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ON THE PSYCHOLOGY AND PHYSIOLOGY OF READING. I.

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In the experimental study of which this is a partial report I have planned to make an analysis and description of the reading process. Until very recently no general attempt has been made to analyze and describe the psycho-physiological processes involved in reading. Isolated studies on the perception of letters, partial investigations of the movements of the eye in reading, etc., have furnished material, and especially, suggestions, valuable for the general study; but neither a synthesis of these partial studies nor any other attempt to tell just what readers do when they read, was to be found. Such work as has recently been done, as the admirable work of Goldscheider and Müller and Erdmann and Dodge, will be considered later.

Some general account of what we do in reading seems to be much needed in view of the fact that reading is one of the most frequently performed psycho-physiological operations, and is fatiguing, often disastrously so. What are the conditions of this fatigue? Do the interpreting processes become tired or the retina or the oculo-motor or accommodation muscles—or is fatigue due to a combination of these causes—or to tiring of the accompanying motorizing or auditizing mechanisms? The answer must finally come from an analytical study.

Moreover, it has been believed, though less strongly at present than a few years ago, that the reading in schools is the cause of the tremendous progress of myopia. What does the eye do in reading that tends to bring such direful consequences?

Again, readers of apparently equal intelligence differ remarkably in speed of reading, some reading four times as fast as others with apparently equal quality of interpretation. Here may be a tremendous loss, which may be remediable in the light of an understanding of the processes involved.

And then typography has been evolving some hundreds of years under stress of economy, not of the eye and brain so much as of printer's paper and printer's ink. Printers and publishers have been industriously developing the system of straight, thin, horizontal lines made up of groups of little black strokes packed in neatly and compactly. But do we know that this development has not been straight away from the arrangement most suitable for quick and easy reading? It is true that fatigued readers have had some selective part in this evolution. But they have been offered a most limited range of variations from which to choose, and the fundamental notion of line arrangement and word arrangement remain as immutable as the fixed species of Aristotle. Can books and periodicals be printed so as to lessen fatigue, to decrease the tendency to myopia, to increase the speed of reading, to permit more fluent interpretation? Can pupils be profitably taught to read faster or more slowly, to visualize or auditize or motorize, in general can they improve their reading method? These are some of the pedagogical problems to be finally solved by such an analysis of the reading process.

To explain fully the "how" of reading would be to write a treatise on the senses and intellect, and, in fact, to say the last word on many of the fundamental problems in psychology. The present study is but a beginning of what should be done in this field. It is hoped that it may at least make the general subject easier of approach.

In view of the fact that the reading process *per se* has been so little studied, and that the many studies bearing on the general problem are of so detached a character, I have thought that historical reference would be most helpfully made in connection with, or introductory to, my own treatment of the different problems, so I shall at once proceed to the discussion of eye movements in reading.[1]

To the many friends who have assisted me during the progress of his research I wish to offer my grateful acknowledgments. I am peculiarly indebted to Professors Hodge and Sanford for cheerfully incurring the inconvenience involved in serving as subjects for the experiments upon the eye, and to Dr. Burnham for criticism and advice. I wish also to express my gratitude to M. Javal for kindly forwarding to me personal papers bearing on his researches.

EYE MOVEMENTS.

What does the eye do in reading? Javal[1] found that he had straight continuous after-images of gray lines after reading, and concluded that the fixation point did not leave the line as the eye moved forward. He evidently believed that the fixation point moved over each line in reading.

Finding that the upper half of the letters was most important for reading, as can be seen at once by dividing a line in halves horizontally and comparing the legibility of the upper and lower halves, he concluded that the fixation point moves along between the middle and top of the small letters.

Ahrens[2] by fastening a bristle 10 cm. long to an ivory cup attached to the eye found that it made a straight sweep forward in reading, but the method could not show stoppages en route, and he does not seem to have suspected their existence. Lamare,[3] working with Javal, finding that the movement of the eye in reading was not continuous, but by little jerks (*par saccades*), devised the following method for counting these: A blunt point placed upon the upper eyelid of the reader put in action a microphone, whose sound, transmitted by a rubber tube, made known each movement to the ear of the experimenter the short reading jerks causing a brief sound, while the extensive movements made in passing from the end of the line to the commencement of the next, caused a more prolonged sound. With a little practice he found himself able to count the movements. He was surprised to find that the number of jerks remained the same whatever the distance from the reader to the book. Javal says: "*Cette distance n'avait donc aucune influence sur la grandeur absolue des sections,*" and, again, "*il devenait donc évident que le lecteur devise la ligne imprimée en sections précisement aussi grandes qu'il convient pour que l'œil dirigé vers le milieu de la section puisse encore distinguer en vision indirecte les lettres qui en forment le commencement et la fin.*" In this he seems to have generalized from insufficient data, as will appear later, but the observations are interesting.

Javal attaches much importance to the changes in accommodation necessitated, he thinks, as the distance from the eye to the point fixated changes during the movement along the line, and he thinks that these changes of accommodation are produced synchronously with the jerks.

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[1] Various articles, especially *Rev. Scientifique* 1879 and 1881.

[2] *Die Bewegung der Augen beim Schreiben*, Rostock, 1891.

[3] Des Mouvements des yeux pendant la lecture, *Comptes rendus de la soc. française d'ophthalmologie*, 1893, and elsewhere.

Landolt[1] found that the movement of the eye in reading was by jerks, and studied them by directly observing the reader's eye. He had his subjects read slowly, and was thus able to count the jerks (though he may well have thus introduced conditions quite foreign to normal reading). He found that an average of one and fifty-five hundredths words were read per fixation at a distance of 30 cm. Reading of a foreign language required more fixations, as did the reading of disconnected words, of numbers, and of lists of proper names. Landolt finds that the angular excursions of the eye are less as the distance increases, though the absolute amount read per fixation is somewhat increased. He claims that the movements through a small angle are very fatiguing, and that this may account in part for tendency of children to bring the book too near the eye, at the expense of the muscles of accommodation and convergence. Landolt, himself, recognizes the inaccuracy of his means of observation, and guards himself against more than general conclusions.

Erdmann and Dodge[2] also used the method of direct observation, watching the movements of the reader's eye as they were reflected upon a mirror. Their results will be referred to from time to time in reporting my own experimental work. As stated in a previous article,[3] I found myself able to determine by direct observation of the reader's eye that the movement was by jerks, and that the eye certainly moved along each line in ordinary reading, though it often seemed to the reader that it did not. But I considered and still consider the method inadequate to give any accurate account of even the number of movements of the eye (at least with some of my subjects), when they read at usual speed. It certainly could give no account of the extent of movement at each jerk, or of the speed, and in general it was entirely insufficient for the purpose. This was recognized in the work of Javal and Lamare, and I have already referred to its insufficiency in the work of Landolt.

I therefore arranged apparatus to get record of the eye's

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[1] *Nouvelles recherches sur la physiologie des mouvements des yeux.*

[2] *Psychologische Untersuchungen über das Lesen, auf Experimenteller Grundlage*, von Benno Erdmann und Raymond Dodge. Halle, Max Niemeyer, 1898. I have elsewhere (*Am. Journal Psych.*, Jan., 1899,) briefly and very inadequately reviewed this most important work. I regret that in the preparation of this article I have not at hand the notes from which I had hoped to make a fuller presentation of some of their results and methods. A fair comparison of our results would involve a critical and somewhat lengthy review of our respective methods of procedure in experimenting. Perhaps it is best, for the present at least, simply to refer the reader to the work itself, which, I hope, may soon be made accessible to those who do not read German.

[3] *American Journal of Psychology*, July, 1898.

movement by a direct attachment to the cornea of the reader's eye. The apparatus at first used has been described in my previous article already referred to.[1] As used later it consisted essentially of (1) a frame for fixation of the head fastened between iron standards, which were clamped to a heavy table; (2) of a light recording arrangement resting on the top of one of the standards, and connecting with a cup capping the cornea by means of a celloidin covered glass filament, or at other times by an aluminum wire, and writing its record on the smoked drum of a kymograph, by means of a light aluminum pointer; (3) of an arrangement for writing a time record on the drum receiving the eye tracings, consisting of a Deprez signal in circuit with a Baltzar interrupting clock set to mark $\frac{6}{23}$ sec.; (4) of a holder for the reading matter arranged to slide on a track allowing of easy adjustment of distance from the reader's eye; (5) of apparatus arranged to write a "spark" time-record on every part of the tracings of eye movements. The spark apparatus as used in most of the experiments was as follows: The secondary current from an induction coil was passed from one pole along the aluminum pointer, and sparked from its point through the smoked paper to the drum, which was connected through the kymograph to the other pole of the secondary circuit. The primary current of the induction coil was furnished by a Grenet cell, and was interrupted regularly by the vibrations of a tuning fork marking 147.4 vibrations per second. In order to reduce to a minimum the electrical resistance in this circuit, and thus get a stronger secondary circuit, this fork was driven by another, a fork of about 50 vibrations, with two Grenet cells in circuit, the 50 fork interrupting itself electro-magnetically. Thus at intervals of about $\frac{1}{150}$ sec. dots of soot were displaced by the spark, as the pointer moved forward, and a record of the eye's speed and movement was written at every point. By using a fast gearing of the kymograph the lengths of the eye's pauses were also recorded in some of the tests. The Deprez signal record at the side also gave the same.

The fixation of the head with reference to the recording apparatus and reading matter was obtained as before by having the subject bite into a mass of partially cooled sealing wax attached to a mouth-piece fastened in the head frame, the imprint of the teeth being preserved when the wax hardened.

The cups used were plaster of Paris of a curvature a very little less than that of the cornea, as light as they could be made and still be handled with safety. A hole was drilled

[1] See also the article by Prof. E. B. Delabarre in the same number of the *Journal*.

through the center of a diameter of 1.7 to 1.9 mm. The cup was placed on the left eye in all experiments.

The eye was rendered anæsthetic by the use of cocaine or holocaine. The latter was found most satisfactory and was used in most of the later experiments. The cocaine usually interfered with the accommodation, the holocaine probably never did so. The eye felt fairly comfortable during the experiment, and the reading proceeded normally.[1] The reader was directed to read by his normal method for the thought. Most of the passages read were taken from the back numbers of the *American Journal of Psychology*, having a line length of 98 mm., the type was 10-point or 8-point.

The tracings show that the eye moves over the matter line by line in all cases or in very nearly all. The movement along the line is in no single case continuous, but by quick jerks of varying length. In reading 89 of the longer lines, varying in length from 60.5 to 121 mm., there were but 13 retraceals,—about one in seven lines. My arrangement of apparatus could not record wanderings of the fixation above and below the line that was being read. There are, however, certain appearances of the tracings which lead me to think that this could have occurred but seldom; but a record in the vertical plane must be obtained before this can be finally determined. I incline to accept the conclusions of Javal on this point, except that I should expect the fixation point to have a somewhat larger range of variation, vertically, than from the middle to the top of the small letters.

The return sweep of the eye is almost invariably unbroken until near the end, where an occasional halt is made apparently to enable the eye to get its bearings in a new line. The tracings from 119 of the longer lines show 21 such stops. These are more numerous in the long line passages than in the shorter ones. This is as we should expect, if the return movement is guided by the peripheral stimulus from the new line's beginning received during the eye's last fixation in the preceding line. Such guidance would be less and less accurate as the length of line increased and might necessitate the haltings that

[1] This last was true so far as either the reader or experimenter could observe. The complexity of the apparatus, and the novelty of having an attachment to the eye, suggest much of distraction. But the subjects were accustomed to doing normal reading amid such surroundings from day to day, and the reader, for the most part, had little direct consciousness of there being any attachment to his eye—the attached eye feeling quite as free to move as the other one. There was some discomfort at times, especially during the removal of the cup, and after the experiment; but during the tests, so far as we can trust the reader's introspection, the reading proceeded as it ordinarily does. In my own case, at least, it seemed to be even a little faster.

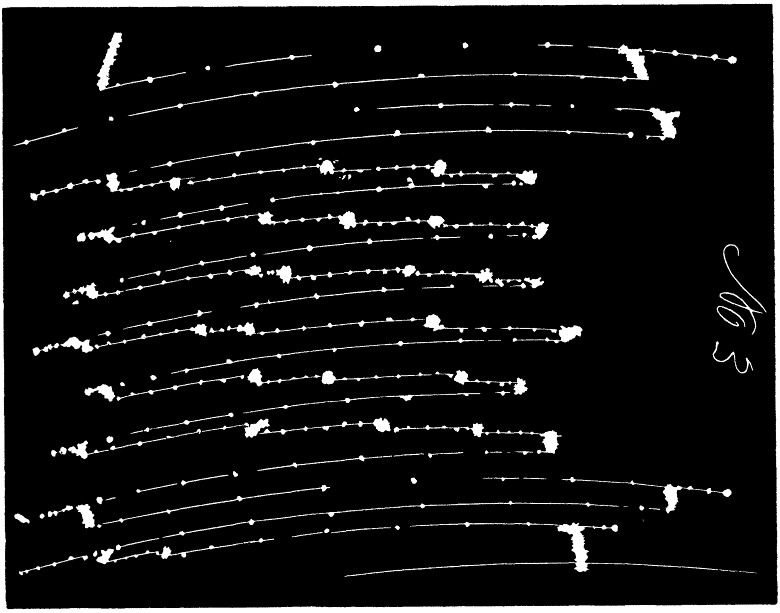
the tracings show and the distraction noticed introspectively when we lose the line. However, several of the passages were read with no halt in the return sweep.

In reading the *American Journal* passages the smallest number of movements in any line was two, the largest seven. The variation, however, is usually not great within a given passage. In reading 30 lines (divided into three readings), subject Hu. averaged 4.8 forward fixations per line, with a mean variation of 0.5. In reading 51 lines (6 passages) under almost exactly comparable conditions, subject Ho. averaged 4.5 forward fixations, with M. V. of 0.6. These readings were at distances ordinarily used in reading, varying from 33 cm. to 42 cm., all but one of the passages being at distances of between 33 to 35.5 cm. The number of fixations per line is not found to vary with distance within these limits, nor indeed is the number decreased very appreciably even when the distance is doubled. The reading of 20 lines (2 passages) of the above by subject Hu. at 35.5 cm. distance, gave an average of 4.7 forward fixations, with M. V. of 0.5. Doubling this distance under otherwise comparable conditions gave an average of 4.5 forward fixations, with M. V. of 0.3. The reading of 47 lines at 35.5 cm. are comparable with a reading of 32 lines at double this distance, 71 cm. The former shows an average of 4.5 forward fixations per line, with M. V. of 0.54. The latter gave an average of 4.48 fixations, with M. V. of 0.45. It should be mentioned that these M. V.'s are averages of M. V.'s within the given passages, and that the variations in the number of fixations from passage to passage was much greater in the double distance passages. Decreasing the size of type seems to have but little effect upon the number of fixations. Thirty lines (three passages) of the smaller size of type, 8-point, from the *American Journal* read at 33 to 35.5 cm. distance, gave an average of 4.9 fixations per line, with M. V. of 0.5. Sixty-seven lines (seven passages) of the larger type of the *Journal*, read under similar conditions, gave an average of 4.7 fixations, with M. V. of 0.54. I have made most use of the results obtained from readings of *American Journal* passages because these are of a line length and type size most frequently met with, perhaps, by the subjects investigated, and I have wished to investigate the process of reading under its most normal conditions. Subjects have been tested, however, with the shorter line lengths.

Nineteen lines of a *Cosmopolitan* article with a line length of 60.5 mm. and the ordinary type size gave an average of 3.6 fixations per line, with M. V. of 0.5. Twenty lines (two passages) from a newspaper column, line length 52 cm., and the ordinary type size, gave an average of 3.8 fixations per line, with M. V. of 0.6, at distance of 35.5 cm. for one subject. With the other subject 14 lines of the same passage gave an average of 3.4 fixations, with M. V. of 0.5, at 35.5 cm.; and an average of 3.6 fixations, with M. V. of 0.6, at distance of 52.7 cm. Shorter line lengths than this are not ordinarily found in reading, and investigation of reading under these special conditions belongs rather to the consideration of what should be than of what is. The results of some investigations in this field are reserved for a later report.

The tracings show that the eye seldom moves along the whole extent of the line, and that usually the first fixation is nearer the beginning of the line than the last is to its end. In the reading by subject Ho. one passage from the *American Journal* (10-point type) the side to side movement averaged 82.3 per cent. of the line length. In a similar passage the same subject averaged 78 per cent. of the line length. In a similar passage, subject Hu. averaged 82.2 per cent. of the line length when reading normally, and in a similar passage, read at maximum speed, 85.8 per cent. The M. V. is usually quite small in all tracings of this line length, the subject tending to maintain a fairly constant extent of movement throughout a given passage. The indentation, though usually greater at the right, is not always so. In some readings the first fixation must have fallen in the first half of the first word in most of the lines, while in other passages it must have fallen in the second or even in the third word. Individual variations in this respect are not demonstrable as between the readings of the two subjects. For a given passage the subject seems to fall into a way of indenting a certain amount right or left, and maintains this tendency throughout the passage.

The extent of the forward movements in reading is subject of great variations in all cases, and the conclusion of Javal that the eye moved over the extent of matter that could be read at one fixation (usually about the space of 10 letters in his opinion) is negatived at every point. To illustrate the great variability of the forward movements I shall give here the chords of the arcs traversed in some consecutive forward movements in reading a representative passage. The chords are very nearly proportional with the arcs within the limits of these movements. Chords (in mms.), 11.0, 26.0, 3.5, 11.5, 16.0, 13.0, 15.5, 23.5, 17.0, 10.0, 40, 12.0, 22.5, 12.0, 13.0, 13.5, 19.0, 4.0. Another passage, showing perhaps less variation than most of the others, gives 14, 14, 16, 14, 16, 19, 19, 5, 18, 18, 12, 11, 14, 9, 21, 13, 20, 18, 22, 7, 12, 15, 26, 17, etc. The extent of forward and return movements will be given in degrees and minutes in connection with the results of the measurement of speed.



Specimen Curve of 'Spark' Record.

This reproduction, cut by a careful engraver upon a block on which the original tracing had been protographed, shows with great accuracy the sort of record from which the times of the eye movements have been determined. The chief difference between the original and the reproduction is in the breadth of the horizontal lines which are finer in the original.

The curve shows the movements of the eye in reading six lines, preceded and followed by two free movements of the eye each way, in which it was swept from one end of the line to the other, the beginning and end alone being fixated. The broad vertical lines and the round blurs in the reading indicate pauses in the eye's movements, the successive sparks knocking the soot away from a considerable space. The small dots standing alone or like beads upon the horizontal lines, show the passage of single sparks, separated from each other by 0.0068 sec. The breaks in the horizontal lines indicate that the writing point was not at all times in contact with the surface of the paper though near enough for the spark to leap across, as shown by the solitary dots.

The tracing shows clearly the fixation pauses in the course of the line, the general tendency to make the "indentation" greater at the right than at the left, and the unbroken sweep of the return from right to left.

SPEED OF EYE MOVEMENTS.

The speed of eye movements has been investigated by Volkmann, by Lamansky,[1] and more recently by Dodge.[2] No direct determination of the speed in reading was made by these authors, but it was assumed by Dodge that the determinations of speed for eye movement in general can be carried over to the reading process, and estimates based on this assumption are given.

Volkmann's method was bad, as Dodge has shown, and on careful examination of the method proposed by him for getting valid results from Volkmann's data I am of the opinion that it cannot be done, and that the results have little value as determinations of speed. Lamansky measured the speed by flashing a pencil of light into the eye at regular intervals, as the eye passed through a given arc, the light passing through the perforations in a uniformly moving disc, and being directed to the eye by a prism, the subject counting the after-images of the flashes appearing during the movement. He found a quicker movement in the horizontal meridian than in the vertical, and the speed increased with the extent of the excursion.

Dodge used a modification of the same method, and found a very much slower speed than Lamansky, which he is unable to explain, except on the ground of individual differences, assuming that Lamansky's work was accurately done. The time occupied in movements through various arcs, as given by these authors, is as follows:

LAMANSKY.	DODGE.
$6° = 10\sigma$	$5° = 15\sigma$
$16° = 16\sigma$	$10° = 16\text{–}20\sigma$
$32° = 22\sigma$	$15° = 30\sigma$
	$30° = 50\sigma$

With the spark apparatus already described I have measured directly the speed of the eye in reading representative passages from the *American Journal*, 10-point type, line length 98 mm., subtending an angle of 15° 14′ at the distance used, viz.: 35.5 cm. The results below give the average arcs described in the movements and the averaged times occupied in traversing these arcs for two passages read by subject Ho., and four read by Hu.[3]

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[1] *Pflüger's Archiv*, 1869, p. 418 ff.

[2] *Op. cit.*

[3] I have selected these passages as least subject to error from the conditions of recording. The times given are subject to a certain range of error, which, however, I believe to be comparatively small. No matter how light the apparatus, there must remain a slight delay in starting, due to inertia, and an "overshoot" of the pointer in stopping. (I had first thought that the "overshoot" shown in the tracings might represent, in part, a movement of the eye beyond its intended fixation,

TABLE I.

Subject Ho.

	Forward Sweep. av. arc.	Forward Sweep. av. time.	Return Sweep. av. arc.	Return Sweep. av. time.
First passage,	3° 46′	41.8σ	12° 4′	51.6σ
Second passage,	3° 55′	40.7σ	11° 40′	54.7σ
Subject Hu.				
First passage,	3° 21′	44.1σ	12° 4′	57.0σ
Second passage,	2° 52′	46.0σ	12° 8′	68.3σ
Third passage,	4° 14′	42.7σ	13° 4′	58.1σ
Fourth passage,	3° 27′	48.0σ	—— ——	——

The forward movements of the eye in reading are found to occupy a tolerably constant time, almost irrespective of the arc traversed. For example, in the first passage read by Ho. (table above) the M. V. of the extent of movement was 34.2% of the average, while the M. V. of the time occupied in these movements was but 10.2%. The smallest and largest arcs described in this reading were as 4 is to 26, while the range of times was as 4 is to 7. Excluding three exceptionally short excursions in this passage the movement range was as 7.5 to 26, and the range of times was 6 to 7. Part of even this small M. V. must be accredited to error in estimation of partial spark intervals, the error to be expected here being much greater than in measuring the corresponding extents of movement, though being of such a nature as to be largely corrected in averaging. So that except for movements of but a few minutes of arc, which would seem to occupy less time, the forward movement of the eye in reading would seem to occupy an almost constant time, with an M. V. that can hardly exceed 5 or 6%, and may be much less.

The measurements of the return movements given in the above table are for the return as far as the first stop. Usually, as has been mentioned, the eye's return sweep was without a

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with quick return. But a careful study of the tracings and comparison of tracings made with tubular glass pointers convinces me that the "overshoot" is of the pointer. The eye may not hit its mark at each move, but it comes as near as it needs to get its data.) Perhaps it will be found that the times given above should be increased slightly from these causes.

I append the weight of recording apparatus: Total weight of all apparatus moved by eye—.597 gram. Weight of cup most used—.092 gram. Weight directly resting on eye (cup, and one-half of celloidin-covered glass tube used as a connecting rod) .139 gram.

The pointer that wrote the tracings was suspended so as to barely touch the glazed paper. Care was taken that in the experiments there should be as little as possible of friction or play of parts.

break. The M. V. here, both for times and extents of movement, is small. In all the passages of above table, except the third and fourth read by Hu., the subjects read at normal speed. In the last mentioned passages the subject read at maximum speed throughout. The extent of the movements is seen to be somewhat greater, and there were fewer per line. But the subject evidently was unable to decrease the time required for the movement,[1] and in general there is nothing to indicate that the rate of movement is under control of the will.

READING PAUSES.

The time occupied in the reading pauses is a very variable one. One of the passages read by Ho. gave an average pause of 190.9σ, with M.V. of 48.6σ. Another representative reading by the same subject gave an average of 108.3σ, with M.V. of 32.6σ. In the latter passage, while the M.V. is certainly given correctly, as compared with the average, the average time of the pauses may be somewhat greater, the time being measured in this case by the spark record, and the current having a tendency to use the same path twice when the dots are so close together, as was the case here when the pointer was at rest. In the first passage referred to the time record is taken from the clock record written on the tracing, and is certainly correct as it stands. In another passage read by Hu., 22 reading pauses gave an average of about 183σ, and the same number of pauses from an equivalent passage read by Ho. gave almost exactly the same average (measurements by the clock record). The pauses in retraceals and those on the return sweep are usually shorter than the reading pauses proper, and are not included in these averages.

The passages read at maximum speed show a decrease in the length of the reading pause, and as the speed of movement is not increased it would seem that increase in speed of reading is brought about solely, or at least mainly, by decreasing the number and duration of the reading pauses. Additional tests must, however, be made before this can be conclusively stated.

In general no individual differences have been clearly made out as between the two subjects tested, except that the speed of eye movements appears to be a very little greater with Ho.

[1] In one of these passages an average rate of 9.4 words per second was maintained, as recorded by the signal record from the laboratory clock, paralleling the spark record. In another passage read at maximal speed by Ho., a rate of 12 words per second was maintained—almost a "skimming" speed. These would certainly be maximal rates under any conditions, and indicate that the eye was free to do its fastest work so far as the apparatus was concerned. The apparatus seemed to do its work fully as well, and the tracings and spark records are as clear as when the reading was at normal speed.

The forward movements being so irregular in extent, it seemed that they might be best interpreted as reactions to word stimuli appearing in the right hand periphery at each pause of the eye in reading. It thus became important to know the reaction time of the eyeball to such stimuli.

The minimum time for such reaction was found by Dodge to be between 180σ and 230σ. His method was briefly as follows: From a point first fixated the subject moved to a second fixation point 12 mm. distant on the appearance there of a small letter *c*. Simultaneously with this a large letter O was exposed in such a way as to fall just within the blind spot while the eye remained at the first fixation point, but to become visible the instant the eye was moved. The length of the O's exposure necessary to make it visible was taken as measure of the eye's delay at the first fixation point or its reaction time, subject to a slight correction. The experiments were not extensive enough to determine even the minimum time more definitely than as above stated. The experiment is an extremely pretty one, but seemed to involve some possibility of error, and the times given seemed very long, as compared, for example, with the wink reflex. I have measured the reaction for one subject (subject S.) with the direct attachment apparatus already described. The subject fixated a large letter *A* at a distance of 36.3 cm., and on the exposure of a type-written word 4° 45′ (30 mm.) at the right moved his eye to that point or to a point somewhat beyond. The removal of the card covering the word at the right interrupted an electric circuit starting the Hipp chronoscope, and the reaction movement of the eye threw the end of the aluminum pointer into a trough of mercury, closing the circuit and stopping the chronoscope hands. A preliminary "ready" was given in the ordinary way. A series of reactions to auditory stimuli (produced to the right from the same fixation point) was also made at the same sitting. The stimulus was given by a sharp blow on a telegraph key.

At a later sitting a series of reactions to the same word stimulus given in the same way was made with the hand by pressing a telegraph key, and a fourth series was taken with the hand reacting to the same stimulus, given at the fixation point instead of in the periphery. The results are as follows: Fourteen visual reactions gave as an average 206.9σ, with M.V. of 20.7σ. Eleven reactions of the eye to auditory stimuli gave as an average 191σ, with M.V. of 31.4σ. Twenty-seven reactions with finger key to the peripherally given stimulus gave an average of 180σ, with M.V. of 13.9σ. Thirteen reactions with the finger key to the foveally given stimulus gave an average of 179.6σ, with M.V. of 9σ. From the time for eye reactions probably 10σ should be deducted for the movement occurring before the pointer reached the mercury. The pointer was necessarily thus removed because of the fact that while the subject was maintaining what he supposed was an absolute fixation, the pointer constantly maintained a tremulous motion, evidenced by the clicking of the chronoscope armature as the circuit was made and broken, and the separation had to be great enough to prevent the possibility of such interference with the chronoscope registration.

The times for visual reaction of the eye showed a marked tendency to decrease even throughout the single sitting in which they were taken. The last six of these reactions (taken immediately after the auditory group which followed the first eight visual) gave an average of 181.7 as against the total average of 196.9. The auditory time showed less tendency to decrease. The visual eye reactions seem to be of the sensory type throughout, the auditory rather of the motor type, the subject remarking upon his tendency to wink and to make general muscular contractions with the auditory reactions. The times thus found for eye reactions are somewhat shorter than those given by Dodge, the minimum for visual stimulus being a little under 170σ, and the tendency being to fall still lower by practice. However, the results are in substantial agreement with his in showing that the reaction to visual stimuli by the eye muscles occupies much the same time as the reaction by means of the hand muscles or others that are under more conscious voluntary control.

In reading it may well be, however, that the reaction is somewhat, even considerably, quicker because of the heightened readiness for the stimulus produced by "associative expectancy," and, perhaps, also by the stimulus to reaction having been actually noted in the remote periphery even while the eye is fixated in the preceding line. The unconscious movements of the eye during fixation, observed in the reaction experiments, give ground for the opinion that "marginal contrast" is due to such movements, and, taken in connection with other phenomena, observed during the experiments with the attachment apparatus, indicate that the supposed fixation point is not at all certain to be the actual one, and that the subjective determination of what has been fixated must not be relied upon when much accuracy is desired. Persons affected with nystagmus will confidently state that they are maintaining fixation when their eyes can be plainly seen to wander through a pretty considerable arc, and the same phenomena seem to be present in a minimum degree in the normal eye. In fact, nystagmus may be regarded as but an accentuation of a normal and constant wavering in the equilibrium of the ocular motor muscles during fixation.

Word Perception and Extent of the Reading Field.

More or less valuable contributions to the study of this part of the reading process have been made by various investigators, beginning with G. Valentine (1844), and continued by Aubert, Donders, Helmholtz, Exner, and Baxt, of the earlier experimenters. These studies give us information as to the time needed for the recognition of letters and of words, and for their enunciation, and discuss to some extent the apperceptive contribution to sense perception in such recognition. The experiments of Baxt[1] give valuable information as to the time needed for retinal impressions (especially impressions from letter or word stimuli) to come to consciousness. It is to be regretted, however, that in most of these studies the actual conditions obtaining in normal reading were lost sight of, and the results cannot be carried over to the reading process.

Cattell[2] investigated extensively the perception of letters and words, and his results are to a considerable extent applicable to the conditions obtaining in reading. He exposed letters, words and sentences on the fall-chronometer, using .01 sec. as the "optimum time" of exposure. He found that from four to five isolated letters could be perceived at one exposure, or three to four short isolated words, and that twice as many words could be seen when given in connection. Short words were read more easily than single letters, and the difficulty of recognizing words did not increase proportionately with their length. For these and other reasons he argued that words are recognized as wholes, and even that sentences are thus recognized. In exposing sentences he arranged the words in double lines so as to get as much as possible within the range of clear vision, thus materially changing the conditions obtaining in normal reading. His investigations of the times needed for the perception and naming of letters, words, etc., need not detain us, as the very different conditions of association and expectation obtaining in normal reading make it very doubtful whether the results are applicable here except in a very general way.

From the side of abnormal psychology Grashey (*Archiv für Psychiatrie*, XVI, S. 654) and Wernicke (*Fortschritte der Medizin*, III u. IV, 1886) have discussed the phenomena of aphasia in their relation to the processes involved in perceiving words and letters, and are led to the conclusion that we read by letters rather than by words.

Goldscheider and Müller[3] took up this question, and made a

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[1] *Pflüger's Archiv*, 1871.

[2] Various articles in *Wundt's Studien*, *Mind* and *Brain*, 1885-86.

[3] *Zeitschrift für klin. Med.*, XXIII.

careful study of the conditions affecting our recognition of words and of letters. They conclude that words are perceived both as syntheses of their perceived component letters and as individual units, the latter being, perhaps, the more usual method. They investigate the relative importance for auditory perception of the different parts of words, discussing the possibility of their being determining letters which stand for the word mainly in its memory picture, and are especially necessary for its perception. The beginning and end of a word, especially the first, were shown to be especially important, the word being recognized pretty readily when only these parts were exposed, for what they consider the optimum exposure time, about .01 second. Various other parts of words as the vowels, consonants, etc., were exposed, and sufficed for more or less prompt recognition in many cases. Goldscheider and Müller are inclined to the belief that the visual perception of certain letters of a word arouses the memory of the corresponding sounds of these letters, and that the sounds of the other letters, and thus of the whole word, are called up from association with these. Vowels were thought to be especially important for arousing the motor elements in word perception, and consonants for the auditory elements. Consonants were not thought to be generally more important than vowels for word perception. The relative importance of these elements might depend upon the reader's tendency to be motor or auditory-minded.

My own study, reported in an earlier article,[1] of the effect on speed and extent of recognition of removing the first or last halves of words from passages to be read, show clearly that the first half was much more important for word perception, as it occurs in actual reading. This by no means implies (though, at least, one reviewer of the article seems to have so understood the matter) that the fixation point is upon the first half of each word. Not over one-half or one-third of the words are fixated at all, and though the part usually fixated has not been accurately determined as yet, the results of the experiments of both Dodge and myself indicate that it may be in any part of the word, or even between the words. The *Blickpunkt* of consciousness has been too often and too closely identified with the eye's fixation point, and this identification cannot be maintained for the reading process.

The legibility of isolated letters and conditions affecting their recognition have been carefully investigated by Cattell[2] and Sanford,[3] and have been discussed more or less helpfully by Javal and Cohn. Helpful as these studies have been it seems to me there

[1] *Op. cit.*
[2] *Op. cit.*
[3] *American Journal of Psychology*, I.

is still greater need of the investigation of the legibility of letters in groups and in indirect vision as we normally make use of them. Here they must certainly have a somewhat different, perhaps a very different relative legibility. The need of such investigation has already been mentioned by Dr. Sanford. Then, again, if words rather than letters are the units, as seems to be already established, an investigation of the legibility of words as optical forms for recognition, and the possibility of improvement in their form and arrangement, may be as much in point as the investigation of letters.

Griffing and Franz[1] have made an admirable study of some of the conditions of fatigue in reading, such as size of type, spacing, leading, color and quality of paper, intensity and quality of illumination, etc., but did not attempt any analysis of the reading process. Quantz[2] has made an extensive study of speed in reading and the conditions affecting it, such as practice, eye-mindedness, intellectual ability, etc. His results will be considered in another connection later, but I may say here that it seems to me that no satisfactory determination, or at least no satisfactory explanation, of the conditions affecting either speed or fatigue can be made until the reading process itself is analyzed; and the treatment of this fundamental problem has not, as yet, been attempted in a thorough manner.

As a step in that direction I arranged a series of experiments intended to throw light on the process of perceiving words and sentences as they occur in reading, and at the same time to afford data for determining the extent of the reading field, as it may be called, *i. e.*, the extent of reading matter as ordinarily printed, which the reader can read at one fixation. For this purpose passages were selected from old numbers of the *American Journal of Psychology* of about average difficulty, and of more or less intrinsic interest to the readers. The type was of the 10-point size used in this article, and the arrangement of words and letters was similar. This material was cut out by lines and pasted end to end, so as to make sense continuously on 20 strips of cardboard, each 46 cm. long; the printed matter extending 36.5 cm. on each card. This printed matter was exposed to subjects, section by section, by the Cattell fall apparatus. The matter on the first two cards was divided into sections of 1.75 cm. each, on the third and fourth cards into sections of two cm. each, and so advancing by differences of 2.5 mm. to and including cards divided into 4 cm. sections. The subject sat in a fairly comfortable position with his head in a head-rest, and with his eye at a distance of 35.5 cm. from the reading matter. A white spot on the screen exactly opposite the mid-

[1] *Psych. Review*, 1896. [2] *Psych. Review*, 1898.

dle of the section to be exposed was fixated at a ready signal from the operator about two seconds before the screen was dropped. The falling screen exposed 73 mm. of sense matter of the usual arrangement of type, at about the ordinary reading distance, with the fixation point in the center, for a period of 15σ. As the investigations into the matter of an optimum exposure time by Cattell, Goldscheider and Müller, Quantz and others, gave a decided preference to the shorter times in the vicinity of 10σ it was decided to use them in preference to the longer time occupied in a reading pause, especially as it was not yet known how short the simple reaction time for the eye might be, and it was desirable to keep within this period. Most of the apparatus and screen was hidden from the subject behind a gray paper shield, which was pierced by a 2 x 9.25 cm. slit opposite the part to be exposed. The apparatus was so arranged that a light from a window should fall directly on the exposed matter. In making the tests before exposing a section the context leading up to it was read to the subject up to the last letter, and then the section containing the passage was exposed. The sections were thus given consecutively always with context. Practice tests were made with each subject before beginning the series, and a few exposures were given for practice before each day's experiments. After each exposure the subject dictated or wrote what he had seen, whether words or letters, marking as doubtful those not clearly seen, and reporting it if a word was merely guessed from context. The result of the first exposure was always regarded as the one to be regularly used, but from time to time second, third, and even tenth exposures were made whenever it seemed likely that this would be of value. The study began with the short section cards, but a return series was also arranged on other cards in an exactly similar manner, and given in reverse order, that is, beginning with large sections, and with equivalent but different reading matter. The smaller section cards of this return series were not exposed, however, and it has been found impossible also to apply the same quantitative treatment to them as to the large sections, owing to the constant overlapping of the extents seen from exposure to exposure. Besides the cards in which context was given a series of cards was exposed without giving context, the sections being 5 cm. apart, and given in reverse order, so that though the matter exposed was sense reading, no section made sense with any other. Four subjects have been tested, there being over 640 exposures to a subject when the complete double series was given, and not less than 360 have been given to any subject. I shall first give the results obtained in the investigation of the reading field. The results of the exposure of sense matter without context gives opportunity for comparison of the amount read in the right and left periphery. The extent of matter read at first fixation continuously and correctly is given in mm. below as *C.* as measured on the exposed line direct. Another measurement (*R.*) is of the total extent of the reader's range of word or syllable perception, as shown by his recognition of a peripheral word or syllable, for example, at the right when not all was read correctly between this and the part perceived farthest on the left.

The extent of line read correctly to the right of the fixation point is given below under *R. C.*, and the corresponding range of perception to the right is given under *R. R.*, all in mm. The measurements under *L. C.* and *L. R.* are for the corresponding correct reading and perception ranges to the left. I give for comparison the measurements from the four cards exposed in four cm. sections with context given up to two cm. from fixation point.

TABLE II.

No Context.

SUBJECT.	C.	R.	R. C.	R. R.	L. C.	L. R.
B	21.33	24.23	9.43	11.50	11.90	12.73
S	10.25	11.25	4.68	4.98	5.57	6.27
T	23.80	27.60	13.90	17.20	9.90	10.40
H	32.40	34.88	19.75	20.90	12.65	13.98
Av. 4 Subj.	21.95	24.49	11.94	13.65	10.01	10.85

Context given to within 2 cm. of Fixation Point.

SUBJECT.	C.	R.	R. C.	R. R.	L. C.	L. R.
B	21.7	22.1	7.3	7.6	14.4	14.5
S	8.8	10.5	4.2	5.0	4.6	5.5
T	23.9	27.3	11.9	14.4	12.0	12.9
H	27.8	28.7	14.3	15.2	13.5	13.5
Av. 4 Subj.	20.55	22.15	9.4	10.55	11.15	11.60

Largest Amounts Read. No Context. One Exposure.

SUBJECT.	C.	R.	R. C.	R. R.	L. C.	L. R.
B	37	40	27	27	10	13
S	45	45	25	25	20	20
T	48	48	40	40	8	8
H	50	50	40	40	10	10

A card given in two centimeter sections was read correctly throughout by one subject with one exposure per section, and large parts of 2.5 cm. cards were similarly read. Usually, however, the special conditions of experimentation caused breaks here and there, even when the fixations were near together.

The fact that exposure of one section permitted reading into the following section which occurred from time to time prevents quantitative treatment of the result except for the cards given in large sections. The data, however, offer much of suggestion for a theory of word and phrase perception. The subjects were instructed to state just what they saw, whether of words or letters. Almost invariably words are given. Only rarely did subjects state that the next word began with certain letters, and it was still more rare that terminal letters at the left were given. From time to time subjects felt that they had seen letters, and that they had been recognized for the instant, but they could not be reproduced after exposure. Smaller forms than single letters, such as commas and other marks of punctuation, were recognized from time to time, subjects stating that they were clearly seen.

There was a general tendency to see phrases and word groups whose components were closely and characteristically associated. This seems to be at the foundation of the tendency noted in all subjects and constantly, to read most at one or other side of the fixation point, instead of in symmetrical arrangement about it, as the conditions of clearest vision would seem to demand. To illustrate, note the appended consecutive measurement for subjects T and B:

TABLE III.

Subject T.				*Subject B.*			
L. C.	R. C.	L. R.	R. R.	L. C.	R. C.	L. R.	R. R.
20	25	20	25	5	0	5	0
7	19	7	19	12	6	12	19
17	10	17	10	13	18	13	18
0	0	5	0	24	0	24	0
9	15	9	15	9	15	9	15
2	13	14	13	14	13	14	13
17	4	17	29	18	4	17	23
10	8	10	8	10	8	10	8

Thus while the average amounts read to the right and left of fixation point are not so very different (except when preceding context is given), as shown in Table II above, the difference of these amounts for particular exposures is often very considerable, and they are seldom equal. It would be interesting to collate these preferred groups (read to side of fixation point) and compare them directly with the groups that would have been read if the conditions of clear vision alone had determined what should be read in the periphery. It is not to be supposed that preferred phrases and parts of sentences were those of which a memory image already existed in the mind of the reader. Many of the combinations read most easily undoubtedly had never been seen before. But the *form* in which they were cast was a familiar form, in which the sequences were such as to run parallel with the habits of expectancy formed in the reader's mind by long experience with such sequence series. In general the more the word groups tended to resemble isolated words, as when divided by punctuation marks, the less easily they were read. Prepositional phrases, substantives with a series of modifying adjectives, or with a closely linked prepositional phrase modifier, series of any kind which had a rhythmic swing were preferred. Certain words, usually rather unfamiliar ones, presented peculiar difficulties. It seemed almost impossible to bring about a recognition of them by repeated exposures when the subject failed to perceive them at the first. The word "titillation" was exposed to one subject ten times successively before recognition had proceeded so far as to call it "tilitation." All subjects had difficulty with this word; the letters would be clearly seen, but, apparently, could not be remembered long enough to enable the subject to construct the word. "*Raison d'être*" was a combination offering similar obstacles to construction from its component letters. It would be interesting, did space and time permit, to give concrete examples of misreadings, and of various other more or less significant phenomena noticed in the experiments.

Perhaps the chief value of these experiments has been the opportunity which they gave of somewhat extensive observation, at first hand, of the process of perceiving words and other reading-units. I hope, in a later article continuing this report, to sketch an outline of a partial theory of word and sentence perception, which has been suggested and supported by the phenomena observed.