EYE MOVEMENT DURATION, PAUSE DURATION, AND READING TIME

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The time taken for fixational pauses plus that for eye movements yields the total reading time of any selection. Erdmann and Dodge (1) first called attention to the fact that a very large proportion of the total reading time is devoted to fixational pauses. They also found that if a printed line passed by a window at the speed of 1 cm. in .01 sec., which is about the speed of saccadic eye movements employed in reading, one did not perceive the material well enough to read it. This led them to the conclusion that perception in reading occurs only during the fixational pauses; we do not pay attention to the visual sensations produced during the accompanying eye movements. In later studies with an improved technique, Dodge (2, 3) showed that there is no clear vision during saccadic [1] eye movements. He also pointed out that the unclear visual sensations received during eye movements in reading are not attended to and therefore are not perceived. Inasmuch as time of perception is fixational pause time the latter has received most of the attention in many investigations of reading. The purpose of this study [2] is twofold: (1) to furnish new data on the extent and duration of eye movements in reading; (2) to show the variation in the ratio between eye movement duration and total reading time in various kinds of material. Some of the reasons for this variation will be stressed.

The first determination of velocity of saccadic eye movements was made by Volkmann (11) in 1846. His results, as

[1] The rapid, sweeping movements of the eye occurring in moving from one fixation to another in the visual field are called saccadic because of their nature. They are best illustrated in reading. Comparatively long fixations alternate with the moves.

[2] The data for this study were collected at Stanford University in the spring of 1927.

corrected by Erdmann and Dodge (1) showed that movement through a visual angle of 10° took 16.66σ. Lamansky (7), under the direction of Helmholtz, devised an after-image method of determining the speed for eye movements and found the following velocities:

10σ for 6° 16σ for 16° 22σ for 32°

With an improved Lamansky method Erdmann and Dodge's investigation showed the velocity of saccadic movements to be:

15σ for 5°	30σ for 15°
16–20σ for 10°	50σ for 30°

Later, with a photographic technique which is much more accurate than the after-image method, the determinations of Dodge and Cline (4) gave the following results:

28.8σ for 5°	54.8σ for 20°
38.8σ for 10°	80.4σ for 30°
48.2σ for 15°	99.9σ for 40°

"From the velocities of longer horizontal movements, according to Dodge and Cline, and with the assumption that the time approaches zero as the magnitude of movement approaches zero, interpolation by Lagrange's Theorem yields the following estimates for movements of less than 5 degrees (9):"

9.9σ for 1°	22.2σ for 3°
17.3σ for 2°	26.0σ for 4°

It will be shown later that these approximate speeds for saccadic eye movements through small visual angles seem to give a valid measure of velocity when applied to eye movements in reading. In all the above determinations the velocities were determined from eye movements in which the eye looked back and forth between two fixation points in response to peripheral stimuli. Dodge and Cline point out that such movements are not materially different, qualitatively or quantitatively from the eye movements used in reading.

TABLE I

SUMMARY OF READING MOVEMENTS AS DETERMINED BY PREVIOUS INVESTIGATORS

Investigator	Line		Moves to Right		Moves to Left	
	Length in mm.	Visual Angle	Visual Angle	Time in σ	Visual Angle	Time in σ
Erd. & Dodge	.....	.....	4° 13′	20.0	.....	.....
Huey	98	15° 14′	3° 36′	43.9	12° 12′	57.9
Dodge & Cline	87	16°	2°–7°	22.9	12°–14°	40.7
Shen: Vert.	155.5	20°	1° 15′	10–15	? –20°	54.0
Shen: Horiz.	155.5	20°	1° 2′	10–15	? –20°	54.0

Table I gives a summary of reading movements as determined by previous investigators. An examination of these results shows that the figures given by Huey (5) are the only ones which differ materially from those obtained in other studies when the extent of the eye movements are considered. Huey's results seem, therefore, unreliable. The extra work of moving the recording pointer which was attached to the eyeball gave abnormal durations for movements through small angles and seems to have increased materially the duration of the return sweeps (moves to the left from the end of one line to the beginning of the next). For moves to the right the results of Erdmann and Dodge (1) and Dodge and Cline (4) are in close agreement with durations of 20.0σ and 22.9σ respectively. For shorter movements Shen (9) found durations of 10σ to 15σ in both vertical and horizontal reading (of Chinese). Moves to the left of 12° to 14° took 40.7σ in Dodge and Cline's investigation and for movements of nearly 20° Shen found an average duration of 54.0σ. All these studies show that moves to the left are much longer in duration (two to three times) than movements to the right.

Table II gives the relation of eye movement duration to reading time for various kinds of material. Computations were made from the data of Erdmann and Dodge. They used one eye movement for each pause and assigned the same duration (20σ) to each movement. In reading each line of a selection the number of moves to the right is one less than

the number of pauses. In addition there is the long movement to the left [8] which is the return sweep. This is true for all lines except the first where no return sweep occurs.

TABLE II

RELATION OF EYE MOVEMENT DURATION TO READING TIME AS COMPUTED FROM ERDMANN AND DODGE'S DATA

Kind of Material	Av. No. Pauses Per Line	Av. Angular Displacement	Total Duration of Pauses in Sec.	Total Duration of Moves in Sec.	Part of R. Time Taken by Movements	Revised: Part of R. Time Taken by Movements
Familiar.....	4.45	4° 56′	1.70	.090	1/20.0 (5%)	1/16.5 (6.1%)
Unfamiliar.....	5.27	4° 11′	1.93	.105	1/18.5 (5.4%)	1/16.3 (6.1%)
Proof Reading.....	15.00	1° 50′	3.77	.300	1/13.8 (7.2%)	1/12.4 (8.1%)
Native Language...	4.74	4° 35′	1.58	.095	1/17.8 (5.6%)	1/14.8 (6.7%)
Foreign Language..	5.04	4° 31′	2.18	.101	1/22.6 (4.4%)	1/18.8 (5.3%)
Average *.....	5.78	4° 13′	2.01	.116	1/18.3 (5.5%)	1/15.7 (6.4%)

* The Average is from the original data given by Erdmann and Dodge; not from the other items in this table.

As shown above the long movements to the left are two to three times longer in duration than those to the right. This should always be considered in computing the ratio of movement duration to total reading time, or the ratio of movement duration to pause duration (perception time). In the next to the last column of Table II is given the ratio of eye movement duration to total reading time, *i.e.*, proportion of the total reading time taken by the eye movements. Each movement duration is assigned the same value of 20σ as in Erdmann and Dodge's original data. In the last column of the table the results given in the previous column are revised by using the return sweep or movement to the left as one of the movements in each line. As Dodge and Cline found that moves to the left averaged 40.7σ in duration we have employed

[8] Regressions made during the reading of a line are, of course, moves to the left but they approximate in extent and duration the moves to the right rather than the return sweep.

this value as an approximation of the return sweep duration for Erdmann and Dodge's subjects.[4] We shall confine our discussion largely to the revised results as they undoubtedly represent a closer approximation to the truth. Values for the proportion of reading time taken by eye movements ranged from about 1/12 to about 1/26,[5] when all movements are given the same duration (20σ), and from about 1/11 to about 1/22 [5] in the revised figures. Inspection of the revised results indicates that this proportion is approximately the same in the reading of familiar and unfamiliar material, namely 6.1 per cent. If we compare proof-reading, reading one's native language, and reading a foreign language we find that the proportions are respectively 8.1, 6.7, and 5.3 per cent. Judd and Buswell (**6**) have shown that performance varies widely with changes in attitude which arise in reading different types of material. An analysis of reading proof, a native language, and a foreign language will demonstrate that the mental processes involved in proof-reading seem to be the least complex and those involved in foreign language most complex of the three. This suggests that as the mental processes during reading become more complex the ratio between eye movement duration and total reading time becomes less.

TABLE III

THE PROPORTION OF READING TIME TAKEN BY EYE MOVEMENTS. A SUMMARY OF PREVIOUS INVESTIGATIONS

Investigator	All Movements Equal	Return Sweep Included
Erdmann and Dodge	1/18.3 (5.5%)	1/15.7 (6.4%)
Shen: Horizontal	1/30 to 1/20 (3.3 to 5%)	1/24.7 to 1/17.8 (4 to 5.6%)
Shen: Vertical	1/29 to 1/20 (3.4 to 5%)	1/24.5 to 1/18.3 (4.1 to 5.5%)

Table III summarizes the results of Erdmann and Dodge and of Shen concerning the proportion of reading time taken by eye movements. Averages from the original data in which all movements were considered of equal duration, and revised results in which the return sweep is included, are given. For the revised results Erdmann and Dodge's find-

[4] Professor Dodge was one of the subjects in both experiments.

[5] Not shown in table.

ings show a proportion of 1/15.7 or 6.4 per cent. Shen's determinations give about the same proportions for horizontal and for vertical reading; about 1/24.5 to about 1/18 or about 4 to 5.5 per cent in each.

Apparatus and Method

A photographic technique was employed to record eye movements made during the reading of various kinds of material. This consisted of a modified form of the Dodge apparatus for photographing eye movements. This apparatus has been fully described by Tinker (10) and by Miles and Shen (8). A pencil of light from a point source, a carbon arc, was reflected into the subject's right eye by means of a system of first surface mirrors. This beam of light was interrupted at regular intervals of 1/50 sec. by a perforated revolving disk run by a synchronous motor which was controlled by a tuning fork. The beam of light was reflected from the surface of the cornea through a lens into a long enlarging camera. At the back of the camera it came to a focus on a kinetoscopic film which moved continuously and at a uniform rate. The direction of the beam of light reflected from the cornea changed with each movement of the reader's eye. As the subject read a selection each fixation was recorded on the film as a sharply focused line. These lines appeared as a series of dots rather than solid lines owing to the beam of light being interrupted at regular intervals. Each dot represented 1/50 sec. Inspection of the films gave (1) the number of fixations employed in the reading and (2) the duration of each fixation. Interfixational eye movements were represented by the perpendicular distances between the records of successive fixational pauses.

Four kinds of material were read. The first consisted of a paragraph of easy scientific prose 13 lines long. In the second kind of material were four paragraphs of elementary chemistry. Each paragraph was about 12 lines in length and contained formulæ. The paragraphs were read separately. The third type of material contained two paragraphs of algebra which were also read separately. One paragraph

was the statement and solution of an easy problem and the other was descriptive material. Both contained some formulæ and were 8 and 9 lines in length respectively. The last kind of material read consisted of four lines of algebraic formulæ of four degrees of complexity. These were divided into two reading selections of two lines each.

After preliminary practice-trials intended to accustom the subjects to read before the camera and to make clear the task, the high school students read the chemistry and the university students read scientific prose, algebra, and lines of formulæ. Comprehension questions were given after each reading.

Two groups of subjects were used, one composed of 10 students from the junior and senior classes of a high school, and the other made up of 16 university students. All but one subject had emmetropic vision. This high school student was near-sighted and tested only 20–30 on the Snellen chart for visual acuity. However, she had been advised by an oculist not to use glasses in reading.

The perpendicular distance between each successive fixational pause made in reading the different materials was measured on the photographic records by a scale graduated in 1/100 inch and used under a magnifying glass. The visual angle which corresponded to 1/100 inch on the photographic records was then computed for each individual. It was obtained from the visual angle covered by the eye in sweeping from one end of the line of copy to the other. This value was employed to change the linear distances of the eye movements to visual angles.

Discussion of Results

The extent and duration of reading movements in the various kinds of material are given in Table IV. The length of movements to the right varied with the material read. For prose these movements covered about 2° of visual angle. This value is smaller than those obtained by Huey (5) and Dodge and Cline (4) which were 3° 36′ and 2° to 7° respectively. However, our average is larger than those of Shen (9) which were about 1° in both horizontal and vertical

reading of Chinese. The small values of Shen are without doubt functions of the type of material read.[6]

Investigations have shown that in reading lines about 90 mm. long, the average reader makes 6 to 7 fixational pauses. This means that each of their eye movements to the right cover from 2° to 3°. Only exceptionally fast readers will have moves which, on the average, cover 4° or more of visual angle.

TABLE IV

EXTENT AND DURATION OF READING MOVEMENTS IN DIFFERENT KINDS OF MATERIAL

Material Read	Line		Moves to Right		Moves to Left	
	Length in mm.	Visual Angle	Visual Angle	Approx. Time	Visual Angle	Approx. Time
Prose	93	16°	2° 3′	17σ	13° 24′	48σ
Algebra	93	16°	1° 43′	17σ	14° 12′	48σ
Chemistry	93	16°	1° 29′	17σ	14° 12′	48σ
Formulæ	93	16°	1° 4′	10σ	15° 48′	48σ

Our table indicates that moves to the right in reading chemistry were approximately 1.5° and in algebra, 1.75°. These shorter movements were undoubtedly functions of the reading attitude. Both the chemistry and the algebra involved formulæ. The reading of these selections was more analytical than that of prose as shown in the great increase in the number of fixations and regressions per line. The number of fixations in chemistry and algebra was about 50 per cent greater than in reading prose; the number of regressions was from 100 to 300 per cent greater. In reading lines of formulæ the length of eye movements to the right was approximately 1°. This is congruent with a very analytical type of reading as shown by the comparatively large number of fixations and regressions per line.

[6] Chinese contains a comparatively large number of words per line and each word is in the form of a small square. This allows a compact arrangement of the words in continuous discourse. Miles and Shen (8) found that while there were more and shorter pauses per line in reading Chinese than in reading English, more words were read per pause in the Chinese.

The moves to the left show an average of about 13° for prose, 14° for chemistry and algebra, and 16° for lines of formulæ (column 6, Table IV). The lengths of these return sweeps in reading prose, algebra and chemistry agree closely with the results of Huey (5) and Dodge and Cline (4) whose subjects read lines of similar length. Their findings showed movements of 12° 12′ and 12° to 14° respectively.

The maximum and minimum reading movements to the right in the various materials are as follows:[7] For prose, 7° 6′ and 15′; for chemistry, 7° 36′ and 14′; for algebra, 8° 28′ and 17′; for formulæ, 8° 23′ and 13′. These figures indicate quite clearly that the maximum movements in reading the various materials were approximately the same. This was also true of minimum movements. As shown by the averages cited above the great majority of eye movements in reading these selections was less than 3° in extent.

The durations of movements to the right are given in the fifth column of the table. For prose, algebra and chemistry the averages were the same (approximately 17σ) but for formulæ the average was 10σ. The value for formulæ is about the same as that found by Shen in reading Chinese (see Table I). For prose the duration of moves was a little less than that of Erdmann and Dodge (20σ) or Dodge and Cline (22.9σ). The length of their moves was greater than ours. Our movements to the left took about 48σ in each kind of reading. The approximate durations given in Table IV were taken from the values given above for saccadic eye movements of different lengths. As already noted such movements are not materially different qualitatively or quantitatively from reading movements. The approximations in Table IV are probably close to the true values. Actual measurement of the records of 50 return sweeps selected at random gave an average duration of 45.4σ which is very close to the approximate value of 48σ.

Table V compares eye movement duration with total reading time. Reading time is total movement duration plus total pause duration. The second column of the table

[7] Not shown in the table.

shows that prose had the fewest number of pauses per line, chemistry and algebra had about the same which was approximately 50 per cent greater than for prose: formulæ had the most which was over 300 per cent greater than for the prose. As indicated in the next column the average duration of the pauses show the same trend as pause frequency. The last column of the table gives the proportion of reading time taken by eye movement duration. For prose 1/13.2, or 7.6 per cent of the time was consumed by eye movements. Erdmann and Dodge's average (revised data) gave a ratio of 1/15.7 or 6.4 per cent. In reading algebra and chemistry the proportions are both approximately 1/15 which allots 6.5 per cent of the reading time to eye movements. Comparatively much less of the time was taken by moves in formulæ. The proportion was 1/36.1 which gives the movements only 2.8 per cent of the total time. These proportions emphasize the great difference between perception duration (pauses) and eye movement duration in reading. In all kinds of material the perception time consumed more than 90 per cent of the total reading time. For the various materials, the average proportion of the time taken by movements was 5.9 per cent.

TABLE V

EYE MOVEMENT DURATION VERSUS READING TIME. TIMES IN σ

Material and No. of Subjects	Av. No. Pauses Per Line	Av. Duration of Pauses	Av. Reading Time Per Line *	Movement Time Per Line	Part of R. Time Taken by Movement
Prose (16)	8.1	254	2,226	169	1/13.2 (7.6%)
Alg. (16)	12.5	272	3,744	244	1/15.3 (6.5%)
Chem. (10)	13.8	276	4,072	264	1/15.0 (6.6%)
Form. (15)	25.5	404	10,595	293	1/36.1 (2.8%)

* Reading time is the total time of pauses plus the total time of movements.

An analysis of the various reading selections used in this study indicates that prose was the easiest, most subjective type of reading. This resulted in a relatively large field of attention. Algebra and chemistry required a more analytical procedure and more of the study attitude. Reading formulæ,

however, demanded the most careful reading of all. It has been demonstrated elsewhere (10) by eye movement records that this analysis of the reading attitudes present in these reading situations is approximately true. The proportions of the total reading time taken by eye movements, as given in Table V, indicates that there is an inverse relationship between complexity of the reading attitude and these proportions. The more careful and analytical the reading was, the smaller the ratio between eye movement duration and reading time. This suggests that as the mental processes present during reading become more complex the ratio between eye movement duration and total reading time becomes less. The same tendency was noted above in the analysis of Erdmann and Dodge's data. The explanation of this comparatively constant relationship is found in the change of reading performance that arises from variation in the reading attitude. Judd and Buswell (6) and Tinker (10) have pointed out the changes in reading performance which accompany these variations of the reading attitude. The former show that the character of eye movements appears to be closely related to the nature of the mental processes involved in the reading. Tinker noted this but pointed out that compactness of printing and uniqueness of the symbols used also influence markedly the character of eye movements. Where the mental processes in reading were more complex and the reading more analytical, *i.e.*, in algebra, chemistry and formulæ, there were many more fixations per line and longer pauses. In this situation the pause duration increased comparatively more rapidly than the eye movement time. This gave proportionally less time to eye movement duration.

Summary and Conclusions

1. Previous results were analyzed and new data given to show the relationship between eye movement duration, pause duration and reading time.

2. A photographic technique was employed to record eye movements made during the reading of various kinds of

material. The extent and duration of the eye movements were calculated and compared with the reading time.

3. Previous investigations showed that reading movements to the right extend over a visual angle of 1° to 7°. Variation occurred with individuals and with type of material read. Moves to the left covered 12° to 20°. Line length influenced the extent of these return sweeps.

4. Our study yielded reading movements to the right which varied from 1° (formulæ) to 2° (prose); movements to the left from 13° (prose) to 16° (formulæ).

5. For all materials, less than 10 per cent of the reading time was taken by eye movements. The total average showed that only 5.9 per cent of the reading time was consumed by eye movements. This allowed about 94 per cent for perception, *i.e.*, pauses. In previous investigations the average proportions of time taken by eye movements were found to be 6.4 per cent (1) and 4 to 5.5 per cent (9).

6. The ratio between eye movement duration and reading time bore a constant relationship to the reading attitude. It was found that the more careful and analytical the reading the smaller this ratio. When the mental processes involved in the reading were more complex the reading pauses consumed a relatively greater per cent of the total time. The same tendencies were found from an analysis of Erdmann and Dodge's data.

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References

1. Erdmann, B., & Dodge, R., 'Psychologische Untersuchungen über das Lesen auf experimenteller Grundlage,' Halle, 1898.
2. Dodge, R., 'Visual Perception During Eye Movement,' Psychol. Rev., 1900, 7, 454–465.
3. Dodge, R., 'The Illusion of Clear Vision During Eye Movement,' Psychol. Bull., 1905, 2, 193–199.
4. Dodge, R., and Cline, T. S., 'The Angle Velocity of Eye Movements,' Psychol. Rev., 1901, 8, 145–157.
5. Huey, E. B., 'On the Psychology and Physiology of Reading,' *Amer. J. Psychol.*, 1900, 11, 283–302.
6. Judd, C. H., and Buswell, G. T., 'Silent Reading; a Study of the Various Types,' *Suppl. Educ. Monog.*, No. 23, 1922.

7. LAMANSKY, S., 'Über die Winkelgeschwindigkeit der Blickbewegung,' Pflüger's *Arch. f. d. ges. Physiol.*, 1869, 2, 418 *f.*
8. MILES, W. R., & SHEN, E., 'Photographic Recording of Eye Movements in the Reading of Chinese in Vertical and Horizontal Axes: Method and Preliminary Results,' J. EXPER. PSYCHOL., 1925, 8, 344–362.
9. SHEN, E., 'An Analysis of Eye Movements in the Reading of Chinese,' J. EXPER. PSYCHOL., 1927, 10, 158–183.
10. TINKER, M. A., 'A Photographic Study of Eye Movements in Reading Formulæ,' *Genet. Psychol. Monog.*, 1928, 3, No. 2.
11. VOLKMANN, in Wagner's 'Handwörterbuch,' 1846, III., 1, 275 *f.*