central causes and should be considered as a symptom rather than a cause of poor reading.

The paper by Dr. Swanson reveals a number of common elements in silent and oral reading and shows that oral reading of the type studied is fairly comparable to silent reading. He makes a number of recommendations that should prove helpful to the reading clinician. The joint study by Drs. Anderson and Swanson indicates a similarity in the eye-movement characteristics of silent and oral reading. These two studies justify the approach to the evaluation of the rôle of eye-movements through oral reading which has been followed by Dr. Fairbanks. The article by the editor and Dr. Fairbanks describes the apparatus used by the latter. Dr. Wagner's article is an evaluation of the importance in reading of certain visual functions as tested by the Bett's Ready-to-Read Tests. It too should be of value to the reading clinician. In all studies reported, comparisons are made between good and poor silent readers in an endeavor to describe the basic differences between the extremes of ability.

The consensus of opinion of the contributors to this volume is that in the majority of cases at the college level, the quality of reading is determined more by central than by peripheral factors. If Dr. Wagner's article does not seem entirely to support this view, it must be remembered that he worked with much younger subjects and, as everyone will admit, a *serious* visual incoördination or malfunctioning certainly will cause difficulty in reading at any age level.

The studies by Dr. Swanson, Dr. Anderson and Dr. Fairbanks are doctoral dissertations directed by the editor of the volume. The study by Dr. Wagner is a doctoral dissertation directed jointly by Professor E. F. Lindquist, of the College of Education, and the editor. These four dissertations have been abridged for publication. Copies of the original manuscripts containing additional experimental data in appendices are on file in the library of the State University of Iowa.

In behalf of the several contributors, I am happy to express our appreciation to Dr. Lonzo Jones, Assistant Dean of Men, through whose office most of the subjects for the investigations were secured; to Dr. Lee Edward Travis, director of the Psychological Clinic, who made this clinic available for several phases of the work; and to Dr. Christian A. Ruckmick, general editor of this series, for helpful advice in editing the volume. The greatest obligation of all is to Dean C. E. Seashore for his encouragement and support of the program.

JOSEPH TIFFIN

Iowa City
January, 1937

CONTENTS

STUDIES IN THE EYE-MOVEMENTS OF GOOD AND POOR READERS

by

IRVING H. ANDERSON

I. Introduction. This study from the Reading Clinic of the University of Iowa is a unit in a program of research devoted to an experimental study of reading. Previous investigations in this series were made by *Murphy* (17) on the rôle of the concept in reading ability, *Robinson* (20) on the effect of 'pacing' exercises on reading proficiency, *Walker* (27) on the eye-movements of good readers, and *Swanson* (22) on common elements in silent and oral reading.

The problem of the clinical utility of eye-movement measures has been raised (25). There has been a great deal of theorizing to explain the relationship between eye-movements and reading comprehension, but there has been no interpretation adequate as a basis for specific clinical procedures. A comprehensive study of eye-movements, designed to uncover clinical material, should yield a clearer understanding of their importance in clinical programs. This is desirable, for the efficiency of reading clinics depends upon specific methods of diagnosis and treatment.

The purpose of the present experiment is to evaluate the importance of eye-movements as measures of reading ability. The experiment involves the following specific problems: (1) to compare the effect of change in difficulty of reading material on the eye-movements of good and poor readers; (2) to compare the effect of change in reading attitude on the eye-movements of good and poor readers; and (3) to evaluate the clinical utility of measures of eye-movements.[1]

[1] *Walker* (27) already has published norms for the eye-movements of good readers, for each of the reading situations with which our study is concerned. Thus, to accomplish the first two of our specific aims, it was necessary only to repeat his experiment with poor readers.

II. Experimental procedure.

Subjects. The *S*s for this study were 174 university freshmen from the academic years 1933–34 and 1934–35. Included in this group were 50 individuals who, on the basis of clinical evidence and *Iowa Silent Reading Test* scores below the 25th percentile, were classified as poor readers.[2] The remaining *S*s, representing all degrees of reading ability, were the experimental group for the clinical section of this study. Interviews with all *S*s were arranged by form letters sent through the authority of the Dean of Men. Good initial *rapport* was thus secured. Unless he could read comfortably without his correction, no *S* wearing glasses was examined. The group of poor readers included no one who customarily read with glasses.

Reading material. Five test and three practice selections, duplicates of *Walker's*, were the reading material for this investigation. Test selections I, II, and III were a series scaled in increasing difficulty; II, IV, and V, equally difficult, were designed to measure the effect of change in reading attitude on eye-movements. Practice selections familiarized the reader with each new level of difficulty. All paragraphs were printed in 10-point De Vinne type, 25 *ems* (106 mm.) per line.

Eye-movement records. Eye-movement records were obtained with the Iowa eye-movement camera (1). Because *Walker* has fully described the method of photography, only a brief description is given. It consists of photographing a beam of light, generated by an automatic carbon-arc lamp and passed through a system of condensing lenses and a cobalt blue filter, reflected first to the cornea of each eye from a pair of first surface prisms, and then through the lenses of the camera to the recording paper.[3]

A segmented disc, mounted in the path of the light, is driven

[2] Walker's group of 50 good readers, with whom this group of poor readers was compared, ranked in the highest decile in both the *Iowa Silent Reading Test* and the *University of Iowa Qualifying Examination.*

[3] Eastman No. 1 recording paper, 1⅞ in. in width, was substituted for the usual moving-picture film. Since it was necessary to photograph the eye-movements of many more than 50 poor readers in order to obtain 50 complete records which fulfilled in every detail the requirements of the experiment, this economical, yet sensitive, paper was well suited to the purpose.

by a synchronous motor. This disc intercepts the light 50 times per sec. and thus time may be measured in units of .02 sec. Since the film is propelled continuously in the vertical plane, the record shows two vertical dotted lines when the eyes fixate and short horizontal lines when the eyes move in the horizontal or oblique directions. Although the camera is equipped to record simultaneous binocular movements of the eyes in both horizontal and vertical directions, in this study only the horizontal movements were photographed.

Movements of the head occur very frequently in the silent reading of inferior readers. In order to distinguish these motor manifestations from the eye-movements proper it was necessary to secure an index of head movements on the photographic records. This was obtained by photographing a beam of light from a tiny puncture in a cylinder surrounding a light bulb mounted on a pair of spectacle rims worn by the reader. The beam of light was directed to a lens and focused directly upon the film.

The sample records in Fig. 1 show horizontal movements of the eyes of four individuals reading a line of printed material. The heavy black line in Record A is the head-line. The two dotted lines represent saccadic movements of the eyes. Each step in the staircase effect represents an eye-movement to a new point in the line. The dots represent .02 sec., the bars occur every .5 sec., and .78 mm. movement on the original record measures one degree of angular displacement of the eyes. The pronounced horizontal movements at both extremes of Record A represent return sweeps to the beginning of new lines. Record B interestingly shows how a superior reader covers two lines in the same time taken by an average reader (Record D) to read one line. Record C illustrates an inadequate return sweep. This individual made three distinct eye-movements to locate the beginning of the line. The small dips in the progression of the dotted lines are regressions. These are quite pronounced in Record D.

During the test period every attempt was made to duplicate the conditions under which *Walker* secured his records. The selections were mounted on cardboard frames and presented 15 in. in front of and slightly above the eyes of *S*. All selections were illuminated and exposed indirectly by a system of mirrors. A screen covered the reading material until all focusing had been completed. Immediately above the first and last letters of the first line of each selection were two dots, so arranged that the screen did not conceal them. At the beginning of each recording, *S* was instructed to fixate alternately upon these points until he had made three complete excursions from left to right. Upon his return to the left for the third time, the screen was removed and he immediately began to read.

Records of these preliminary fixations were used to measure the shift of the eyes over 100 per cent of the line. By adjust-

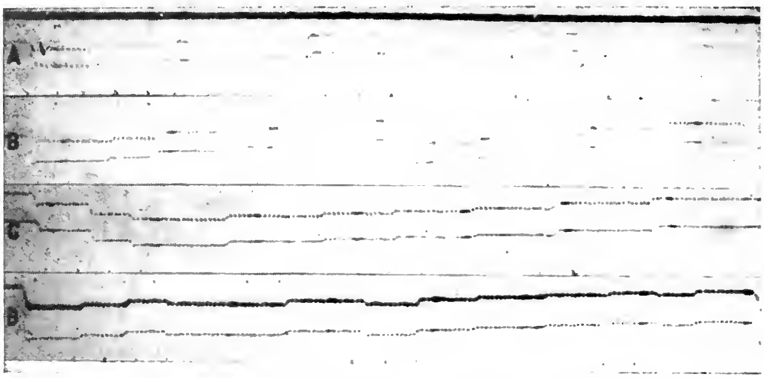

FIG. 1. Sample records showing the eye-movement variables which can be read accurately from the film

ing a pantograph to these marginal limits, it was possible to measure shifts within the line in terms of a certain percentage of the total excursion.[4]

The *Ss* were instructed to read the selection once, to make necessary regressions within any one line, but not to return to a previous line. Upon reading the last word of the paragraph, *S* closed his eyes as a signal to *E* that he had finished reading.[5] The recording situation is somewhat distracting, so every attempt was made to put *S* at ease, to adjust him to the situation, and to make clear to him what was wanted.

[4] The *cm* was used as a unit of linear extent. The mean size of fixation, mean extent of forward shift of the eyes, and rate of reading were translated into measurements in *cms.* This measure is independent of differences in size of words. Since all spaces between words and sentences were included in our measurements, the *cm* becomes a constant fraction of the line.

[5] Since the first and last lines of each selection are usually read atypically, these were omitted from the computations.

III. Results.

Effect of Difficulty of Reading Material on Eye-Movements of Good and Poor Readers

The purpose of this analysis is to compare the eye-movements of good and poor readers in adjusting their silent reading to changes in difficulty of material. Three selections, increasingly difficult in vocabulary, length of sentence, and complexity of meaning, were used as reading material. Selection I, a passage slightly under seven lines in length, was copied from an elementary primer; II, slightly less than 11 lines in length and comparable to reading material of first year university text-books, was moderately difficult; III, slightly more than 17 lines in length and copied from an advanced text, was extremely difficult.

The selections were presented to *S* in the order indicated above, and each was preceded by a practice paragraph comparable in difficulty to the test selection. To produce a constant attitude in reading, *E* instructed the *S*s to read all selections as they 'normally would read such material.' Comprehension was checked immediately after the reading of each practice and test selection by requiring a correct response to three out of four true-false statements on the content. This modest comprehension requirement was felt to be necessary to insure a serious attitude toward the experiment.

Seven eye-movement measures were made, each of which is identified in the legend of Table I. This table presents a comparison of the eye-movement scores of good and poor readers for each measure and for each selection. The present analysis is confined to the entries under headings I, II, and III of the table.

All measures except mean size of fixation clearly differentiated between good and poor readers at each level of difficulty. The ratio in column three of each section of Table I is a statistical expression which indicates whether the obtained difference between any eye-movement score of good and poor readers is greater than could occur by chance. It is customary to accept a ratio of 2.5 (approximately) or larger as indicative of a true difference. In the table these probabilities are placed immediately under their respective ratios. The ratios were not signifi-

TABLE I. *Differences between mean scores for seven measures of eye-movements of good and poor readers on five selections, and the significance of each difference*

Selection	I M_1 (good)	I M_2 (poor)	I CR	II M_1	II M_2	II CR	III M_1	III M_2	III CR	IV M_1	IV M_2	IV CR	V M_1	V M_2	V CR
A	.246	.295	7.0	.255	.304	6.1	.277	.316	4.9	.240	.320	11.4	.285	.335	5.6
	.035	.035	100	.033	.043	100	.035	.045	100	.026	.042	100	.040	.046	100
B	.091	.111	3.5	.101	.120	2.9	.108	.130	2.4	.086	.129	7.3	.119	.146	2.8
	.035	.022	100	.032	.033	100	.025	.060	99	.020	.037	100	.037	.058	100
C	.220	.256	4.3	.213	.261	5.7	.233	.252	2.2	.216	.258	4.2	.233	.261	2.9
	.033	.048	100	.033	.049	100	.041	.046	99	.046	.053	100	.035	.060	100
D	3.40	2.66	7.3	2.92	2.68	2.3	2.66	2.60	.7	3.75	2.59	10.4	2.52	2.39	1.4
	.54	.47	100	.60	.44	99	.43	.40	76	.67	.43	100	.48	.47	92
E	4.31	3.58	5.3	4.31	3.61	6.0	4.06	3.66	3.5	4.55	3.71	5.8	3.91	3.55	3.4
	.75	.62	100	.64	.52	100	.56	.59	100	.80	.65	100	.52	.55	100
F	.44	1.01	5.2	.70	1.04	4.0	.92	1.28	3.3	.33	1.32	7.6	1.02	1.55	3.0
	.06	.72	100	.06	.62	100	.12	.77	100	.29	.88	100	.66	1.06	100
G	758.2	497.4	11.1	690.9	489.8	9.2	558.1	454.3	5.2	882.4	453.6	15.4	513.3	397.7	5.0
	130.0	103.8	100	110.5	109.0	100	101.8	97.7	100	169.2	102.0	100	127.9	102.5	100

A, mean duration per fixation; B, mean of the individual SDs of the duration per fixation; C, mean mode of duration per fixation; D, mean size of fixation in *ems*; E, mean extent of forward shift of eye in *ems*; F, mean regressions per line; G, mean rate of reading in *ems* per minute. In this and subsequent tables, the SD for each measure is placed immediately under the mean. The figure immediately under each CR indicates the chances in 100 that the true difference is greater than zero.

N=50 in each group.

cant in only four instances, namely, mean size of fixation on Selections II and III, mean of the individual SDs of duration per fixation, and mean mode of duration per fixation on Selection III. However, these differences, although not completely reliable, were somewhat greater than might be expected according to chance and they consistently favored good readers.

Mean duration per fixation. In their adjustment to increased difficulty of reading material, good and poor readers tended to modify eye-movement behavior in a similar way. The mean duration per fixation for both groups increased with each increase in difficulty of the reading material, and the ratio of this increase from condition to condition was approximately the same for both groups. The reliability of the mean differences between any two paragraphs for all measures of eye-movements of good and poor readers is indicated in Table II. The difference in mean duration per fixation between I and II is not completely reliable for either group; the differences between II and III, and between I and III, were statistically significant, the CRs being 4.0 and 3.2 for good readers, and 3.4 and 4.5 for poor readers. In average duration per fixation, the range over which the *S*s varied for the three passages was greater in the case of the good readers, the advantage being the difference between .031 sec. and .021 sec. This greater flexibility of good readers in duration per fixation is true for each measure except the individual variability of duration per fixation.

Mean of the individual SDs of duration per fixation. The mean individual variability of duration per fixation increased for the two groups with each increase in difficulty of the reading material. Table II reveals that the magnitude of this increase was reliable in only one instance. However, the differences between any two means of good or poor readers in each comparison were larger than merely chance differences, and were consistent with the direction of change in difficulty.

Mean mode of duration per fixation. There is a physiological limit below which mean duration per fixation cannot be reduced;

TABLE II. *Differences between any two means of the five selections for good and poor readers*

Measure	A (good) CR_1	A (poor) CR_2	B CR_1	B CR_2	C CR_1	C CR_2	D CR_1	D CR_2	E CR_1	E CR_2	F CR_1	F CR_2	G CR_1	G CR_2
I and II	1.8	2.3	1.5	1.9	1.9	.8	3.6	.4	.03	.8	2.9	.3	6.6	.8
	96	99	93	97	97	79	100	65	50	79	100	62	100	79
II and III	4.0	3.4	1.5	1.5	3.3	1.3	3.2	2.0	3.1	1.2	2.5	3.5	6.8	3.7
	100	100	93	93	100	90	100	98	100	88	99	100	100	100
I and III	3.2	4.5	3.6	2.3	2.4	.6	7.0	1.0	3.1	1.6	3.8	2.8	11.9	3.2
	100	100	100	99	99	73	100	84	100	94	100	100	100	100
IV and II	3.6	3.8	1.4	1.7	.7	.4	8.7	1.8	2.1	1.7	3.7	3.2	6.8	3.0
	100	100	92	96	76	65	100	96	98	96	100	100	100	100
II and V	4.1	6.9	3.5	3.3	2.5	.0	5.3	5.3	3.1	1.5	5.6	4.2	5.4	7.7
	100	100	100	100	99	50	100	100	100	93	100	100	100	100
IV and V	7.4	3.2	6.1	2.6	1.2	.3	12.3	3.8	4.7	3.5	5.0	2.6	10.7	6.1
	100	100	100	99	88	62	100	100	100	100	100	99	100	100

Legend same as in Table 1.

$CR = \frac{M_1 - M_2}{SD_{diff}}$

therefore this measure is disproportionately influenced by higher time values for which there is no definite limit. For this reason the mode of duration per fixation was computed. The mode of duration per fixation was smaller than the mean for each selection for both groups. It also was more stable in that it did not vary significantly from selection to selection. A reliable difference in the mode of duration per fixation occurred for good readers between II and III, but this difference was not important, because the consistency in direction of change was interrupted by II, which gave a lower value than I.

Mean size of fixation in ems. With increasing difficulty of reading material, good readers exhibited a striking tendency to reduce the size of fixation as measured in *ems*. The extent of this change from selection to selection in each case is statistically significant. Poor readers showed no such tendency; the differences were neither reliable nor consistent with the direction of change in difficulty. The CR between I and II was .4; between II and III, 2.0; and between I and III, 1.0.

Mean size of fixation, which correlates .62 (uncorrected) with the total comprehension score on the *Iowa Silent Reading Test*, is the most critical measure of eye-movement.[6] We may assume, on the basis of the differences between good and poor readers in variation of size of fixation, that one of the essential peripheral signs of an effective adjustment to difficulty of reading material is a characteristic variation in the mean size of fixation.

Miles and *Segel* (**15**) found that the number of fixations of third grade pupils increased with difficulty of reading material, but our results do not support their further contention that "duration of fixation tends to remain the same for different lines and different selections." *Erdmann* and *Dodge* (**4**) report that the number and duration of fixations varies with familiarity of reading material. *Tinker* (**23**) found the number of fixations and their duration to increase in reading algebra, chemistry, and mathematical formulæ. *Judd* and *Buswell* (**12**), in examining the effect of difficulty of material on eye-movement performance of 10 fifth-grade pupils and five university students, concluded that "when the content of a passage becomes increasingly difficult for a mature reader, he is thrown back by the increasing difficulty into the class of immature readers. . . ."

Mean extent of the forward shift of eye in ems. Although the mean extent of the forward shift differentiated clearly

[6] Cf. Table IV, page 20.

between good and poor readers on each selection, it remained fairly constant from condition to condition within each group of readers. The range of variation for good readers was between 4.31 *ems* for I and II and 4.06 *ems* for III. There was no difference between I and II, but a comparison of both I and II with III yielded a significant CR, 3.1. In their adjustment to very difficult material, good readers tended to include less in the mean forward shift. Poor readers slightly but consistently increased the extent of forward shift with each increase in difficulty of material. Thus there is a discrepancy between the two groups in the way the forward shift changes. It may result from the tendency of inferior readers to read persistently in single word units. The extent of the forward shift of word readers will vary directly with the size of the unit to which their eyes adapt, and since the average number of *ems* per word in the three passages increased from 1.97 for I to 2.28 for III, the mean values of the forward shift for each paragraph would be weighted accordingly.

Regressions. The average number of regressions per line increased for both groups with increase in the difficulty of material. The only unreliable difference between any two means of the three selections was between I and II, CR, .3, for the inferior group. The only measure which showed important differences in group variations was mean regressions per line. The SDs for the three selections in order of difficulty were: .06, .06, and .12 for the good readers, and .72, .62, and .77 for the poor readers. Those regressions following the first fixation in a line were omitted in calculating mean regressions, because they properly belong to the return sweep.

Mean rate of reading. Mean rate of reading is the undifferentiated measure of eye-movements to which each of the component measures contributes. For this reason, the differences between superior and inferior readers, as well as the differences between any two means within each group, were somewhat accentuated. Table I shows that there was a notable decrease in rate of reading for good readers with increased difficulty of reading material, from 758 *ems* (380 words) per minute for I to 558 *ems* (242 words) per minute for III. The CRs between the selections are all significant: for I and II, 6.6; for II and III, 6.8; and for I and III, 11.9. Although the rate of reading was reduced less for poor readers, the direction of change with difficulty of material was the same as for good readers. Reliable differences existed between the comparisons of both I and II with III, the CRs being 3.7 and 3.2 respectively.

Summary. The above analysis shows that every measure of eye-movements distinguishes good from poor readers at each level of difficulty. An evaluation of these differences in eye-movements must be tempered somewhat in view of the relatively small difference existing in mean size of fixation, the most valid measure of eye-movements. Furthermore, there is a slight but measurable tendency for the differences between eye-movements of good and poor readers to decrease with increased difficulty of reading context.

The eye-movements of both groups are influenced similarly with increased difficulty of context, *i.e.*, the eye-movements approach a pattern common in more immature stages of reading development. In adjusting to increasingly difficult reading material, good readers modify their eye-movements over a more flexible range than do poor readers, and the greatest modification occurs in the measures most highly correlated with reading ability, *i.e.*, mean size of fixation, mean regressions per line, and mean rate of reading. In their peripheral signs of adjustment, poor readers do not show this selective mode of variation.

From these observations we may conclude that eye-movements, as modes of reaction conditioned by the structures upon which they are based and by individual differences in ability and reading history, respond in a highly modifiable manner to the more severe demands required of the apprehending functions by increasingly difficult reading situations.

Effect of Reading Attitude on Eye-Movements of Good and Poor Readers

The modifications in oculomotor behavior summarized in the above section were governed by factors largely beyond the control of the reader, *i.e.*, by the objective difficulty of the reading material. The basic differences in eye-movements of good and poor readers on Selection I, which was easily within the limits of complete comprehension for both groups, also appeared for Selections II and III. The alterations in eye-movements produced by each increase in difficulty of material were superimposed upon the original differences in eye-movements of the two groups, and the extent to which the eye-movements of good and poor readers were affected alike emphasizes the relative importance of objective over subjective factors in the control of these changes.

This part of the study is confined to an analysis of the changes which occur in eye-movements of good and poor readers in response to three silent reading attitudes, all of which are subjectively initiated and controlled. Three passages, equally difficult, were the reading material. Selection IV, slightly less than 10 lines in length, was read to secure only the general idea of the contents; II, described in the preceding section, was read to obtain a moderate knowledge of the text; and V, slightly less than 12 lines in length, was studied to obtain a knowledge as complete and detailed as possible from one reading. Comprehension on IV and V was checked by the use of a verbal report from the reader immediately after each reading. The eye-movement records secured under these conditions are summarized in Tables I and II.

Several studies show that variations in eye-movements occur in response to different reading attitudes. *Gray* (**8**) compared the eye-movement records of three adults who, in one case, read with the purpose of answering questions, and in another with the purpose of reproducing what was read. The greatest variation from one type of reading to the other occurred in the increased number of pauses and regressions required to answer questions on the material. *Judd* and *Buswell* (**12**) found differences in eye-movements between rapid superficial reading and slow careful reading preparatory to answering questions. Since they used the same passage for both types of reading, their results are somewhat affected by the learning which resulted in the initial reading. Only three *Ss* were university students. *Tinker* (**23**) reports figures computed from the data of *Erdmann* and *Dodge* (**4**) to show that the number of pauses and their duration was greatly increased in proof-reading. *Vernon* (**26**) has shown that effort to understand, and interest in, the reading material results in an increased irregularity of eye-movements.

Mean duration per fixation. For each reading situation the mean duration per fixation of poor readers was longer than for good readers. The largest and most important difference occurred for IV, which the *S*s were instructed to read for the general idea. The CR for this difference was 11.4. Attention here should be directed to the fact that, for all measures of eye-movements, instructions to read for the general idea were most effective in producing large differences between good and poor readers. The shortest pause duration for superior readers occurred on IV, while for poor readers the shortest pause duration occurred on II. For both groups, the mean duration per fixation was greatest on V, .285 sec. and .335 sec. for good and poor readers respectively. The range of change in mean duration time for the three reading situations was .045 sec. for superior readers and .031 sec. for inferior readers. The corresponding values for change with difficulty were smaller, .031 sec. and .021 sec. Table II shows that the mean difference between any two selections within either group was statistically reliable.

Mean of individual SDs of duration per fixation. Not only was the mean duration longer for each selection but the individual variability of duration per fixation was greater for poor readers than for good readers. This result may be anticipated from the correlation (.71, uncorrected) between the measures. Selection IV again showed the largest group difference, the CR being 7.3. The greatest individual variation for both groups resulted from their detailed reading of V. While the differences between IV and II were not reliable for either group, mean comparisons of these selections with V showed significant CRs for both groups.

Mean mode of duration per fixation. Although the mode of duration differentiated good from poor readers in each reading situation, the mean differences between any two selections within either group were negligibly small. The differences between good and poor readers for each selection were unquestionably greater than chance, the probabilities being 100 in each comparison. Again, the mode of duration for both groups was smaller than the corresponding mean on each selection.

Mean size of fixation in cms. On each selection the mean size of fixation was consistently larger for good readers than for poor readers. The mean difference on IV again was the most striking. While the two groups did not differ reliably on II and V, the probabilities for significance of the obtained differences, 99 and 92 chances in 100 respectively, are evidence against their being determined by chance. The superior group showed the largest mean size of fixation, 3.75 *ems*, on IV; inferior readers showed the largest mean, 2.68 *ems*, on II. The size of fixation for both groups decreased almost to a common figure on V, 2.52 *ems* and 2.39 *ems* for good and poor readers respectively. The extent of change from condition to condition for good readers was 1.23 *ems*, for poor readers, .29 *ems*. The corresponding changes with increase in difficulty were .74 *ems* and .08 *ems*. Mean differences between any two selections for good readers were all reliable while for poor readers the only unreliable difference occurred between IV and II, for which the CR was 1.8.

The above facts emphasize findings that are, in general, true for every measure of eye-movements, namely, good and poor readers react in an opposite manner to instructions to read for the general idea, and in a similar way to directions to read for details. Also, the eye-movements of both groups showed a greater flexibility in their response to differing instructions than in their adjustment to difficulty of reading material. Finally, the changes in eye-movements which accompany altered instructions are larger and more effective for good readers than for poor readers.

Mean extent of forward shift of the eye in ems. Good readers included a significantly larger percentage of the line in their mean forward shift in each reading situation than did poor readers. Since the results for this measure merely recapitulate the foregoing findings they need to be summarized only briefly. The mean forward shift of good readers on IV was 4.55 *ems*, on II, 4.31 *ems*, and on V, 3.91 *ems*. Reliabilities of the mean differences within this group are confirmed statistically in Table II. The mean forward shift of poor readers on IV was 3.71 *ems*, on II, 3.61 *ems*, and on V, 3.55 *ems*. Although the mean differences for the inferior group were not without exception so large as to be absolutely significant, all of them were greater than merely chance differences. A minor discrepancy exists between the results of this and the other measures in the tendency of poor readers to secure their highest score on IV. However, the failure of this attempt to include more than is customary in the forward shift in reading for the general idea is indicated by the increased number of regressions which occur on IV for the inferior group.

In their effort to include a larger unit in the forward shift, poor readers frequently over-reach their maximum span and find

TABLE III. *Differences between the mean forward shift in ems preceding regressions (M_1) and the mean of all other forward shifts (M_2), poor readers*

Selection	M_1	M_2	$r_{1.2}$	CR
I	4.04 1.08	3.55 .63	.47	3.48 100
II	3.86 .79	3.55 .49	.58	3.26 100
III	4.17 .86	3.56 .54	.81	8.13 100
IV	4.04 1.07	3.64 .49	.61	3.25 100
V	3.86 1.00	3.48 .52	.65	3.73 100

N=50. Included just below each mean is its SD.

it necessary to regress in order to grasp the meaning. Evidence to support the contention that regressions follow longer forward shifts is contained in Table III.

This table shows that for poor readers on every selection the mean forward shift preceding regressions was significantly longer than the average of all other forward shifts. It does not follow necessarily that there is a correlation between the number of regressions and the extent of forward shift. The actual coefficient is .01. These results merely indicate that if a poor reader includes more in his forward shift than he can perceive, a compensatory regression will follow.

The mean number of regressions per line correlates —.58

with rate measured at the eye-camera, and —.40 with total comprehension score on the *Iowa Silent Reading Test.* These correlations indicate that from a clinical point of view it would be highly desirable to eliminate unnecessary regressions of the type discussed above by cautioning the reader to avoid forward shifts longer than he is able to perceive.

Mean regressions per line. The mean number of regressions per line on each selection indicated that the eye-movements of poor readers were more irregular than those of good readers. When required to reproduce the general idea of a paragraph, good readers made only .33 regressions per line; poor readers, in reacting to the same instructions, made 1.32 regressions per line. That regressive movements occupy a necessary rôle in certain reading situations is indicated by the relatively large number of them made by superior readers on V. On this selection good and poor readers respectively made 1.02 and 1.55 regressions per line. Although an excessive number of regressions usually accompanies ineffective reading, in situations requiring a very comprehensive report of the contents of a paragraph, the regressive movements may be utilized to good advantage in order to fix firmly in reproductive memory the critical points of a selection. Large and reliable differences existed between any two paragraphs within either group.

Mean rate of reading in ems per minute. The reliable differences in mean rate of reading between good and poor readers for each selection were the necessary result of the differences noted for the other measures of eye-movements. The mean rates for good readers on IV, II, and V were 882 *ems* (397 words), 690 *ems* (308 words), and 513 *ems* (248 words) per minute, respectively. Poor readers read IV at the rate of 453 *ems* (204 words), II at 489 *ems* (219 words), and V at 397 *ems* (192 words) per minute, respectively. All mean differences within both groups are reliable.

Summary. The group differences were more decisive and the variations within either group were greater when the analysis of eye-movement records was made in terms of different reading attitudes, rather than in terms of difficulty of reading material.

A striking contrast appeared in the eye-movements of the two groups when they were instructed to read IV for the general idea only. In reading this passage, good readers made their most favorable eye-movement scores, *i.e.*, there were few and short pauses and regular sequences of fixations along the line of print; poor readers made scores on this passage exceeded in irregularity only by those for their detailed reading of V.

This disparity in the way good and poor readers reacted to instructions to read for the general idea indicates a fundamental difference in their reading development. Effective reading for the general idea is a highly refined skill which presupposes a mastery of certain reading fundamentals, *i.e.*, accurate perception, word recognition, vocabulary, and sentence meaning. Unless these elementary skills function with a minimum of effort, the reader will fail to make the psychological transition which reading for the general idea requires. Good readers, in whom the specific skills are well developed, succeed in adopting reading attitudes which demand more subtle interpretations of the material. Poor readers, because they are so engrossed in problems of an elemental nature, tend to read all materials in about the same way and with the same 'mental set.' If they try to comply with the instructions, their efforts lead to ineffectual attempts and finally to mental confusion.

When studying V for the purpose of remembering all details and points of information, the reading of both groups was accompanied by an irregularity of eye-movements exceeded by no other reading situation. In order to satisfy the more severe requirements of comprehension, a more deliberate and careful scrutiny of the reading material was necessary; this was immediately reflected in the eye-movements by an increased number of forward and regressive shifts of long and variable duration. The irregularities of eye-movements found in this reading situation are not comparable to the erratic and inconsistent eye-movement behavior of the immature reader. The peripheral signs in this situation rather are a characteristic pattern which reflects an increasing dependence upon the reading material and a peculiar mode of attack necessary to satisfy the requirement of comprehension. Although the differences between good and poor readers on this selection were considerable, they were smaller than on either IV or II.

Poor readers showed their most favorable eye-movement behavior when instructed to read II as they 'normally would read such material.' This result logically follows from the inability of poor readers to adopt any other than their ordinary everyday reading attitude. Good readers, on the other hand, showed their most regular eye-movement patterns in reading IV. Since the objective cues necessary to reproduce the general idea are fewer than those required in the other reading situations, the effective reader will show a considerable independence of the reading page. The subsequent reduction in the number and duration of fixations indicates that the comprehending activities are enhanced and contribute more to the successful realization of the task than would a careful and deliberate exposure to the reading material.

The above results suggest the following conclusions: (1) an important determinant of the differences between the eye-movements of good and poor readers is a difference in the number and kind of cues necessary to satisfy the requirements of a particular reading situation; and (2) the variations produced in the eye-movements by a change of reading attitude are a function of the number and kind of cues required to achieve the purpose for which the reading is done.

Clinical Evaluation of Measures of Eye-Movements

The results summarized in Tables I and II indicate a characteristic difference between the eye-movement phenomena of good and poor readers. This relationship between oculomotor behavior and reading proficiency brings up the problem of the clinical utility of eye-movement measures. These measurements require expensive apparatus and are time consuming if done accurately, so a critical investigation of the desirability of eye-movement studies in the reading clinic is necessary.

The reliability and validity of eye-movements. A test, to be useful for individual diagnosis, must possess high reliability and validity. The reliability of measures of eye-movements has been well established. *Litterer* (14), *Eurich* (5, 6), *Tinker* and *Frandsen* (24), and *Frandsen* (7) have obtained for various measures of eye-movements reliability coefficients which compare favorably with most standardized educational and reading tests.

The validity of eye-movement measures is not so well established. Typical validity coefficients reported in the literature range on the average between .25 and .40. The usual practice in computing these correlations is to employ as a criterion the scores made on some standardized reading test. This procedure introduces variables which make it difficult to secure high correlations. It is impossible to duplicate in the camera room the conditions under which the paper and pencil tests were taken. Even if we employ as reading material a part of an alternate form of the standardized test, the strangeness of the recording situation interferes with a normal performance by the reader. Furthermore, the cost of securing and the labor involved in analyzing the photographic records prohibits the measurement of an adequate sample of *S*'s reading. Thus when standardized reading test scores are used to validate measures of eye-movements, we may consider as a reliable correlation the highest one which experience has shown it is possible to obtain under these conditions.

Validity coefficients in this study were computed by correlating the scores of 76 unselected university freshmen for each measure of eye-movements on Selection II with their scores on the *Iowa Silent Reading Test* and the *University of Iowa Qualifying Examination*. The reading test score, which is included in the battery of qualifying examinations, was subtracted from the composite rating. The correlations obtained by this method are given in Table IV.

As indicated in the table, four of the individual measures of eye-movements are fairly valid, while two measures show unreliable correlations with the criterion. *Litterer* (14), using university sophomores, with the *Iowa Silent Reading Test* as a criterion, obtained validity coefficients of .48 and .41 respectively for fixation frequency and perception time. Our correlations for the same measures are higher, .62 and .50. *Eurich's* (5) correlations, computed from data of 175 university students, are all unreliable.

Our results support previous studies which show that mean duration per fixation is questionable as a measure of compre-

TABLE IV. *Correlations between each measure of eye-movements and the Iowa Silent Reading Test and the University of Iowa Qualifying Examination*

		I.S.R.	U.I.Q.E.
A	Mean duration per fixation	$-.05\pm.08$	$-.11\pm.08$
B	SD of the duration per fixation	$-.06\pm.08$	$-.12\pm.08$
C	Mean size of fixation in *cms*	$+.62\pm.05$	$+.62\pm.05$
D	Mean extent of forward shift	$+.44\pm.07$	$+.43\pm.07$
E	Mean regressions per line	$-.40\pm.07$	$-.35\pm.07$
F	Rate of reading in *cms* per minute	$+.50\pm.06$	$+.41\pm.07$

hension in reading. This measure probably depends on factors which underlie sensory or apprehensive reaction. There is no proof that individual differences in apprehensive reaction time selectively contribute directly to good or poor reading. However, since the mean duration per fixation and the individual SDs of the duration per fixation correlate .60 and .68 respectively with rate of reading as measured at the eye-camera, the accumulated effect of individual differences in time of apprehension may contribute indirectly to comprehension scores on tests done under time limits. *Dearborn* (2), *Dodge* (3), and *Schmidt* (21) have pointed out the dependence of the duration of reading fixation on the 'personal equation,' showing that it exceeds the average reaction time of the eye by only a slight amount.

Although our correlations are higher than those previously reported, they are not, without exception, high enough to permit conclusions in individual cases. However, in view of the conditions under which these correlations arise, any coefficient four times its probable error is indicative of a relationship significant enough to permit group comparisons in experimental studies of eye-movements.

The fact that the comprehending activities involved in reading go far beyond the movement of the eyes explains this lack of relationship between measures of eye-movements and reading ability as measured by standardized tests. The primary function of the eye-movements in reading is to provide the proper constellation of objective cues which may serve as a basis for releasing the psychological functions involved in getting the meaning from the printed material. The cues provided by very similar eye-movements will ' touch off ' thought processes which differ widely from one individual to another. Thus there exists no one-to-one relationship between eye-movements and comprehension.

The closest relationships between eye-movements and reading ability have been found in studies done with children. Here the variety in amount and kind of psychological activity involved is very much more limited than it is in adults. Furthermore, pupils in the grades are engaged in the mastery of the mechanics of reading. In this situation the eye-movement behavior will reflect the progress of the child in mastering the specific reading skills. Since all children at this stage are confronted with the same problems, the correspondence between eye-movements and reading ability will be closer, in that the relationship shown will be indicative of the stage in development toward reading maturity which the child has reached. *Buswell* (1) has shown that once the fundamentals in reading have been mastered, measures of eye-movements thereafter tend to remain constant. Since the elaborative processes continue to develop throughout life, the correspondence between eye-movements and reading ability will tend to decrease with age.

Combining measures to secure optimum predictive efficiency. In the preceding pages we have described the process by which validity coefficients between each measure of eye-movements and a suitable criterion were secured. We found that all individual measures of eye-movements except that for the mean size of fixation in *ems* correlated too slightly with the criterion to be of value in individual diagnosis. The problem with which we are now confronted consists in determining statistically the particular combination of eye-movement measures which will yield the maximum correlation with the criterion. This approach should enable us to discover the most useful combination of eye-movement measures to include in a battery of diagnostic tests.

If several measures are to be combined into a battery we must consider not only the correlation of each measure with the criterion, but also the correlations between measures. If the criterion and all measures are scored so that a large score is a favorable score, a general rule in selecting tests for a battery is to choose those measures which show low correlations with each other but high correlations with the criterion. However, *Hull* (10) explains that in a case such as ours, where validity coefficients of both positive and negative signs appear, an exception to this general statement occurs. If some measures correlate positively and others negatively with the criterion, it is desirable that the coefficients between measures which correlate by opposite sign with the criterion should be negative and as large as possible.

To take into account the above stated principles of test selection, and to secure a satisfactory estimate of the possible correlation between a battery of measures and the criterion, we may utilize the coefficient of multiple correlation. We have chosen for trial the four measures in Table IV which individually correlated highest with the criterion. The mean duration per fixation and the individual variability of the duration per fixation, two measures which were found to be without value as measures of reading ability, were discarded at once.

The joint correlations of all possible combinations of two and three measures of the four selected for trial are given in Table V. This table shows that a rather close relationship between eye-movements and reading ability was present in all instances. Yet no combination of eye-movement measures gave a correlation with the criterion significantly higher than that secured for mean size of fixation alone.

In the light of these results we may say that the prognostic efficiency of the mean size of fixation cannot be reliably improved by combining it with other measures of eye-movements, and that in clinical diagnosis the mean size of fixation is the only eye-movement measure which need be secured. However, the rate of reading, a measure easily and economically computed, might be retained, although it contribues relatively little. The correlation between rate of reading combined with mean size of fixation and the scores made on the *Iowa Silent Reading Test* is .64. Since the remaining measures do not contribute enough to the diagnostic efficiency of eye-movements to justify the labor

TABLE V. *Multiple coefficients of correlation showing the relationship between any combination of two or three measures of eye-movements and reading ability*

$R_{1.CD} = .62$	$R_{1.CDE} = .63$
$R_{1.CE} = .62$	$R_{1.CDF} = .63$
$R_{1.CF} = .64$	$R_{1.CEF} = .63$
$R_{1.DE} = .60$	$R_{1.DEF} = .54$
$R_{1.DF} = .53$	
$R_{1.EF} = .52$	

1 Criterion (*Iowa Silent Reading Test*)
C Mean size of fixation in *ems*
D Mean extent of the forward shift
E Mean regressions per line
F Rate of reading in *ems* per minute

involved in their computation, they may be dispensed with in the diagnosis of reading deficiency.

The relationship between intelligence and eye-movement behavior. The correlations in Table IV showed that the various measures of eye-movements were almost as closely related to general intelligence, as measured by the *University of Iowa Qualifying Examination*, as they were to silent reading ability.[7] In clinical work the intelligence of *S* should be one of the first items considered. Numerous investigations show a high correlation between intelligence and reading ability; and remedial work in the clinic also has shown that the benefit an individual derives from training in reading is always related to his general intelligence.

The following experiment was designed in order to reduce the altogether too general description of the function of intelligence to more specific terms. We sought to determine the effect

[7] The validity of this examination as a measure of intelligence is indicated by the fact that the correlations between scores on this examination and scores on other tests of adult intelligence are as high as the inter-correlations between most intelligence tests.

of intelligence on eye-movements when reading test scores were held constant. Two groups of university freshmen, representing the extremes in intelligence as measured by the *University of Iowa Qualifying Examination*, were matched on the basis of scores earned on the *Iowa Silent Reading Test*. One group was composed of 38 individuals ranking on the average at the 29th percentile in intelligence and at the 38th percentile in reading ability. The second group, also 38 individuals, ranked on the average at the 62nd percentile in intelligence and at the 36th percentile in reading proficiency. That the two groups did not represent further extremes in intelligence is due to the close relationship between reading ability and intelligence. The correlation between the *Iowa Silent Reading Test* and the *University of Iowa Qualifying Examination*, exclusive of the reading test, is .84. Such a close relationship permits only a limited degree of independent variation between the measures.

Eye-movement records from all *S*s were secured from their silent reading of Selection II. Upon completing the reading, all *S*s were required to make three correct answers to four questions on the contents of the selection. Unless this requirement of comprehension was met, the record was discarded. A practice paragraph, comparable in difficulty to the test selection, was first presented to *S* to familiarize him with the requirements of the experiment.

An analysis of the eye-movement records was made to discover how the group with low intelligence compensates in terms of eye-movements to satisfy the same demands required of the group of high intelligence. The results of this analysis are contained in Table VI.

An inspection of this table shows that while the difference between the groups for any one measure is not large enough to be completely reliable, most of the differences are somewhat larger than chance differences.[8] The signs of these differences indicate that every measure consistently contributes to a greater irregularity of eye-movements in the group of low intelligence.

[8] The standard errors of these differences and those in Table VII were computed by means of *Lindquist's* (13) modification of this formula to correct for matching.

We therefore may argue that these differences, although small, indicate a real difference in eye-movements between the groups.

These results suggest that the handicap of the less intelligent group is such that a larger number of objective cues is required to initiate thought processes which approximate those of a group of high intelligence in the same reading situation. This adjustment is accomplished by a more careful and deliberate scrutiny

TABLE VI. *Differences between eye-movements of two groups paired on reading ability and representing extremes in intelligence*

	Measure	Low intell. M_1	High intell. M_2	Diff.	CR and chances in 100
A	Mean duration per fixation	.296	.280	.016	2.08
		.034	.033		98
B	Mean of individual SDs of duration per fixation	.117	.102	.015	2.42
		.034	.019		99
C	Mean mode of duration per fixation	.251	.233	.018	1.88
		.049	.033		96
D	Mean size of fixation in *cms*	2.72	2.74	—.02	.18
		.68	.58		56
E	Mean regressions per line	1.37	1.10	.27	1.33
		1.09	.82		90
F	Mean rate of reading in *cms* per minute	506.5	532.5	—26.0	.91
		154.4	131.6		82

N=38 in each group. Included just below each mean is its SD.

of the reading material. Conversely, in order to satisfy the requirements of the experiment, the readers of high intelligence supplement fewer objective aids by richer interpretative processes.

In order to employ a test of general ability which itself does not depend on reading proficiency, we repeated the above experiment using as a measure of intelligence the scores made on the *Iowa Mathematics Aptitude Examination.* The justification for using this examination as a measure of intelligence is indicated by the fact that the correlation between this test and the entire battery of qualifying examinations is .86. Since scores on the *Iowa Mathematics Aptitude Examination* correlate only .68 with scores on the *Iowa Silent Reading Test*, it was possible to secure individuals who deviated quite widely in intelligence and yet who were of approximately equal reading ability.

Following the procedure of matching described above, we selected two new groups of 31 individuals each. One group was composed of university freshmen who ranked on the average at the 20th percentile in mathematics aptitude and at the 35th percentile in reading ability. The individuals of the other group ranked on the average at the 77th percentile in mathematics aptitude and at the 34th percentile in reading proficiency.

The eye-movement measurements obtained in this experiment are summarized in Table VII. Generalizing upon the contents

TABLE VII. *The differences between the eye-movements of two groups paired on reading ability and representing extremes in mathematics aptitude*

	Measure	Low math. M_1	High math. M_2	Diff.	CR and chances in 100
A	Mean duration per fixation	.290 .029	.278 .038	.012	1.50 93
B	Mean of individual SDs of duration per fixation	.116	.101	.015	2.05
C	Mean mode of duration per fixation	.247 .041	.230 .034	.017	1.79 96
D	Mean size of fixation in *cms*	2.68 .65	2.74 .65	—.06	.46 67
E	Mean regressions per line	1.39 1.17	1.01 .76	.38	1.52 93
F	Mean rate of reading in *cms* per minute	505.9 151.7	533.8 151.3	—27.9	.84 79

N=31 in each group. Included just below each mean is its SD.

of this table, we may reassert the findings contained in Table VI. The differences between eye-movements of the two groups are quite small, yet only two, those for mean size of fixation in *cms* and the mean rate of reading in *cms* per min., are probably merely chance differences. Worthy of note also is the fact that the differences agree in sign, measure for measure, with the differences shown in Table VI.

These findings supplement the observations previously made relative to the handicap of low intelligence as expressed in eye-movement behavior. The group of inferior intelligence must examine the reading material longer and more carefully to approximate the reading performance of a more intelligent group.

Conversely, by virtue of their superior intelligence the *S*s in the latter group supplement a deficit in objective aids with richer elaborative functions.

The further question arises as to what practical clinical implications these observations suggest. Apparently eye-movements are conditioned by general intelligence, and, if this factor were to be held constant, eye-movement behavior would bear only a minor relationship to reading proficiency. Partial coefficients of correlation computed from the data contained in Table IV showed such a condition. Holding intelligence test scores constant, we found that no single measure of eye-movements correlated reliably with scores made on the *Iowa Silent Reading Test*. It would seem, then, that the clinical cases from whom most improvement can be expected are those with a low *Iowa Silent Reading Test* score and a high *University of Iowa Qualifying Examination* rating. With the proper diagnosis and training, cases chosen in this way quite readily raise their reading performance to the level of their other abilities. Individuals of low intelligence, unless highly motivated, derive very little benefit from training in reading.

In the latter group the reading difficulty is usually incidental to a more general deficiency. Because the level to which reading ability can be raised is always conditioned by general intelligence, the situation is serious. Yet the program of reading clinics must somehow include provisions for the treatment of cases with many degrees of general ability. Let us consider those aspects of remedial training by which the individual of low intelligence might profit.

As soon as the clinician has ascertained beyond a doubt the low intelligence of a case, he must plan a program of instruction which takes this obstacle into account. Now it is true that most college students habitually function below the level of their optimum capacity. Thus all students, including those of reduced mental ability, can take advantage of the margin of improvement which their ability permits. Experience also has shown that students of low intelligence generally are the worst offenders in their failure to utilize what ability they have. Only the most exceptional individuals push themselves to their maximum level of accomplishment.

The most obvious clinical recommendation which we can make is to motivate these individuals in their reading to take full advantage of all the resources at their command. The problem of motivation is one to which clinicians adjust in varying ways, so no attempt is made here to outline motivating devices. However, successful motivation produces increased effort to understand the reading material. A product of this renewed effort is a more careful and deliberate scrutiny of the reading page; hence there appears also an increased irregularity of eye-movements.

The reading of individuals with low intelligence is, at best, predominantly perceptual. Therefore the reader should make every attempt to insure smooth and accurate perception of the reading material. At first this requires considerable dependence upon the printed page. As soon as smooth and accurate habits of perception are established, the reader may begin to cultivate some of the more subtle processes which occur in effective reading. Yet the individual with an intellectual handicap never can be as effectively weaned from the objective reading page as the superior individual.

The principles of motivation discussed in the above paragraphs are applicable also to students of average or superior mental endowment. However, the reading deficiencies encountered in cases of high intelligence are more often due to faulty training, lack of practice, or environmental obstacles than to lack of motivation. The specific problem here is to train these individuals so that their superior intelligence will contribute its full share to their reading performance. Thus remedial treatment should be confined less to problems of apprehension and more to cultivation of effective habits of comprehending and thinking. Well established habits of a fundamental nature are necessary even to individuals of substantial ability. But in the course of their reading development these tend to become subordinate to more subtle processes of an elaborative kind.

The reader will have noticed that the group of high intelligence, according to both Tables VI and VII, made scores on the

Iowa Silent Reading Test which were significantly lower than their general intelligence ratings. The remarks presented in the above paragraph apply particularly to individuals of this category. Although they made more regular eye-movements than the group with whom they were compared, the small difference suggests that they are not taking full advantage of their superior intelligence. Thus a program of remedial instruction should be outlined to cultivate habits of silent reading which are relatively independent of a very complex pattern of objective cues. Refined processes of comprehending and thinking, rather than detailed apprehendings, should be cultivated to carry the topical meaning. The extent to which this program is realized will determine the regularity of eye-movement behavior.

Rate vs. comprehension in reading. It has been customary in clinical procedure to distinguish between comprehension and rate of reading. These two aspects have been treated as if they were independent variables. Techniques have been developed to improve comprehension, apart from devices designed to improve rate. This distinction is as superficial as it is arbitrary

Reading is a performance which is the product of certain psychological functions involved in getting meaning from printed symbols. These psychological functions exist in time: they have a beginning, a course, and an ending. The elapsed time in course is the rate of reading. Thus comprehension and rate do not exist independently; rather, rate is the necessary outcome of time consuming processes in reading. All factors which affect the comprehending activities contribute to the time in course of those activities. Thus reading rate will vary as the *result* of variations in the comprehending functions. An alteration in rate which is not adjusted to the difficulty of material, the purpose in reading, and the general ability of the individual will disturb the normal course of the thought processes involved.

In spite of the dependence of rate upon comprehension, certain writers have contended that improvement in the rate of reading will improve reading generally. Since eye-movement records are essentially measures of rate, the obvious procedure has been to devise techniques for the training of eye-movements.

Correlations of individual measures of eye-movements with rate as measured at the eye-camera are given in Table VIII below. These coefficients were computed from data from 76 unselected university freshmen. Eye-movement records were obtained on Selection II, as administered previously. As indicated in the table, an unusually high correlation exists between the mean size of fixation in *cms* and the rate of reading. On the basis of this relationship *Pressey* (18), *Ring* and *Bentley* (19), *Gray* (9), *Moore* and *McLaughlin* (16), and *Robinson* (20) have designed

TABLE VIII. *The relation of individual measures of eye-movements to rate of reading*

		Rate of reading in *cms* per min.
A	Mean duration per fixation	—.60±.05
B	SD of the duration per fixation	—.68±.04
C	Mean size of fixation in *cms*	+.90±.01
D	Mean extent of forward shift	+.62±.05
E	Mean regressions per line	—.52±.05

exercises for 'pacing' eye-movements in order to increase the span of visual apprehension in poor readers. These writers imply that eye-movements are important causal factors in reading and that training of eye-movements will improve reading proficiency.

In reviewing our data we find no evidence to support the conclusion that eye-movements govern reading ability. However, we have ample evidence to show that variations in eye-movements are produced by conditions which control the course and needs of central processes in reading. Thus we found that eye-movements were variously modified by (1) changes in the difficulty of reading material, (2) changes in the attitude or 'mental set' in reading produced by alterations in instructions, and (3) differences in general intelligence. This remarkable flexibility of eye-movements which follows changes in central processes of apprehension and comprehension emphasizes again the dependence of eye-movement behavior upon reading ability.

There seldom is any representation in consciousness of these motor adjustments following the demands of central processes in reading. It is true that the movements of the eyes can be appreciated kinæsthetically; however, because attention in reading is always directed elsewhere, these muscular adjustments are usually hidden from consciousness. For this reason the intimate relationship between eye-movements (rate) and comprehension often has been overlooked. It seems as though these motor manifestations of adjustments which are psychological in character function independently of the latter. Yet it must be recognized that the eye-movements are dictated by conscious processes and are innervated subsequent to the initial conscious orientation made by *S* to the conditions of the reading situation.

The implications of this discussion are quite clear. Eye-movements are determined by the kind of conscious activity which accompanies them. Of these conscious determinants the attitude or 'mental set' in reading is the most important. Attempts to improve reading ability by training eye-movements violate laws governing the direction of the relationship between eye-movement behavior and the conscious processes involved.

If we arbitrarily change the nature of eye-movements in reading, we find no qualitative changes whatsoever in the conscious processes which occur. Hence the better plan, based on sound psychological principles, is to control the conscious activities which occur in reading by introducing changes in the cognitive phase of the total response system. Such a program of instruction might include emphasis on accurate perception, training in vocabulary, emphasis on the organization of ideas, practice in reading for the general idea, training in the critical evaluation of details, and reading for the purpose of answering specific questions. As *Tinker* (25) has contended previously, this program or its equivalent not only will be based upon sound principles of psychology, but the improvement in general reading ability which follows such instruction will be accompanied by an increased regularity of eye-movements.

IV. General summary and conclusions. The data of this study have been presented in two parts. In the first part photographic records of the eye-movements of 50 good and 50 poor readers were secured in order to compare the way in which the two groups adjust in their silent reading (1) to changes in the difficulty of reading material, and (2) to instructions to read for different purposes.

The subjects were segregated on the basis of clinical evidence and scores made on the *Iowa Silent Reading Test* and the *University of Iowa Qualifying Examination.* The analysis of the eye-movement records was made in terms of the following measures: (1) mean duration of fixation; (2) SD of the duration of fixation; (3) mode of duration of fixation; (4) mean size of fixation; (5) mean extent of the forward shift; (6) mean regressions per line; and (7) rate of reading.

Although every measure distinguishes good from poor readers at each of three levels of difficulty of reading material, the results indicate that the eye-movements of both groups tend to be influenced similarly by increased difficulty. With each increase in difficulty there was an increase in the number of pauses, the duration of fixations, and the number of regressions. There also was an increase in the SD of the duration of fixation and a significant reduction in the rate of reading. Furthermore, good readers not only showed a greater flexibility in eye-movements than poor readers in adjusting to increasingly difficult material but they varied most in the eye-movement measures best related to reading ability, *i.e.*, mean size of fixation, mean regressions per line, and rate of reading. The eye-movements of poor readers did not vary selectively in terms of the measures most important to good reading.

From the above results it is concluded that one of the determinants of the regularity of eye-movements is the difficulty of reading material to which the reader must adjust psychologically. The fact that good readers were more flexible in their eye-movements indicates that one aspect of their superior reading ability is the flexibility of their central processes in adjusting to increasingly difficult reading situations.

The group differences were more decisive and the variations within either group were greater when the analysis of eye-movement records was made in terms of various reading attitudes rather than in terms of the difficulty of reading material. The largest differences in eye-movements between the groups appeared when they were instructed to read for the general idea only. In reading for the general idea, good readers made their most regular eye-movements. There were relatively few pauses and regressions. The duration of fixation was reduced and there was a significant increase in rate of reading. In reacting to the same instructions, poor readers showed eye-movements exceeded in irregularity only by those made in their detailed, study type of reading.

When reading for the purpose of remembering all details and points of information, both groups made their most irregular eye-movements. Although the differences in eye-movements between the groups in this situation were significant, they were smaller than the differences which appeared between them in reading normally or for the general idea.

The above results indicate that another important determinant of the regularity of eye-movements is the purpose of reading. The fact that controlling the attitude in reading produced such large group differences and such striking variations within the groups suggests that the purpose in reading is a more important determinant of eye-movement behavior than the difficulty of reading material. Furthermore, the fact that poor readers could not effectively adopt any other than their ordinary everyday reading attitude, as evidenced in the inadequacy of their reports in reading for the general idea and details, indicates that an essential difference between good and poor reading is the better ability of good readers to adapt their reading to different purposes.

In the last part of this study a clinical evaluation of eye-movement measurements is made in terms of their reliability and validity, their relationship to intelligence, and their relationship to rate and comprehension in reading. Since many previous studies have shown that measurements of eye-movements are highly reliable, no further measurements of their reliability were made. However, the validity of eye-movements was thoroughly investigated.

No single measure was correlated highly enough with scores on either the *Iowa Silent Reading Test* or the *University of*

Iowa Qualifying Examination to be of much value in individual diagnosis and prediction. Mean size of fixation, which correlated .62 with both criteria, was the most valid measure of eye-movements. However, all measures except mean duration of fixation and SD of duration of fixation were valid enough to permit group comparisons in experimental studies of eye-movements. Since multiple correlations between various combinations of eye-movements and *Iowa Silent Reading Test* scores did not reliably raise the correlations between the individual measures and the criterion, it was concluded that in clinical diagnosis the mean size of fixation is the only eye-movement measure necessary to secure.

The individual measures of eye-movements were almost as closely related to general intelligence as they were to reading ability. Two experiments were conducted to determine the nature of the relationship between intelligence and the regularity of eye-movements. It was found that a group of low intelligence makes more irregular eye-movements than a group of high intelligence to approximate the reading performance of the latter group. Consistent results were obtained in two experiments using different measures of intelligence. From these experiments it is concluded that some individuals, especially those of low intelligence, might profit more by training which emphasizes careful and detailed reading rather than by exercises designed to increase the regularity of eye-movements.

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COMMON ELEMENTS IN SILENT AND ORAL READING

by

Donald E. Swanson

I. Introduction. This study is a continuation of research being conducted in the Reading Clinic of the University of Iowa to obtain a more adequate understanding of the reading deficiencies of college freshmen.

The majority of previous investigators have represented silent reading as being quite different from oral reading. *Judd* (8) has concluded that "oral reading and silent reading are very different processes. Silent reading consists of a series of pauses determined in number and length by the demands of recognition, while oral reading consists of a series of pauses dominated by articulation, recognition in this latter case being more than adequately provided for within the pauses required for pronunciation." Basing his conclusions upon a study of eye-movements of adult readers, *Judd* found that "the number of pauses in oral reading is greater than in silent reading, and the average length of pauses is greater. The unit of recognition in silent reading is broader than the unit of recognition and articulation in oral reading."

O'Brien (9) states that numerous investigations (8, 12) have demonstrated "the unmistakable superiority of silent over oral habits, namely, the wider perceptual span as shown in the smaller number of fixations, the shorter duration of fixation-pauses, the decrease in the number of regressive movements and the greater regularity and more rhythmical swing of the eye-movements."

The superiority of silent over oral reading, as to rate, has been shown by *Huey* (6), *Judd* (8), *Pintner* and *Gilliland* (10) and *Quantz* (11).

Thus, on the basis of different mechanical manifestations, silent reading and oral reading have been considered distinct processes. The finding that the mechanics of oral reading differ from the mechanics of silent reading does not indicate, however, that the fundamental process of thought-getting is different in the two types of reading. Investigations of the more complex psychological processes of perception accuracy and comprehension as related to the two modes of reading are in large part lacking. Instead of emphasizing mechanical differences between oral and silent reading it would seem more important to unravel the psychological similarities between the two processes. Therefore the present investigation was undertaken to determine whether or not there are any common elements in poor silent and poor oral reading. If poor silent readers are found to be poor oral readers in ways which are common to both types of reading, silent reading deficiencies may be studied to advantage by an oral reading technique. This technique would have supplementary value in the analysis of poor silent reading because oral reading is explicit and can be reproduced objectively and accurately by phonographic recording. The present study is concerned with the type of oral reading which occurs when *S* attempts to understand the material read. It is not concerned with oral interpretative reading.

On the basis of a preliminary study of the oral reading of 10 poor and 10 good silent readers, a research program was set up (1) to demonstrate whether or not there are common factors in poor silent and poor oral reading; (2) to permit an analysis of the errors made in oral reading by poor silent readers; and (3) to show what effect change of comprehension requirements has on the accuracy of oral reading.

II. Experimental procedure. The main group of *Ss* for this study consisted of 70 poor silent readers who ranked at the 30th percentile or below in total comprehension on the *Iowa Silent Reading Test* (7) and at the 59th percentile or below on the *University of Iowa Qualifying Examination* (13) when they entered the university. These *Ss*, freshmen from the academic years 1932–1933 and 1933–1934, were sent to the University of Iowa reading clinic for diagnosis. A subsidiary group of 10 good silent readers ranked in the highest decile on both the *Iowa Silent Reading Test* and the *University of Iowa Qualifying Examination.* The number in this group is small but was considered large enough to be quite representative of good silent reading ability. *Whipple's High School and College Reading Test* (19) was given at the time of the initial interview to 51 of the poor readers as a further check upon their silent reading ability. Scores on a test of *Reading Comprehension Maturity* by *Feder* (3) were available for 35 *S*s.

Oral reading material. The three selections of reading material used for this study contained informative material of moderate difficulty. Selection I (two paragraphs of 199 words) was taken from the article 'Individual Differences' by *Henmon* in *Psychology Today* (a series of radio lectures, edited by *Bingham*, 2). Selection II (120 words) was the selection II used by *Walker* (17) in studying the eye-movements of good readers. Selection III (103 words) was taken from the article 'The Vibrato,' by *Seashore*, also in *Psychology Today*. Selections I and III were read from the original text; selection II, set up in 10-point DeVinne type by *Walker*, was mounted on cardboard.

Recording apparatus and procedure. The oral reading was recorded with a standard apparatus which cut the record on 12-inch aluminum discs. Each *S* sat in a chair directly before a condenser microphone, in a room adjacent to the recording apparatus. The reading material was placed on a book holder attached to the writing arm of the chair, in a convenient reading position. At the flash of a signal light *S* removed a shield which covered the reading material and began reading. A practice paragraph was given to make *S* feel at ease before the microphone and to permit *E* to adjust the recording apparatus. Comprehension was checked at the completion of the trial selection.

In selections I and II *S* was asked to read the material once so that the meaning would be clear to himself as well as to a listener. He was instructed to read in a normal manner, 'as though he were reading to his roommate.' Comprehension was checked by objective questions at the end of each selection to make sure that *S* would read to understand the content. In selection III *S* was instructed to read as effectively as possible, so that the meaning would be clear to a listener. He was assured that his comprehension of the reading would not be checked. The purpose of this selection was to find the effect, upon the accuracy of oral reading, of removing the comprehension requirement.

Analysis of records. The phonographic records of oral reading were played several times to permit *E* to determine what errors had been made. As a further means of checking the accuracy of analyzing the errors, *E* and an assistant checked the records of the first 20 *S*s and jointly passed judgment upon the errors made. Since errors could be heard over and over again, no difficulty was experienced in analyzing the records. It was found unnecessary to have the records checked for statistical reliability by an independent worker.

With a double-spaced typewritten copy of the selection before him, *E* listened as each record was played and indicated the errors by a convenient and uniform system of symbols. In the case of substitutions and insertions the words substituted or inserted were written in full above the correct word. This system of indicating what actually was read allowed a quantitative and qualitative classification of the errors in various categories and sub-categories.

III. Analysis of common elements in poor silent and poor oral reading. In order to demonstrate the existence or non-existence of common elements in poor oral and poor silent reading it is necessary to ascertain the relationships between certain variables in oral reading and the same variables in silent reading. This phase of the study will attempt to determine whether or not there are factors which are common to both modes of reading by finding the relationship (1) between perception accuracy in oral reading and tachistoscopic perception accuracy; (2) between silent reading comprehension and oral reading comprehension; and (3) between rate of silent reading and rate of oral reading.

Perception accuracy in oral reading and tachistoscopic perception accuracy. An analysis of oral reading demonstrated that poor silent readers perceived inaccurately when reading orally. These readers made an average of 34 oral errors on selections I and II. Oral inaccuracies, discussed in detail in section IV of the present study, were classified into six categories. Substitutions, repetitions, omissions, insertions, mispronunciations, and miscellaneous errors constituted 30, 22, 17, 13, 10, and 7 per cent of the total errors, respectively. The question now arises: do poor silent readers also tend to perceive inaccurately when they read silently? The only available approach for testing the hypothesis that poor readers make perceptual errors in silent reading as well as in oral reading was an analysis of perception of tachistoscopically exposed material. A series of 50 phrases, each phrase containing two or three words, was cut from the oral reading material. These phrases were mounted on white cards and exposed in a *Whipple* tachistoscope (18). The length of exposure time was 225 σ. Forty-one of the *S*s whose oral reading was recorded participated in this experiment. Half of them did the experiment before the recordings of their oral reading and the other half 10 months afterward. Several practice trials were given. *S*s wrote their responses after each stimulus was exposed. A perception accuracy score was determined by obtaining the total number of errors made in 50 trials.

Inaccurate perception was found to be common to both poor oral and silent reading in so far as perception accuracy in silent reading is adequately measured by the tachistoscopic technique. A correlation coefficient of .81±.04 obtained between the total number of oral reading errors and the total number of tachistoscopic errors. This relationship is close enough to be significant and shows that individuals who were inaccurate in perception in oral reading tended to perceive inaccurately material presented tachistoscopically. A closer relationship was found between the total number of errors in oral reading and tachistoscopic perception than between any single error category in both variables. A coefficient of .68±.06 was found between the number of substitutions in oral reading and tachistoscopic presentation, and a coefficient of .50±.08 was found when the numbers of omissions in each variable were correlated.

An analysis of the various types of errors made on phrases tachistoscopically exposed showed that substitutions of words occurred most frequently, comprising 67 per cent of the total number of errors, and that omissions and insertions made up 30 and 3 per cent of the total, respectively. Reversal of word order occurred very infrequently, constituting only .5 per cent of the total number of errors. The mean number of total errors was 30.

Another experiment was designed to measure the effect of changing the times of exposure on the accuracy of tachistoscopic perception of simple sentences. Fifty meaningful sentences, each consisting of five words, were cut from the simple story of *Aladdin* and mounted on cards identical with those of the previous experiment. These were subdivided into five series with 10 trials in each series. The series were subjectively equated in difficulty and length. Even though difficulties of vocabulary and comprehension were largely eliminated by the choice of simple material, a rotating order of presentation of the five series served further to rule out any possible differences in difficulty among the series. The first series was given the longest time of tachistoscopic exposure, 225 σ; the last series was given the shortest time exposure, 42 σ; and the intervening series were exposed at 150 σ, 100 σ, and 50 σ, respectively. Practice trials were given before each series. *S*s were given sufficient time to write their responses. The number of correct word responses was divided by the total number possible, 50, to determine the per cent of accuracy at each length of exposure time. Fifty poor readers who ranked below the 30th percentile on the *Iowa Silent Reading Test* acted as *S*s for this experiment. Thirty-nine of these *S*s participated in the previous experiment.

As shown in Fig. 1, poor silent readers tended to perceive more inaccurately as the exposure times were decreased in length. Moreover, at the 225 σ and 150 σ exposure times, the poorest silent readers tended to maintain a level of accuracy lower than the accuracy of individuals who had better reading ability. The 10 poorest readers, who ranked in the lowest decile on the *Iowa Silent Reading Test*, did not attain 75 per cent accuracy in any of the series, whereas the 12 *S*s who ranked between percentiles 11–30 on the *Iowa Silent Reading Test* maintained more than 75 per cent accuracy on the three longest exposure times. The finding that perception accuracy decreases among poor readers with decrease of exposure time suggests that any attempt of the poor reader to speed up his rate of reading, without first correcting his perception difficulty, would enhance error tendencies.

The correlations between scores on the *Iowa Silent Reading Test* and per cent accuracy at the various time-series, show that the series with the longer exposure times were more closely related to scores on the *Iowa Silent Reading Test* than the series with the shorter exposure times. The coefficients obtained (N=39) at the 225 σ, 150 σ, 100 σ, 50 σ, and 42 σ series were .41±.09, .51±.08, .32±.10, .32±.10, and .13±.10, respectively. The correlation between the *Iowa Silent Reading Test* and total

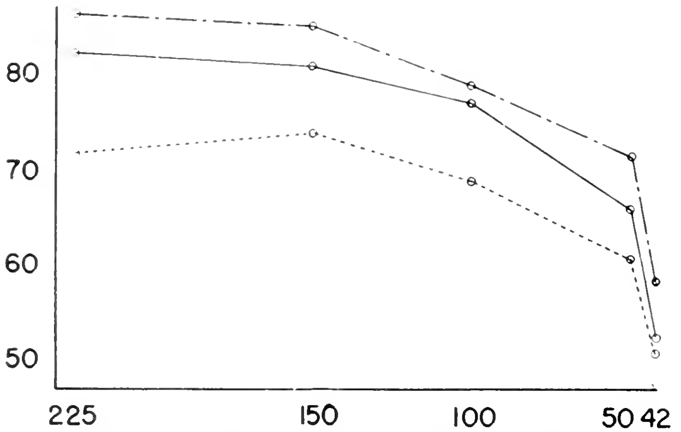

FIG. 1. Effect of decreasing time of tachistoscopic exposure on perception accuracy. Time in .001 sec. plotted on abscissæ and per cent accuracy on ordinates. Solid line, 50 poor readers who ranked at the 30th percentile or below on the *Iowa Silent Reading Test,* dotted line, 10 poor readers who ranked in the lowest decile, broken line, 12 poor readers who ranked between percentiles 11–30. The circles indicate the significant points of the graph.

errors made on the phrases exposed tachistoscopically in the previous experiment was .37±.09, and between the *I.S.R.T.* and oral reading errors, .44±.07. Thus, the frequency of errors made in oral reading tended to be as closely related to silent reading ability as was the number of errors on the tests of tachistoscopic perception accuracy. Since the oral reading technique can be administered easily and involves a situation which approximates normal reading, it should be a useful supplementary devise in the diagnosis of perception accuracy among poor silent readers.

A correlation of .64±.06 obtained between the total number of errors made on the phrases presented tachistoscopically at a time exposure of 225 σ and the per cent accuracy in the 225 σ series of the sentences exposed tachistoscopically in the present experiment. The per cent accuracy on sentences in the 225 σ series correlated .59±.07 with the total number of errors in oral reading. As previously stated, a correlation of .81±.04 obtained between tachistoscopic errors on phrases and oral reading errors. Thus, the relationships between the tachistoscopic tests of perception accuracy at an exposure time of 225 σ and oral reading errors indicate that these tests of perception accuracy agree to quite an extent as to what they measure.

Comprehension in poor silent and poor oral reading. Comprehension in oral reading of selections I and II was checked by 22 recall questions for 32 *S*s and by 16 multiple choice questions for 38 *S*s. The present study did not aim to make a detailed analysis of comprehension in oral reading. Comprehension was checked primarily to be sure that the *S*s would attempt to read to understand the content. The reliability of the recall test, .54, was computed by correlating the odd items against the even items and using the *Spearman-Brown* formula to estimate reliability for the full length of test. The reliability coefficient of the multiple choice test, which was computed in the same manner, was only .17. These low reliabilities were to be expected because the questions were based on easy material which was short enough to be practicable for recording purposes, because there were too few items in the tests, and because the range of the group tested was very restricted. The multiple choice questions obviously were too unreliable to be used as a measure of oral reading comprehension, and the results on the recall questions should be used only as an indication of tendencies and not as a reliable test. The 32 *S*s who were given questions of the recall type scored, on the average, nine correct out of 22 questions (40 per cent accuracy), whereas the 10 good silent readers averaged 18 correct on the same questions (80 per cent accuracy).

Since oral reading comprehension scores of the recall type were available, even though somewhat unreliable, they were correlated with silent reading comprehension scores. A correlation of .36±.11 obtained between oral reading comprehension and total comprehension scores of the *Iowa Silent Reading Test*. The correlation between Part I (paragraph meaning) of the *Iowa Silent Reading Test* and oral reading comprehension was .45±.10. The latter relationship, although low, is four times its probable error and suggests that those whose comprehension is poorest in silent reading tend to show the poorest comprehension in oral reading. The relationship between silent and oral reading comprehension probably would be closer in an unselected group of readers tested with reliable instruments.

The indication that poor comprehension is common to both poor oral and poor silent reading is supported in a further study by *Swanson and Anderson* (14) who found no statistically significant differences between comprehension scores when material of moderate difficulty was read silently, orally, or presented on a phonograph record. Two selections were chosen from the *Buffalo Reading Test* (16) for each method of presentation, and 13 multiple choice questions which accompanied the reading material were used to check comprehension for each method. The selections and methods of presentation were rotated among 52 poor readers so as to control any inconstancies in difficulty among the paragraphs and to rule out any favoring tendencies toward any one order of presentation. The difference between scores in oral reading and silent reading comprehension was only .56 times the $SE_{diff.}$, indicating that on the particular test used in this experiment a group of poor readers tended to comprehend as well in oral reading as in silent reading.

The above experiment can be criticized because too few questions were used in measuring comprehension for each method. Therefore the test was lengthened so that eight selections instead of two were read silently and eight selections were read orally. Thus the number of questions was increased from 13 to 50 for each method of reading. If a selection in *Form A* of the *Buffalo Reading Test* was read silently, a selection comparable in difficulty in *Form B* was read orally. The selections in *Form A* were read silently by six and orally by the other six of 12 *S*s. The mean number of questions answered correctly out of 50 was 36.25 for silent reading and 33.83 for oral reading. The $SE_{diff.}$

between the means was not computed because the group was too small. The very fact that the difference between the means was small supports the finding of the present investigation that poor comprehension tends to be common to both poor silent and oral reading.

Rate of poor silent and poor oral reading. The mean rate of oral reading for 70 poor silent readers on selections I and II (319 words) was 132 secs., or 145 words per min., whereas the mean oral reading rate for 10 good silent readers on the same selections was 107 secs., or 178 words per min. The range of the oral reading rates was from 98 seconds to 219 seconds among the poor readers. The fact that there is not such a marked difference in the oral reading rate of poor and good readers can be accounted for by such factors as physiological limitations of the articulatory mechanism, and a quite constant reading attitude and situation. It is important to note, however, that there was greater variability in the rate of oral reading among the poor readers (SD, 22.56 sec.), than among the good readers who read orally with very little variation in rate (SD, 4.24 sec.).

The correlations between the tests of silent reading rate used in this experiment and rate of oral reading were positive but low, indicating that only a slight relationship existed between rate of oral and rate of silent reading among poor readers. The correlation between oral reading rate (total seconds in reading selections I and II) and Part VI of the *Iowa Silent Reading Test* (number of lines read) was $.26 \pm .08$ ($N=70$); between *Whipple's Silent Reading Test* (number of items tried) and the *I.S.R.T.* the coefficient was $.31 \pm .09$ ($N=51$).

Further analysis, however, demonstrated that the slowest silent readers also tended to be the slowest oral readers. The mean rate of oral reading on selections I and II of the 25 slowest silent readers as measured by Part VI of the *Iowa Silent Reading Test* was 141 sec., whereas the mean rate of the 25 fastest silent readers among the 70 *S*s was 124 sec. The SDs of the two groups were 25.4 and 20.72 secs., respectively. The difference between the means of the two groups was 2.60 times the $SE_{diff.}$, indicating that the difference obtained was statistically reliable.

The finding that those who have a slow rate of silent reading tend to have a slow rate of oral reading is substantiated in an eye-movement study by *Anderson* and *Swanson* (1) who found a correlation of .78±.05 between silent and oral rate among poor readers. The reason that the relationship between silent and oral rate is closer in the *Anderson* and *Swanson* study than in the present investigation is that the measures of rate in the two variables were more comparable.

It is interesting to note that the poor readers who made the greatest number of oral errors also tended to read most slowly. A coefficient of .54±.06 obtained between total oral errors and rate of oral reading. It is probable that frequent oral inaccuracies had a cumulative effect upon rate. The 25 silent readers who had the slowest rate on Part VI of the *Iowa Silent Reading Test* made an average of 38.16 errors in oral reading while the 25 fastest silent readers made an average of 30.84 errors. The SDs for the two groups were 19.12 and 17.19 errors, respectively. The difference between the means of the two groups was 1.42 times the $SE_{diff.}$. This CR is not large enough to be statistically reliable, but indicates that there were 92 chances in 100 that the slowest poor silent readers tended to make a greater number of errors in oral reading than the fastest poor silent readers. The above finding conflicts with the viewpoint advanced by *Judd* (8) who has cited cases to show that the slow silent reader is a good oral reader because he is careful, whereas the rapid silent reader is a poor oral reader because he is careless and neglects details.

IV. Analysis of the errors made in oral reading. On the basis of an analysis of the oral reading of 70 poor silent readers, oral inaccuracies were classified into the following six categories, listed in order of the frequency of occurrence: substitutions, repetitions, omissions, insertions, mispronunciations, and miscellaneous errors. These various error categories constituted 30, 22, 17, 13, 10, and 7 per cent of the total errors, respectively, whereas for good silent readers the same errors constituted 14, 20, 18, 24, 10, and 13 per cent of the total errors, respectively. The poor silent readers made an average of 34 errors in the oral reading of selections I and II, whereas the good readers made an average of only eight errors on the same selections. The SD among the poor readers was 18.23 errors and the number of errors ranged from 6 to 88.

As shown in Fig. 2, the oral errors which most definitely differentiated poor from good silent readers were substitutions, repetitions, and omissions. The graph presents a comparison

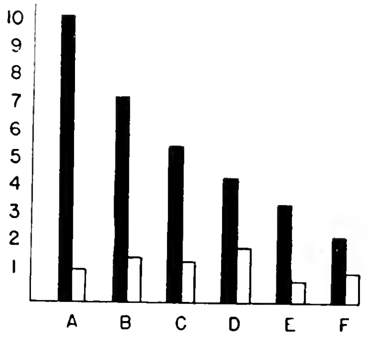

FIG. 2. Comparison of poor and good silent readers as to mean number of oral reading errors in each error category for selections I and II (319 words). Mean numbers of errors are plotted on the ordinates and error categories on the abscissæ. Black columns, poor readers, white columns, good readers. A, substitutions; B, repetitions; C, omissions; D, insertions; E, mispronunciations; F, miscellaneous.

of the poor and good readers for the mean number of oral reading errors in each of the error categories for selections I and II. Substitutions, repetitions and omissions, the errors characteristic of poor readers, thus may be considered the most significant and diagnostic in the analysis of poor silent reading. Good readers made approximately the same mean number of errors in all of the error categories, the most common error being insertions. The errors of good readers usually did not alter the meaning of the selection. Poor readers, on the other hand, made errors which tended to change the meaning significantly.

Graphs B, C, and D, Fig. 3, show that poor readers made oral errors on the easy as well as on the difficult words in selections I and II. Five levels of word scarcity were chosen arbitrarily on the basis of frequency of occurrence, in *Thorndike's* (**15**) word list, of the words in the above selections. The per cent of substitutions, mispronunciations, and omissions, made at the various levels of word scarcity are presented in graphs B, C, and D, respectively. B, Fig. 3, shows that poor readers substituted for easy words as often as for more difficult words. This indicates

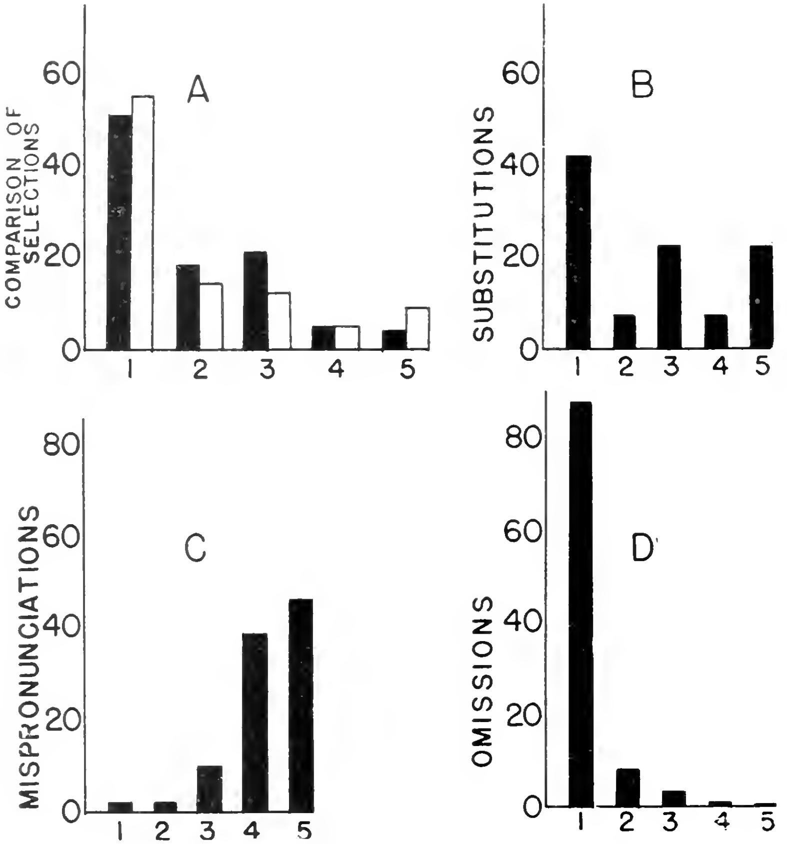

FIG. 3. Graph A, comparison of selections I and II with selection III as to difficulty of words. Five levels of word scarcity, based on frequency of occurence in *Thorndike's* word list, are plotted on the abscissæ and the percentages of words at each level on the ordinates. Black columns, selections I and II, white columns, selection III. Graphs B, C, and D show, for selections I and II, percentages of substitutions, mispronunciations, and omissions, respectively, made by poor readers at the various levels of word scarcity. Word scarcity is plotted on the abscissæ and percentages of errors on the ordinates. 1, words occurring in *Thorndike's* list from 1–100; 2, 101–500; 3, 501–5000; 4, 5001–10,000; 5, above 10,000.

that substitutions were not due entirely to the difficulty of the words in the selections. On the basis of the ratio of per cent of substitutions to per cent of words at each scarcity level, poor readers showed a greater probability of substituting for the more difficult words, since 51 per cent of the words were at the easiest scarcity level and only four per cent were at the most difficult level. Clinical observation shows, however, that word scarcity cannot be used as the sole criterion for frequency of substitutions since the longer and more difficult words are usually examined more carefully by the poor reader. The fact that oral inaccuracies occur so frequently on very simple words suggests that poor readers are quite unaware that they are not perceiving correctly. As shown in C and D, Fig. 3, mispronunciations occurred on the more difficult words, whereas only the easier words were omitted.

The errors made in oral reading were classified further into the number of errors corrected and the number uncorrected in each error category. Repetitions were arbitrarily omitted from this classification because they differed in nature from the other types of errors. Only 11 per cent of the total number of errors (excluding repetitions) made by the poor readers were corrected. Nineteen per cent of the substitutions, 10 per cent of the omissions, three per cent of the insertions, eight per cent of the mispronunciations and two per cent of the miscellaneous errors were corrected.

The good readers corrected 12 per cent of the total number of errors. Thirty-three per cent of the substitutions, 20 per cent of the omissions and 13 per cent of the mispronunciations were corrected. Insertions and miscellaneous errors were not corrected.

A systematic treatment of each of the error categories. Substitutions.—Substitution of a word of similar configuration constituted 60 per cent of all the substitutions made by the poor readers. Substitution of an unlike word occurred in 22 per cent of the total number of substitutions. Substitution of a jumbled word, one which does not make sense, and substitution of another word each made up eight per cent of the total. If part of another word was substituted, the error was recognized by *S* before he finished the word and a correction usually was made. Substitution of a synonym, a syllable, and substitution of one word for two words occurred very infrequently.

The good readers substituted a word of similar configuration in 42 per cent, an unlike word in 50 per cent and part of another word in eight per cent of their total substitutions. Substitution of a word which does not make sense, substitution of one word for two words, or substitution of a synonym or a syllable did not occur among the good readers.

Repetitions.—The poor readers repeated part of a word more frequently than they repeated a word or a group of words. Repetition of part of a word made up 41 per cent of the total number of repetitions, repetition of a word constituted 32 per cent of the total, and repetition of a group of words accounted for 27 per cent of the repetitions. Nearly all (92 per cent) of the repetitions of a word were within a sentence rather than at the beginning or at the end of a sentence.

Forty-seven per cent of the repetitions of good readers were of a word, all within a sentence, 35 per cent were of a group of words, and 18 per cent were of part of a word. The finding that good readers tended to repeat words or groups of words more often than they repeated part of a word, whereas poor readers repeated part of a word more frequently than they repeated words or groups of words, suggests that good readers perceived larger units than poor readers. It appears that poor readers were so preoccupied with the task of word recognition that they were unable to attend to the meanings of the larger thought units.

Further analysis showed that 51 per cent of the repetitions of poor readers were repetitions of correct material. The remaining 49 per cent were repetitions of error material. Eighty-two per cent of the repetitions of error material resulted in corrections of the errors, and in 18 per cent of such repetitions correction was not achieved. Fifty-three per cent of the repetitions made by good readers were repetitions of correct material and 47 per cent were repetitions of error material. Good readers, unlike poor readers, always achieved correction when they repeated error material.

Omissions.—Omission of a letter constituted 43 per cent of the total number of omissions, omission of a syllable made up 13 per cent, and omission of a word made up 33 per cent of the total. A syllable was omitted within a word or at the end of a word but never at the beginning of a word. Omission of a group of words and attempted pronunciation of part of a word with omission of the rest of that word each occurred in one per cent of the total number of omissions.

The term 'skipping' was introduced to differentiate between omissions which were not corrected by repetition and omissions which were corrected. Skipping was characterized by a tendency to pronounce a word or words ahead in the sentence, or a tendency to omit part of a word or a letter, followed by a correction, of that which was tentatively omitted. Skipping constituted about 10 per cent of the total number of omissions. One word was skipped more frequently than several words, a part of a word, or a letter.

The good readers omitted a letter in 53 per cent, and omitted a word in 27 per cent, of their total omissions. Skipping of a word characterized 20 per cent of their total omissions. There were no omissions in the other sub-divisions of this error category.

Insertions.—Fifty-four per cent of the total number of insertions made by the poor readers were whole words. Insertion of a letter and insertion of a syllable made up 23 and 21 per cent of the total, respectively. Insertion of a group of words, insertion of a word from the line above or the line below, or the carrying over of parts of the previous word occurred very infrequently. Insertion of an extra word, a letter and a syllable constituted 55, 25, and 20 per cent of the total insertions made by the good readers. The other types of insertion did not occur.

Mispronunciations.—Mispronunciations were sub-divided into major and minor errors. Errors were placed in the former class when more than one part of a word was pronounced incorrectly. These constituted only eight per cent of the total mispronunciations in the group of poor readers. Minor errors included mispronunciation of a part of a word, substitution of a vowel sound and use of a wrong accent, which occurred in 24, 12, and 56 per cent of the total mispronunciations, respectively.

The good readers made only minor mispronunciations; 88 per cent of the total were wrong accentuations and the remainder were mispronunciations of part of a word.

Miscellaneous errors. A vocalized pause,[1] which indicated that the reader was having difficulty with some word or with the meaning of a sentence, accounted for 50 per cent of the miscellaneous errors made by the poor readers. Slurring words together occurred in 23 per cent and disregard for punctuation occurred in 13 per cent of the total errors. Rising inflection at the end of a word, which made up nine per cent of the total, was counted as an error because *S* seemed to express doubt as to the accuracy of his pronunciation or recognition of a word. A reversal of words, spelling out a word letter by letter and a return sweep to the line above or the line below occurred very infrequently.

The slurring together of words constituted 82 per cent, and reversals of words and vocalized pauses each made up nine per cent of the miscellaneous errors of the good readers.

The relationship between oral reading errors and various tests of silent reading ability. In the present study scores for total oral errors were ranked in decreasing size when correlated with scores in other variables. The correlation between scores on the *Iowa Silent Reading Test* and the total number of errors made in oral reading by 70 poor silent readers was $.44 \pm .07$. Although this relationship is not close enough to permit predictions of individual performance it indicates that the poorest silent readers tended to make the greatest number of oral errors. The fact that the above coefficient is more than four times its probable error indicates that it is statistically reliable enough to allow group comparisons between variables. A correlation of $.36 \pm .07$, between the total substitutions in oral reading and scores on the *Iowa Silent Read'ng Test*, is further evidence that some relationship existed between oral accuracy and reading ability. As shown

[1] A vocalized pause is a meaningless sound similar to the first vowel in the word 'under.'

in Table I, the correlation between oral reading errors and total comprehension scores on the *Iowa Silent Reading Test* was somewhat higher than those between oral reading errors and other tests of silent reading comprehension. Even though all the coefficients are not statistically reliable they are positive, and suggest a measurable relationship between the various tests and frequency of oral errors. The relationship probably would have been closer under more favorable conditions and with more efficient instruments of measurement. Furthermore, a correla-

TABLE I. *Correlations between oral reading errors and various tests of silent reading comprehension among poor readers*

	r	N
Iowa Silent Reading, Total Comprehension	.44±.07	70
I.S.R. Pt. II, Word Meaning	.42±.07	70
Whipple's Silent Comprehension (gross scores)	.30±.09	51
Whipple's Silent Comprehension (per cent accuracy)	.26±.09	51
Feder's Comprehension Maturity Test	.28±.11	35

Total error scores ranked in decreasing size.

tional technique would tend to yield a lower relationship in a homogeneous group of poor readers with a restricted range of reading ability than in an unselected group representing the whole range of reading ability. This was substantiated in a separate experiment using 88 university freshmen selected at random. The *S*s read aloud a selection of 109 words which was comparable in difficulty with selection II. With the range of reading ability increased, the coefficients of correlation between scores on the *Iowa Silent Reading Test* and frequency of oral errors and substitutions were raised to .53±.05 and .47±.06, respectively. These coefficients still are not high but show some measurable relationship between silent reading ability and oral accuracy.

The finding that oral inaccuracies tended to increase with decrease of silent reading ability, in both poor readers and an unselected group is supported in still another way. When a comparison was made between the mean number of oral reading errors of the 25 *S*s who scored lowest on the *Iowa Silent Reading Test* and the mean number of oral reading errors of the 25 *S*s who scored highest among the 70 poor readers on the *Iowa Silent Reading Test*, a significant difference was obtained. The mean number of oral reading errors was 47.04, SD, 18.76, for the first group; for the second group the mean was 25.36, SD, 15.92. The difference between the mean scores of the two groups was 4.41 times the $SE_{diff.}$, satisfying the usual statistical requirement of being at least three times the $SE_{diff.}$, and indicates that those who scored lowest in silent reading ability tended to make a significantly larger number of errors in oral reading than the poor readers who scored highest in silent reading ability.

The relationship between oral reading errors and intelligence. To determine the effect of intelligence on oral inaccuracies the *S*s were segregated into two groups. Group I contained 22 *S*s who ranked in the lowest decile on the *University of Iowa Qualifying Examination*, while group II contained 22 *S*s who ranked between percentiles 11–33. The mean composite scores for groups I and II were 261 and 344, respectively. The validity of using the *University of Iowa Qualifying Examination* as a measure of intelligence lies in the fact that the correlations between this battery and tests of general mental ability at the college level are as high as the correlations between standard tests of intelligence (*Feder*, 4). The individuals of group I were matched in reading ability with the individuals of group II. The mean score of group I on the *Iowa Silent Reading Test* was 86, whereas the mean score of group II on the same test was 90. The two groups, thus approximately equated in reading ability, but varying in intelligence, made approximately the same number of errors in oral reading. The average oral reading errors in group I and in group II were 33.64 and 33.86, respectively. Moreover, the mean numbers of substitutions for the two groups were 9.64 and 10.09.

The above results must be tempered somewhat by the finding that with intelligence held constant by the partial correlation technique the coefficient between scores on the *Iowa Silent Reading Test* and oral reading errors was reduced from .44±.07 to .20±.08. That intelligence plays some rôle in oral accuracy is further indicated by the correlation of .42±.07 between scores on the *University of Iowa Qualifying Examination* and oral errors. The latter relationship is probably influenced somewhat by reading ability since the *Iowa Silent Reading Test* is one of the tests in the battery of the *University Qualifying Examination.* The correlation between scores on the above tests was .76±.03.

V. The effect of change of comprehension requirements on the accuracy of oral reading. Selection III, which was read by 61 poor readers after they had read selections I and II, was included to ascertain the effect of removing the requirement of answering comprehension questions on the accuracy of oral reading. Fig. 3, A, shows that selection III is approximately equal in difficulty to selections I and II on the basis of frequency of occurrence of the various words in Thorndike's (15) word list. Five levels of word scarcity were chosen arbitrarily for purposes of comparison. The graph indicates that 51 per cent of the words in selections I and II and 55 per cent of the words in selection III are found in the 100 most frequently used words in *Thorndike's* list, whereas only 4 and 9 per cent of the words in selections I and II and selection III, respectively, are not included in his list of the 10,000 most frequently used words. Thus, the selections contain relatively easy material.

As previously stated, the poor readers were instructed to read selections I and II so that they could comprehend questions at the completion of each reading. However, for selection III each *S* was instructed to read as effectively as possible so that the meaning would be clear to a listener, but he was assured that no questions would be asked.

In the latter situation poor readers made a greater number of oral reading errors per 100 words than in selections I and II. The number of errors per 100 words on selection III and selections I and II were 14.86 and 10.76, respectively. The more significant errors, such as substitutions, repetitions, and mispronunciations, occurred more frequently in selection III, whereas omissions and insertions occurred somewhat more frequently in selections I and II. A comparison between selection III and selections I and II on the basis of the mean number of oral reading errors and the mean number of errors per 100 words in each of the error categories is presented in Table II.

The fact that poor readers persisted in making frequent errors in selection III as well as in selections I and II indicates that inaccurate perception may function among poor readers in a variety of reading situations. Furthermore, the finding that the frequency of oral errors tended to increase on selection III suggests that the reading was less meaningful and less mature when the *S*s were not required to meet specific comprehension demands.

TABLE II. *Comparison among poor readers of selection III and selections I and II for the mean number of oral reading errors and the mean number of errors per 100 words in each of the error categories*

	Selection III (N=61)		Selections I and II (N=70)	
	Mean	Mean errors per 100 words	Mean	Mean errors per 100 words
Substitutions	6.05	5.87	10.37	3.25
Repetitions	3.93	3.82	7.60	2.38
Omissions	1.30	1.26	5.74	1.80
Insertions	1.20	1.17	4.59	1.44
Mispronunciations	2.00	1.94	3.60	1.13
Miscellaneous	.84	.82	2.44	.76
Total errors	15.31	14.86	34.34	10.76

Clinical observation of the oral reading of poor silent readers who perceive inaccurately shows that they often persist in making the same errors on repeated readings of a given selection. Errors may occur in a later reading after *S* has been made to recognize his mistakes. Observation reveals also that very poor readers make serious errors in spite of instructions to read the words exactly as they are printed. The above clinical evidence should be checked experimentally in future research. If serious errors should persist consistently, even when *S*s strive to read material exactly as it is printed, such errors may be considered genuine and would tend to be a handicap in reading normally for comprehension. It seems unnecessary to confirm the above hypothesis in the present section, however, since the usual functions of reading orally are to convey meaning to the reader or to his listener. Our major point here is the finding that significant errors existed both when comprehension questions were omitted and when the comprehension requirements were emphasized. The poor readers who perceived inaccurately in reading selections I and II also tended to perceive inaccurately in reading selection III. Substantiation of the above is found in the rather high correlation coefficient, $.78 \pm .03$ ($N=61$), obtained between the total number of oral reading errors in the two situations. The fact that the *S*s tended to maintain their same relative positions within the group from selection to selection further supports the finding that errors in perception accuracy persist with variation of the reading situation.

VI. Summary and conclusions. The present study demonstrates that a rather close correspondence exists between certain processes involved in poor silent and poor oral reading. The elements common to both silent and oral reading among poor readers were: (1) inaccurate perception, (2) poor comprehension, and (3) slow rate of reading. The factor which was most closely related to the two types of reading was perception inaccuracy. Poor silent readers who perceived inaccurately in reading orally were inaccurate in the perception of material presented tachistoscopically. Moreover, those who comprehended poorly in silent reading tended to comprehend poorly in oral reading. Another factor common to poor silent and poor oral reading was slow rate. The latter relationship is important since rate is an index of the time consumed in the integrated functioning of various psychological and physiological processes during reading.

Previous investigators usually have considered silent and oral reading as distinct processes because of the more efficient peripheral manifestations of silent reading. The findings of the present investigation suggest that a thorough study of the complex psychological processes common to the two types of reading would give greater insight into the fundamental nature of the relationship between silent and oral reading than continued emphasis upon their mechanical differences.

Since poor silent readers tended to be poor oral readers in elements common to both types of reading, certain aspects of silent reading deficiencies may be studied advantageously by an analysis of oral reading. The fact that perception inaccuracy was the factor most intimately related to the two modes of reading suggests that in poor reading perception is a prominent function in both processes. Now, since oral reading is explicit and can be reproduced accurately by phonographic recording, the oral reading technique would be a convenient and efficient device for the analysis of perception accuracy.

An analysis of phonographic recordings of the oral reading of 70 poor silent readers showed that these readers made an average of 34 errors in reading orally to understand two selections of moderate difficulty. Oral inaccuracies were classified into six categories in order of frequency of occurrence: substitutions, repetitions, omissions, insertions, mispronunciations, and miscellaneous errors. Ten good silent readers averaged only eight oral errors on the same selections, the most common error being insertions. Poor readers made errors on easy as well as difficult words and corrected only 11 per cent of the total errors (excluding repetitions). Each of the error categories was further classified into various types. A study of repetitions revealed that poor readers tended to perceive smaller units than good readers.

Correlations between oral reading errors and tests of silent reading comprehension were not high enough to permit predictions of individual performance but indicated that, for the groups studied, oral inaccuracies tended to decrease with increase of silent reading ability. The reason that the relationship between oral errors and silent reading ability is not closer is that higher psychological functions as well as perception accuracy contribute to the acquisition of meaning and comprehension. Accurate perception is a means toward the goal of adequate assimilation in reading. An indication that frequency of oral inaccuracies tend to increase with decreased functioning of the more complex psychological processes was found when the poor readers were not required to answer comprehension questions after their reading. On the other hand, the requirement to meet specific comprehension demands tended to produce more meaningful and consequently more accurate reading.

The finding that significant oral inaccuracies occurred both when the comprehension requirement was stressed and when comprehension questions were omitted, and the fact that the correlation between the frequency of errors in the two situations was rather high, indicate that perceptual errors persisted with variation of the reading situation. The finding that the frequency of errors was approximately the same in two groups matched in reading ability, but varying in intelligence, suggests that other factors as well as mental ability cause perceptual errors. The etiology of these errors should be determined.

The data of the present investigation suggest further that the technique for testing the oral reading achievement of grade school pupils by a series of standardized paragraphs, as developed by *Gray* (5), may be extended advantageously to the college level. The oral reading technique for the analysis of perception inaccuracy will give the clinician supplementary information which will aid in the diagnosis of reading difficulties. A poor silent reader, who is inaccurate in oral reading, should be trained to read more accurately before attention is directed to remedial work on other phases of reading, such as comprehension and rate. The finding in the present study that errors increased with decreasing lengths of tachistoscopic exposure time suggests that an attempt to increase the rate of a poor silent reader who perceives inaccurately, without first improving his perception, would enhance his difficulty rather than remedy it.

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COMMON FACTORS IN EYE-MOVEMENTS IN SILENT AND ORAL READING

by

Irving H. Anderson and Donald E. Swanson

1. Introduction. *Swanson* (4) has shown that certain skills are common to both silent and oral reading, *i.e.*, perception accuracy, comprehension, and rate in reading. In general, poor readers who show an immature development of these skills in silent reading also exhibit similar deficiencies in oral reading. The present study attempts to determine whether eye-movement characteristics of the two types of reading exhibit corresponding similarities.

Anderson (1) and *Tinker* (5) have shown that eye-movements in reading vary with central processes. If the conscious processes are hesitant and confused, the eye-movements will be halting and irregular; but if the comprehending aspect of reading is efficient, the eye-movements will be regular and rhythmical. Thus, the degree to which the eye-movements in silent and oral reading are correlated will indicate the similarity of the conscious activity involved in the two types of reading. If the correlations between eye-movement measures in silent and oral reading are high, it may be concluded that the central processes which occur in the two performances are closely related. However, if these correlations are low, it must be inferred that the central processes are quite different in the two types of reading.

Another purpose of this experiment is to determine whether the degree of correlation between eye-movements in silent and oral reading is related to the reading ability of *S*. Is the correspondence of eye-movements in silent and oral reading smaller in *S*s of superior silent reading ability? Is one index of effective silent reading its independence of oral reading, or is the correspondence in eye-movements in silent and oral reading uniform throughout the range of reading ability?

II. Experimental procedure. The *S*s for this study were 124 university freshmen from the academic year 1934–35. In this group were 32 poor readers and 29 good readers, selected on the basis of total comprehension scores in the lowest and highest deciles, respectively, on the *Iowa Silent Reading Test.* The remaining *S*s were 63 unselected readers.

Each *S* read two short selections of moderate difficulty. The first selection was read silently; the second selection was read orally. Practice selections, comparable in difficulty to the test selections, were given and comprehension was checked at the completion of each reading. The requirement of comprehension was a moderate knowledge of the reading material, measured by a correct response to three out of four true-false statements on the content.

The *S*s were instructed to read each selection once, to make necessary regressions within any one line, but not to return to a previous line. In reading orally *S*s were further instructed to read to understand, not to interpret the material. After reading the last word of each paragraph, *S* closed his eyes as a signal to *E* that he had finished reading.

Binocular, horizontal eye-movement records of the test readings were secured with the Iowa eye-movement camera (3). The following eye-movement measurements were computed from each record: (1) mean duration per fixation; (2) mean size of fixation in *cms*; (3) mean regression per line; and (4) rate of reading in *cms* per minute. Since *Walker* (6) and *Anderson* (1) have fully described the method of securing and plotting the photographic records, no further description will be given here.

III. Results: the relationship of reading ability to common factors in silent and oral reading eye-movements. Table I shows that the correlations between each eye-movement measure in silent reading and the same measure in oral reading were consistently positive and rather high for each group of *S*s. For each measure of eye-movements in the two types of reading, the members in each group maintained to a rather marked degree their relative positions within the group. For example, in any one group, those having a large mean size of fixation in silent reading tended to have a relatively large mean size of fixation in oral reading; again, those having a rapid rate of silent reading also tended to have a rapid rate of oral reading. In general, the highest correlations occurred for those measures most highly related to reading ability, *i.e.*, mean size of fixation and rate of reading.[1] Table I also shows that the correlations for the poor readers were slightly but consistently higher than for either of the two other groups; and the correlations for the unselected

TABLE I. *Correlations between eye-movement measures in silent and oral reading*

Measure	(N=32) Poor readers	(N=63) Unselected group	(N=29) Good readers
Mean duration per fixation	.67±.07	.50±.06	.60±.08
Mean size of fixation in *cms*	.74±.06	.68±.05	.56±.08
Mean regressions per line	.72±.06	.59±.06	.71±.06
Rate of reading in *cms* per min.	.78±.05	.68±.05	.64±.07

group were somewhat higher than for the good readers for mean size of fixation and rate of reading, the two most valid measures of eye-movements.

The above results indicate that eye-movements in silent and oral reading correspond somewhat more closely in poor readers than in more proficient readers. It follows that the central processes occurring in the two types of reading also are more intimately related in poor readers than in average or good readers. However, these correlations between silent and oral reading eye-movements indicate that the comprehending activities in the two processes are substantially related, even in the two latter groups.

Although rather high correlations exist between eye-movements in silent and oral reading, there are significant numerical differences between eye-movement scores in the two types of reading. The eye-movements in each group were more regular in silent than in oral reading, *viz.*, in silent reading there were fewer and shorter pauses and more regular sequences of fixations along the line of print. Table II shows that the differences between the mean of each measure in silent reading and the mean of the same measure in oral reading were statistically reliable for all

[1] *Cf.* Anderson, I. H. Studies in the eye-movements of good and poor readers, this volume, p. 20, Table IV.

groups. The differences ranged from 4.22 to 12.56 times the $SE_{diff.}$. Table II also indicates that for all measures except mean duration per fixation in oral reading, the poor readers showed less efficient eye-movements in both silent and oral reading than the unselected group. The unselected *Ss*, in turn,

TABLE II. *Comparison of silent and oral reading eye-movement measures*

Measure	Group	(Silent) M_1	(Oral) M_2	CR
Mean duration per fixation	Poor	.293	.328	8.08
		.027	.033	100
	Unselected	.275	.325	12.55
		.030	.035	100
	Good	.274	.345	9.56
		.046	.046	100
Mean size of fixation in *cms*	Poor	2.35	1.90	7.97
		.47	.30	100
	Unselected	2.69	2.18	10.49
		.52	.29	100
	Good	3.32	2.54	5.89
		.85	.35	100
Mean regressions per line	Poor	1.52	2.21	4.22
		1.32	1.08	100
	Unselected	1.23	1.68	4.80
		.89	.72	100
	Good	.85	1.30	4.34
		.63	.79	100
Mean rate of reading in *cms* per minute	Poor	430.3	319.8	9.30
		102.2	62.8	100
	Unselected	529.3	372.9	12.56
		126.3	51.2	100
	Good	657.8	413.2	7.12
		211.2	46.5	100

The SD for each measure is placed immediately under the mean. The figure immediately under each CR indicates the chances in 100 that the true difference is greater than zero.

except for mean duration, had more irregular eye-movements in the two types of reading than the good readers. The variations in mean eye-movement scores, except for mean regressions, were larger from group to group in silent than in oral reading. The reason for this is that good readers are prevented by the requirements of oral reading from showing the superiority which they possess in silent reading.

Fig. 1 shows that the differences between silent and oral reading for all measures of eye-movements except mean regressions per line were smallest for the poor readers. The numerical difference in eye-movement scores between the two types of reading was larger in the unselected group than in the group of poor readers. The largest discrepancy in mean eye-movement scores between silent and oral reading occurred for the superior readers. Thus, there was a tendency for the differences in eye-movements between the two types of reading to increase with higher levels of reading ability. The graphs in Fig. 2 represent directly the amount of this cumulative discrepancy with each increase in reading ability, for mean duration per fixation, mean

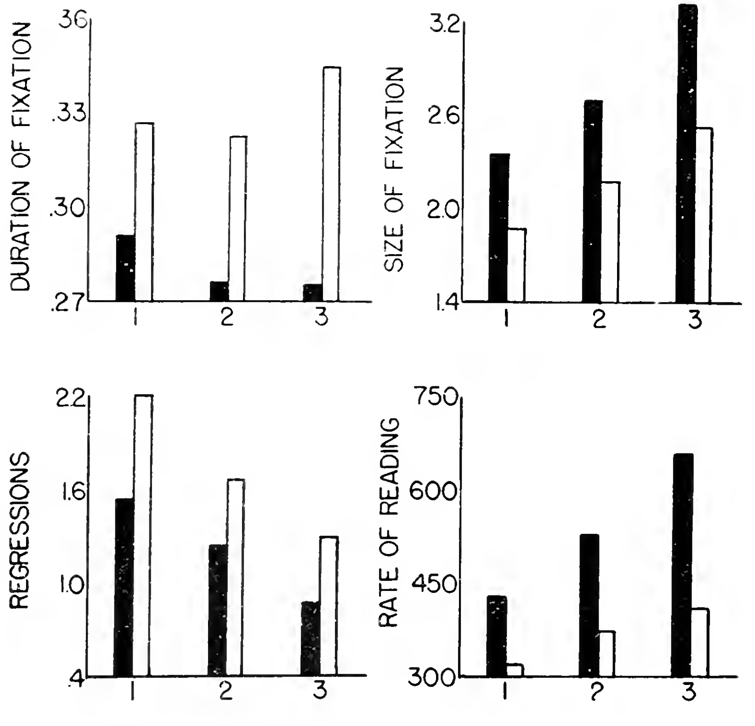

Fig. 1. Graphs showing a comparison of silent and oral reading eye-movements. Plotted on the ordinates are the values for four measures of eye-movements: mean duration per fixation in sec.; mean size of fixation in *ems;* mean regressions per line; and mean rate of reading in *ems* per minute. 1, 2, and 3 on the abscissæ represent poor, unselected, and good readers, respectively. The black columns represent the variations occurring in eye-movements during silent reading; the white columns represent oral reading.

size of fixation in *ems*, and mean rate of reading in *ems* per minute.

The differences between eye-movements in silent and oral reading of good readers were significantly larger than the differences between eye-movements in silent and oral reading of poor readers. The CRs for mean duration per fixation, mean size of fixation, and mean rate of reading were 4.37, 2.24, and 3.74, respectively. A comparison of the differences between eye-movements in silent and oral reading of good readers with the

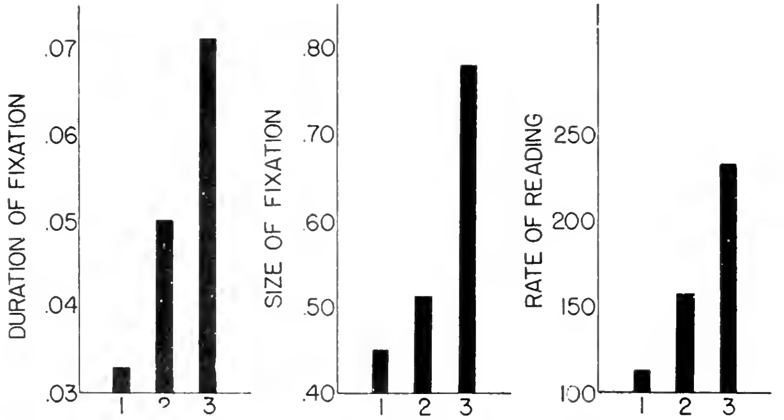

Fig. 2. Graphs representing the amount of cumulative increase in the differences between silent and oral reading eye-movements with each increase in reading ability. Plotted on the ordinates are the differences for three measures of eye-movements: mean duration per fixation in sec.; mean size of fixation in *ems*; and the mean rate of reading in *ems* per minute. 1, 2, and 3 on the abscissæ represent poor, unselected, and good readers, respectively.

differences between the eye-movements in silent and oral reading of the unselected group gave somewhat lower CRs, 2.62, 1.91, and 2.44, respectively, for the above measures. A comparison of the differences between the silent and oral eye-movements of the unselected group with the differences between the silent and oral reading eye-movements of poor readers gave CRs of 2.55, .74, and 2.73 for the above measures. These CRs are consistently large enough to indicate the increase in the difference between the eye-movements in silent and oral reading from one level of reading ability to another is significant.

In Fig. 3 are given the differences between silent and oral reading eye-movement scores for the above measures, for each successive quartile in reading ability of the unselected group. These graphs are sufficiently similar to those in Fig. 2 to support the major findings presented there. Here again the differences between silent and oral reading eye-movements increase with an increase of reading ability.

IV. Discussion. The finding that the correspondence between silent and oral reading is closer in poor reading than in good

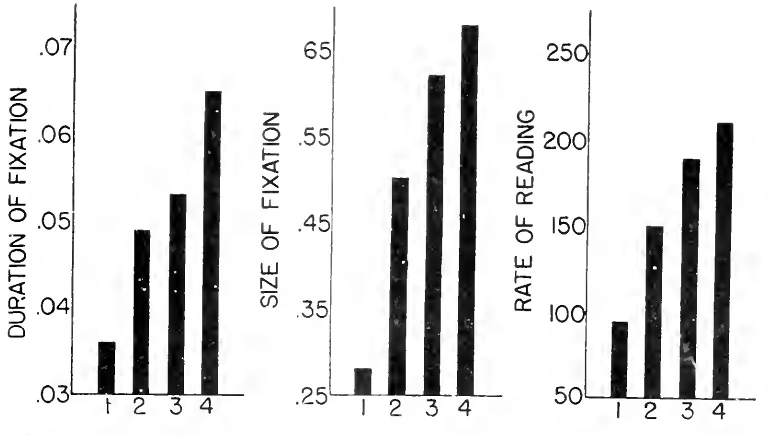

FIG. 3. Graphs representing the amount of cumulative increase in the differences between silent and oral reading eye-movements with increase in reading ability. Plotted on the ordinate are the differences for three measures of eye-movements: mean duration per fixation in sec.; mean size of fixation in *cms*; and mean rate of reading in *cms* per minute. 1, 2, 3, and 4 on the abscissæ represent successive quartiles in reading ability of the unselected group.

reading might be explained in the following way. *Swanson* (4) found that, for the skills he examined, perception accuracy was the factor most highly related to both silent and oral reading. Thus, the degree to which a correspondence in the two types of reading appears on other measures of reading is determined mainly by the extent to which perception is important in that measure. Since perception plays a relatively prominent rôle in oral reading, the degree to which silent reading will correspond to oral reading is primarily determined by the predominance of perception in an individual's silent reading.

The reason that poor readers show a higher correspondence than good readers in both types of reading is that perception plays a very prominent rôle in both their silent and oral reading. This is shown by the fact that in both silent and oral reading the eye-movements of poor readers are greatly modified by such characteristic features of the stimulating situation as word length, word difficulty, punctuation, *etc.* Any experience which is in this way determined by the characteristics of the stimulating situation is highly dominated by perception. As *Fairbanks* (2) has shown, good readers in reading orally are also influenced by certain objective factors, but to a lesser degree than poor readers. However, good readers, unlike poor readers, are quite independent of highly patterned perceptions in their silent reading. In good silent reading topical meanings are carried more by unpatterned processes of comprehending and thinking than by detailed perceptions and memories. The fact that in good silent readers detailed and highly patterned perceivings are subordinated to the more refined processes of comprehending and thinking tends to lessen the degree to which the central processes in silent and oral reading correspond.

V. Summary. The eye-movements in silent reading of good, poor, and unselected readers have been compared with their eye-movements in reading orally. Correlations between each measure of eye-movements in silent reading and the same measure in oral reading were uniformly positive and rather high for all groups. The correlations for poor readers were consistently higher than those for either of the two other groups. The correlations for the unselected group were somewhat higher than for good readers for mean size of fixation and rate of reading, the two most critical measures of eye-movements.

There were significant numerical differences between mean eye-movement scores in silent and oral reading. In silent reading there were fewer and shorter pauses and more regular sequences of fixations along the line of print for each group. Also, the eye-movements in both silent and oral reading increased in regularity with an increase in reading ability. In general, the variations in mean eye-movement scores were larger from group to group in silent than in oral reading. Thus there was a tendency for the differences in eye-movements between the two types of reading to increase in readers of average or superior ability.

Since this increase in the discrepancy between silent and oral reading eye-movements is primarily a function of an increase in silent reading ability, the data presented in the above pages indicate a highly significant difference between good and poor reading. In their silent reading, poor readers resort to a mode of attack characteristic of oral reading. Since oral reading is the medium through which silent reading usually is taught, the intimate relationship between silent and oral reading in poor readers emphasizes the prominence of generically simple functions in their silent reading. On the other hand, mature readers are sufficiently 'weaned' from habits of oral reading to permit more refined psychological functions to operate in their silent reading.

The present study further supports the contention that there are common elements in silent and oral reading, especially among poor readers. The analysis of difficulties in silent reading by an approach through oral reading is justified among poor readers because of this intimate relationship between the two modes of reading.

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AN EYE-VOICE CAMERA FOR CLINICAL AND RESEARCH STUDIES

by

Joseph Tiffin and Grant Fairbanks

I. Introduction. The value of eye-movement records in research studies of reading disability cases has long been realized. Likewise, many investigators have demonstrated that oral reading is a serviceable approach to the study of the reading function, particularly in the diagnosis of certain types of difficulty. It is obvious that in oral reading there is a functional relation between eye-movements and voice. It therefore seems that an apparatus which simultaneously records the voice and movements of the eyes will make possible the study of certain problems which could not be dealt with by either technique alone. A preliminary description of an apparatus developed for this purpose has been published by *Tiffin* (3). The present article describes an improved and portable form of this device.

II. Apparatus. The camera used was the oculo-photometer[1], which utilizes the principle of corneal reflection originated by *Dodge* and *Cline* (2) and now employed in most eye-movement cameras. By means of two eye-lenses, binocular records of eye-movements are photographed on Eastman super-sensitive panchromatic motion film. The following modifications of and additions to this instrument were made.

Voice-line. The oral reading was recorded by a Dorsey phonelescope[2], Fig. 1, A, mounted on top of the camera approximately 3½ in. from the forward end of the ground glass focus-

[1] Originally distributed by the Educational Laboratories, Inc., Brownwood, Texas, and now marketed by the American Optical Company under the trade name of Ophthalmograph.

[2] An optical lever so connected to a diaphragm as to change the pressure variations in the sound wave into fluctuations of a beam of light. This device is distributed by C. H. Stoelting and Co., Chicago, Ill.

ing window, B. A mirror, C, was mounted on the bottom of the phonelescope and set at such an angle that the beam of light, represented by the dotted line, D, was focused on the film, E, at the same vertical level as the beams of light from the eyes, shown by the dotted line, F. A flexible tube, G, led from the phonele-

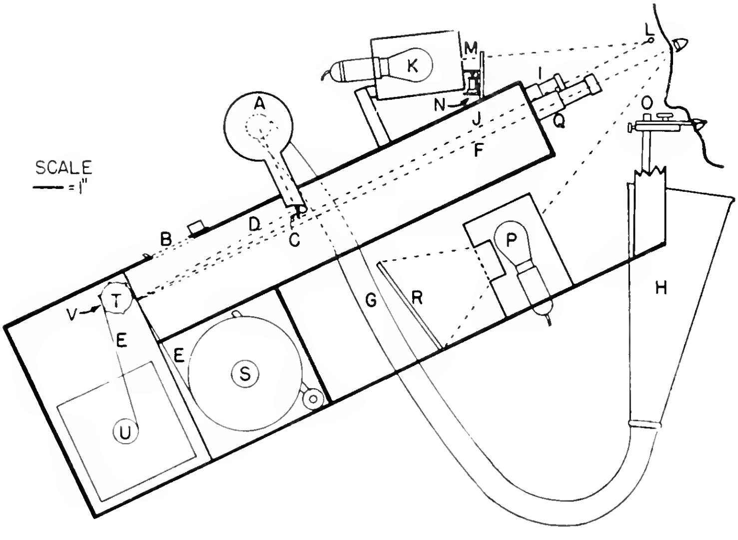

Fig. 1. Schematic drawing of the eye-voice camera. A, phonelescope; B, focusing window; C, mirror; D, beam of light from phonelescope; E, film; F, beam of light from eye; G, speaking tube; H, horn; I, head-line lens; J, beam of light for head-line; K, source of light for head-line; L, bead on spectacle frames; M, point of time line interruption; N, 60 cycle vibrator; O, jaw rest; P, eye and reading material light source; Q, eye lens; R, reading material; S, film supply spool; T, film sprocket; U, film take-up box; V, motor shaft.

scope to a horn, H, situated so that *S* in position to have his eye-movements photographed would speak directly into the horn. The position of *S*'s head and the reading matter were identical with those used before the phonelescope addition was made. The point of light from the phonelescope was focused at one side of the film so that a graphical record of the voice in oral reading was photographed simultaneously with the movement of the eyes.

Head-line and time-line. An additional lens, I, was mounted on the front of the camera directly above and midway between the two eye-lenses with which the camera was originally equipped. This lens was used to photograph a head-line on the film by reflecting a beam of light, J, from a source, K, by means of a bead, L, mounted on the nose-piece of a pair of spectacle frames worn by *S*. This beam of light was intercepted at the point, M, by a silent 60-cycle vibrator, N, thereby making the head-line serve the double purpose of showing movements of the head and marking the time in sixtieths of a second.

Head-movement control. In order to have *S*'s lower jaw free for verbalization and at the same time to maintain the head in a fixed position, the lower-jaw clamp was removed and an upper-jaw rest, O, installed. This consists essentially of a rigid metal bar, 1/8 in. thick and 3/4 in. wide, which projects into *S*'s mouth. This support is variable in all directions. The incisors of the upper jaw are placed in a transverse slot near the end of the bar, and the weight of the head allowed to rest upon this support. Vertical movement thus is made impossible, while horizontal movement is minimized through use of the standard head-clamps on the camera in combination with this added fixture. This head-rest was chosen in preference to several others because it furnishes rigid fixing of the head without interfering with the manipulation of the vocal organs.

Film speed. The film was speeded up from 1/2 in. per sec. to 37 mm. per sec. by substituting a more powerful motor for the one with which the machine originally was equipped. The original light intensities provided by the camera were found to be ample for recording at the higher film speed.

A sample record, taken with the apparatus described, is shown in Fig. 2. The eye-movement records are of conventional type and need no explanation. The voice-line does not show individual sound-waves at this slow film speed. Instead, it records amplitude-duration patterns of the speech sounds. It is a relatively easy matter to locate the words and phrases exactly from this type of record. In Fig. 2 the words have been identified and written immediately below the sound wave. The identification of words as here shown would be very difficult, if not impossible, without an auxiliary phonograph record which is cut as the original record is made. A standard apparatus for making phonograph records on aluminum discs was used for this purpose.

Fig. 2 illustrates an interesting phenomenon. At B the voice makes an error, beginning the word 'rain' although the text calls for the word 'snow.' The eye-movement record shows that ⅕ sec. later, about the normal speed of reaction time, the eyes make a regression, A, to correct this error. As soon as this

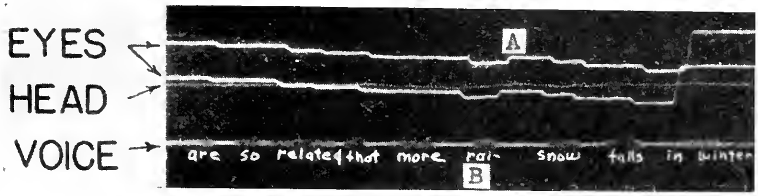

FIG. 2. Typical eye-voice record. A, regression; B, error

fixation is completed the voice pronounces the correct word 'snow' and the reading proceeds. Many regressions appear to be of this type, *i.e.*, they are preceded by some kind of error in the reading. This case is mentioned here to illustrate a typical problem which may be approached with this technique.

III. Method of measurement. The points of fixation are determined by projecting the original record upon a duplicate of the actual selection used in the experiment. The width of the passage is considered as 100 per cent of a line and the passage is divided by vertical lines into 100 equal parts. The per cent of the line upon which the projection of each fixation falls is recorded as the film is drawn through the projector.

Prior to the reading of the test passage *S* is instructed to fixate two dots in turn, one immediately above the top line at the left edge of the material, or at zero per cent of the line, and the other at a corresponding point at the right edge, or at 100 per cent of the line. The projector is adjusted so that the records of these preliminary fixations fall exactly at the above described points on the duplicate selection. The per cent of line at which the head-line falls is noted and the record is drawn through the projector with this line as a reference, kept always at the same point. In this manner the point of each fixation throughout the record may be determined. Reliability of measurement by this method was checked and found to be satisfactory, as the width of the eye-movement lines upon projection proved to be only two per cent of the line.

IV. Calibration of the camera. As explained by *Dodge* (1), eye-movement records obtained by the corneal reflection technique

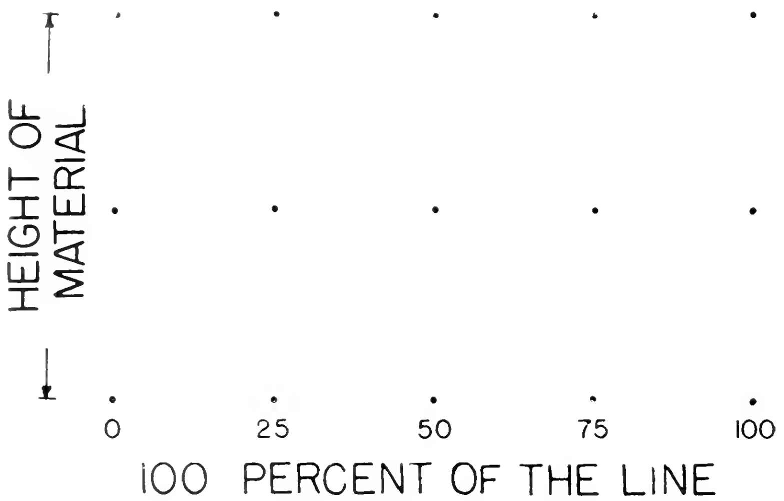

FIG. 3. Positions of the dots used in calibration of the camera

indicate exact points of fixation only when the light source is at the center of the lens and when the material being read is close to the lens in the same horizontal plane. The oculo-photometer, which is primarily a clinical instrument, does not fulfill these difficult conditions. Hence, because of the change in the angular relationships of the light sources, eyes, and eye-lenses with vertical displacement of the eyes, binocular records made by this camera show what appears to be progressively increasing convergence as the eyes move from line to line down the page. The large extent of this apparent convergence and its presence in the records of all *S*s created a definite presumption that the error lay in the camera. This was checked in the following manner:

the eye-movements of 10 trained *S*s, graduate students in psychology, were photographed as they fixated the dots shown in Fig. 3, beginning with the top row and fixating each dot in turn from left to right. The extreme dots in the top row were situated on the card at the same points (zero per cent and 100 per cent of the line) as the two dots used for preliminary fixation in reading experiments, and the other two rows being analogous to the fifth and ninth lines in the reading passage. Horizontally

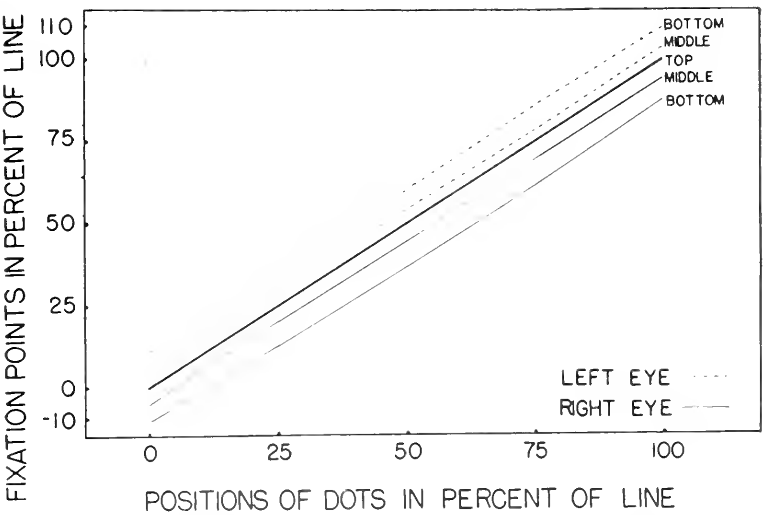

FIG. 4. Curves showing the calibration of the camera. See text for explanation

the dots in each row were placed at zero, 25, 50, 75, and 100 per cent of the line. The records from these 10 *S*s were read in the manner described above. They were then averaged and the curves reproduced in Fig. 4. In the figure the points of fixation as recorded by the camera are plotted against the horizontal positions of the dots in per cent of line. It is seen that in this experiment, if the camera records accurately, a rectilinear relationship will obtain between the points of fixation as recorded and the points of fixation as they actually occurred, *i.e.*, at zero, 25, 50, 75, and 100 per cent of the line, at all three rows. That this is true in the case of the top row, the extreme dots of which are used as references as described above, is evinced by the heavy line of Fig. 4 which represents the records of both eyes fixating the dots in that row. When the record of the left eye, as shown in the dash-line, is read for points of fixation, an error in the positive direction occurs. When the record of the right eye is read the error is in the negative direction. These errors increase as the eyes move down the page. The lines are seen to be approximately parallel, indicating that, although errors obtain as

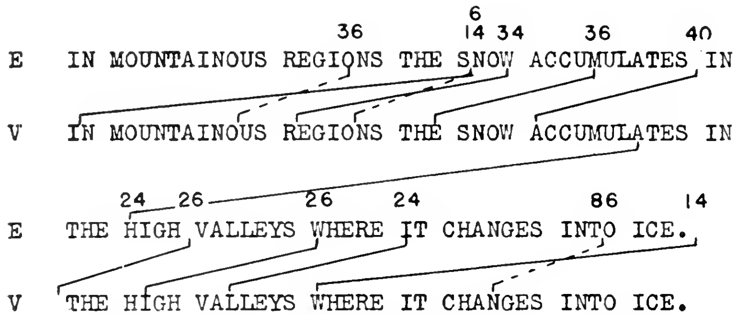

FIG. 5. Diagram of the spatial eye-voice relation during the reading of a sentence. E, pauses of the eyes; V, position of the voice at the moment of each eye pause. Points of regression connected to the voice line by broken lines. Duration of the eye pauses marked in hundredths of a second above the point of each pause.

described with vertical displacement of the eyes, horizontal displacement is not subject to such systematic error. In other words, the amount of error, in a positive or negative horizontal direction, depending upon the eye measured, bears a direct relationship to the amount of vertical displacement, but is constant horizontally for any given line.

From these data the amount of error introduced by the camera at each line was computed, and correction factors, subtractive when the left and additive when the right eye is measured, were derived and applied to the points of fixation as recorded by the camera. When these corrections are made and the voice-line identified, any type of space or time relation between the eyes and voice may be described. Fig. 5 shows a plotting of the spatial difference between the eyes and voice of a good reader at each eye fixation made in the reading of a sentence. The diagonal lines connect points of fixation in the eye-line, E, to simultaneous points in the voice-line, V. Points of regression are connected to the voice-line by dotted lines. The duration of each fixation in hundredths of a second is indicated above the eye-line. The eye is seen to be spatially in advance of the voice at all times, although the amount is by no means constant. Similar determinations of the temporal eye-voice relation may be made by measuring the time elapsing between the fixation of the eye on a given word and the pronouncing of that word by the voice.

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THE RELATION BETWEEN EYE-MOVEMENTS AND VOICE IN THE ORAL READING OF GOOD AND POOR SILENT READERS

by

GRANT FAIRBANKS

I. Introduction. The relationship between reading disability and poor eye-movements has been observed by many investigators, but their experimentation has failed to reveal, except by inference, which is cause and which is effect, or whether both are determined by a third factor. Certain experimenters, for example, *Pressey* (9), *Moore* and *McLaughlin* (8), and *Robinson* (10), have assumed that poor reading is in part caused by inefficient eye-movement habits, and that training the eye-movements as such will result in improved reading. On the other hand, *Miles* and *Segel* (7), *Erdmann* and *Dodge* (6), and, more recently, *Anderson* (1), have demonstrated that eye-movements are not habitual, but vary with comprehension as it is changed by the attitude of the reader, or with the variations of mental activity determined by difficulty of the material. They conclude, therefore, that the central processes in reading determine the nature of the eye-movements. It is the chief purpose of the present study to investigate the causal relationship between the peripheral and central phases of the reading process, and to determine if possible the nature of this relationship.

Ideally, the technical requirement of such a research is an objective record of both eye-movements and the central processes. The latter, however, must be investigated indirectly at present. This is accomplished in the present study by means of the eye-voice technique described by *Tiffin* and *Fairbanks* (13), in which simultaneous records of eye-movements and the sound waves from the voice in oral reading are photographed.

The application of this technique to the present problem involves a number of assumptions, the most important of which is that oral reading [1] is comparable to silent reading. Eye-movement studies invariably have contrasted the two types of reading, and it is undeniable that differences exist. In a recent study, however, *Anderson* and *Swanson* (2) found that this difference in eye-movements is one of degree rather than of kind. *Swanson* (11) has shown, on the basis of number of oral reading errors alone, that the relation between silent reading comprehension and oral reading is significant. Furthermore, a record of oral reading seems to be the only objective technique available at present for studying the central processes occurring serially during reading. The present research utilizes oral reading errors as convenient and critical approaches to the study of this serial process. Their selection as samples of the central phase of reading involves a second basic assumption, namely, that oral reading errors are representative of central errors. It is obvious of course, that they do not represent all of the central errors, but it seems reasonable to assume that a large fraction of the overt errors have central correlates.

Proceeding upon these assumptions, the chief aims of the investigation are to determine the type of eye-movement behavior which accompanies oral reading errors, the nature and direction of the relationship between errors and eye-movements, and the effect upon them of objective factors such as word difficulty. Good and poor reading is contrasted throughout.

II. Experimental procedure. Apparatus. The eye-voice camera described by *Tiffin* and *Fairbanks* (13) was employed. By means of this instrument, records of eye-movements and voice are photographed on the same film. A phonograph record cut at the same time furnishes a permanent reproduction of the vocal performance and facilitates identification of the voice-line on the eye-movement record.

Measurement of records. The pauses of the eyes are located spatially in terms of the per cent of the line at which they fall. A line perpendicular to the edge of the film bisects the record of

[1] Reference is not made to interpretative reading, but to that type of oral reading which may be thought of as verbalized silent reading.

each pause [2] and intersects the voice line, synchronizing the two. The position of the voice in the reading material for the instant of time represented by this intersection also is recorded in per cent of line, and the difference between these recorded points is the distance separating the eyes and voice.

Units of measurement. All spatial measures in this study are expressed in per cent of line. In the selection used, one per cent of the line is equal to .65 of the average letter space, .12 of the average word, and .24 of an *cm.* Multiplication of per cent of the line measures by these coefficients converts them roughly into the above units for comparison with the results of other investigations. The per cent of line unit is a constant fraction of the width of the reading passage, and renders the measures comparable at all points in the selection. One per cent of the line in this particular passage is equal to a linear distance of one mm. The time unit employed is in every case the second.

Reading material. The following passage of moderate difficulty from the *Buffalo Reading Test*, printed in 10-point Kentonian type, 100 mm. per line, served as a test passage.

> "Any region whose temperature and precipitation (amount of snow and rain) are so related that more snow falls in winter than melts in summer will have glaciers, for glaciers are simply the accumulations of the residual snow of many years, compacted into ice and moving down slopes under the urge of gravity. In mountainous regions the snow accumulates in the high valleys where it changes into ice. Thus the common alpine, or valley, glacier is formed. It is, in appearance, a great river of ice which moves with extreme slowness, averaging a few feet a day."

A practice selection of approximately equal difficulty, set in the same type, and of the same length was used.

Subjects. Twenty-five college freshmen scoring above the 90th percentile on the *Iowa Silent Reading Test*, and 23 scoring

[2] In corneal reflection photography, as noted by *Dodge* (**5**), the point of regard, *i.e.*, the spatial midpoint of the segment subtended by the fixation, is recorded, and the segment reaches its maximum perceptual clearness about this point. The temporal midpoint of the duration of the fixation is the best approximation which can be made at present to a point of time when this area is maximally clear.

below the 10th percentile, served as *S*s for the experiment. These two groups are referred to as good and poor readers.

Instructions. It was desired that the silent reading situation be approximated as closely as possible. In instructing the *S*s, *E* emphasized this point in every possible way. Each *S* was informed that he need not in any manner convey meaning to anyone but himself, and that he need not read loudly[3]. He was told to minimize the interpretative element, including such factors as inflection, pause, and stress.

It was further pointed out that neither speed of reading nor detailed comprehension was the object of the experiment, but that general comprehension would be checked by four objective questions, to which three correct responses were necessary for retention of the record.

Procedure. Before any adjustment of the apparatus, each *S* was permitted to practice verbalization of his silent reading as described above. He then was placed in position and instructed as to the preliminary fixations of the reference dots above the left and right margins (13), being told to fixate each one in turn from left to right three times, returning to the left and naming the dots 'Left' and 'Right' as he made the fixations. *S* was cautioned to fixate the dots exactly and to move to the next dot as soon as a precise fixation was secured. A shield concealing the reading material but revealing the dots was removed after the final fixation of the left dot. The practice selection, preceded by dot fixations and followed by objective questions, was run but not recorded. It was followed by an exact duplication of the procedure for the test passage recording.

To control visual adaptation, general illumination was provided until immediately preceding the actual experiment.

III. Results[4]. *Eye-movement and eye-voice measures.* Stand-

[3] The phonograph amplifier was sufficiently powerful to permit the cutting of sounds of low intensity. The level was adjusted during the practice selection. In no case was *S* told that a phonograph record was being made.

[4] The absence of measures of variability and of critical ratios will be noted. In treating the data it was deemed superfluous to deal with differences statistically. Their consistency is validation of this method of treatment. The following terminology relative to the eye-movement pauses is employed: forward shift—a left to right eye-movement; fixation—a pause resulting from a left to

ard measures of eye-movements corroborate previous findings and do not need summary here, although they are referred to from time to time. All computations, with the exception of measures of mean duration, show marked differences between good and poor reading.

Mean eye-voice measures for the two groups of readers are compared in Table I. The results agree in general with those of *Buswell* (3), who has made the most extensive investigation

TABLE I. *Mean eye-voice lead measures in per cent of line, good and poor readers*

Points of measurement	Good readers	Poor readers
All pauses	21.87	16.45
Fixations	23.58	18.35
Regressions	13.13	9.70
Re-fixations	19.65	15.33
Beginnings of lines	33.49	27.03
Ends of lines	21.42	14.86
Beginnings of sentences	20.52	14.57
Ends of sentences	16.04	11.19

of this relation[5]. As would be expected, the eye-voice lead is greater at fixations than at regressions. At re-fixations it is not greatly different than the mean for all pauses. The separation distance is greatest at the beginnings of lines, *i.e.*, at the first fixations, and least at the ends of sentences. At the ends of lines, *i.e.*, at the last fixations, and at the beginnings of sentences, it is nearly equal to the mean for all pauses. For diagnostic purposes, then, an easily obtained and fairly valid measure is the

right eye-movement; regression—a pause resulting from a right to left eye-movement; re-fixation—a regression immediately following the first fixation on a new line; perception time—the total reading time, minus the time consumed in eye-movement. The first and ninth lines of the reading material are omitted from all computations.

[5] The eye-voice lead is defined as the spatial or temporal amount by which the eyes lead the voice at a given pause of the eyes. Previous investigators have employed the term 'span.' It is felt that 'lead' is more descriptive of the eye-voice relation as it usually obtains. All eye-voice lead computations in this study are spatial measures, in terms of per cent of line. *Buswell* (3) measured the distance between the words read by the voice and the points fixated simultaneously by the eyes. In the present study it was possible to employ the pauses of the eyes as the basis of measurement (see above, *Measurement of records*). The determination of the mean eye-voice lead for the entire reading selection is obtained in the case of the poor group, for example, from 2,675 individual measures of eye-voice lead.

mean eye-voice lead for the last fixations in the lines of the reading material.

1. Eye-voice lead at the beginnings and ends of sentences. *Buswell* (3) found that the eye-voice lead was longest at the beginnings and shortest at the ends of sentences. The present study shows (Table I) that the lead is indeed shortest at the ends of sentences, but that it is close to the mean at the beginnings. These differences appear to be due in part to the types of oral reading used, and in part to the measuring techniques. In *Buswell's* work, typical oral reading was recorded, while in the present study an approach was made to silent reading, minimizing the expressive element. The effect of the latter is to increase rate and cut down pause time, thus giving the eyes less opportunity to increase their lead during pauses of the voice. In the type of oral reading studied by *Buswell,* the last word, A, in a given sentence is followed by a pause of the voice of considerable duration before the first word, B, of the next sentence is pronounced. The duration of this pause is the determining factor in the increased lead. Measuring from word A pronounced by the voice to the simultaneous point of fixation of the eyes, it is found that the eyes are already fixated on the next sentence. The pause between sentences then occurs, and when the separation distance of eyes and voice is next measured at the time word B is pronounced, the eyes are far in advance.

But when, as in this study, the measures are made from eyes to voice, the pause is not included. The first of the above two calculations is made when the eyes last fixate word A and the voice is reading the first sentence, of which A is the last word. The next calculation is made when the eyes fixate word B. This fixation, in general, immediately follows the fixation on word A. Since the mean extent of the forward shift is over twice as great as the mean distance (four per cent of the line) which separates sentences, an eye-movement of only average extent would bridge this distance between the sentences. When the eyes fixate word B in the second sentence, the voice has advanced only as far as an amount of time equal to one-half the duration of the first fixation plus one-half the duration of the second fixation (see above, *Measurement of records*), an average of approximately .25 sec. In good reading, for example, the eye-voice lead at the ends of sentences is 16 per cent of the line. Since the mean perception time per line is three secs., the temporal eye-voice lead at that point is 16 per cent of three secs., or .48 sec., and approximately that interval of time will elapse before the voice reaches the end of the sentence. But since the eyes move from the end of the first sentence to the beginning of the next in .25 sec., the voice does not have time to finish the sentence before the second of the two measurements is made. Hence, the pause of the voice between sentences is not measured, and cannot cause the difference between the eye-voice lead at these two points.

It is felt that this difference is due to the relative difficulty of ending one sentence and beginning another. The lead is reduced by the eyes as the end of a given sentence is approached, in anticipation of a punctuation mark (see below, *Relation of eye-movement measures to the difficulty of the material*), and because ends of sentences are frequently critical to the meaning. Once having passed this critical point with his eyes, the reader may increase his lead to normal. He perhaps takes advantage of the space between the sentences, and increases the lead with a long eye-movement over the space and into the next sentence.

2. Eye-voice lead at the beginnings and ends of lines. Table I reveals that the mean eye-voice lead at the first fixation in a line is abnormally long. But since 67 per cent and 74 per cent of these first fixations of good and poor readers, respectively, are made too far within the line, as shown by the number of re-fixations which follow them, the data show return sweep inaccuracy more than anything else. The eye-voice lead at re-fixations is probably a better measure of the lead at beginnings of lines, and has been seen to approximate the mean for all pauses. The same figure is approached at the last fixation in the line. Further data revealed below (*Relation of eye-movement measures to the difficulty of the material*) indicate that the difficulty of the material is probably the most important determinant of the amount of eye-voice lead.

3. Relation of eye-voice lead to reading ability. Table I

shows the mean eye-voice lead of good readers to be greater than that of poor readers at all points measured. The lead may be increased by forward movement of the eyes or by lagging of the voice; it is decreased by the reverse type of inter-action. Since both eye-movements and voice are related to the central processes of reading, the amount of eye-voice lead is expressive of the combination of important factors involved in reading. It is a measure of the rate of recognition and assimilation.

The differences between the two groups of readers in these latter functions are greater than the measures in Table I indicate. Unmistakable attributes of poor oral reading are slowness and hesitation of the voice. By virtue of this slowness, which increases the eye-voice lead, poor readers have leads which are not directly proportional to their rates of assimilation. Good readers are penalized, relatively, by the very facility and rapidity which is characteristic of most good reading.

Relation of eye-movement measures to the difficulty of the material. 1. Analysis of the difficulty of the lines of the reading material. *Thorndike's* (12) classification of the most common words on the basis of their frequency in written English furnishes a point of departure for an analysis of material. The 81 words in the seven lines used range from those occurring in the most frequent 500, to 'residual,' which is first included by a list of the 19,000 most common words. Each word in the passage was given a value dependent upon its frequency as thus classified. Words appearing among the most frequent 500, for example, received a value of .5, those among the most frequent 1,000 words, 1.0, etc. The mode scarcity value for the lines used is .5; the mean is 1.6.

The top graph in Fig. 1 shows the mean word scarcity values for the seven lines of the selection, while the other graphs show parallel variations in errors and repressions[6]. Line four is seen to contain the most difficult words, and lines two and eight the least difficult words.

[6] For a more detailed discussion of these inter-relations, see below, *Relation of errors to difficulty of words.*

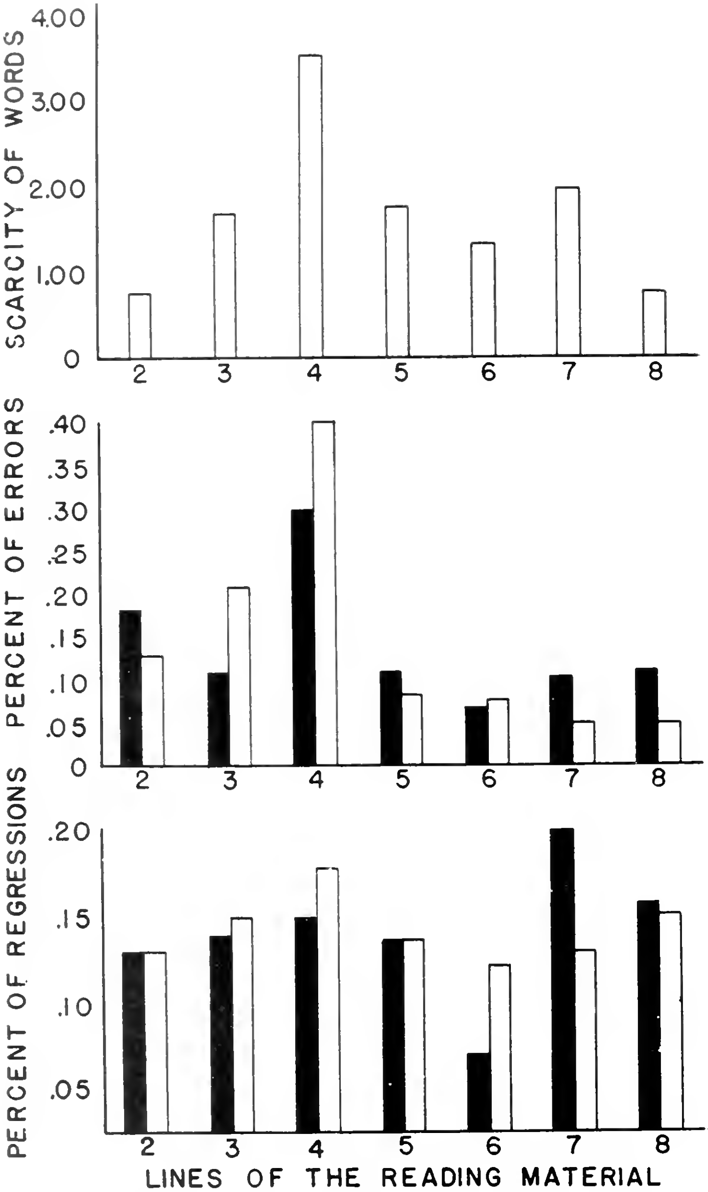

FIG. 1. Relationship of the percentage of errors and regressions per line to the mean word scarcity of the lines. The abscissæ are the same for all three graphs and refer to the lines of reading material. The ordinates are: upper, mean scarcity of words in each line according to *Thorndike's* (12) word list; middle, mean percentage of errors at each line; lower, mean percentage of regressions at each line. In the two lower figures the solid bars represent the measures for good readers, and the open bars the measures for poor readers.

Fig. 1 reveals the fact that the scarcity of words is a fair measure of the difficulty of material, if number of overt errors may be considered as evidence of the latter. Other features of context, such as punctuation marks, are of recognized difficulty, but are not amenable to quantification. These other features may not cause as many overt errors as do unfamiliar words; they need not influence the quality of reading at all. But many investigations have shown that they do influence eye-movements. Eye-movement behavior is related to the difficulty of the words, plus other contextual difficulties.

Recent investigations have shown that number of fixations is the eye-movement measure most closely related to reading ability. By virtue of that fact this measure should reflect the relative difficulty of the lines of the reading material. The lower graph of Fig. 2 shows this relation for the reading passage used. Not only do poor readers invariably average a larger number of fixations per line than good readers, but the shape of the two curves is different. Good readers exhibit less variability from what might be called their 'normal' number of fixations per line.

2. Relation of composite eye-movement scores to the difficulty of the lines. In order to arrive at a composite measure of eye-movements which would differentiate between the lines of the reading material on the basis of the combined effect of the most important measures, the rank-order method was employed. The lines were ranked from one to seven in each of the measures used, one being the most favorable ranking. Line six, for example, required the shortest perception time in good reading and receives a rank of one, while line seven required the longest and is ranked seventh. The arithmetic mean of these rankings for each line is influenced, therefore, by all measures of eye-movements. These composite rankings of the lines of the reading material are shown in the upper graph of Fig. 2. Line four is seen to have a marked effect upon the eye-movements of poor readers, while the scores of the good group give this line equal ranking with lines two, three and five. Line six is relatively easy for both groups. Line eight affected the eye-movements of the poor readers as greatly as did lines two, three, five and seven, while

good readers found this line relatively easy. This graph shows a striking similarity to the lower graph in the same figure, reflecting the dependence of all eye-movement scores upon number of

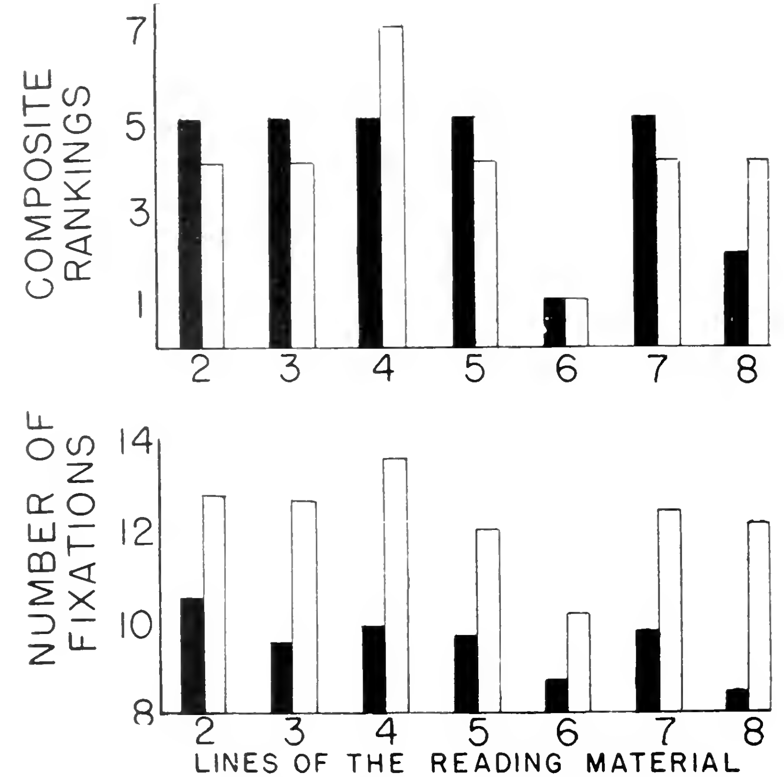

FIG. 2. Composite eye-movement scores and mean number of fixations for the lines of the reading material. Solid bar, good readers; open bar, poor readers.

fixations, and at the same time lending validity to the method of composite ranking.

If this figure be compared with Fig. 1 it is seen that uncommon words (line four) have more effect upon poor readers than upon good readers. Line eight, composed of familiar words, but containing a parenthetical construction, is easy for good readers, but gives poor readers as much difficulty as the majority of the other lines. Fig. 1 shows that both lines two and eight have a lower mean scarcity value than line six. Yet the most favorable eye-movement scores almost invariably are made on line six. Examination of the reading selection shows that this is the only line not broken by punctuation.

From these data it may be concluded that the eye-movements of both good and poor readers reflect variations in the difficulty of the reading material, but that the negative effect of increased difficulty is more marked in poor than in good reading, while the positive effect of easy material is greater in good reading. Poor readers are more affected than good readers by unfamiliar words and contextual difficulties, and are less able to take advantage of easy material.

3. Variation of measures at different sections of the line. Various investigators, notably *Dearborn* (4), have held that the eye-movements in reading follow a comparatively constant motor pattern. It has been demonstrated above that the eye-movement behavior at both extremes of reading ability is contingent upon variations in difficulty from line to line and that these variations affect poor readers more than they do superior readers. Such variability in the mean scores of different lines might conceivably obtain, while the 'pattern' within the line maintains a relative constancy. To test this possibility the lines of the reading selection were divided in four equal sections and eye-movement measures for each section were secured by averaging the corresponding sections in all lines. The means thus derived are average measures for each of the four quarters of an average line of the passage used. By the same computational method, data on word scarcity, word length in per cent of line, and mean number of errors were obtained. Fig. 3 depicts the data graphically. In all the curves per cent of the line is plotted along the abscissæ, while the ordinate values vary with the nature of the measures plotted. All of the eye-movement scores represent means per *S*, while the error measures are group means. The means are plotted at the mid-points of the quarters and connected by lines.

The most obvious feature of these graphs is the consistency of the difference between the two extremes of reading ability. In none of the variables considered is the best average score for the poor group as good as the poorest average score for the good group. A second feature is the variability of the scores in the different sections of the line. In Fig. 3, A, the number of fixa-

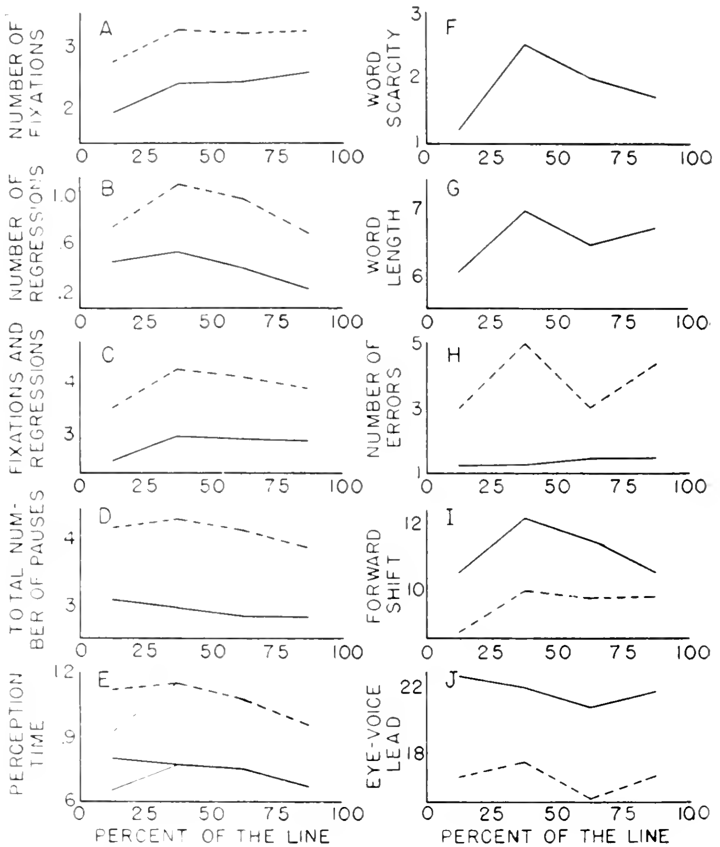

FIG. 3. Variations of mean eye-movement measures, total number of errors, mean word scarcity, and mean word length at different sections of a line of reading material. Solid line, good readers; broken line, poor readers.

tions, *i.e.*, pauses after forward shifts, is seen to increase progressively. B shows that the number of regressions is greater in the middle of the line. Summing these means tends to level off the last half of the curves, C, with a slight sloping after the peak is reached in the second quarter. With the addition of the re-fixations, D, the curve for the good group shows that the mean number of all pauses remains relatively the same, decreasing slightly as reading progresses across the line, while the curve of poor reading is still slightly 'humped' at the second quarter. Measures of perception time, E, forward shift, I, and eye-voice lead, J, exhibit a like variability.

4. Relation of measures to word scarcity, word length and errors. Comparison of F and G, Fig. 3, reveals the expected relationship between scarcity and length of words. The fourth quarter of the line presents, however, an adventitious discrepancy in this relation which provides a means of describing the effect of the two variables upon eye-movements. This part of the line contains, on the average, relatively familiar but long words. Graphs F and G are practically identical in shape for the first three quarters of their length. If a curve of eye-movement scores is similar to these curves for the first 75 per cent of the line, it is impossible to determine, from that part of the curve alone, to which of the word measures—scarcity or length—it is most closely related. But from the direction which the curve takes for the last quarter, the relationship may be deduced. If, for example, a given curve shows an upward inclination at the end of the line, it may be assumed not only that word length has determined the score for that quarter, but also that word length rather than word scarcity has dictated the shape of the entire curve.

Inspection of the curves shows that the relation between number of fixations, A, and either word scarcity or word length, F and G, is not close, although there appears to be a slight tendency for more fixations to be made on longer words. Number of regressions, B, appears to be allied to word scarcity in both good and poor reading, but more closely in inferior reading. Summation of fixations and regressions, C, shows that scarcity, by determining the number of regressions, is the predominant cause of the combined number of the two types of pauses. This effect is more pronounced in poor reading. Addition of re-fixations increases the total number of pauses, D, in the first quarter only. A gradual decrease in number is shown for the superior group, while the curve for the poor group is somewhat similar to the scarcity curve. The graph of perception time, E, follows approximately the same form for the heavy lines. Since re-fixations probably indicate adjustments which are largely motor in character, curve C is a more valid picture of the number of pauses necessary for central reading. The number of these pauses is more closely related to the difficulty, *i.e.*, scarcity, than to any other pre-determined attribute of the material. Re-fixations likewise increase the amount of perception time. The light lines in graph E show the effect of ruling out this factor; the curves are seen to assume a form analogous to that of the scarcity curve.

Graphs G and H, Fig. 3, show that the errors of poor readers are related to word length, while those of the good group apparently are determined by neither scarcity nor length. It is shown below that the coefficient of correlation between errors and scarcity is substantial. Correlating number of errors and word length, however, results in coefficients of .28 and .29 for the good and poor groups, respectively. The discrepancies between the correlation coefficients and the error graphs are probably explained by the fact that neither word scarcity nor word length is a perfect measure of context difficulty, or even of word difficulty. The error graphs pictured are particularly susceptible to distortion because of this lack of perfect relationship, and the small number of both words and errors.

Graph I, Fig. 3, presents the apparently paradoxical coincidence of difficult words and long forward shifts. This measure is a differential between good and poor reading, as shown in this graph, and by virtue of that fact should be negatively correlated with difficulty[7]. Several explanations of this discrepancy are possible. Long words, for example, might increase the extent of the eye-movements, since they provide larger reading units. A more potent factor in this increase, however, seems to be the presence of regressions. It is shown below, Table V, that the forward shifts contiguous to regressions are longer than the

[7] This view has been substantiated by previous investigators who have measured forward shift.

mean of all forward shifts. Examination of B, Fig. 3, reveals the fact that the distribution of regressions is directly proportional to the mean extent of the forward shift over the four quarters of the line.

Graph J, Fig. 3, substantiates the findings cited above, that the eye-voice lead is more dependent upon the variations in difficulty of material than upon position in the line. The curve of the poor readers shows a close relation to word length, while that of the good readers is maintained relatively constant. Long words are difficult for poor readers, if errors are taken as the measure. Since one of the most obvious effects of difficulty in poor oral reading is hesitation of the voice, it appears that this is the cause of increase in eye-voice lead at the points represented by peaks of the curve, rather than the ability to assimilate long words more rapidly. This same effect also apparently operates to a slight extent in good reading.

From the data discussed in this section, there is little evidence to indicate a fixed pattern of eye-movements for the average line. It would appear, rather, that as in the case of differences between the lines, the nature of the material is the important determinant. This is more marked in poor than in good reading. The eye-movements of superior readers are more closely related to word scarcity than to any other quantifiable measure of text difficulty. In poor reading the influence of word scarcity is even greater. Word length has little effect upon good readers, but, to a degree at least, appears to be a measure of difficulty in inferior reading.

Errors in oral reading. 1. Frequency of different types of errors. The group of good readers made a total of 43 oral reading errors, an average of 1.72 per *S*, .25 per *S* per line and 2.1 per 100 words. Poor readers made 108 errors in all, averaging 4.7 per *S*, .67 per *S* per line, and 5.8 per 100 words. Classification of the errors into the common categories resulted in the distribution shown in Table II. Because of the small total number of errors, the per cent figures may not be heavily relied upon, although they agree in general with the work of *Swanson* (11). Substitution is the most frequent error of both good and poor readers. Worthy of note is the fact that, while 51 per cent of the poor readers' substitutions seriously perverted the meaning, no substitution made by the superior group was of that type.

Repetitions were subdivided into repetitions of words, parts of words, and groups of words. In the poor group repetitions are fairly evenly distributed among the three types, while the most common repetition of good readers is of groups of words. Another re-classification of repetitions into repetitions of correct material and of material containing errors shows that correct

Table II. *Frequency of different types of errors, good and poor readers*

	Omissions		Insertions		Mispro-nunciations		Substitutions		Repetitions	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
Good	9	21	2	5	7	16	13	30	12	28
Poor	9	8	9	8	25	23	45	42	20	19

material is more often repeated than error material by the poor group, whereas 67 per cent of the repetitions of the good readers were of errors. Repetitions of errors compose 19 per cent of the total errors of the good group, and achieve correction of the error in every case. Poor readers correct only seven per cent of their errors.

Hesitations are omitted from error computations since their determination is essentially qualitative. By careful re-checking, an approximate count of hesitations was made. In the passage used, good readers averaged 1.56, and poor readers 8.87 per *S*.

2. Relation of errors to difficulty of words. Comparison of the mean scarcity of error words, 3.6 for the good and 5.1 for the poor group, with that of all words in the selection, 1.6, shows that, on the average, errors are made more frequently on the scarcer words. It is of significance also that the value is higher in poor than in good reading. Errors of substitution and repetition are made by both groups on slightly more common words than the means of all error words, while the average scarcity of mispronounced words is higher than the mean. Mispronunciation of 'residual,' the rarest word in the selection, was the most common error of that type made by poor readers. Good readers had little difficulty with this word, unimportant errors of accent on 'com-

pacted' being their most frequent mistake. Inserted and omitted words invariably are common words. An additional fact of interest is that in poor reading the words for which substitutions are made have a mean scarcity value of 3.9, while the substituted words are more common, having a mean scarcity value of 2.9. In good reading, however, substituted words are of approximately the same average scarcity as the original words.

Coefficients of correlation between the scarcity values of the words (N=81) and the number of errors made on them are .60 and .64 for good and poor readers, respectively, indicating a definite relationship. The two upper graphs in Fig. 1 show this relationship graphically for the seven lines of the selection. Line four, containing the most difficult words, has the greatest number of errors in both groups. In Fig. 4 this line serves as abscissa, and a comparison of the bottom curve with the two top curves shows this relationship in detail for the words of that line. The relation is not perfect. 'Accumulations,' the first syllable of which occurs at the end of the previous line, should by virtue of its scarcity give rise to more errors than 'compacted.' This, however, is the only outstanding discrepancy. It may be concluded from these data also that, in general, errors occur on the more difficult words.

Errors and eye-movements. 1. Analysis of first fixations on error words. Seventy-seven per cent of the errors of good readers and 82 per cent of the errors of poor readers are accompanied by fixations falling within distances from the midpoints of the errors of one-half the mean size of fixation in per cent of line[8]. This is a criterion so small as actually to be exclusive of many fixations which include this point, and hence it is not surprising that some of the errors are not accompanied by fixations within this distance. The only hint of causal relation between lack of precise fixation and errors is the fact that five of the nine omissions of good readers are not accompanied by fixations within the above described distance. This is certainly not the

8 The reading span, *i.e.*, the mean size of fixation, is invariably smaller than the perception span. A fixation falling within one-half the mean size of fixation from the midpoint of a word is certain to subtend visually the latter point, and in fact indicates a precise fixation far within perceptual span limits.

cause of such errors in poor reading, however; all of the points of omission of the poorer group are fixated precisely.

It was thought that if faulty eye-movements caused errors, the characteristics of the first fixation on a given error would be different from those of an analogous fixation when no error is made, that the duration, for example, might be abnormally short, the preceding or following forward shift too long, the eye-voice lead too great, or the fixation placed at the very limit of the

TABLE III. *Eye-movement measures of first fixations on error words*

Measures	Good readers: Error group	Good readers: Control group	Poor readers: Error group	Poor readers: Control group
Mean distance from midpoint of error	2.38	2.88	2.35	2.34
Mean duration	.28	.29	.29	.29
Mean forward shift preceding	12.50	12.55	11.77	10.06
Mean forward shift following	8.75	9.55	8.00	7.94
Mean eye-voice lead at error	22.88	24.38	20.73	18.75
Mean eye-voice lead preceding	20.78	20.63	16.41	15.12
Mean number fixations within span	1.26	1.41	1.67	1.37
Mean number regressions within span	.79	.50	.79	.56
Per cent preceded by regressions	6	21	14	24
Per cent followed by regressions	26	26	45	21

Time in seconds, space in per cent of the line, matched controls.

reading span. The first fixation on each error made by both groups was analyzed for the measures listed in Table III. Each of these fixations was matched with a fixation at the same point by another reader of the same ability who did not make an error at that point. Control groups of equal size and reading ability thus were secured.

Inspection of Table III reveals no differences of any magnitude between the error and control groups. Fixation is equally precise when an error is made as when it is not. Mean duration of fixation is practically identical. The forward shifts preceding and following the fixation are not significantly different. The eye-voice lead at the error is greater than the lead preceding the error by about the same amount for all groups, indicating that, whether or not an error is made, difficulty affects the eye-voice relationship similarly, probably retarding the voice. The mean number of fixations within the span is nearly equal for all groups.

The obvious conclusion from these data is that movements of the eyes to words upon which errors are subsequently made are not related to the errors, and do not, therefore, determine them.

2. Analysis of regressions to error words. The relatively large number of regressions within the span when an error is made (Table III) is indicative of a relationship between errors and regressions. Further, when an error occurs, the number of the fixations in question which are immediately followed by regressions is greater than the number preceded by regressions. When an error is not made, approximately equal percentages of these fixations are preceded and followed by regressions. These findings are suggestive of a temporal sequence in which recognition of error is followed by regressive movement, and indicate that investigation of errors and regressions is important in determining the nature of the causal relationship between central and peripheral factors in reading.

Calculation of the number of regressions to the points of error reveals the fact that the errors of poor readers are somewhat more frequently accompanied by regressions than those of good readers. The difference, however, is small, the percentages being 43 and 37, respectively. Approximately 65 per cent of the repetitions of both groups are accompanied by regressions, the large percentage probably being due to the fact that part of them are of groups of words and include a larger average per cent of the line. Few regressions are made to points of insertion and omission, and there is no difference between the groups in this respect. In errors of mispronunciation and substitution the percentages are greater for poor readers.

Repetitions of correct material average .75 and 1.00 regressions each for the good and poor readers, respectively. When error material is repeated, the difference between the groups is greater, being 1.25 for good and 2.11 for poor readers. Good readers achieve correction of error material with a mean of 1.25 regressions, while the poorer group average 2.25 regressions per correction. The obvious inference is that something more than mere number of objective cues determines ability to deal with material. This conclusion is established even more firmly when it is recalled that good readers corrected 19 per cent of all their errors, while poor readers corrected only seven per cent.

3. Relation of regressions to errors. It has been shown above that the relation between errors and word scarcity is high. Additional coefficients of correlation between regressions and word scarcity are .47 and .53 for the good and poor groups. It would be expected, therefore, that the correlations between the number of errors and the number of regressions made on the 81 words of the selection would likewise be definitely positive. The coefficients are found to be .50 and .67 for good and poor readers.

According to these coefficients the relationships between errors and regressions, and between word scarcity and regressions, are lower than that between errors and word scarcity. These differences in degree of relationship have been shown in Fig. 1, which reveals a marked similarity between the two upper graphs, less between the upper and lower graphs, and less when the lower two are compared. Fig. 4, which plots the same variables in detail for line four, again shows that the three are correlated, and also indicates the differences in degree of correlation.

The latter figure illustrates another fact expressed by the coefficients, *viz.*, the relation between the variables is higher in poor than in good reading. This is understandable when it is remembered that the mean scarcity of error words is higher for poor readers. Furthermore, since the reading span of good readers is three per cent of the line wider than that of poor readers, regressions need not be made so precisely either upon error words or upon difficult words. And the speculation might also be made that number of regressions is less highly correlated with number of errors in good reading because the good readers' regressions are more effective in the prevention of overt errors.

Further correlations, computed on the basis of number of errors per *S*, show that hesitations also are related to regressions, the coefficients being .63 for the good readers, and .68 for the poor group. The combined number of errors and hesitations correlate even more highly with number of regressions. There also is a positive relationship between errors and hesitations.

The obtained data suggest that in both extremes of reading ability, number of regressions is more highly related to the combination of errors and hesitations than to either of the latter alone. This would seem to indicate that the inclusion of hesitations as errors adds additional peripheral indices of central errors, although their determination is more difficult because of its qualitative nature. This relation is further discussed below.

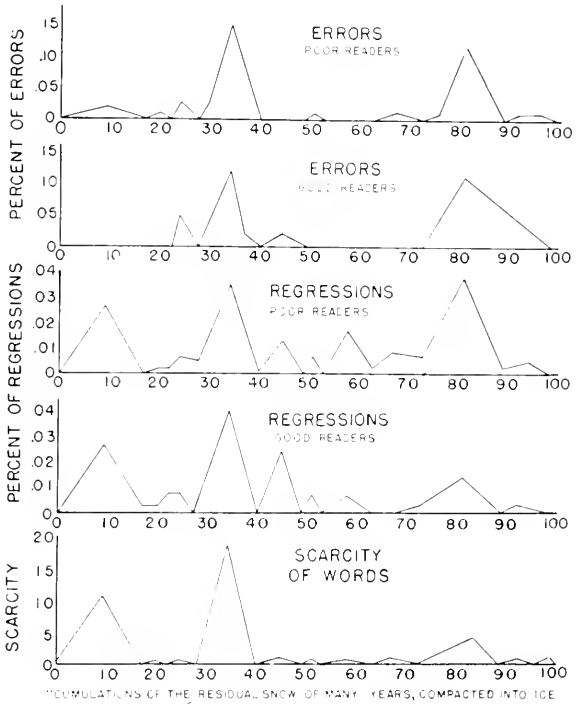

Fig. 4. Relationship of the percentage of errors and the percentage of regressions made on the fourth line of the reading material to the scarcity of the words in the line.

4. Temporal sequence of errors and regressions. Eye-movement scores and error scores both are related to reading ability, and it is found that eye-movements, *i.e.*, regressions, are related to errors. That reading is chiefly a mental function has been pointed out by many investigators. Both errors and regressions are shown therefore to be related to mental activity.

It is impossible that overt errors determine the mental activity of greatest importance in reading; the only tenable view is that overt errors indicate mental errors. If, on the other hand, eye-movement behavior determines the central phase of reading, then regressions to the points of error logically might be posited as causes of error. If they are causes, they must precede the errors temporally. Conversely, if it is shown that they do not, it is not conceivable that they are causes. In the present investigation, since both eyes and voice were recorded, it was possible to determine the temporal sequence of errors and regressions to the points of error. These data are summarized in Table IV.

TABLE IV. *Temporal sequence of regressions to errors and the beginnings of the voiced errors*

Time of occurrence of regressions	No. Good	No. Poor	Percentage Good	Percentage Poor
Preceding errors	5	19	21	23
After the beginnings of errors	19	63	79	77

Number of regressions to errors: good group, 24; poor group, 82.

Seventy-nine per cent of the regressions accompanying the errors of good readers, and 77 per cent of those of poor readers, follow the errors temporally. These particular regressions cannot have caused these particular errors. The connection between, and the spatial contiguity of, these phenomena both have been demonstrated; this evidence shows that errors have temporal priority. It is inevitably concluded that errors cause regressions.

The fact becomes even more significant when it is remembered that the errors considered are, perforce, overt, and occur subsequent to their central counterparts. In spite of this limitation the percentage of regressions which follow errors is great, and, in the light of other evidence, the assumption is conservative that, were a technique of recording the exact time of occurrence of the mental error available the percentage would be greater.

Regressions occurring after the error is begun were re-classified as to their exact time of occurrence relative to the error. Meaningful differences between the two groups are disclosed. Comparison reveals the following: in poor reading, 29 per cent of the regressions, as opposed to zero per cent in good reading, occur during hesitation immediately preceding the error; 35 per cent and 21 per cent are made during the error proper; 22 per cent, in contrast to 74 per cent in good reading, transpire before repetitions of errors in which correction is achieved, while five per cent compared to zero per cent for the better group, occur before repetitions in which correction is failed. These data indicate that when good readers hesitate before pronouncing words, for the purpose of making regressions to the words, errors are not made. Poor readers make errors in spite of hesitating and regressing. From a clinical point of view, good readers might be advised to make regressions, while in the case of poor readers, it again appears that a plurality of pauses upon words will not result in prevention of errors. The data also justify the inference that good readers notice errors more often than do poor readers, and that, in this material at least, they invariably are able to correct errors when they regress for that purpose. Further, the data show a greater tendency on the part of poor readers to make ineffectual regressions, not leading to correction of the error, during hesitation immediately after the error is made.

Computation of the mean distance from the midpoint of the error to the regressions mentioned above shows no difference between good and poor readers, the amounts being 3.21 and 3.68 per cent of the line, respectively. The eye-voice lead at these regressions averages 2.29 per cent of the line for the better group, and 7.41 for the poor readers. Regressions of this type reduce the lead practically to zero in good reading, while in poor reading the amount is not strikingly lower than the average lead at all regressions (Table I). This finding is in opposition to previous speculation that coincidence of the eyes and voice at a given point in the line is an invariable sign of immaturity. While this may be valid as a generalization, the opposite appears to apply to the eye-voice relationship at the regressions to errors. Good readers apparently are able to regress almost exactly to the point of the voice when an error is made, without hesitation. The eye-voice lead of poor readers apparently is lengthened because of the need for hesitation.

5. Regressions to error words which precede the overt errors temporally. The findings discussed above show that most regressions to error words occur after the voiced error. The possibility that those which take place before the overt error might be causes of the error was investigated by analysis of the eye-movements at, and contiguous to these regressions. Table V presents

TABLE V. *Measures* of eye-voice lead and forward shift contiguous to the regressions to error words which precede the errors temporally, compared to the same measures for all regressions*

	Good readers		Poor readers	
Measures	Regressions to errors	All regressions	Regressions to errors	All regressions
Eye-voice lead				
preceding regressions	30.00	30.49	28.63	23.12
at regressions	16.75	13.13	16.00	9.70
following regressions	21.00	21.30	17.81	14.88
Forward shift				
preceding regressions	13.33	14.33	11.50	10.54
following regressions	11.25	14.08	10.86	11.15

* Values refer to space in per cent of the line.

results of this analysis in comparison to the same average measure on all regressions.

No essential differences are found. The forward shifts preceding regressions are slightly longer than the mean for all forward shifts. But this is equally true whether or not an error is made. It is of small moment that abnormally long forward shifts precede regressions and may be posited as causes of regressions, as long as these regressions do not cause errors. Ninety-four per cent of all regressions in good reading, and 87 per cent of all regressions in poor reading, are not connected with overt errors; it likewise has been demonstrated that most of the remaining regressions which are involved in errors follow the overt error.

From this evidence it is undeniable that regressions of these two types do not cause errors. Since the forward shifts preceding regressions which are involved in errors are not significantly different from those preceding all other regressions, and since the forward shifts preceding the latter do not cause errors, the extent of the forward shifts preceding the former must be ruled out as cause of the errors.

The eye-voice lead measures on poor readers show substantial differences, and it might be argued that these cause the errors involved. Peripherally, the eye-voice lead may be increased above the average in two ways; by long forward shifts of the eyes, or by lagging of the voice. The extent of the forward shifts preceding the regressions in question is not sufficiently greater than that preceding all other regressions to produce entirely the increase in eye-voice lead which differentiates the former from the latter. And since abnormally long forward shifts have been ruled out as causes of errors, the small contribution of these forward shifts to the increased lead is likewise ruled out as a causal factor. By elimination, the chief factor in the increase is the lagging of the voice. Furthermore, although the eye-voice measures preceding, at, and following regressions differentiate regressions on error words from other regressions, the general behavior of the eye-voice lead is consistently the same in both types. It is greater preceding the regression, markedly reduced at the regression, and increased somewhat, but not to its former extent, following the regression. It may be concluded that increased eye-voice lead at regressions to the point of errors, when these regressions precede the errors temporally, is largely due to the voice and not to the movements of the eyes, and hence, in general is not the cause of errors.

6. Occurrence of regressions. All regressions were classified as to time of occurrence. Four per cent of the 415 regressions of good readers, and six per cent of the 619 regressions of poor readers occurred during errors. Only 10 of the good group's regressions were made during definitely hesitant pauses, in comparison to 165 of the regressions of the inferior group. The remaining regressions of both groups took place during normal, uninterrupted reading.

These findings suggest the chief reason for the large number of hesitations in poor reading: the necessity for pause of the voice while the eyes regress. In good reading, over 90 per cent of all regressions are made without interruption of the voice by either error or hesitation.

IV. Summary and conclusions. By means of a technique for photographing synchronously the eye-movements and sound waves from the voice, a study was made of the relationship between central and peripheral factors in oral reading. Groups of good and poor readers were compared with respect to this relationship.

1. Measures of eye-movement behavior and of the eye-voice relationship agreed with the findings of previous investigators in showing marked differences between the scores of good and poor readers.

2. The difficulty of the material determines variations in eye-movement scores. There is a close although not perfect relationship between eye-movements, number of errors, and the mean difficulty, *i.e.*, unfamiliarity, of the words. Other variations in context, such as punctuation marks and sentence structure, also affect eye-movement behavior. Good readers are less affected than poor readers by difficult material, and are able to take advantage of easy material.

3. Exhaustive investigation of eye-movement behavior at different sections of the line failed to disclose the presence of a fixed 'pattern' of eye-movements, but indicated that these variations also are contingent upon the reading material. However, this relationship is less close in good reading than in poor reading, which suggests that superior readers, while able to adapt to the material, are less influenced by objective factors, and therefore maintain more constant eye-movement behavior.

4. Analysis of oral reading errors showed that substitution is the most frequent error at both levels of ability. Over half of the substitutions of the poor readers seriously affected the meaning, while none of the good readers' substitutions were of that type. Repetition of correct material is more frequent in poor reading than repetition of error material, while the reverse situation is found in good reading. The average poor reader makes three times as many errors as the average superior reader and

hesitates six times as often. He corrects only seven per cent of all his errors, while the good reader corrects 19 per cent.

5. The errors of both groups were found to occur most frequently on unfamiliar words, but all errors were not made on equally unfamiliar words. Mispronunciations, for example, usually occurred on scarce words, while omitted and inserted words invariably are common. In poor reading, substituted words were found to be more familiar than the words which they replace, while good readers substitute words of equal scarcity.

6. The errors of poor readers were found to be more frequently accompanied by regressions than those of good readers, the differences being greater for mispronunciations and substitutions than for other errors. Likewise, the poor readers employed almost twice as many regressions in correcting errors as did the good readers.

7. Substantial positive inter-correlations between errors, hesitations, regressions, and the combined number of errors and hesitations were obtained, and the coefficients almost always were greater in poor reading, substantiating the findings mentioned above. Inclusion of hesitations as errors raised the correlation between errors and regressions, suggesting that even though the determination of hesitations is a qualitative step, more central errors were included, and that diagnosis of reading ability by means of describing oral reading should include this measure.

8. Classification of regressions to error words, as to the time of their occurrence during the voiced error, disclosed some interesting differences between good and poor reading. Good readers notice more of their errors than poor readers, and are able to correct errors when noticed. Poor readers make errors in spite of hesitating and regressing, and exhibit a tendency to make ineffectual regressions after the error is made.

9. Another difference between the extremes of reading ability was found in the fact that the eye-voice lead at regressions to error words is 45 per cent as great as the average lead in poor reading, and only 10 per cent as great in good reading. In this instance a small eye-voice lead is indicative of reading maturity. Without hesitation of the voice, the superior reader is able to

reduce his lead practically to zero by regressive eye-movements, while the poor reader is forced to hesitate, with consequent lengthening of the lead.

10. A generic classification of all regressions as to their time of occurrence during errors, hesitations, and uninterrupted reading resulted in the conclusion that one of the reasons for hesitation in poor reading is the necessity of regressing to words which give difficulty. The good readers, on the other hand, hesitated for only 2 per cent of a total of 415 regressions, and made over 90 per cent of the regressions without interruption of the voice by either error or hesitation.

11. Approximately 80 per cent of all error words were fixated with great precision. The criterion of precise fixation was a distance from the midpoint of the error equal to one-half the mean size of fixation, and this excludes many fixations which are well within the perceptual span. In view of this high percentage and the smallness of the criterion, it is seen that lack of precision in fixating error words is not a cause of errors.

12. The initial eye-movements to words upon which errors subsequently are made do not cause errors. Detailed comparison of these fixations with fixations on the same words when errors are not made, revealed that the characteristics of the fixations, and of the eye-movements contiguous to them, are practically identical whether or not an error is made.

13. Most of the regressions to points of error, 79 per cent in poor and 77 per cent in good reading, occurred after the overt error had begun, establishing the priority of errors. It is obvious that the percentages would be higher if the exact time of central errors could be recorded.

14. Regressions which precede errors temporally were ruled out as causes of error, since neither the regressions themselves nor the eye-movements contiguous to them differed significantly from regressions which were not involved in errors.

15. Since faulty eye-movements cannot have caused the errors, errors must be central in origin[9], and the other peripheral mani-

[9] Another possible origin is dysfunction of the articulatory mechanism. When the nature of the errors is considered, however, it is impossible to attribute more than a few to this source. *Swanson's* (**11**) findings suggest that more

festations of reading, likewise, must have a similar dependence upon central processes. The important differences, therefore, between good and poor readers, are central differences.

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errors occur in oral reading when the attention of the reader is directed to articulation and away from comprehension. This is not to be interpreted as evidence that emphasis upon vocal mechanics causes more errors, but as evidence that better comprehension reduces the number.

THE MATURATION OF CERTAIN VISUAL FUNCTIONS AND THE RELATIONSHIP BETWEEN THESE FUNCTIONS AND SUCCESS IN READING AND ARITHMETIC

by

Guy W. Wagner

I. Introduction. This study is an analytical investigation of the maturation of certain visual functions which are tested by the *Betts Ready to Read Tests*, namely, fusion, amplitude of fusion, lateral imbalance, visual acuity, and stereopsis. One purpose was to establish norms and maturation trends for children in grades kindergarten to six, inclusive. Another was to determine the effectiveness of the various tests in discriminating between good and poor pupils in reading and in arithmetic.

It seemed important to the investigator that norms for these tests be established so that the reading clinician could quickly determine the normality or extent of abnormality of the pupil being tested. *Betts* (3) has established norms for children in grade one and *Swanson* and *Tiffin* (11) have established norms for college freshmen. The present investigation serves to help complete the records between these two independent studies. In addition, it furnishes maturation trends which aid in corroborating the evidences of maturation disclosed by a comparison of the two studies mentioned above. *Betts* (3), the author of the tests used in this study, has stated that maturation is an important factor in reading ability. It would seem essential, therefore, that the many users of these tests be cognizant of the positive or negative maturation of the various visual functions measured. Certainly any interpretation of the test results would be influenced by a study of the maturation trends.

Aside from a knowledge of norms and maturation trends the relationship between success on these tests and achievement in school work is needed. Of special value to the reading clinician would be a series of graphs depicting the relative values of the various tests in the series in selecting the pupils of inferior achievement. A study by *Fendrick* (6) indicates that tests of visual acuity are the most significant in selecting the poor reader. *Eames* (5), using other tests which measure eye defects, came to the conclusion that the correction of eye difficulties is important in the treatment of children showing reading disability.

As a subsidiary study the writer measured the relation between visual functioning and success in reading and arithmetic. The relative value of each of the various visual tests in distinguishing between the pupils of high and low achievement in these two subjects was determined.

This investigation makes no attempt to analyze and study the entire field of possible eye defects. Neither structural defects nor errors of refraction were isolated for study. The tests used are primarily concerned with measuring several physiological functions of the eyes which are related to binocular vision. The results support to some extent the opinion of many educators and eye specialists that permanent injury to the vision of school children may be caused by visual strains imposed upon these children in the learning situations brought about by modern schoolroom practices. As a result, school achievement may lag behind potential achievement. *Reik* (10) clearly explains the serious effects which are likely to result when young children whose eyes tend to be hyperopic are coerced to use binocular vision. He says that many children who dislike to study and are considered dull are merely suffering under the handicap of defective vision. *Henderson* and *Powell* (8) say that in certain schools in Germany far-sighted and near-sighted children are given special exercises in an effort to control the growth of the eye and to improve vision. *Ramsey* (9), ophthalmic surgeon, Glasgow Royal Infirmary, even discusses certain constitutional troubles which may originate as a result of eye strain.

The writer does not attempt to minimize other factors, such as mental age, motivation, apperceptive background, *etc.*, as listed by *Gates* (7), which are highly important in school achievement.

If normal visual functioning is, however, an important corollary of school achievement it is surely desirable to focus the attention of educators and parents upon the problems involved and to supply evidence which will aid in the elimination of what *Henderson* and *Powell* (8) have called visual vices. Furthermore, it seems advisable for educators to understand that isolating and curing the causes of poor school achievement is more important than merely measuring the symptoms.

II. Approach to the problem. Arrangements were made with the administrative officers of the Syracuse, New York, public schools to test approximately 850 children in grades kindergarten to six, inclusive. The children were located in the Frazer and Huntington schools. Permission was obtained to give the tests over a period of five days. Approximately six hours were devoted to testing each day. The tests were given during the last month of the school year, in 1935.

The testers were selected from among the best students in the 1934–35 sophomore class of the State Normal School, Oswego, New York. These students were trained by the investigator and the Normal School reading clinic assistant in giving specific tests of the *Betts Ready to Read* series (2). A form for recording the results for each pupil tested was prepared by the investigator.

Eight ophthalmic telebinoculars [1] were set up in a large room suitable for testing. An assistant with a specific test was seated at each of the telebinoculars. About 10 children at a time were brought to the testing room by a monitor. Each pupil had his record sheet with him, containing his name, chronological age, and grade in school, filled in by his home room teacher. The reading clinic assistant and the investigator located the incoming children at the proper tables and checked outgoing record sheets for consistency and completeness. In addition they gave advice on problem cases and relieved the regular testers periodically throughout the day. Identical procedures were followed at the Frazer and Huntington schools.

Five different tests were given, namely, fusion, amplitude of

[1] This apparatus is distributed by the Keystone View Co., Meadville, Pa. In addition to the telebinocular this company has all of the *Betts'* visual tests constructed on stereoscopic cards and assembled in convenient form.

fusion, lateral imbalance, visual acuity, and stereopsis. These tests were all constructed on stereoscopic cards and given with the aid of the telebinocular. The last three tests were exactly the same as those described in the manual for the *Betts Ready to Read* tests (2). The test for fusion was similar to the one described in the *Betts* manual but considerably more elaborate. The amplitude of fusion test is a new test suggested by *Betts* and constructed by the writer. A complete description of each test will be given later.

It should be noted that due to lack of time all of the tests were not given to all of the children. Sometimes it was necessary to spend as much as a half-hour in successfully administering such a test as the one for amplitude of fusion. This was especially true in testing kindergarten and first grade children. The ordinary fusion test, however, was given to nearly all of the children for it was easy to administer and the writer was especially concerned with deriving rather comprehensive data for this test.

Teachers' marks were used as the criterion of pupil achievement in reading and arithmetic. Because the several teachers varied considerably in the range of marks given, it was deemed wise to select the upper and lower quartiles and the upper and lower halves by determining the quartiles and halves for each specific room rather than by ranking the entire population tested in a continuum for each grade. This method of selection is more certain to place the pupils in the proper achievement categories. The writer felt justified in using teachers' marks rather than standardized tests as the criterion of success because this was not an experimental study in which achievement over the period of the experiment was to be measured. It was felt that the periodic tests given throughout the year by the teachers, together with their subjective opinions, would rank the pupils in their proper achievement categories quite as accurately as a single standardized test. It would have been valuable, however, to check the teachers' marks with a standardized test, had such a procedure been expedient.

III. The inter-correlations of the various tests. Correlations were computed between several of the tests. If any of the correlations were high one might fairly assume that the tests in question were measuring aspects of visual functioning which are very closely associated with each other, and it would be unnecessary to give more than one of the group of closely related tests.

The several correlations calculated show quite clearly that the tests are measuring relatively unrelated functions. Even when the results of the same tests for far and near point are correlated, the highest coefficient found was $r = .67$, between lateral imbalance at far point and lateral imbalance at near point for primary grades. A glance at Tables I and II shows that most of the correlations were much lower than the one just mentioned. The lack of relationship is more evident when different tests in the series were correlated with each other. For instance, when the correlation between amplitude of fusion at near point and stereopsis at near point (for primary grades) was completed the result was $r = +.11$. All of the possible correlations were not calculated, since it was felt that the samples selected were sufficiently adequate to show the general lack of relationship between the several tests.

TABLE I. *Inter-correlations of tests for the primary grades*

Tests	r	PE
Fusion at far point—Fusion at near point	.44	.05
Amp. of Fusion at far—Amp. of fusion at near	.46	.05
Lat. imb. at far—Lat. imb. at near	.67	.03
Right-eye acuity—Left-eye acuity	.24	.06
Stereopsis at far—Stereopsis at near	.37	.06
Fusion at near—Amp. of fusion at near	.02	.06
Fusion at near—Lat. imb. at near	.18	.06
Amp. of fusion at near—Stereopsis at near	.11	.07

TABLE II. *Inter-correlations of tests for the intermediate grades*

Tests	r	PE
Fusion at far point—Fusion at near point	.49	.05
Fusion at near—Amp. of fusion at near	.16	.07
Amp. of fusion at near—Stereopsis at near	.02	.07

One logically may conclude on the basis of the low correlations existing between these tests that a high score on any one is very unlikely to signify accurately a similar rating on any other.

IV. Fusion. Two tests for fusion were used in the testing program, one for reading distance (near point—13 in.) and one for far point (40 in.). These tests provide an index to the level of binocular coördination of the individual at the distances mentioned.

Whenever an individual with binocular vision looks at a single object, each eye receives a separate image of the object. The process by which the two distinct visual impressions conveyed to the cortex from the right and left eyes are merged into a single sensory impression is called fusion (*Fuchs,* 4). If fusion does not occur the result usually is double images. Double images interfere with vision and result in confusion, so the physiological mechanism of the eyes 'tries' to avoid them as much as possible. This is accomplished by the muscular effort necessary to turn in (converge) the visual axes of the eyes so that the double images coalesce. This effort to bring about union or superposition is called the fusion tendency. For normal reading or seeing of fine detail the fusion takes place on the fovea centralis in the macular area of the retina. Larger images fall upon the peri-macular area. Whenever the eye muscles are unable to focus the right-eye and left-eye images of the object of regard upon corresponding parts of the retinas, fusion does not occur. In such cases there is no single binocular vision. In brief, because of the physiological tendency to fuse and thus eliminate diplopia (two images), the adductors (internal recti) or abductors (external recti) focus the eyes simultaneously in a position such that the rays of light from the object of regard impinge upon corresponding parts of the retina. In the case of very fine detail this fusion takes place in the fovea, in the case of somewhat larger images, in the macula lutea, and in the case of large images, in the peri-macula area.

According to medical terminology there are three degrees of fusion. Because nearly every one is familiar with the old-fashioned stereoscope it will be possible to explain these by simple illustrations.

First degree: ability of an individual to see two dissimilar objects in proper relationship. For example, if a cage is on the left side of a stereoscopic card and a parrot is on the right side, an individual looking at the card through a stereoscope will see the parrot in the cage.

Second degree: two part objects can be fused into one. For instance, if on a stereoscopic card a girl with a basket in her right hand is seen through a stereoscope with the left eye and the same girl in the same position with an apple in her left hand is seen by the right eye, the result of fusion should give the single image of a girl with a basket in her right hand and an apple in her left hand.

Third degree: stereoscopic vision or depth perception (this will be discussed in a later section).

The tests for fusion used by the investigator may be classified as second-degree tests. On a stereoscopic card the left eye sees two balls, and the right eye sees two balls. When viewed through a stereoscope two of the balls which are in a horizontal plane should fuse so that *S* will say that he sees three balls. Eight stereoscopic cards were used, with the balls on cards A through H being progressively larger in size, the range being from one mm. on card A to 14 mm. on card H. The *S* was given approximately three seconds to fuse the smallest targets. If he did so his score was recorded as A. If he did not fuse these targets the next card in the series was placed in the stereoscope. In each case the score was that of the smallest target which *S* could fuse within the time limit allowed. The results of these tests are indicated in the following pages in both graphic and tabular form.

Maturation trends. Chart 1 portrays graphically a decrease of fusion ability with age. In Table III exact percentage relationships are presented. For instance, 82 per cent of the pupils in the primary grades could fuse targets A, B, or C, while only 71 per cent of the pupils in the intermediate grades could fuse the same targets. By reference to Table VII it can be noted that this percentage difference is statistically significant, the CR being 3.49. This means that there are 99.9+ chances in 100 that there is a true difference. Chart 3 shows even more vividly the negative relationship existing between chronological age and fusion ability. In this chart the percentage relationships have been computed on the basis of age levels rather than grade levels. From the youngest age group to the oldest age group there is a steady decline in fusion ability, and we logically may assume a corresponding decrease in the level of single binocular vision.

Charts 2 and 4 and Tables IV and VI show that a somewhat similar decrease in the fusion power of older children occurs at near point (reading distance). Here, however, the decrease is not quite so marked. By reference to Table VII it will be noted that there are only 91 chances out of 100 that there is a true difference.

Research by *Betts* (3) and *Swanson* and *Tiffin* (11) serves to corroborate the present evidence which points toward a decrease in fusion ability with chronological maturity. *Betts*, using a

TABLE III. *Summary of data for fusion at far point*

Grade	Freq.	A	B	C	D	E	F	G	H	No fus.	Per cent fus. A	Per cent fus. A, B	Per cent fus. A, B, C
Kdgn. & Prim.	456	190	121	61	17	15	14	16	11	11	42	68	82
Inter.	307	102	74	42	21	15	13	18	9	13	33	57	71
Total	763	292	195	103	38	30	27	34	20	24	38	63	77

TABLE IV. *Summary of data for fusion at near point*

Grade	Freq.	A	B	C	D	E	F	G	H	No fus.	Per cent fus. A	Per cent fus. A, B	Per cent fus. A, B, C
Kdgn. & Prim.	456	298	84	37	9	7	4	7	6	4	65	84	92
Inter.	307	183	59	31	11	4	7	1	6	5	60	79	89
Total	763	481	143	68	20	11	11	8	12	9	63	82	91

TABLE V. *Summary of data for fusion at far point*

Age	Freq.	A	B	C	D	E	F	G	H	No fus.	Per cent fus. A	Per cent fus. A, B	Per cent fus. A, B, C
4 and 5	91	43	25	13	1	4	1	1	0	4	47	75	89
6 and 7	224	92	61	28	9	6	6	10	8	4	41	68	81
8 and 9	196	76	51	27	9	4	8	10	3	8	39	65	79
10 and 11	172	58	41	23	13	10	8	5	7	7	34	58	71
12+	82	24	18	14	6	5	4	8	2	1	29	51	68

TABLE VI. *Summary of data for fusion at near point*

Age	Freq.	A	B	C	D	E	F	G	H	No fus.	Per cent fus. A	Per cent fus. A, B	Per cent fus. A, B, C
4 and 5	91	62	12	9	1	3	0	0	1	2	69	82	92
6 and 7	224	140	51	17	3	4	1	4	2	2	63	85	93
8 and 9	196	129	29	15	6	1	4	3	6	3	66	81	88
10 and 11	172	104	34	19	5	2	4	1	1	2	60	80	91
12+	82	47	18	7	5	1	2	0	2	0	57	79	88

fusion card similar to the C card of this investigation, found the incidence of normal fusion for first-grade entrants for both far and near point to average 86 per cent. *Swanson* and *Tiffin*, using the *Betts* fusion cards which correspond to the B cards of the present investigation, found in testing an unselected group of college freshmen (wearing corrections) that 73 per cent and 28 per cent had normal fusion at far and near point, respectively.

TABLE VII. *Measurement of the reliability of the difference in terms of SE difference*

Table	Comparison of per cent fusing A, B, C, made between	Diff.	SE diff.	CR	Chances in 100
1	Prim. and inter. far point	11	3.15	3.49	99.9+
2	Prim. and inter. near point	3	2.19	1.37	91
	Upper and lower halves in reading				
6	Prim. far point	1	4.29	.23	59
6	Inter. far point	4	5.23	.76	77
6	Total far point	3	3.36	.89	82
7	Prim. near point	2	3.04	.66	74
7	Inter. near point	5	3.67	1.36	91
7	Total far point	4	2.34	1.71	96
	Upper and lower halves in arith.				
8	Prim. far point	6	4.25	1.41	92
8	Inter. far point	—5	5.27	.95	83
8	Total far point	1	3.37	.30	62
9	Prim. near point	4	3.04	1.32	90
9	Inter. near point	—6	3.61	1.66	95
9	Total near point	—1	2.40	.42	66
10	Prim. boys and girls far point	6	3.62	1.66	95
10	Inter. boys and girls far point	9	5.23	1.72	96
10	Total boys and girls far point	7	3.03	2.31	98.9
11	Prim. boys and girls near point	1	2.48	.41	65
11	Inter. boys and girls near point	2	3.61	.55	71
11	Total boys and girls near point	2	2.09	.96	83

A comparison of these two separate investigations seems to produce definite evidence substantiating the facts on fusion maturation presented by this study.

A logical and perhaps highly important question which may arise from a survey of the above facts is, "how may we account for this decrease in fusion ability when the more reasonable assumption would be that, due to practice in binocular single vision, fusion power should increase?" A possible explanation is that unhygienic habits in the use of the eyes have developed during this maturation period. As a result the older children may respond less readily and less successfully with muscle innervation for accurate accommodation and binocular coördination.

Relationship of success in reading and arithmetic to fusion ability. The primary purpose of this investigation is to establish norms and to determine maturation trends, and not to determine the effectiveness of the tests in discriminating between good and poor readers. Had the latter been the primary purpose, a smaller number of cases would have been selected and these chil-

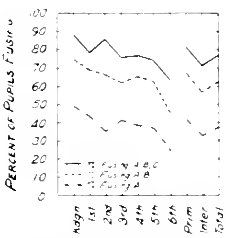

Chart 1 Percent of Pupils Fusing Targets of Various Sizes at Far Point (Grade Level)

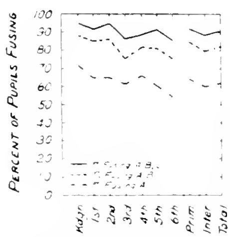

Chart 2. Percent of Pupils Fusing Targets of Various Sizes at Near Point (Grade Level)

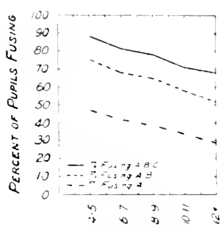

Chart 3 Percent of Pupils Fusing Targets of Various Sizes at Far Point (Age Level)

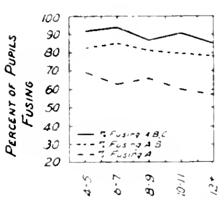

Chart 4 Percent of Pupils Fusing Targets of Various Sizes at Near Point (Age Level)

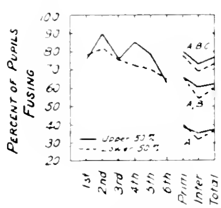

Chart 5. Percent of Upper and Lower Half Pupils in Reading Fusing Targets of Various Sizes at Far Point

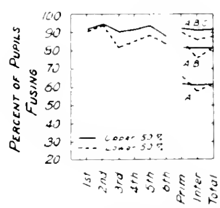

Chart 6 Percent of Upper and Lower Half Pupils in Reading Fusing Targets of Various Sizes at Near Point

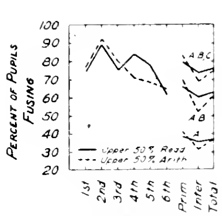

Chart 7. Percent of Upper Half Pupils in Reading and Upper Half Pupils in Arithmetic Fusing Targets of Various Sizes at Far Point

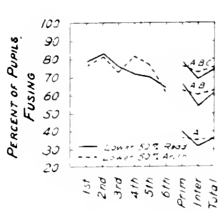

Chart 8 Percent of Lower Half Pupils in Reading and Lower Half Pupils in Arithmetic Fusing Targets of Various Sizes at Far Point

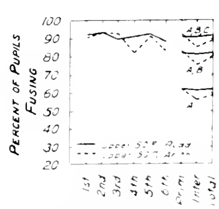

Chart 9. Percent of Upper Half Pupils in Reading and Upper Half Pupils in Arithmetic Fusing Targets of Various Sizes at Near Point

dren would have been divided into two distinct categories, namely, those with definite reading disabilities and those who were definitely superior readers. It also would have been necessary to make a study of such factors as home environment, and mental age as determined by individual intelligence tests which do not involve reading.

With the data at hand, however, from which the norms and maturation trends had been developed for these children, it was

TABLE VIII. *Comparison of data for fusion at far point between pupils ranking in the upper and lower halves in reading*

Grade	Per cent fus. A Upper half	Per cent fus. A Lower half	Per cent fus. A Diff.	Per cent fus. A, B Upper half	Per cent fus. A, B Lower half	Per cent fus. A, B Diff.	Per cent fus. A, B, C Upper half	Per cent fus. A, B, C Lower half	Per cent fus. A, B, C Diff.
Prim.	39	40	—1	66	66	0	80	79	1
Inter.	35	31	4	60	54	6	73	69	4
Total	37	36	1	63	61	2	77	74	3

felt that a comparison of the upper and lower 50 per cent in reading achievement might shed some light upon the relationship between failure on these tests and reading disabilities. Test results for the high and low achievement pupils in arithmetic also were compared. It was felt that children who had reading disabilities but whose intelligence, motivation, apperceptive background, *etc.*, were normal, might possibly achieve a fairly high level in arithmetic, even though visual defects had caused a lower achievement in reading. The writer wishes to make it clear that the conclusions drawn from these comparisons must be regarded as tentative and might be considerably modified by a more intensive investigation of this specific problem.

Chart 5 and Table VIII present data which indicate that the upper-half readers fuse somewhat better than the lower-half readers at far point. In Table VII we may note that there are 82 chances in 100 that this is indicative of a true difference. The reliability of the difference is greater for the intermediate grades than for the primary grades.

Chart 6 and Table IX also show a greater difference in fusion ability at near point in favor of the upper-half readers. The chances are 96 in 100 that this is a true difference. Again we find the reliability of the difference in the intermediate grades in favor of the better readers greater than it is in the primary grades. The significance of these differences is measured by the CR of .66 for the primary grades and 1.36 for the intermediate grades. Perhaps the aggravation of fusional disturbances in the intermediate grades due to more intensive close work has served

TABLE IX. *Comparison of data for fusion at near point between pupils ranking in the upper and lower halves in reading*

	Per cent fus. A			Per cent fus. A, B			Per cent fus. A, B, C		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	62	65	—3	81	85	—4	92	90	2
Inter.	61	57	4	81	76	5	91	86	5
Total	62	61	1	81	81	0	92	88	4

TABLE X. *Comparison of data for fusion at far point between pupils ranking in the upper and lower halves in arithmetic*

	Per cent fus. A			Per cent fus. A, B			Per cent fus. A, B, C		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	42	37	5	70	63	7	83	77	6
Inter.	31	35	—4	52	60	—8	68	73	—5
Total	37	36	1	62	62	0	76	75	1

TABLE XI. *Comparison of data for fusion at near point between pupils ranking in the upper and lower halves in arithmetic*

	Per cent fus. A			Per cent fus. A, B			Per cent fus. A, B, C		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	62	66	—4	82	84	—2	93	89	4
Inter.	56	62	—6	75	82	—7	86	92	—6
Total	59	64	—5	79	83	—4	89	90	—1

to reduce the reading efficiency of some of the low-level fusion cases. This may have aided in allocating them to the lower half in reading achievement.

It is interesting and perhaps significant to read from Tables X and XI that while the upper half in arithmetic are apparently slightly better able to fuse than are the lower half, the CR is only .30 at far point as compared with a CR of .89 when comparing the upper and lower halves in reading. At near point, the comparison is even more significant, for the CR in arithmetic comparisons is .42, in favor of the *lower* half in achievement, while the CR in reading is 1.71 in favor of the *upper* half in achievement. Charts 7 and 9, which compare the upper halves in reading and arithmetic at far and near point respectively, and charts 8 and 10, which compare the lower halves in reading and arithmetic at far and near point, respectively, give a graphic picture of this situation.

TABLE XII. *Comparison of data for fusion at far point, between boys and girls*

Grade	Freq. Boys	Freq. Girls	Per cent fus. A		Per cent fus. A, B		Per cent fus. A, B, C	
			Boys	Girls	Boys	Girls	Boys	Girls
Prim.	241	214	44	40	71	66	85	79
Inter.	165	141	36	29	61	52	75	66
Total	406	355	41	36	67	60	81	74

TABLE XIII. *Comparison of data for fusion at near point, between boys and girls*

Grade	Freq. Boys	Freq. Girls	Per cent fus. A		Per cent fus. A, B		Per cent fus. A, B, C	
			Boys	Girls	Boys	Girls	Boys	Girls
Prim.	241	214	66	66	85	83	93	92
Inter.	165	141	63	56	82	75	90	88
Total	406	355	65	62	84	80	92	90

The possible interpretation of these data is that low fusion ability is less of a handicap to achievement in arithmetic than in reading. If future experiments in this field substantiate these data, it will be rather convincing evidence that low fusion ability is likely to be a correlate of low achievement in reading.

Fusion ability of boys and girls. When boys are compared with girls in fusion ability they appear to have quite a definite superiority at far point and a somewhat less significant superiority at near point. Charts 11 and 12 present graphic pictures of these comparisons, and Tables XII and XIII summarize the data. Reference to Table VII indicates that there are 98.9 chances in 100 that the boys in the elementary grades can fuse better than the girls at far point. This superiority is slightly greater in the intermediate than in the primary grades. At near point there are 83 chances in 100 that the boys are superior to the girls in fusion ability. This superiority is again slightly greater in the intermediate grades.

The rather evident superiority of the boys over the girls is contrary to the results of most studies comparing the achievements of boys and girls in the elementary grades. A reasonable interpretation seems to be that boys are more likely to use their eyes most of the time for distance seeing, while girls in general are likely to read and study more, do needle work and the like, and thus tend to develop myopia and a corresponding inability to fuse well, especially at far point.

In observing a myopic person read, one will note that the reading page is brought very close to the eyes in order to have the image focused clearly upon the retina. This is because in the myopic eye the ciliary muscle is already relaxed as much as possible, and it has no power to adjust the shape of the lens, which is much more spherical than in the normal eye. The myope must, therefore, be closer to the reading material or hold it closer to the eyes if clear images are to be obtained. This necessitates extra convergence and imposes an added strain upon the extrinsic muscles. Under this condition of abnormal strain, a high level of fusion will be difficult to attain for those children tending to be myopic.

Henderson and *Powell* (8) say that myopia occurs during the third and fourth grades in school when close work begins to accumulate. If the above interpretation for the superiority of boys over girls in fusion ability is true, the necessity of adjusting our school programs to the visual capacities of children is again emphasized.

V. Amplitude of fusion. The amplitude of fusion tests might well be called the span-of-convergence-and-divergence tests. This statement will become clear as the explanation develops. To understand what is being measured by the amplitude of fusion tests it is first necessary to know something about the external muscles of the eye.

The ocular muscles are classified into two groups, the internal muscles and the external muscles. The internal muscles are the sphincter pupillæ, the muscle that closes the pupil, and the ciliary muscle, the muscle that governs the focusing action of the lens. The external muscles move the eyeball and are six in number: the internal, external, superior and inferior recti, and the superior and inferior obliques. These muscles are innervated by the third, fourth, and sixth cranial nerves (*Ramsey,* 9). They serve to turn the eyeball inwards and outwards, upwards and downwards.

It is unnecessary to describe here the associative functions of these muscles in effecting the various movements of the eye. Keeping in mind that the action of these muscles is rather complex, let us consider, for the sake of brevity and clearness, the action of the two muscles with which we are most concerned in the study of amplitude of fusion, the internal and external rectus muscles.

The internal and external recti are fastened to the sclera just on the inner and outer side of the cornea, respectively. The internal rectus pulls the eye inwards, the external rectus pulls the eye outwards. Now the visual axes of a pair of normal eyes when looking straight ahead are parallel. If the internal recti turn the visual axes nasally the eyes are said to converge (act of adduction). If the external recti turn the visual axes outward the eyes are said to diverge (act of abduction).

The amplitude of fusion stereoscopic cards contained two vertical parallel lines which were centered between the top and bottom of the cards. The cards were constructed so that the right eye saw the line on the right of the card and the left eye saw the line on the left of the card when viewed through the telebinocular. Thirty-five cards were made with the distances between the lines ranging from 30 to 100 mm., a progression in distance of two mm. per card. If the internal recti were strong enough to converge the eyes so that fusion could take place when *S* was viewing the 30 mm. card, the adduction span was very large. If the external recti could diverge the eyes so that fusion could take place when *S* was viewing the 100 mm. card, abduction was very strong.

S was considered to be fusing when he reported seeing only one line with a ball at the top and one at the bottom (the left line had a ball at the top and the right line had a ball on the bottom, hence in fusion *E* could detect accuracy of response by checking the location of the two balls). To illustrate with a specific case, pupil X could see two lines until the 44 mm. card was used. From there on he saw only one line until the 82 mm. card was used, at which point he was unable to see the two lines in such a way as to focus them upon corresponding macular areas of the retina and attain fusion. His amplitude of fusion was scored as

TABLE XIV. *Summary of amplitude-of-fusion data at far point*

Grade	Freq.	0–15	16–30	31–45	46–70	Per cent with fusion span of 16 mm.+	31 mm.+	46 mm.+
Prim.	109	22	42	38	7	80	41	6
Inter.	84	21	22	23	18	75	49	21
Total	193	43	64	61	25	78	45	13

TABLE XV. *Summary of amplitude-of-fusion data at near point*

Grade	Freq.	0–15	16–30	31–45	46–70	Per cent with fusion span of 16 mm.+	31 mm.+	46 mm.+
Prim.	111	18	78	15	0	84	14	0
Inter.	79	9	43	22	5	89	34	6
Total	190	27	121	37	5	86	22	3

82—44, or 38 mm. Sometimes *S* would report only one line and upon being questioned would indicate that there was only one ball attached to it. In such an instance, *E* would recognize that there was suppression of vision in one eye and of course would not give credit for fusion.

Maturation trends. By reference to charts 13 and 14 and Tables XIV and XV it will be noted that in general the older children had a greater amplitude of fusion at both far and near point. Table XX presents statistical corroboration of this evidence. At far point there are 86 chances in 100 that the intermediate grade children have a wider amplitude of fusion. At near point there are 99.9+ chances in 100 that the older children have a superior amplitude of fusion. These conclusions are based on the column of data which shows the per cent of children whose fusion span was 31 mm. or more. A study of the above mentioned charts and tables reveals the fact that the intermediate grade children were superior to the primary grade children if fusing an amplitude of 46 mm. or more. This maturation trend is in the opposite direction to the maturation trend for ordinary fusion. When one considers, however, that there is practically no correlation between the fusion and the amplitude of fusion tests this condition is explained in part.

This lack of correlation can be explained further by comparing the physiological conditions necessary for ordinary fusion with

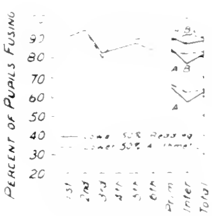

Chart 10 Percent of Lower Half Pupils in Reading and Lower Half Pupils in Arithmetic Fusing Targets of Various Sizes at Near Point

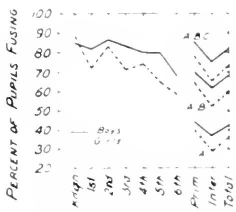

Chart 11 Percent of Boys and Girls Fusing Targets of Various Sizes at Far Point

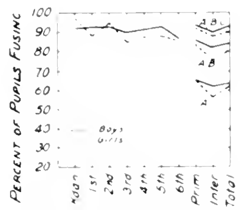

Chart 12 Percent of Boys and Girls Fusing Targets of Various Sizes at Near Point

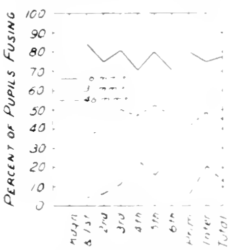

Chart 13 Percent of Pupils Having Various Amplitudes of Fusion at Far Point

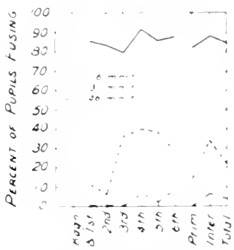

Chart 14 Percent of Pupils Having Various Amplitudes of Fusion at Near Point

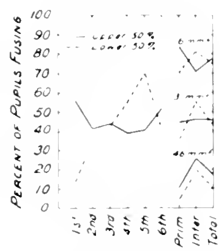

Chart 15 Percent of Upper and Lower Half Pupils in Reading Having Various Amplitudes of Fusion at Far Point

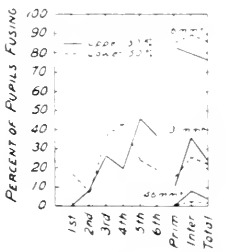

Chart 16 Percent of Upper and Lower Half Pupils in Reading Having Various Amplitudes of Fusion at Near Point

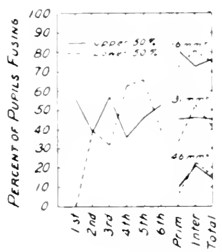

Chart 17 Percent of Upper and Lower Half Pupils in Arithmetic Having Various Amplitudes of Fusion at Far Point

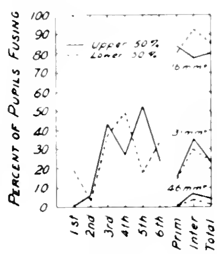

Chart 18 Percent of Upper and Lower Half Pupils in Arithmetic Having Various Amplitudes of Fusion at Near Point

those necessary for amplitude of fusion. Ordinary fusion depends upon the state of lateral balance and the refractive ability of the lens to form clear retinal images. If normal lateral balance exists, if the lens refracts normally and if the visual acuity of each eye is sufficient to detect the small images, ordinary fusion should be at a high level. On the other hand, success on the amplitude of fusion tests depends upon the power of the external

TABLE XVI. *Comparison of amplitude-of-fusion data at far point between pupils ranking in the upper and lower halves in reading*

	Per cent 16 mm.+ fus. span			Per cent 31 mm.+ fus. span			Per cent 46 mm.+ fus. span		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	84	70	14	45	36	9	11	4	7
Inter.	72	83	—11	46	56	—10	26	20	6
Total	78	75	3	46	45	1	19	11	8

TABLE XVII. *Comparison of amplitude-of-fusion data at near point between pupils ranking in the upper and lower halves in reading*

	Per cent 16 mm.+ fus. span			Per cent 31 mm.+ fus. span			Per cent 46 mm.+ fus. span		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	82	85	—3	11	17	—6	0	0	0
Inter.	80	90	—10	37	27	10	9	2	7
Total	81	87	—6	23	22	1	4	1	3

eye muscles to converge and diverge the eyes co-ordinately through a relatively large number of degrees of arc.

The relationship of success in reading and arithmetic to amplitude of fusion ability. On the basis of the data gathered in this investigation it would be difficult to defend the thesis that a low amplitude of fusion has much to do with a low level of achievement in reading. When the children in the upper and lower halves in reading are compared on the basis of their amplitude of fusion scores there is no significant difference found. There seems to be approximately as insignificant a difference when the children ranking in the upper and lower halves in arithmetic are compared. Charts 15, 16, 17, and 18 and Tables XVI, XVII, XVIII, XIX supply the data for these conclusions. Table XX presents CRs for the total group on the basis of the 31 mm. fusion span data. At far point and near point in reading the CRs are .14 and .16 respectively. At far point and near point in arithmetic the CRs are .41 and .32 respectively.

The lack of relationship between these tests and success in reading may be a result of the technique for measuring amplitude

TABLE XVIII. *Comparison of amplitude-of-fusion data for far point between pupils ranking in the upper and lower halves in arithmetic*

	Per cent 16 mm.+ fus. span			Per cent 31 mm.+ fus. span			Per cent 46 mm.+ fus. span		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	81	72	9	46	33	13	10	7	3
Inter.	73	81	—8	47	53	—6	22	23	—1
Total	77	76	1	46	43	3	15	15	0

TABLE XIX. *Comparison of amplitude-of-fusion data at near point between pupils ranking in the upper and lower halves in arithmetic*

	Per cent 16 mm.+ fus. span			Per cent 31 mm.+ fus. span			Per cent 46 mm.+ fus. span		
Grade	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.	Upper half	Lower half	Diff.
Prim.	84	80	4	16	15	1	0	0	0
Inter.	78	93	—15	36	31	5	7	5	2
Total	81	86	—5	25	23	2	3	2	1

TABLE XX. *Measurement of the reliability of the difference in terms of SE Difference*

Table	Comparison of per cent with ampl. of fusion of 31 mm.+ made between	Diff.	SE diff.	CR	Chances in 100
14	Prim. and inter. far point	8	7.20	1.11	86
15	Prim. and inter. near point	20	6.27	3.19	99.9+
	Upper and lower 50 per cent in reading				
16	Prim. far point	9	10.0	.90	82
16	Inter. far point	—10	10.69	.94	83
16	Total far point	1	7.35	.14	56
17	Prim. near point	—6	7.05	.85	80
17	Inter. near point	10	9.95	1.01	84
17	Total near point	1	6.18	.16	56
	Upper and lower 50 per cent in arith.				
18	Prim. far point	13	9.79	1.33	91
18	Inter. far point	—6	10.64	.56	71
18	Total far point	3	7.29	.41	65
19	Prim. near point	1	7.35	.14	56
19	Inter. near point	5	10.11	.49	69
19	Total near point	2	6.30	.32	63

of fusion. Further experimentation with a refined technique may show a more positive relationship between success in reading and a wide amplitude of fusion. The data from this investigation, however, cannot be used to support a contention that a low amplitude of fusion is a correlate of low achievement in reading.

VI. Lateral imbalance. In a book published by the American Optical Company (1) an analogy is made between a pair of eyes and a team of horses. The eye-muscles are likened to the reins by means of which the teamster, *i.e.*, the controlling nervous centers, guides and co-ordinates the movements of the eyes. Normal eyes are so harnessed together and controlled by the muscles that they function efficiently and economically but poor eyes are frequently maintained in harmonious co-operation only through an excessive expenditure of nervous energy. Now if the horses (the eyes) tend to bite each others' necks, they are converging too much from normal and there is consequently an excessive strain on the nerve centers and muscles in an attempt to maintain harmonious normal action. The same is true if the horses (the eyes) tend to pull away from each other, the one to the left and the other to the right. In either case the teamster (the controlling nervous centers) is kept constantly busy in an effort to promote harmonious action (binocular co-ordination).

If such a condition as the above exists the eyes are said to be in a state of lateral imbalance. Esophoria is the name given to the condition of over-convergence (the visual axes of the eyes deviate inwards); and exophoria is the state of over-divergence (the visual axes of the eyes deviate outward).

The tests for lateral imbalance may appear at first to be measuring the same function as the tests for amplitude of fusion. They differ, however, in that they measure the amount of abnormal convergence or divergence that exists. The amplitude of fusion tests measure the total range of adduction and abduction while fusion is occurring and make no effort to find any abnormal imbalance condition.

A complete description of the lateral imbalance tests may be found in the *Betts'* manual (2). It is sufficient here to say that on the stereoscopic card there is an arrow in front of the left eye and before the right eye is a horizontal scale, 70 mm. long. Figures numbered consecutively from 1 to 15 and proceeding from left to right appear at distances of 5 mm. apart on this scale. Number 1 is 45 mm. to the right of the arrow and num-

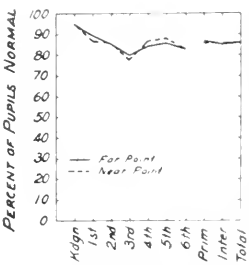

Chart 19. Percent of Pupils With Normal Lateral Balance at Both Far and Near Point

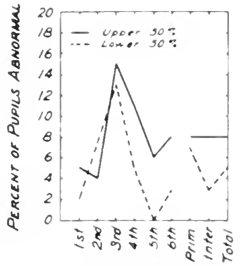

Chart 20. Percent of Upper Half and Lower Half Pupils in Reading Having Exophoria at Far Point

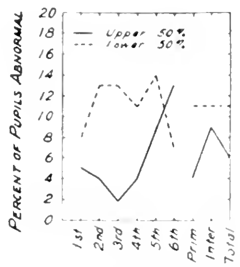

Chart 21. Percent of Upper Half and Lower Half Pupils in Reading Having Esophoria at Far Point

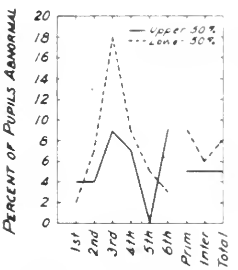

Chart 22. Percent of Upper Half and Lower Half Pupils in Arithmetic Having Exophoria at Far Point

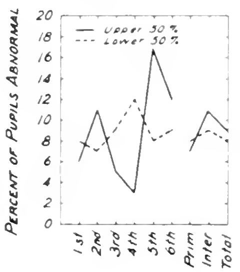

Chart 23. Percent of Upper Half and Lower Half Pupils in Arithmetic Having Esophoria at Far Point

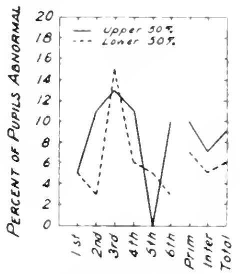

Chart 24. Percent of Upper Half and Lower Half Pupils in Reading Having Exophoria at Near Point

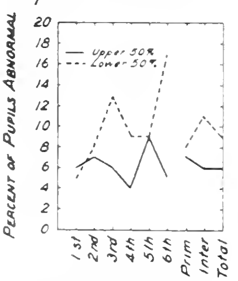

Chart 25. Percent of Upper Half and Lower Half Pupils in Reading Having Esophoria at Near Point

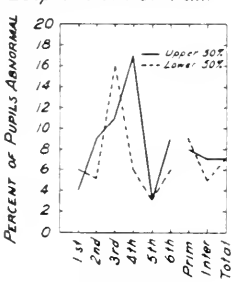

Chart 26. Percent of Upper Half and Lower Half Pupils in Arithmetic Having Exophoria at Near Point

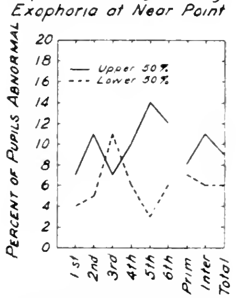

Chart 27. Percent of Upper Half and Lower Half Pupils in Arithmetic Having Esophoria at Near Point

ber 15 is 115 mm. from the arrow. The amount of convergence or divergence is shown by the number to which the arrow apparently points when the card is viewed in the telebinocular.

Maturation trends. Chart 19 indicates that there is no significant change when the primary grade children are compared with the intermediate grade children in lateral imbalance. This is true when abnormalities of laterality are checked at both far

Table XXI. *Summary of lateral imbalance data at far point for all pupils*

Class interval	Kdg.	1st	2nd	3rd	4th	5th	6th	Total
12+								
11+					1			
10+		1	1	3				
9+		3	5	11	4	2	4	
8+	21	45	28	22	22	18	20	
7+	28	52	44	41	25	34	22	
6+	4	19	27	17	10	15	15	
5+	2	4	9	3	4	9	7	
4+		3	1	1	1			
3+		1	1	2				
2+		1						
1+								
—1								
Freq.	55	129	116	100	67	78	68	613
No. normal	53	116	99	80	57	67	57	529
Per cent normal	96	90	85	80	85	86	84	86
Mean	7.81	7.57	7.42	7.73	7.69	7.23	7.49	

and near point. However, there is a somewhat marked increase in lateral imbalance from the kindergarten to the third grade. This is compensated for by a decrease from the third grade to the sixth grade.

Tables XXI and XXII show that the logical range for the normal is from 6 to 8+ inclusive at far point, and from 3 to 5+, inclusive at near point. It was assumed that all scores above or below these ranges were abnormal. On this basis, 14 per cent of all the pupils tested at both far and near point exhibited abnormal lateral imbalance. Both the primary and intermediate grade groups averaged approximately 14 per cent abnormal. These data agree fairly well with *Betts'* study (3) in which 17 per cent of the 190 first grade children tested were found to be abnormal at far point and eight per cent abnormal at near point when his data were analyzed on the basis of the norms established for this study. Using the same norms, the data of the *Swanson* and *Tiffin* study (11) reveal abnormalities of 14 per cent at far point and 21 per cent at near point. These data suggest a possible increase of lateral imbalance conditions at near point. However, the evidence pointing toward a definite maturation is not very substantial.

In order to check further on the possible maturation of lateral imbalance conditions the means were determined for both far

TABLE XXII. *Summary of lateral imbalance data at near point for all pupils*

Class interval	Kdg.	1st	2nd	3rd	4th	5th	6th	Total
12+								
11+								
10+								
9+								
8+			1					
7+				6				
6+	1	6	7	8	5	2	5	
5+	13	31	18	19	17	10	10	
4+	30	62	46	46	28	37	23	
3+	10	21	35	13	13	22	24	
2+	1	6	8	5	4	7	5	
1+		3	1	2			1	
—1				1				
Freq.	55	129	116	100	67	78	68	613
No. normal	53	114	99	78	58	69	57	528
Per cent normal	96	88	85	78	87	88	84	86
Mean	4.55	4.35	4.34	4.69	4.59	4.22	4.25	

and near point (Tables XXI and XXII). These means give no evidence whatsoever of maturation. The means of *Betts'* group were 7.54 and 4.66 at far point and near point, respectively. *Swanson* and *Tiffin* found means of 7.46 at far point and 4.46 at near point. The means in all three investigations are very similar, and thus disclose no evidence of maturation.

Relationship of exophoria and esophoria to success in reading and arithmetic. Charts 20 and 24 seem to indicate that there is a rather close association between success in reading and exophoria as measured by the lateral imbalance test. In Table XXIII it will be noted that there are 92 chances in 100 at far point and 91 chances in 100 at near point that the good readers are more exophoric than the poor readers. Charts 22 and 26 show that low achievement in arithmetic is likely to be related to exophoric conditions, especially exophoria at far point. It may be concluded from these data that an exophoric condition as measured by these tests has no negative effect upon reading ability.

Charts 21 and 25 show that esophoria is quite definitely more closely associated with the poor reader than with the good reader. Referring again to Table XXIII we find that there are 98 chances in 100 at far point and 91 chances in 100 at near point that this

TABLE XXIII. *Measurement of the reliability of the difference in terms of SE difference*

Chart	Comparison made between	Diff.	SE diff.	CR	Chances in 100
	Upper and lower halves in reading				
20	Prim. far point exophoric	1	2.87	.35	64
20	Inter. far point exophoric	5	3.17	1.58	94
20	Total far point exophoric	3	2.11	1.42	92
21	Prim. far point esophoric	—7	3.07	2.28	98.8
21	Inter. far point esophoric	—2	4.33	.46	67
21	Total far point esophoric	—5	2.52	1.98	98
24	Prim. near point exophoric	3	3.05	.98	84
24	Inter. near point exophoric	2	3.29	.61	73
24	Total near point exophoric	3	2.26	1.33	91
25	Prim. near point esophoric	—1	2.88	.35	64
25	Inter. near point esophoric	—5	3.81	1.31	90
25	Total near point esophoric	—3	2.25	1.33	91
	Upper and lower halves in arithmetic				
22	Prim. far point exophoric	—4	2.77	1.44	93
22	Inter. far point exophoric	—1	3.17	.32	63
22	Total far point exophoric	—3	2.11	1.42	92
23	Prim. far point esophoric	—1	2.87	.35	64
23	Inter. far point esophoric	2	4.18	.48	68
23	Total far point esophoric	1	2.39	.42	65
26	Prim. near point exophoric	—1	3.04	.33	63
26	Inter. near point exophoric	2	3.31	.60	73
26	Total near point exophoric	0	2.19	.00	50
27	Prim. near point esophoric	1	2.87	.35	64
27	Inter. near point esophoric	5	3.89	1.29	90
27	Total near point esophoric	3	2.26	1.33	91

difference is a true one. It would seem, therefore, that the test for esophoria, especially at far point, would be extremely valuable in the selection and analysis of reading disability cases.

The relationship between esophoria and low achievement in reading is made even more striking when the esophoria charts for reading and the esophoria charts for arithmetic (charts 23 and 27) are compared. While the esophoric group in reading are located largely in the lower 50 per cent, the esophoric group in arithmetic seem to fall in the upper 50 per cent, especially when tested at near point. The inability of a test of a visual function to relate visual abnormality with low achievement in a subject such as arithmetic, while at the same time the function appears to be an important factor in the isolation of poor readers, seems to the writer to be highly significant. It bolsters the belief that reading, more than certain other subjects, is dependent upon normalcy in visual functions.

VII. Visual acuity. *Fuchs* (4) says that central or direct vision takes place when the eyes are focused in such a way as to cause the image of the object of regard to fall upon the fovea centralis. The latter, because of its peculiar anatomical structure, gives us the clearest and keenest vision of any part of the retina. It is with reference to central vision that tests for refraction and visual acuity are constructed.

It seems apparent that from a functional as well as from an anatomical viewpoint it is necessary to distinguish the central (macula lutea) from the peripheral (peri-macular) part of the retina. The macular area is very small but it is the most sensitive part of the retina. *Ramsey* (9) says that its size corresponds roughly to that of a thumb-nail held at arm's length. However, even the macula has a most sensitive part, the fovea centralis, a small depression about a millimeter or so wide and upon which the image is normally focused when the object of regard is very small, *e.g.*, small print. It may help the reader to think of the retina as divided into two parts, the peripheral portion for discovery and general orientation, and the macula for inspection.

The smaller the target which an eye can clearly see, or the greater the distance at which a given object can be held from the eye and still be distinguished clearly is a measure of vision of that eye. In other words, the true level of visual acuity depends upon the minimum visual angle which can exist with the eye still seeing clearly. For example, suppose that in a room of uniform luminosity the word 'dog' is placed at a distance from the eye so that it subtends an angle of eight degrees. If an eye can clearly distinguish the word we shall say it has an *X* level of visual acuity. Now if the word 'dog' is moved to a distance twice as far away, the visual angle is reduced by half and now subtends only four degrees. The retinal image is also reduced one-half. If the eye can still clearly see the word it has a 2X level of visual acuity. This analogy could of course be carried further. The smaller the angle which is subtended by the light rays which pass from the terminal points of the object of regard through the optical center of the eye, the smaller the retinal image, and the higher the level of acuity if the eye continues to distinguish the object of regard.

In many cases visual acuity may be good but due to refractive errors it may test low. For instance, the macular area of *S* may be highly sensitive but due to a myopic condition the retinal

TABLE XXIV. *Comparison of visual acuity means*

Investigator	Binocular	Left eye	Right eye
Betts (1st grade)	96	94	94
Wagner (Kdgn.–6th)	96 to 100	93 to 99	95 to 100
Swanson and Tiffin (unsel. group)	101	96	99

images formed are blurred. In such a case any test for visual acuity would result in an inaccurate report. The visual acuity measured would be only relative. To know absolute visual acuity it is necessary to test the eye when it is in the state of emmetropic refraction (image focused exactly and clearly on the retina). With cases who are normally emmetropic the absolute visual acuity will be as tested. For those who are hyperopic, myopic, or astigmatic it will be necessary to supply lens corrections which produce a condition of emmetropic refraction if the absolute visual acuity is to be accurately measured. It will be clear, therefore, that the data gathered for visual acuity in this investigation may not be true data in all cases. However, as all pupils who had corrections were measured with their corrections on, the results are likely to be fairly true.

Maturation trends. Table XXV shows that there is no regular increase or decrease in mean scores throughout the grades. When the means for the scores made on the visual acuity tests in *Betts'* (3), *Swanson* and *Tiffin's* (11), and the writer's studies are compared there seems to be little evidence for any maturation of visual acuity. In Table XXIV these means are compared. Although the means give no evidence of maturation, a study of chart 28 shows that a much higher percentage of the older children are above normal in visual acuity. That this difference is significant is substantiated by the CRs in Table XXX. These CRs are 2.82 for binocular, 1.48 for left eye, and 4.08 for right eye acuity above normal, and all favor the intermediate grade children. Chart 29 gives no indication that there is a maturation trend in visual acuity below normal.

It is important to determine possible maturation trends as far as pupils above and below normal are concerned. It is of equal

TABLE XXV. *Summary of visual acuity data*

Per	Kdgn.			1st			2nd			3rd	
cent	Bin.	Lt.	Rt.	Bin.	Lt.	Rt.	Bin.	Lt.	Rt.	Bin.	Lt.
110					2	1				4	6
105	2	2	2	8	3	6	6	2	5	9	10
100	34	23	30	97	73	82	50	38	45	54	37
90	14	22	16	10	33	22	3	14	5	9	17
80	1	4	3		3	1		3	2	2	2
70								1			2
60						1			1	1	2
50	1	1	1			1			1		1
40											
30											1
20					1			1			
0						1					1
Freq.	52			115			59			79	
Above norm	2	2	2	8	5	7	6	2	5	13	16
Below norm	2	5	4	0	4	4	0	5	4	3	9
Mean	96.1	93.4	95.0	99.4	96.2	96.6	100.	94.9	97.3	98.9	94.1
SD	8.37	8.94	8.83	3.16	9.06	11.7	2.83	11.9	9.33	7.00	9.59

Per	3rd		4th			5th			6th	
cent	Rt.	Bin.	Lt.	Rt.	Bin.	Lt.	Rt.	Bin.	Lt.	Rt.
110	2			1	5	1	5	1	1	
105	8	11	7	11	13	12	15	11	4	12
100	53	53	43	46	56	55	51	51	43	49
90	10	2	12	7	3	5	5	3	10	3
80	4	1	1	2	1	5	2		5	1
70	1				1	1		1	1	1
60	1		2				1		2	
50			1						1	
40										
30										
20										1
0			1							
Freq.		67			79			67		
Above norm	10	11	7	12	18	13	20	12	5	12
Below norm	6	1	5	2	2	6	3	1	9	3
Mean	97.6	100.	95.0	99.3	100.	98.6	99.9	100.	95.1	98.5
SD	8.06	3.74	15.4	5.20	5.57	6.78	6.85	4.90	11.1	11.0

importance, however, to ascertain whether the individuals who have deviated from the normal tend to remain on a plateau or tend to get better or worse as the case may be. An effort to determine the amount of spread from the normal was made by calculating SDs (Table XXV) for each distribution. As will be noted the size of the SD per grade is sporadic and not progressive in nature. The erratic and non-progressive nature of the obtained SDs probably can be explained by the variability in

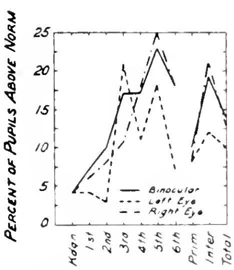

Chart 28 Percent of Binocular, Right-Eye and Left-Eye Acuity Above Normal

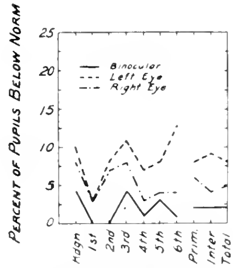

Chart 29 Percent of Binocular, Right-Eye and Left-Eye Acuity Below Normal

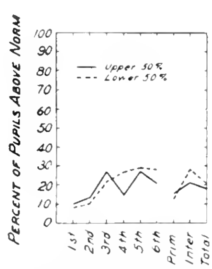

Chart 30. Percent of Upper and Lower Half Pupils in Reading Having Binocular, Left-Eye, or Right-Eye Acuity Above Normal

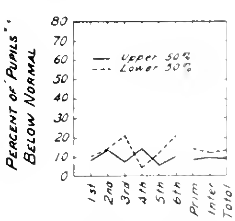

Chart 31. Percent of Upper and Lower Half Pupils in Reading Having Binocular, Left-Eye, or Right-Eye Acuity Below Normal

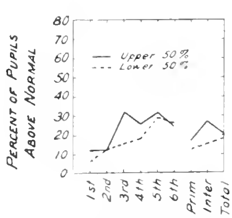

Chart 32 Percent of Upper and Lower Half Pupils in Arithmetic Having Binocular, Left-Eye, or Right-Eye Acuity Above Normal

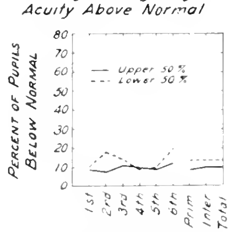

Chart 33 Percent of Upper and Lower Half Pupils in Arithmetic Having Binocular, Left-Eye, or Right-Eye Acuity Below Normal

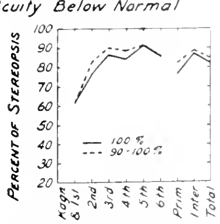

Chart 34 Percent of Pupils Having 100% or 90-100% Stereopsis at Far Point

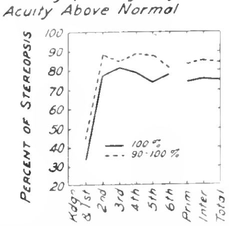

Chart 35 Percent of Pupils Having 100% or 90-100% Stereopsis at Near Point

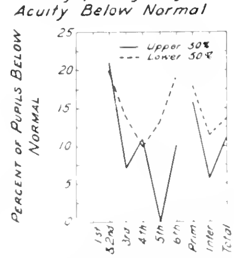

Chart 36 Percent of Upper and Lower Half Pupils in Reading Having Below Normal Stereopsis at Far Point

the skewness of the several distributions. The skewness of the distribution can easily be accounted for by chance; for instance, in the distribution of the binocular scores in the first grade it will be noted that no child has varied far from normal. However, a glance at the right eye scores for the same grade shows that three children were so far below normal that a highly skewed distribution is inevitable. A fortuitous circumstance which placed three children[2] with low right eye acuity in the first grade has resulted in an SD of 11.66 for the right eye distribution as compared with an SD of only 3.16 for the binocular distribution. There seems to be little evidence from the measures of variability described here that the degree of abnormality, either above or below normal, changes very much.

The only maturation trend which appears rather clearly in this study is the tendency of the older children to gain the small degree of added acuity necessary to place them slightly above the normal. As there were only approximately 225 children tested for visual acuity this gain can be accounted for by the likelihood that the refractive errors which militate against good acuity have been better taken care of in the intermediate grades than in the primary grades[3]. In other words, it seems probable to the writer that visual acuity is not a visual function which shows much maturation in elementary school children. A possible interpretation would be that the acuity of primary grade children could be improved if educators could convince parents of the necessity of having causal visual defects corrected by a competent eye-specialist.

The relationship of success in reading and arithmetic to visual acuity. A study of chart 30 and Table XXVI reveals the fact that visual acuity above normal is not associated with success in reading. In fact, there are 71 chances in 100 that it is more closely related to low achievement in reading. A possible explana-

[2] It is quite possible that these low degrees of visual acuity are due to errors of refraction. It is equally possible that within the next few years these children will be fitted with glasses. This would reduce the SD of this group markedly.

[3] 3.5 per cent of all the children tested in the primary grades and 7.5 per cent of the intermediate grade children wore glasses.

tion of this anomaly is that if either of the eyes has an acuity markedly higher than the other, an ineffective type of binocular co-ordination may result.

Chart 31 and Table XXVII reveal a positive relationship between low visual acuity and low achievement in reading. This relationship is somewhat more marked in the primary grades

TABLE XXVI. *Per cent of upper and lower half pupils in reading having binocular, left-eye, or right-eye acuity above normal (100 per cent)*

	Upper half			Lower half			
Grade	Freq.	No. above normal	Per cent above normal	Freq.	No. above normal	Per cent above normal	Per cent diff.
Prim.	134	22	16	122	15	12	4
Inter.	101	21	21	107	30	28	—7
Total	235	43	18	229	45	20	—2

TABLE XXVII. *Per cent of upper and lower half pupils in reading having binocular, left-eye, or right-eye acuity below 90 per cent*

	Upper half			Lower half			
Grade	Freq.	No. below 90 per cent	Per cent below 90 per cent	Freq.	No. below 90 per cent	Per cent below 90 per cent	Per cent diff.
Prim.	134	12	9	122	17	14	—5
Inter.	101	10	10	107	13	12	—2
Total	235	22	9	229	30	13	—4

TABLE XXVIII. *Per cent of upper and lower half pupils in arithmetic having binocular, left-eye, or right-eye above normal*

	Upper half			Lower half			
Grade	Freq.	No. above normal	Per cent above normal	Freq.	No. above normal	Per cent above normal	Per cent diff.
Prim.	128	22	17	128	14	11	6
Inter.	100	27	27	108	25	23	4
Total	228	49	21	236	39	17	4

where it is likely that the errors of refraction have not been cared for as adequately as in the intermediate grades. For the entire group tested, the chances are 92 in 100 that the lower half in reading are more likely than the upper half to have visual acuity below normal.

Chart 32 and Table XXVIII disclose a higher percentage of the upper half in arithmetic having visual acuity above normal.

Chart 33 and Table XXIX show that a higher percentage of the lower half have visual acuity below normal. These data reveal very little difference in response to the visual acuity tests between the comparable groups in reading and arithmetic. There is a trend, however, which indicates that low acuity scores may characterize the lower half pupils in both reading and arithmetic. Possibly a relatively low acuity in one eye may be a disturbing factor resulting in failure to achieve a normal level of binocular co-ordination.

TABLE XXIX. *Per cent of upper and lower half pupils in arithmetic having binocular, left-eye, or right-eye acuity below 90 per cent*

	Upper half			Lower half			
Grade	Freq.	No. below 90 per cent	Per cent below 90 per cent	Freq.	No. below 90 per cent	Per cent below 90 per cent	Per cent diff.
Prim.	128	12	9	128	17	13	—4
Inter.	100	10	10	108	14	13	—3
Total	228	22	10	236	31	13	—3

TABLE XXX. *Measurement of the reliability of the difference in terms of SE difference*

Table	Comparison made between intermediate versus primary	Diff.	SE diff.	CR	Chances in 100
25	Binocular above normal	9	3.19	2.82	99.7
25	Left eye above normal	4	2.71	1.48	93
25	Right eye above normal	13	3.19	4.08	99.9+
25	Binocular below normal	0	1.25	0	50
25	Left eye below normal	1	2.50	.40	65
25	Right eye below normal	—2	1.91	1.05	85
	Upper and lower halves in reading bin., left, or right-eye acuity				
26	Prim. above normal	4	4.32	.93	83
26	Inter. above normal	—7	5.94	1.18	88
26	Total above normal	—2	3.64	.55	71
27	Prim. below normal	—5	4.00	1.25	89
27	Inter. below normal	—2	4.33	.46	67
27	Total below normal	—4	2.90	1.38	92
	Upper and lower halves in arithmetic bin., left, or right-eye acuity				
28	Prim. above normal	6	4.32	1.39	92
28	Inter. above normal	4	6.01	.67	75
28	Total above normal	4	3.64	1.10	86
29	Prim. below normal	—4	3.90	1.03	85
29	Inter. below normal	—3	4.41	.68	75
29	Total below normal	—3	2.96	1.01	84

VIII. Stereopsis. Stereoscopic vision is vision which produces an image of three dimensions. Stereopsis tests not only measure the ability of the eyes to produce binocular single vision but they also measure the ability of the eyes to achieve depth perception. Thus these tests go beyond the tests of ordinary fusion in measuring successful eye-coördination. The *Betts* stereopsis tests measure only approximately 50 per cent of the stereopsis possible. Thus 100 per cent on this test represents only a percentage score relative to the tests in question and not 100 per cent of the depth perception possible. A score of 90 or 100 per cent was considered normal stereopsis for this test.

TABLE XXXI. *Summary of the data for stereopsis at far point*

Grade	Freq.	100	90	80	70	60	50	40	30	20	10	0	Per cent of 100 per cent ster.	Per cent of 90–100 per cent ster
Prim.	102	80	4	3	4	5	3	2	0	1	0	0	77	82
Inter.	89	78	1	1	4	4	0	0	0	0	0	1	87	89
Total	191	158	5	4	8	9	3	2	0	1	0	1	83	85

TABLE XXXII. *Summary of the data for stereopsis at near point*

Grade	Freq.	100	90	80	70	60	50	40	30	20	10	0	Per cent of 100 per cent ster.	Per cent of 90–100 per cent ster.
Prim.	98	73	8	4	3	3	2	2	3	0	0	0	74	83
Inter.	89	68	8	4	1	0	1	1	2	1	0	3	76	85
Total	187	141	16	8	4	3	3	3	5	1	0	3	75	84

Maturation trends. There appears to be a rather definite relationship between stereoscopic vision and age when measured at far point. Table XXXVIII indicates that there are 92 chances in 100 that the intermediate grade children have a higher degree of stereopsis than the primary children. At near point, however, depth perception is not markedly at a high level in the older children. Here the chances that they are superior are only 64 in 100. Charts 34 and 35 and Tables XXXI and XXXII should be studied for further evidence relative to the maturation trends in stereopsis.

Evidence from the *Betts* study (3) and from the *Swanson* and *Tiffin* study (11) substantiate the evidences of maturation found in this investigation. On the stereopsis test for far point 63 per cent of the *Betts* first-grade entrants showed a 100 per cent score. Comparable results were found for the first-grade children of this investigation.

In the unselected group of college freshmen studied by *Swanson* and *Tiffin*, when *Ss* were permitted to wear their glasses, 100 per cent stereopsis was found in 87 per cent of the cases. This increase in stereoscopic vision from first grade to

TABLE XXXIII. *Per cent of Ss having 100 per cent stereopsis at far point*

Investigator	First grade	Primary	Intermediate	College
Betts	63			
Wagner	62	77	87	
Swanson and Tiffin				87

TABLE XXXIV. *Per cent of upper and lower half pupils in reading having below normal stereopsis at far point*

	Upper half			Lower half		
Grade	Freq.	No. abnormal	Per cent abnormal	Freq.	No. abnormal	Per cent abnormal
Prim.	43	7	16	44	8	18
Inter.	48	3	6	42	6	14
Total	91	10	11	86	14	16

college age is directly in line with the positive maturation found in this investigation (Table XXXIII).

It is difficult to account for these positive maturation trends in depth perception when the ordinary fusion trends were found to be decidedly negative. Success on both tests depends upon a high level of binocular co-ordination. It may be that the high degree of hyperopia characteristic of younger children does not affect success in ordinary fusion but militates against success in stereoscopic vision.

The relationship of success in reading and arithmetic to stereopsis. Although stereopsis is not necessary for reading on a flat surface, it would seem that the degree of binocular co-ordination needed to pass these tests would be a corollary of rapid reading habits. It is well known that rapid reading is highly correlated with comprehension.

The results of the stereopsis tests bear out the above assumption to a slight degree. There are 83 chances in 100 that the lower half readers at far point are more likely to be below normal in stereoscopic vision than the upper half. At near point the chances are 65 in 100 and in the same direction. Chart 36 and Tables XXXIV and XXXV present additional data relative to this trend.

Tables XXXVI and XXXVII give further evidence supporting the contention that normal visual functioning is more closely associated with achievement in reading than with achievement in

TABLE XXXV. *Per cent of upper and lower half pupils in reading having below normal stereopsis at near point*

Grade	Upper half			Lower half		
	Freq.	No. abnormal	Per cent abnormal	Freq.	No. abnormal	Per cent abnormal
Prim.	43	6	14	44	7	16
Inter.	47	6	13	43	6	14
Total	90	12	13	87	13	15

TABLE XXXVI. *Per cent of upper and lower half pupils in arithmetic having below normal stereopsis at far point*

Grade	Upper half			Lower half		
	Freq.	No. abnormal	Per cent abnormal	Freq.	No. abnormal	Per cent abnormal
Prim.	46	7	15	41	8	20
Inter.	44	4	9	46	5	11
Total	90	11	12	87	13	15

TABLE XXXVII. *Per cent of upper and lower half pupils in arithmetic having below normal stereopsis at near point*

Grade	Upper half			Lower half		
	Freq.	No. abnormal	Per cent abnormal	Freq.	No. abnormal	Per cent abnormal
Prim.	46	7	15	41	6	15
Inter.	44	7	16	46	5	11
Total	90	14	16	87	11	13

arithmetic. Although at far point there are 73 chances in 100 that the lower half in arithmetic are more likely to have poorer stereoscopic vision than the upper half, at near point the chances are 72 in 100 that the reverse is true. These data, although not of great statistical significance, tend to bear out the trends established by the other tests, namely, that success in reading is peculiarly associated with normal visual functioning.

IX. General summary and conclusions. This study has established norms and indicated maturation trends for five visual functions, namely, fusion, amplitude of fusion, lateral imbalance, visual acuity, and stereopsis. In addition, the relationship between these functions and success in reading and arithmetic was studied. These functions were measured by certain of the *Betts' Ready to Read Tests* which are constructed on stereoscopic cards and given with the aid of an ophthalmic telebinocular. The *Ss* were approximately 850 children in the public elementary

TABLE XXXVIII. *Measurement of the reliability of the difference in terms of SE difference*

Table	Comparison made between	Diff.	SE diff.	CR	Chances in 100
	Intermediate versus primary				
31	Far point normal (90–100%)	7	5.05	1.39	92
32	Near point normal (90–100%)	2	5.36	.37	64
	Upper and lower halves in reading				
33	Prim. far point below normal	—2	8.05	.25	60
33	Inter. far point below normal	—8	6.36	1.26	89
33	Total far point below normal	—5	5.14	.97	83
34	Prim. near point below normal	—2	7.65	.26	60
34	Inter. near point below normal	—1	7.22	.14	56
34	Total near point below normal	—2	5.22	.38	65
	Upper and lower halves in arithmetic				
35	Prim. far point below normal	—5	8.17	.61	73
35	Inter. far point below normal	—2	6.32	.32	63
35	Total far point below normal	—3	5.14	.58	72
36	Prim. near point below normal	0	7.67	.00	50
36	Inter. near point below normal	5	7.20	.69	76
36	Total near point below normal	3	5.29	.57	72

schools of Syracuse, New York. The tests were administered by 10 trained testers and the testing period lasted five days.

Maturation trends. This study corroborates the maturation trends disclosed by a comparison of *Betts'* study (3) at the first-grade level with a similar investigation by *Swanson* and *Tiffin* (11) at the college level. It indicated a fairly definite and, in a few cases, a statistically significant maturation with age.

In studying the interpretations of maturation which are made below, the reader should recognize that unless the CR is three or more, the difference measured between the two groups in question (primary and intermediate grades) is not a statistically significant difference. However, the CR is a convenient measure to use in presenting the trends on a quantitative basis. Consequently it is used here for that purpose and the reader should not interpret the descriptive terms such as 'a slight positive maturation,' *etc.,* to mean that the difference is absolute. In any case in which the CR is less than three, the trend might show a reversal in a subsequent investigation.

1. *Fusion at far point:* a statistically significant *negative* maturation with age (CR, 3.49).
2. *Fusion at near point:* a moderate indication of *negative* maturation with age (CR, 1.37).
3. *Fusion at far and near point for boys and girls:* both boys and girls show a decrease in fusion with age. The girls evidence a more marked *negative* maturation (CR, F. pt., 2.31) (CR, N. pt., .96).
4. *Amplitude of fusion at far point:* a slight positive maturation with age (CR, 1.11).
5. *Amplitude of fusion at near point:* a statistically significant positive maturation with age (CR, 3.19).
6. *Lateral imbalance at far and near points:* there is an increase in lateral imbalance throughout the primary grades. However, when the primary grades are compared with the intermediate grades, there appears to be no maturation with age.
7. *Visual acuity above normal:* a quite definite positive maturation with age especially with right eye and binocular acuity (CR, Bin., 2.82) (CR, L.E., 1.48) (CR, R.E., 4.08). This may be due to the corrective or refractive errors in many of the intermediate-grade children and not to a change in the absolute visual acuity.
8. *Visual acuity below normal:* a slight maturation is exhibited by the right eye (CR, Bin., .00) (CR, L.E., .40) (CR, R.E., 1.05).
9. *Stereopsis at far point:* a moderate maturation with age (CR, 1.39).
10. *Stereopsis at near point:* no maturation (CR, .37).

The relationship between success in reading and arithmetic to success in the visual functions tested. Although the prime object of the investigation was to determine norms and maturation trends, it was possible also to determine certain facts indicating, at least, the probable direction and approximate magnitude in the relationship between the visual functions measured and the success of pupils in reading and arithmetic. It was necessary to measure a large group of pupils for the main investigation, and it was not expedient so to measure these same pupils in reading and arithmetic that the extreme cases in achievement could be matched carefully on the basis of intelligence, home conditions, and the like. Consequently the investigator divided the pupils into upper and lower halves in achievement and analyzed the data for *trends*.

The relationships which were found to exist between the visual functions tested and success in reading and arithmetic must be interpreted only as probable and not as absolute trends. In certain of these comparisons, given below, the *upper* half in achievement is superior to the lower half in the visual function described.

In such cases, the CR corresponding to the difference is not underlined. In other instances, the *lower* half is superior to the upper half in achievement in the visual function measured. In all such cases, the CR corresponding to the difference is underscored. For example, the pupils in the *lower* half in the distribution of arithmetic achievement are *superior* to those in the *upper* half in fusion at near point (as indicated by the underscoring of the CR, .42), but are inferior to those in the upper half in fusion at far point (as indicated by the fact that the CR, .30, is not underscored). In all but one instance where there is a negative relationship indicated for either subject (as indicated by the underscored CR) the relationship of the visual function to the other subject is in the opposite direction, as is the case in numbers 2, 5, 8, and 11 of the following list:

	CR Read.	CR Arith.
1. *Fusion at far point:* a slight relationship with success in reading; practically no relationship with success in arithmetic.	.89	.30
2. *Fusion at near point:* a moderate relationship with success in reading; a slight negative relationship with success in arithmetic	1.71	.42
3. *Amplitude of fusion at far point:* a slight relationship with both reading and arithmetic.	.14	.41
4. *Amplitude of fusion at near point:* a slight relationship with both reading and arithmetic.	.16	.32
5. *Non-exophoric at far point:* a moderate negative relationship with success in reading; a moderate positive relationship with success in arithmetic.	1.42	1.42
6. *Non-exophoric at near point:* a moderate negative relationship with reading; practically no relationship with arithmetic.	1.33	.42
7. *Non-esophoric at far point:* a moderate relationship with success in reading; no relationship with success in arithmetic.	1.98	.00
8. *Non-esophoric at near point:* a moderate relationship with success in reading; a		

moderate negative relationship with success in arithmetic.	1.33	1.33
9. *Normal or above normal visual acuity:* a moderate relationship with success in reading; a slightly less moderate relationship with success in arithmetic.	1.38	1.01
10. *Normal stereopsis at far point:* a moderate relationship with success in reading; a slight relationship with success in arithmetic.	.97	.58
11. *Normal stereopsis at near point:* a slight relationship with success in reading; a slight negative relationship with success in arithmetic.	.38	.57

In interpreting the above data the reader should notice the following:

1. In no single case is the CR statistically significant.
2. In every case except exophoria, there are slight or moderate differences favoring the upper half in reading.
3. In all cases but four there are slight or moderate differences favoring the upper half in arithmetic.
4. The positive differences as a whole are greater in reading than in arithmetic.

The universality of differences in favor of the upper half in reading may be interpreted as pointing toward a positive relationship between normal visual functioning and success in reading. Only approximately 10 per cent of the population are likely to need especial attention with regard to reading (3). If it is this small percentage which has been instrumental in producing the differences found in the group tested, the results are even more significant.

The data show that certain of the tests are more highly related than others to achievement in reading and that, therefore, certain of these tests are more useful than others for the purpose of identifying good or poor readers. The three tests most reliable for this purpose are ranked below in the order of their discriminating power.

	Chances in 100 that there is a true diff. between good and poor readers in the function measured
First: test of *Esophoria* at far point	98
Second: test of *Fusion* at near point	96
Third: tests of *Visual Acuity*	92

In fairness to the entire series of tests it should be mentioned that the tests of ametropia (which test the refractive errors of hyperopia, myopia, and astigmatism) were not used in this investigation as they refer to structural anomalies and are not directly related to binocular co-ordination. That these are important tests in the diagnosis of reading disability cases is confirmed by the recent study by *Fendrick* (6), who ranked the visual acuity tests first and the ametropia tests second in value in the analysis of reading disability cases. Thus, ametropia, in addition to the three tests mentioned in the preceding paragraph, would seem to be of greatest value to the reading clinician.

The differences in visual functioning between good and poor readers are small, and in some cases, perhaps, due to chance. However, the fact that in almost every case the difference favors the good readers supports the general hypothesis that visual inefficiencies, as revealed by the *Betts* battery, are basically associated with poor reading at the age levels considered in this study.

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