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THE MOVEMENTS OF THE EYES IN READING

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It was thought, at one time that in reading the eyes move backwards and forwards smoothly and continuously, and perception of the words takes place during the movement. One is not conscious during reading of anything but a smooth and regular motion of the eyes. But in 1878, and the following years, Javal⁽¹⁶⁾ and others working with him observed the movements of a subject's eye while he was reading, and found that this was not the case. Movement takes place in a series of jerks, with a pause after each movement during which the eyes are relatively at rest. Only during the backward sweep of the eyes from the end of one line to the beginning of the next is movement smooth and regular. It was observed that the short jerky, or saccadic, forward movements are very rapid; and that the durations of the pauses during which the eyes are fixated upon the print are much greater. The number and duration of the pauses vary considerably for different subjects and different types of reading matter.

Erdmann and Dodge⁽⁷⁾ in 1898 and Huey⁽¹⁴⁾ in 1900 made a number of observations on eye movements and fixation pauses, and a more extensive research was made by Dearborn⁽⁴⁾ and published in 1906. At a later period C. T. Gray,⁽⁹⁾ W. A. Schmidt⁽²³⁾, and G. T. Buswell^(2, 3) made similar determinations. The results of these and of other observers are summarized in Tables I and III.

TABLE I.
NUMBER AND DURATION OF FIXATION PAUSES IN READING.

NAME OF OBSERVER AND CLASS OF SUBJECT.	Length of Line of Print in cms.	No. of Fixation Pauses per Line.		No. of Words read per Fixation.	Duration of Fixation Pauses in secs.	
		Range.	Mean.		Range.	Mean.
Javal (16) ...	9.0	—	5	(10 letters)	—	—
Landolt (19) ...	—	—	—	1.55	—	—
Erdmann and Dodge (7) ...	8.3	3 to 5	—	—	—	—
"	12.2	5 to 7	—	—	—	—
Huey (15) ...	2.1	—	—	3.0	—	0.185
"	5.0 to 6.0	3 to 4	3.6	3.6	—	—
"	9.8	2 to 7	4.5	1.9	—	—
Dearborn (4) ...	5.7	3 to 7	4.8	1.9 to 1.0	0.16 to 0.40	—
"	9.6	5 to 8.5	—	1.5 to 1.1	0.20 to 0.30	—
"	10.7	5 to 7.5	—	—	0.17 to 0.25	—
C. T. Gray (9) ...	(7 to 10 words)	—	6.9	—	0.174 to 0.364	0.226
"	—	—	10.0	—	—	0.284
Schmidt (23) ...	9.0	4.7 to 10.8	6.5	0.93 to 2.15	0.214 to 0.470	0.308
"	9.0	5.0 to 9.6	7.0	1.04 to 2.04	0.244 to 0.414	0.311
"	9.0	4.1 to 9.3	6.3	1.04 to 2.44	0.264 to 0.438	0.314
Buswell (3) ...	8.8	—	5.9	—	—	0.252
"	8.8	—	6.9	—	—	0.248
"	8.8	—	12.7	—	—	0.416
Judd and Buswell (18) ...	9.7	—	6.9	1.19	—	0.250
"	10.0	6.1 to 8.5	7.2	—	0.176 to 0.236	0.221
Terry (26) ...	9.3	—	6.1	1.7	—	0.215
Miles and Shen (20) ...	—	—	—	1.9 to 1.8	—	0.300

TABLE II.
READING OF DIFFERENT TYPES OF MATERIAL BY FOUR CHILDREN AGED ABOUT 16.

Type of material read.	Av. No. of Fixations.		Av. Duration of Fixations in secs.		Av. No. of regressive Movements.	
	Range of 4 subjects.	Mean.	Range of 4 subjects.	Mean.	Range of 4 subjects.	Mean.
	Fiction	6.1—8.5	7.2	0.176—0.236	0.221	0.2—3.0
Geography	7.3—11.2	8.7	0.208—0.252	0.237	0.7—3.2	1.6
Rhetoric	7.7—11.7	9.1	0.200—0.300	0.228	0.6—3.7	1.8
Easy Verse*	8.4—13.1	10.2	0.200—0.272	0.246	0.3—3.7	1.8
Blank Verse*	8.5—16.8	11.7	0.208—0.272	0.248	0.5—6.1	2.7
French Grammar	8.0—14.1	11.1	0.204—0.300	0.264	0.4—4.0	2.3
Algebra	8.1—14.4	11.1	0.212—0.264	0.246	0.6—4.5	2.3

*The length of the lines of the verse was less than that of the other material; but the values given have been corrected accordingly.

TABLE III.
RANGE AND DURATION OF INTER-FIXATION EYE MOVEMENTS IN READING.

Name of Observer.	Short forward movements.		Long return movements.	
	Angle of movement.	Duration in secs.	Angle of movement	Duration in secs.
	Dodge (5)	2° to 7°	Mean 0.023	12° to 14°
Huey (15)	3° to 4°	0.040 to 0.048	12° to 13°	0.051 to 0.058
Dearborn (4)	4° (approx.)	Mean 0.035	10° (approx.)	Mean 0.039
Schmidt (23)	—	0.010 to 0.030	—	0.030 to 0.050

Fixation pauses

It will be seen that the number and duration of the fixation pauses are variable; and the variation has been found to depend upon a number of different factors, objective and subjective. Chief among the former is the nature of the material read. In Table II are given the average number and duration of the fixation pauses in reading different types of material by four children, aged about sixteen years, as determined by Judd and Buswell⁽¹⁸⁾. It will be seen that the variation is very considerable. Familiarity with a given text also tends to decrease the number and duration of the pauses (see Table II).

The number of pauses is considerably affected by the length of the line of print. As far as can be judged from the figures given in Table I, the number of words read per fixation is greatest for a line of 5 to 6 cms. in length; on these grounds Huey⁽¹⁵⁾ considered this to be the optimum length of line. The distance of the print from the eye seems to have little or no effect upon the number of fixations, and a reduction in the size of the print only slightly increases it.

Some observers have considered that the duration of the pauses is inversely proportional to their number. That this is only occasionally the case has been shown by Buswell⁽³⁾. He found that with children there was a correlation of $+0.49 \pm 0.056$ between length and duration of pauses; that is to say, few and short pauses went together. But for adults the correlation was -0.08 ± 0.055 , showing that the length and duration were independent.

Dearborn⁽⁴⁾ and, later, Schmidt⁽²³⁾ made a careful research into the location of the fixation pauses in the line of print. Huey⁽¹⁴⁾ had shown that only 78 to 82 per cent. of the line of print is usually traversed by the eye; and that in general the indentation is greater to the right than to the left. Dearborn substantiated these findings. The indentation is greater for rapid than for slow readers; and it varies with the character of the end words of the line. The exact point of fixation is not of great importance; it may lie on any part of a word or on the space between two words. It is merely the point about which are grouped the letters and words which form the unit of perception, that is to say, the amount perceived during a single fixation. Schmidt concluded that there is a tendency to fixate the apperceptive unit centrally; but that this by no means invariably takes place. The number of words covered by a fixation varies greatly; it is large in the case of nouns, adjectives and verbs, and smaller for conjunctions and prepositional phrases, relative pronouns and auxiliary verbs. Familiarly associated words and well-known phrases are read at single fixation. This fact is in

agreement with the observations showing that the number and duration of the fixation pauses are much less for more familiar material; and that words the context of which is known are read more rapidly than when they are exposed singly and without context.

Dearborn considered that the duration of the pauses often varies regularly according to their position in the line of print. Readers have a tendency to form "short-lived motor habits" in regard to the duration of the fixations, after reading a particular piece of material for a short time. The first pause in each line is then, in general, the longest, followed by two or more very short ones, and a longer one towards the end of the line. This appears to indicate that the first pause involves a general survey of the line, or at least of its first part. These habits are, however, dependent upon the regularity of the print; they are not formed if the lines are of unequal length, or the margins irregular. Moreover, their formation is dependent upon the maturity of the reader and the ease and familiarity of the material read.

Both F. M. Hamilton⁽¹²⁾ and R. Dodge⁽⁶⁾ have drawn attention to the importance of marginal perception in reading. The right-hand marginal impressions serve as preliminary partial perceptions, and are essential for stimulation of the reflex eye movements (described below). They may vary from almost complete recognition to mere consciousness of "something there." There is an inverse correlation between the area of distinct vision and that of the marginal impression; but what is lost from a diminution of the breadth of clear perception is made up for by the preparatory and orientating effects of the marginal impressions. These effects may possibly be carried over a number of fixation pauses. Thus the marginal impressions gained in the first long fixation pause of the line may serve as stimuli not only for the immediately succeeding eye movements, but also for those following the next one or more fixation pauses, thus accounting for the extreme brevity of the latter. Dor⁽⁶⁾ (*v. Brit. Jl. of Ophthal.*, Vol. VII, p. 196, 1923) cites the case of a woman with hemiopic scotoma of the right eye, which impaired almost the whole of the visual field, and with amblyopia of the left eye. She was quite unable to read with either eye singly. But when both eyes were used the very vague perception in the peripheral field of the right eye was sufficient to give a marginal impression which enabled the left eye to read. C. T. Gray⁽¹⁰⁾ has also pointed out that it is extremely important that children beginning to read should learn to make use of their marginal impressions correctly, in order that the "leads" obtained from them may give rise to a correct final interpretation.

Inter-fixation and intra-fixation eye movements

It was found that the time occupied by the inter-fixation movements is very short compared with that occupied by the fixation pauses, *i.e.*, not much more than one-tenth as great; and that large-angled movements take not much longer to execute than small-angled movements (see Table III). The duration appears to be relatively constant for each individual. Probably the movements are not under voluntary control; they are dependent simply upon the speed of muscular reaction. This speed is approximately the same for eye muscles as for those of the hand, etc.; if it is slightly greater, this is due to the readiness of the muscles for stimulation, which in turn is set up by peripheral retinal stimulation. It was concluded that no perception takes place during movement; for the rate of movement is sufficiently great to cause fusion of stimuli, that is to say, a blurring of the print, should perception occur. Holt⁽¹³⁾ was able to demonstrate central anaesthesia during eye movements. Assimilation of the reading matter takes place during the movements and also during the latter part of each fixation pause (see Table III).

The backwards and forwards movements have been shown to be confined more or less to the horizontal plane; that is to say, the eyes rarely stray above or below the line of print. This direction of movement has apparently become habitual to the eyes. Thus Stratton⁽²⁵⁾ showed that if the eyes are made to follow out the lines of a simple diagram, they move much more directly in the horizontal plane than in any other, with fewer corrective glides and angular changes of direction.

Very slight movements of the eyes also occur during fixation. The eye is never completely at rest, but fluctuates about a central position, moving through an angle of the order of 1'. This may be due to the fact that a number of nearly related points on the retina will give objectively the same stimulation to the brain (Dodge⁽⁵⁾). In addition, movements of convergence and divergence take place during reading. Divergence occurs during the inter-fixation movements, the eyes moving gradually downwards and outwards. During the fixation pauses convergent adjustment takes place (W. A. Smith⁽²⁴⁾). The two eyes are not exactly co-ordinated either in the saccadic movements or the convergent and divergent movements. Schmidt found that with immature readers, whose convergent and divergent movements had not been perfected, a rapid movement of both eyes took place at the beginning of each fixation pause in a direction opposite to the normal direction of movement.

There is no doubt that the eye muscles are subject to fatigue as the result of prolonged reading. Landolt⁽¹⁹⁾ found that small

angle eye movements are particularly fatiguing. Hence children tend to bring their books close to their eyes in order to increase the angle of movement; but the work of the accommodative muscles is thereby increased, resulting in a tendency to myopia. Dearborn found that unusually large-angled movements were also fatiguing; or rather, the fatigue incident on prolonged reading was particularly manifest in such movements, for in the course of a number of such movements the angle velocity decreased rapidly. The conclusion is that lines of print of moderate length, not more than 8.5 cms., are the least fatiguing to the eyes; the forward movements are not too short, nor the return movements too long.

Regressions and re-fixations

The earlier observers noted that in reading the eyes did not always move straight forwards along the line of print, but that frequently movements of regression occurred, and words were re-fixated. Dearborn found that these regressions were unusually numerous when the subject was beginning to read a passage, before he had time to establish any "short-lived motor habits." They also occurred when the print was irregularly arranged; and they were less noticeable with rapid than with slow readers. Moreover he noticed that with certain readers all such movements were merged in a semi-nystagmoid drift, during which the eyes moved at a rate much slower than normal, and perception took place. This phenomenon he considered to be related to the nature of the processes of assimilation of the meaning.

Schmidt observed that with children regressions are very frequent; he considered that the chief difference between mature and immature reading lies in the larger number of re-fixations shown in the latter. Buswell⁽⁹⁾ found that the average number of regressions in the reading of a line of print 8.8 cms. in length was 3.1 for children under 9 years of age; 1.2 for children over 9; and 0.5 for adults; that is to say, the decrease is continuous, and the number does not reach its minimum until the age of 18 years or over. C. T. Gray⁽⁹⁾ found that the length of the regressive movements also decreased with experience in reading. Later, Judd and Buswell⁽¹⁸⁾ demonstrated that the most regular type of reading is shown by the mature reader when he is attending to the context rather than to the analysis of the material into its elements, as in the study of style, vocabulary, grammar, etc. In the process of analysis the reader returns to his immature habits. There are long pauses and many regressive movements; and in extreme cases, as was shown in the reading of Latin⁽¹⁸⁾, the eyes may wander aimlessly backwards and forwards over the print, while the reader tries to assimilate the meanings of the

individual words. This strikingly different method of procedure is probably similar to the one noticed by Dearborn. C. T. Gray⁽¹⁰⁾ considered that a regular "rhythm" was far more important for rapid and accurate reading than the actual number and duration of the fixation pauses.

Buswell⁽²⁾ also noted another type of regressive movement among mature readers; when too long a forward movement has been attempted, and the eye has overshot the mark, it is obliged to re-fixate the words which have been missed.

Individual differences in eye movements and reading

It was noted above that the number and duration of the fixation pauses, and hence also the rate of reading (since they are highly correlated), are dependent upon many subjective factors. As would be expected, age has a large influence; this can be seen from the figures given in Table I. The decrease in the average number and duration of the pauses is very rapid up to the age of nine or ten years; after that it is much slower, and the average duration becomes practically constant about the age of eleven. The most efficient readers have been found to have very few, though sometimes rather long, pauses. The effect of age on the number of regressions was described above.

The differences between the eye movements and fixations of different individuals are very remarkable. Some adults appear more or less to retain their immature reading habits. Thus Schmidt found that in reading a 9 cm. line of print, the perception time, which is the product of the average number and duration of the fixations per line, varied from 1.14 to 3.68 seconds for adults; that is to say, it was three times as long for some individuals as for others. The perception time is dependent, apart from the regressive movements, chiefly upon the perceptual span, or span of recognition as it is called by some writers to distinguish it from the perceptual span for short exposure experiments; it is measured by the number of words read per fixation. It is in all probability a function of central rather than of peripheral processes. Ruediger⁽²²⁾ showed that there is no correlation between the number of pauses and rate of reading on the one hand, and the extent of the visual field, visual acuity, and retinal sensitivity on the other. Judd, McAllister, and Steele had previously come to the same conclusion⁽¹⁷⁾; and C. T. Gray⁽⁹⁾ found that though reading rate and perceptual span are highly correlated, neither correlates with visual span. The perceptual span is thus in all probability dependent upon the rate of central assimilation of the meaning of the material read. Ruediger also considered that Dearborn's motor habits were probably a function of the ease and rapidity of reading, *i.e.*, of

central assimilation, rather than *vice versa*. This is borne out by the results of Judd and Buswell⁽¹⁸⁾, who found that the individual differences in reading the various types of material listed in Table II were very considerable. That is, some individuals were able to assimilate more readily certain types of material, while some showed superiority with others, according to their individual interests in the subject matter.

It is probably true that some differences in ease and rapidity of reading are due to training. Those who are encouraged to concentrate upon rapid and efficient assimilation and comprehension of the meaning of the material, are, according to Freeman⁽⁸⁾, likely to be better readers than those whose attention has chiefly been directed to the mere mechanics of reading. In general, efficient assimilation will engender rapid and regular fixations. On the other hand the work of C. T. Gray⁽⁹⁾ and J. A. O'Brien⁽²¹⁾ seems to show that children's rate of reading can be increased, without loss of comprehension, by speeding up the mechanical processes. They instituted speed drills in which the children were encouraged to read straight forwards without allowing their eyes to regress; and the perceptual span and rate of reading were increased to a greater extent than is normal among children learning to read.

W. S. Gray⁽¹¹⁾ has described a case in which disability in reading was very largely due to faulty eye movements. The subject, a boy of about ten years, was of good intelligence, and not in any way "word blind"; but his rate of reading was very poor, he was unable to recognize many simple words at sight, and could not understand their meaning when they were grouped in thought units. Photographic records of his eye movements showed:

(1) At least one fixation on every word in the line, and, whenever a word of any difficulty was encountered, a period of confusion involving several long fixations.

(2) Very irregular wandering forward movements, with many regressions while the subject tried to pick out familiar words.

(3) Irregular return sweeps, the eye moving gradually back over the line and not going straight back to the beginning.

The subject was given remedial training. He was required to read material in which the lines of print, and at first the words, but later the thought units, were widely separated from one another; this was in order to prevent confusion between the different lines, words and thought units. He was instructed to direct his eyes straight forwards and backwards along the lines. By means of these and similar methods his reading ability was greatly increased.

Anderson and Merton⁽⁴⁾, also doing remedial work in reading, recommended that readers with very narrow recognition spans should be given "phrase drills," that is to say, short exposures of single phrases, to teach them to take in phrases at a single glance; and that new words should be presented as parts of sentences, in order to teach interpretation by means of the context.

The important part played by the movements of the eyes has thus been outlined by summarizing the results of the work of numerous observers on the subject. These movements, though differing for different individuals, show a number of general similarities, particularly for the best readers, whose movements are regular and fixations few and short. It is probable that the nature of the movements is dependent to a considerable extent upon the central processes connected with the assimilation of the meaning and comprehension of the material read. But the movements can nevertheless be regulated both by direct training in the physiological processes, and also by means of the printing and general lay-out of the material read.

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