PHOTOGRAPHIC RECORDING OF EYE MOVEMENTS IN THE READING OF CHINESE IN VERTICAL AND HORIZONTAL AXES: METHOD AND PRELIMINARY RESULTS

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The observation of eye movements by means of photographic recording for the purpose of studying the reading process has already been extensively made in the case of the English language.[1] Many such studies have been carried out at the University of Chicago, and published in the *Supplementary Educational Monographs*.[2] From personal sources, we recently learned that Dr. Shigeru Otomo in a study, also made at Chicago, used Japanese texts. His results are not yet available to the public. The present paper will present the method and some results of our first attempts, made at Stanford University, at photographing eye movements in the reading of Chinese.

The experiment is especially interesting because Chinese is radically different from most other languages that have been studied in this manner. It is not based upon phonetic spelling. All characters are essentially perfect squares, though each may contain from one to more than thirty strokes. The simplest form is a horizontal line, while other characters sometimes look disconcertingly complicated. A-

[1] Raymond Dodge, 'The Psychology of Reading,' *Cyclopedia of Education*, 1917, *5*, p. 117.

[2] W. A Schmidt, 'An Experimental Study in the Psychology of Reading,' Suppl. Educ. Mono., 1917, *1*, Whole No. 2, pp. iv + 125, Uni. Chicago Press. C. T. Gray. 'Types of Reading Ability as Exhibited Through Tests and Laboratory Experiments,' *ibid.*, 1917, *1*, Whole No. 5, pp. xi + 196. These studies, now unfortunately out of print, were the first of this important series of investigations to come from the School of Education at Chicago. For illustrations showing their elaborate equipment for photographing simultaneously the movements of both eyes see: A. R. Gilliland, 'Photographic Method for Studying Reading,' *Visual Education*, 1921, *2*, p. 21.

side from the vocabulary, the style has a wide range of difficulty. While traditionally the characters have always been arranged in vertical columns, a large number of recent Chinese publications have adopted the horizontal axis for alignment. The punctuation marks also vary in elaboration, from their entire absence through uniform dots or circles to a system more complicated than that used in English. The photographing of the eye movements thus affords an excellent means of studying various problems arising from such differences.

Method

A general view of the apparatus is shown in Figure 1, *A*.[1] It will be recognized as a compact form of the Dodge type [2] of equipment mounted as a complete unit on one table which is secured to the floor in a manner calculated to avoid vibration. The adjustments to be made are simple and direct and offer such ranges of possibility that the apparatus may readily serve for photographing eye movements under a considerable variety of conditions. The subject is seated at a firm headrest; one eye is illuminated from a point-source type of lamp with the use of small mirrors; the lens of the enlarging camera is directly in front of the eye to be photographed and the film at the other end may be continuously moved horizontally or vertically as required.

The source of light was a carbon arc lamp (*L*). A time wheel (*M*) operated by a synchronous motor (*N*), the tuning fork control of which is not visible in Fig. 1, was turned at the rate of 5 revolutions per second.[3] Openings in this

[1] Nearly all of this equipment was very generously given to Stanford University, Dept. of Psychology, by the Carnegie Institution of Washington, Washington, D. C., in 1922. It had formerly been in use at the Nutrition Laboratory, Boston, Massachusetts.

Dr. Francis G. Benedict, Director of Nutrition Laboratory, most kindly suggested the transfer of this apparatus to Stanford University.

The arc lamp and the film camera were made possible by the Thomas Welton Stanford Fund for Psychological Research.

[2] Raymond Dodge, 'An Experimental Study of Visual Fixation,' Psychol. Rev. Monog. Suppl., 1907, *8*, Whole No. 35. Pp. iv + 95. See Plate III. *Cf.* also Dodge and Cline, 'The Angle Velocity of Eye Movements,' *Psychol. Rev.*, 1901, *8*, p. 145.

[3] This time marker was devised by M. Bull of the Marey Institute, Boulogne-sur-Seine, for use in electro-cardiography. Made by Pirard and Coeurdevache, Paris.

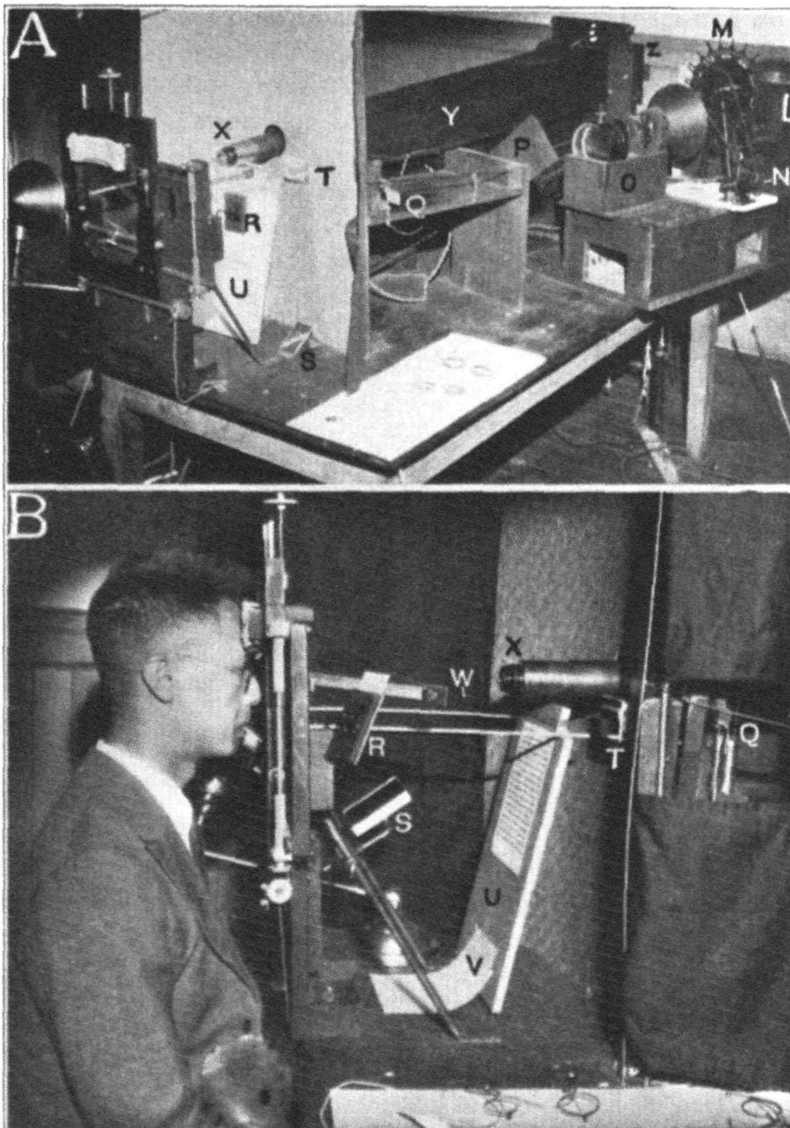


FIG. 1. Equipment for photographing eye movements during reading.

(*A*) General view showing compact arrangement of the apparatus mounted as a unit on one table, which is securely braced to the floor.

(*B*) Subject in position for having eye movements photographed during reading. The mirrors, *R* and *S*, for conducting the recording light to his eye were at the subject's right and did not obstruct his binocular view of the copy. See text for description of lettered parts.

wheel interrupted the light at its focal point so that the photographs obtained were series of dots, each having a certain time value. The unit of time recorded was variable according to the number of openings in the wheel, *i.e.*, according to the position of the wheel in the beam of light, as the wheel has concentric rows of openings varying in number. For our purpose it was found most expedient to use the fiftieth-seconds, with one opening filled in so as to produce a prominent break in the line of dots at every fifth of a second to facilitate reading of the records. The light passed through a double projection lens, so placed that it was directed into a parallel beam. A blue glass-plate and a cooling cell (*O*) were intercepted to reduce the intensity of the light. All the marginal light was cut off by the use of a diaphragm (*P*) 1 cm. in diameter. This served the important purpose also of reducing the size of the reflected image on the cornea so that the photographic record was a finer line and the time dots were more clearly distinguishable than when the full aperture of the projection lens was exposed. A control shield (*Q*) was set beyond the diaphragm so that the light might be entirely shut off from the subject's eyes when desired. It was operated by cords attached to the back end of the camera near where the experimenter sat. Both the arc light and the time wheel were also within his reach for adjustment.

Two small first surface mirrors near the subject were for the purpose of reflecting the light upon his right eye. In the close-up view of the front end of the apparatus (Fig. 1, *B*), which shows a subject in position, the relation of the mirrors may be made out. The light from the lantern was received by *R*, reflected to *S*, or to *T* as conditions required, and from this latter mirror to the eye. The entire eye is, of course, illuminated. However, the feature that is of prime importance for photographic records of eye movement by the Dodge method is the sharp high-light that, due to the curvature, is reflected from the cornea. It is this small bright spot that is focused upon in photographing. It is desirable that the position of mirror *S*, be such that the light can only be seen in indirect vision when the subject is reading and also that the high-light shall be reflected from the central portion of the cornea. Provision must also be made that the light shall come to the eye from such an angle that movements of the upper lid, which are associated with directing the line of regard downward, shall not obstruct it.

The reading material was placed on an inclined copy holder (*U*) below the lens (*X*) of the camera. The distance from the subject was easily adjustable as can be seen. A screen (*V*) was held over the copy by means of a rubber band. The latter was attached to a cord (*W*) which the experimenter could pull, without movement of the copy holder, and with no change in the lighting, thus quietly dropping the screen and exposing the text after the subject had fixated certain dots that represented the total length of the printed line. An ordinary reading lamp placed at the left of the headrest, gave satisfactory illumination to the reading matter. The reading was done with binocular vision, although only movement of the right eye was recorded. To register any possible head movement, a spectacle frame carrying a metal bead was worn, as shown in *B* of Fig. 1. The head and tooth rest, which were adjustable, as was also the height of the chair, made it possible for the subject to be comfortable and at the same time to hold the head still, during reading. The subject had a wide and unobstructed view and the arrangements were such that a relatively large sheet of copy (6¼ inches square of text) could be read in one continuous record. The advantages of using these full pages of copy for securing natural reading performance are obvious.

The barrel, or hood of the enlarging camera (*Y*) including the tube which carried the lens and projected into the foreground, was about 66 inches long. A Bausch and Lomb Protar lens was used. The magnification in this study was five times. Other magnifications up to nine times may be obtained with this equipment. The lens end of the camera could be raised or lowered and the whole camera, as it rested on a firm table top, was capable of any adjustment in the horizontal plane.

The most difficult feature to arrange in such a photographic outfit is doubtless the film moving unit. It is desirable to move the film continuously with even speed at any one of several different rates and in horizontal as well as vertical axes. We discovered a commercial form of pano-

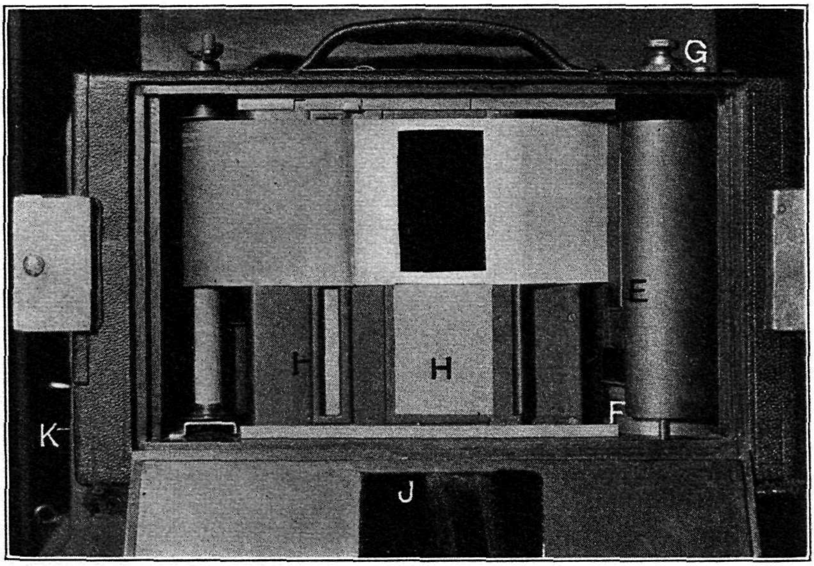


FIG. 2. Film box of panoramic type with back opened as when focusing for recording eye movements. The film is given a continuous even movement by being rolled upon drum *E*, which is revolved by spring motor, *F*, when the drum is clamped to the motor by nut, *G*. The focusing glass, *H*, may be moved behind the opening cut in the paper attached to the first end of the film. The box is easily clamped in any axes along which it is desired to move the film.

ramic camera which almost without any modification meets these needs admirably. This camera[1] is so useful as a photo-kymogrgph either by itself or in combination with other photographic equipment that it warrants brief description. The essential nature of the device may be readily understood from Fig. 2, which shows it attached to the hood (*Y* of Fig. 1) in one of the possible positions and ready for focusing. The rugged, leather-covered box is 12 x 7 x 4 inches, outside measurements. It will carry film 5 inches

[1] Manufactured by Folmer and Schwing Division of Eastman Kodak Co., No. 5 Cirkut Camera. The lens, bellows, and rack and pinion parts were taken off.

wide. The film, or rather the paper leader, is fastened to the drum (*E*), which is 9½ inches in circumference. This drum turns freely until clamped to the shaft of the spring motor (*F*) by a lock-nut (*G*). The spring motor is regulated by a centrifugal friction governor and a train of gears. The rate may be quickly changed by a speed control index near the release lever at *K*. Due to the even rate of the motor and the large diameter of the drum the movement of the film is very regular. The ground glass (*H*) may be slid behind the opening cut in the leader and thus, immediately after focusing and sliding the glass back, the film is ready to be started and reading begun. The recording light is admitted to the film through the opening above *H*, or through the narrower window (*I*). On closing the door the velvet cushion (*J*) holds the film closely against the exposure window. There is a revolution counter for the drum. By releasing the lock (*G*) the film may be rolled back on the spool by means of a small crank. In our investigation we used strips of film 60 inches long by 2½ inches wide. Two or three records could be taken side by side on such a strip.

Illustrative Records

The Dodge method of recording eye movements makes use of the fact that the cornea of the eye, illuminated by a constant beam of light, changes its angle of reflection during movement. The nature of these shifts in the reflected light may be made clear by photographs taken of the whole eye with a stationary negative as shown in Fig. 3. When the eye made a steady fixation during the entire exposure period the cornea reflected a single spot of light as photograph *A* will show. The spot is not perfectly sharp due to very slight eye movements during the attempted steady fixation. The eye made a horizontal movement of 40° during the exposure while *B* and *C* of Fig. 3 were taken, and for *D*, a vertical movement of the same angle. In these three pictures the spectacle frame carrying the metal bead was worn to make possible the recording of the head movement. During the exposure in each case the subject tried to make a steady fixation at each of the two terminal points and to pass directly from one to the other by one continuous movement, but it can easily be seen that the eye failed to do what the subject thought he did. Photograph *C* best illustrates this interesting feature and was in fact purposely selected from several records. It shows the difficulty, in spite of practice and voluntary effort, of maintaining an absolute fixation for a few seconds. The path of movement apparently is not

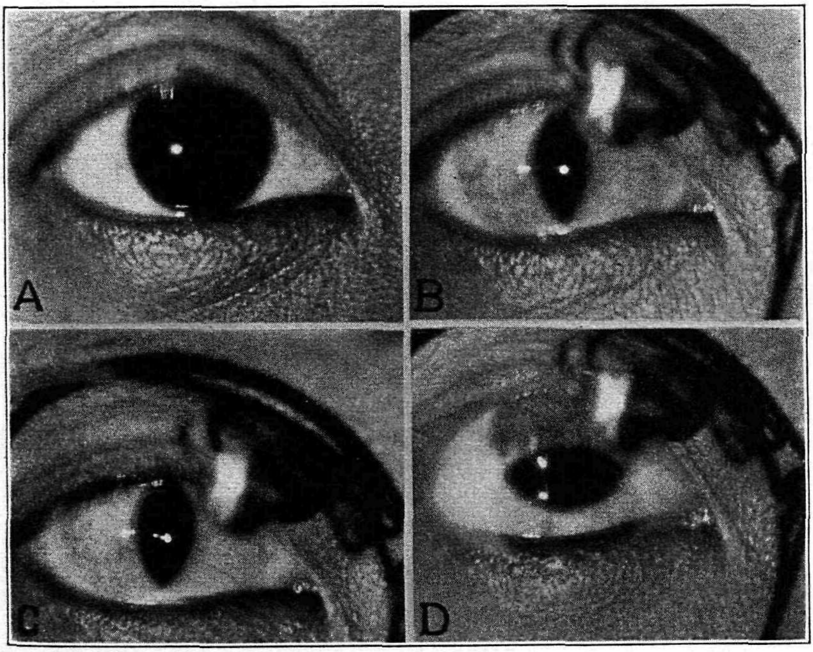
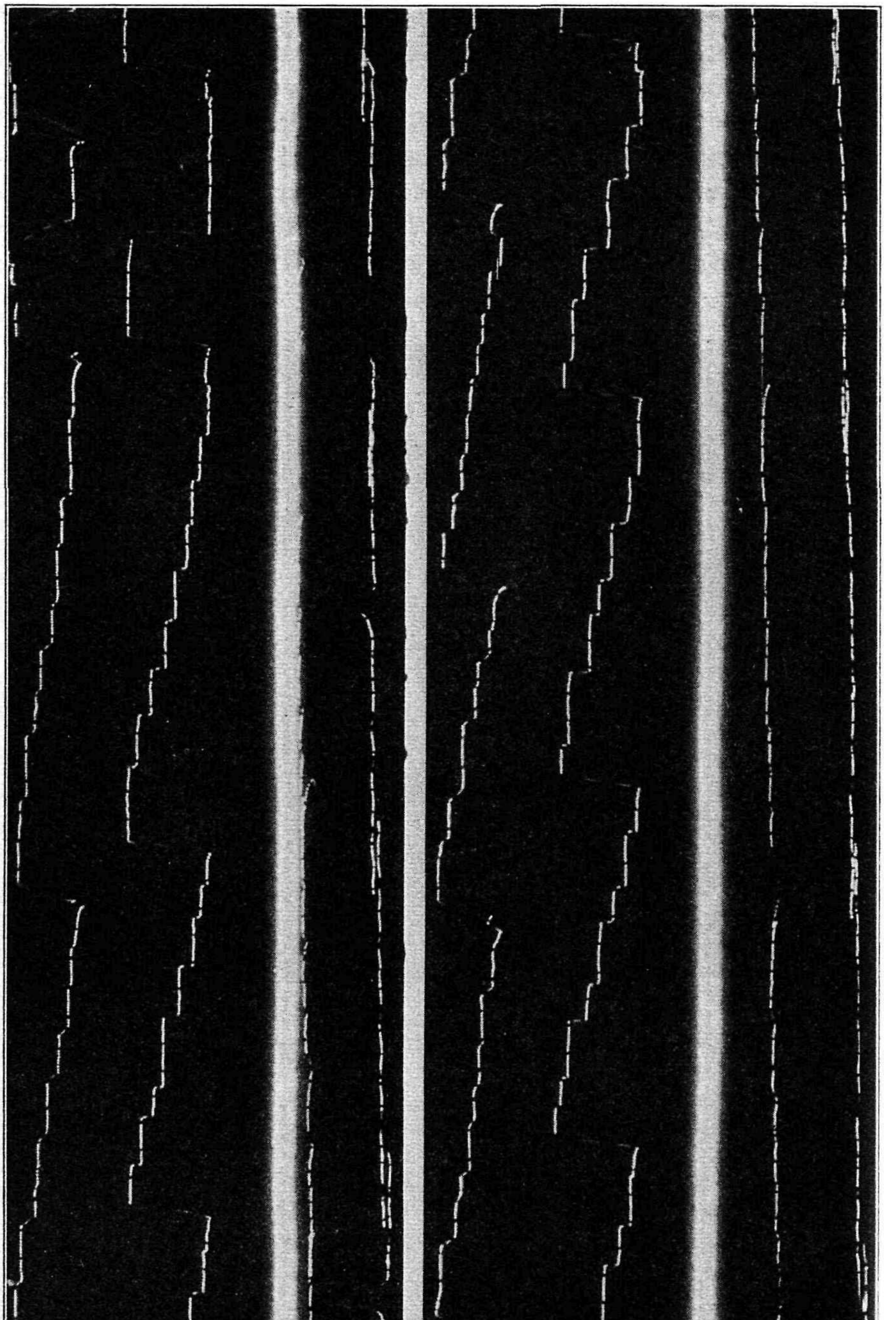


FIG. 3. Photographs (right eye of Chinese subject) with negative stationary, showing the brilliant corneal reflection of a carbon arc and the movements of this reflection associated with eye movements.

(*A*) Fixation practically constant during the entire exposure of the negative, no definite movement of the corneal reflection indicated.

(*B* and *C*) During the first half of the exposure the subject looked at a certain mark, then shifted the gaze to another mark 40° away on the horizontal axis and fixated this second mark during the latter half of the exposure. The approximately horizontal shift of the high-light is clearly indicated and it is noteworthy especially in *C* that the eye stopped at several points.

(*D*) Two fixation points, separated by 40° in the vertical were viewed. First the upper one and then the lower mark. In lowering the line of regard the movement was slightly nasalward. In *B*, *C*, and *D* the spectacle frame carrying the bright metal bead indicates the method of recording possible head movements.


A 1 2 3 4 5
B 1 2 3 4 5

straight, the horizontal makes a convex curve upward while the vertical slants nasalward as the fixation is lowered. Numerous reading records confirm this tendency for the saccadic movements to fail of executing a straight line between two fixation points.

A sample record of the eye movements in reading Chinese in both vertical and horizontal axes is reproduced in Fig. 4. During the reading the film was moved continuously by the spring motor mechanism (Fig. 2) described above. Four different reading trials are represented. In some the film was moved perpendicular to the line of type, *i.e.*, to the plane of eye movement, while in the others the film ran parallel and in the same direction as the print.

In the former, see records 1 and 2 (*B* is a continuation of *A*), each large displacement after the preliminary fixation at

Fig. 4. Illustrative records of the eye movements in reading Chinese in both vertical and horizontal axes. The length of line (6¼ inches) and the number and size of characters were the same and the difficulty of reading material approximately the same for both alignments. Photographs reproduced full size. The two sections are parts of the same record, *B* is a continuation of *A*. Both should be interpreted from the top downward. Four different reading performances are represented. Record 1 is vertical reading with the film moved horizontally; the headline (3, light from metal bead on spectacle frame) belongs with this record.

Record 2 is for horizontal reading with the film moved in the vertical.

Record 4 represents vertical reading with the film moved downward in the vertical.

Record 5 is for horizontal reading when the film was moved from the subject's left to right.

At the top of *A*, 1 and 2, the movements represent successive fixations of dots placed one at each end of the first line of copy. The screen (*V*, in Fig. 1) while covering the reading material and before it was dropped left these dots exposed. The fixation of these dots makes it possible to compare these movements with the shifts which occur between successive lines in reading. Characteristic differences are shown between the preliminary fixations for vertical and horizontal axes. The latter seems to be rather less complicated, with movements more direct and also more rapid. The amplitude for the horizontal axis is greater by about 3 mm. the values being approximately 8 and 11 mm. This difference modifies somewhat the appearance of the two reading records. The time is recorded in fiftieths of a second. Every one fifth second one dot of light is dropped out. Therefore the records show 9 closely joined dots of light between breaks. Shifting vision from the end of one line to the beginning of the next, in this case a distance of 6¼ inches, requires about .05 of a second. The individual pause of the eye on some character during reading occupies more nearly .20 seconds. Records 4 and 5 show that the lateral deviations of the eye away from the direction of the line of reading are relatively small. The two prominent deviations with breaks in record 5 of *A* are winks of the eye.

the very beginning of *A* means a movement to a new line, while the shift from one reading pause to another within the line shows lesser displacements. The relative magnitude of each movement can be seen and the record can be projected upon the reading material by means of a lantern, thus locating the positions of the pauses within the several lines. In the figure it will be noted that eight or nine pauses are used in the reading of each line of copy, whether the arrangement is vertical or horizontal. It should be said that this material was fairly familiar to the man who made this record.

In the records when the film is moved parallel to the reading (4 and 5) forward movement of the eye, *i.e.*, progress within the line is represented by slight breaks and the return sweep to a new line by overlapping, which can be best seen in the case of 5. Records of this sort were taken to examine the shifting of the eye above or below, to the right or the left, of the line of reading material.

Regressive movements are not easily observable in such records, but the duration of the pauses can be determined in both types by counting the dots with the aid of a magnifying glass. The individual time dots do not show well in a reproduced record. By counting the fifth second intervals (gaps in the white line of time dots) the reader may gain a fairly accurate idea of the time values represented.

There are noticeable differences between the records for vertical and horizontal reading. In the latter the pauses seem more steady and distinct, while in vertical reading, they show a tendency to gliding into a continuous curve. This seems to be true aside from the fact that the horizontal print records as a somewhat larger lateral deflection in our photographs. Casual inspection of the records reveals no characteristic difference in the number of pauses, length of pauses, or in the number of regressive movements. There is, however, a distinct difference shown at the time of changing to a new line of print. When reading vertical print, the return sweep of the eye to the beginning of a new line characteristically shows a sharp loop just preceeding the first fixation pause. This feature is commonly found in the records for all Chinese subjects whom we have used. We have observed it also in records of fixation movements covering 40° in the vertical axis with subjects used to reading only English and European languages in the horizontal.

Results

Two groups of experiments are reported in this paper: (1) a comparison of the eye movements in reading short selections of English and horizontal Chinese of two sizes, with the line length equal, and (2) a comparison of the reading records for Chinese texts of vertical and horizontal alignment. We will present the results for these latter experiments first.

Data were collected from the reading of four selections by each of 11 subjects, all Chinese students at Stanford University. Each selection was a complete paragraph containing 10 to 12 lines, from magazine articles. Selections *A* and *B* were vertical, while *C* and *D* were horizontal. A full vertical column was 6¾ inches in length with 35 characters, and the horizontal line was 5½ inches long with 23 characters. The punctuation system was also slightly different between the vertical and horizontal passages. The characters were of the same size for both alignments. With *B* and *D*, the records were taken while the film moved in the same plane as the eye, in order to detect any lateral shifting in reading a line. The other two were made while the film ran perpendicular to the eye movements, thus recording the spacing of the successive pauses. All four selections were read, in alphabetical order, during one session, preceded by the reading of preliminary material under the same conditions, without actual recording. The subjects were instructed to read silently and understandingly. Speed was left to each subject's own habit and inclination, and comprehension was tested by questions without warning, after all four selections were read.

The average duration in hundredths of a second for the reading pauses of the 11 subjects and for the four selections used are shown in Table I., which gives as well the standard deviation for each average value. The subjects are indicated by initial letter in the left hand column. Unfortunately there are a few gaps in the table as some of the records were too faint to be read with exactness. In the calculation of the means which are shown in the bottom line of the table, only those subjects having legible records for all four selections have been included. In general it will be observed that the

TABLE I

AVERAGE DURATION OF READING PAUSES, WITH STANDARD DEVIATIONS
(Time units hundredths of a second)

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	25 (8.9)	26 (9.3)	23 (8.3)	27 (8.2)
H	43 (16.6)	41 (16.9)	34 (12.8)	36 (13.1)
L	33 (14.1)	35 (14.6)	29 (10.9)	— —
J	27 (7.5)	— —	34 (11.8)	— —
R	34 (10.9)	34 (9.3)	28 (6.1)	32 (9.4)
E	31 (11.1)	32 (11.4)	29 (9.1)	31 (10.9)
W	31 (10.4)	35 (7.9)	33 (12.7)	36 (13.6)
Y	29 (10.4)	34 (14.8)	29 (10.9)	30 (9.3)
K	27 (7.6)	29 (5.7)	— —	30 (7.0)
T	27 (6.8)	28 (9.3)	— —	30 (10.2)
C	— —	29 (11.2)	31 (10.5)	— —
Mean [1]	32 (11.4)	34 (11.6)	29 (10.0)	32 (10.7)

reading pause for both vertical and horizontal material is about 0.3 seconds. The standard deviation is about ⅓ this value but more variable. The means for selections *A* to *D* in order are .32, .34, .29, and .32 seconds. While, as stated above, *A* and *C* were taken in one manner, that is with the film moving in a direction perpendicular to the line of eye movements and *B* and *D* in another it is not just to compare *A* only with *C* and *B* only with *D* in reference to the duration of the reading pauses. There are really four comparisons to be made: *A–C*, *A–D*, *B–C* and *B–D*. Out of 32 such individual comparisons, 18 are longer for the vertical, 12 longer for the horizontal, and 2 equal.

A more consistent difference for the two alignments as represented by the texts employed, is shown in the average number of words covered by one reading pause. These

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

results are given in Table II., which is arranged in the same manner as the preceding one for the duration of reading pauses. The average number of words perceived, during the time that the eye is quiet in one position in the line, varies from 1.0 to 3.3, but in general is approximately two characters. For the selections *A* and *B* printed in the vertical the mean values for the subjects having legible records are 2.1 and 2.5. The comparable results for selections *C* and *D*

TABLE II

AVERAGE NUMBER OF WORDS PER READING PAUSE

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	2.1	2.5	1.6	1.8
H	1.3	1.7	1.0	1.2
L	2.1	1.5	1.4	—
J	2.9	—	2.8	—
R	2.2	2.1	2.3	1.7
E	2.7	3.3	2.1	2.0
W	2.6	3.2	2.8	2.3
Y	2.0	2.1	1.4	1.6
K	2.7	3.2	—	2.2
T	2.7	2 6	—	2.2
C	—	2.0	1.8	—
Mean [1]	2.1	2.5	1.9	1.8

in the horizontal are 1.9 and 1.8 words per pause. To state the results in terms of speed of reading the average number of words per second of time is indicated in the figures of Table III. Here the range is from 2.9 to 11.0. It is observable that the conspicuously high values occur in the columns for vertical selections. The mean values for these selections, *A* and *B* are 6.9 and 7.6 words per second. The results for the horizontal axis are 6.5 and 5.7, for selections *C* and *D* respectively.

Wide individual variations are present, as the tables show and are more prominent than any differences between the texts. In other words, the same subject reads the different selections more uniformly than the different subjects read the same selection. The speed of reading is of course a

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

function of the temporal duration and the spatial span of the pauses. Short duration and long span result in rapid reading, while long duration and short span result in slow reading. Subject *H*, for instance, has the longest pauses as well as the shortest span and consequently reads about half as rapidly as the average and but little more than a third as fast as the most rapid reader.

TABLE III

SPEED OF READING. AVERAGE NUMBER OF WORDS PER SECOND

Subject	Selection *A* Vertical	Selection *B* Vertical	Selection *C* Horizontal	Selection *D* Horizontal
P	8.2	9.4	7.0	6.8
H	2.9	4.2	2.9	3.3
L	6.4	4.3	4.6	—
J	10.7	—	8.2	—
R	6.5	6.3	8.2	5.4
E	8.8	10.6	7.4	6.6
W	8.3	9.0	8.4	6.5
Y	6.9	6.1	5.0	5.3
K	9.9	11.0	—	7.4
T	9.8	9.1	—	7.4
C	—	7.1	5.6	—
Mean[1]	6 9	7.6	6.5	5.7

The number of pauses per line is not tabulated. But from Table II., it can be seen that on the average 14 to 17 pauses are required for a vertical column and 12 to 13 pauses for a horizontal line. As the latter has a length equivalent to only 81 per cent. of the former, the apparent great difference need cause no wonder.

A general comparison between vertical and horizontal reading in the three tables shows that the vertical has a slightly longer duration of the reading pauses but each pause covers a greater number of words. The resultant of these considered in terms of number of words read per second, therefore, seems to give the vertical some advantage. It must be said however that no unequivocal conclusion for comparing vertical with horizontal could be stated on the basis of these experiments, since comparisons in regard to length of line, leading, and punctuation as well as content

[1] In calculation of the means only those subjects having legible records for all four selections have been included.

are not warrantable. However, further experiments made with strictly comparable texts for the two alignments although not yet ready for publication bear out these results.

Our data on different sizes of Chinese and on English were gathered during the preliminary stages of our study under conditions slightly different from those described above. Instead of the moving film, we used a Dodge falling plate camera.[1] Chinese was used only in the horizontal form, and each piece of reading material was limited to not more than four lines. These were exposed by means of a tachistoscope placed to the left of the lens at an adjustable distance from the subject. The reflecting mirror *S* was farther to the left than the position shown in Fig. 1, *B*. We employed the two sizes of Chinese characters, No. 4, about 3/16 in. sq., 23 characters to the line; and No. 5, about 2/16 in. sq., in lines of 30 characters. Also we used two sizes of English, 9-point modern style, which has an average of 14–15 words to a line, and 12-point old style, 13 words to a line.

The length of line was practically equal, being 5½ inches except for the 9-point English, which was 5 inches. The English and Chinese texts were the ordinary sizes of magazine print and seemed to us comparable in legibility. The large size Chinese was exposed three lines at a time, all others four lines. Only the writers served as subjects, but no less than 75 records were made in all. Thus the average values given in Table IV. are representative of the subjects. Although

TABLE IV

COMPARISON OF THE READING OF CHINESE AND ENGLISH AND OF DIFFERENT SIZES OF TYPES

Subject	Language	Size	Pauses per Line	Time per Pause (Seconds)	Words per Pause	Words per Sec.
M.	English	9-pt.	10.5	.30	1.4	4.7
M.......	"	12-pt.	9.9	.33	1.3	3.9
S.......	"	12-pt.	11.9	.32	1.1	3.4
S.......	Chinese	No. 4	13.7	.24	1.7	7.1
S	"	No. 5	16.4	.27	1.8	6.7

[1] See note 1, on p. 345.

these results may not be typical of the general reader, a comparison between the type sizes and the two languages is justifiable.

From Table IV., it is seen that in Chinese as well as in English the smaller size (9 pt. English and No. 5 Chinese) requires a greater number of pauses per line, but each pause covers a slightly greater number of words. The duration per pause is slightly shorter for small-size English and large-size Chinese, than for large-size English and small-size Chinese, respectively. The results in terms of words per second reflect the fact that the difference between the two sizes of Chinese was not so marked as between those of English.

The more interesting comparison is between Chinese and English. It appears rather definitely that the reading pause in the case of Chinese is shorter than in English, both spatially and temporally. This twofold difference influences the speed of reading in two opposite directions. But the number of words read per pause is much greater for Chinese, which has more words to a line. If, therefore, the number of words read per unit time is taken as the criterion for reading speed, Chinese is apparently read more rapidly than English. It should be mentioned that English is to S a foreign language, but the general tendency holds no less well if we only use the record of M for English.

Discussion

In general, we may say that the process of reading Chinese is essentially the same as for reading English. Each line is covered by a series of pauses and movements, and by each pause usually more than one character is read. Differences between Chinese and English in the number of pauses per line, of words per pause, and of words per second are attributable to the fact that Chinese words are all squares and are more compact than the English words. The space for an English word of average length can more than accommodate one Chinese character that is of equal visibility; hence the difference in the number of words per pause. On the other hand, one fixation placed at a significant part may be adequate for reading a long English word, while several Chinese words occupying the same space may not be all clearly perceptible at once; hence the difference in the number of pauses per line. The difference in the duration of the reading pause we shall not attempt to explain, since a comparison between Tables I. and IV. indicates that S had a shorter duration of pauses for Chinese than the average of the group of subjects, and that the latter is rather similar to the pause duration for English.

The square shape of the Chinese characters makes the accurate location of a reading pause, from the photographed record, relatively more difficult. Shifting seems to often occur within a pause, rendering it occasionally impossible to locate the pause upon a single character. A slight amount of lateral shifting is also present, suggesting that either the eye movements lack perfect coördination or some part of a character attracts attention more than the other parts. In extremely slow reading, movements are sometimes so short that accurate separation into pauses becomes very difficult.

Regressive movements occur rather often and are to be explained differently on different occasions. The most frequent cases are undoubtedly due to inadequate perception, when the eye leaps too great a distance or leaves a fixation too soon. When the movement is long, faulty attention is probably involved, or it may be due to misinterpretation which is not discovered until revealed by subsequent reading. Several cases are found where a regressive movement sweeps back to the end of the preceding line after landing at the beginning of a new one. Here, besides the explanations already suggested, landing at a wrong line may be responsible. Regressive movements at the beginning of a line, which are more frequent than elsewhere, mean that the return sweep often stops short of the requisite distance. This error of doing too little rather than enough or too much is confirmed by measurements of simple saccadic eye movements. It appears to be a tendency to abbreviate the coördination.

That vertical and horizontal eye movements are qualitatively different has already been mentioned in connection with the illustrative records. The making of a loop in the upward return sweep is a rather common occurrence. We are not entirely satisfied with any explanation of this curious phenomenon, although it may be attributable to the generally accepted assumption that vertical eye movements involve a more complicated coördination of the muscles than do horizontal movements. Photographic records of vertical and horizontal reading where the length of line is identical show a greater displacement of the terminal points in the horizontal. This is also a feature for which we shall not here attempt any definite explanation.

Naïve speculation upon grounds of the position and opening of the eyes, of the external muscles involved in movement, of the movement of the eye-lids, and of the usual over-estimation of vertical distance would lead one to expect horizontal reading to be the more efficient. But our results do not bear this out. While the data presented in this paper warrant no hard and fast conclusion for lack of strictly comparable reading material, it may be stated that vertical reading seems also to be at an advantage in a more elaborate study, now near completion. This other study made use of duplicate forms of six kinds of material with varying degrees of difficulty, each form being especially printed in the two axes, with equal length of line and equal spacing of the characters. As the horizontal method of reading is of comparatively recent origin as an alignment for Chinese texts, our subjects have undoubtedly had more experience in vertical reading. It is conceivable that long continued practice *may* have more than balanced any inefficiency for the vertical axis, but nothing yet has come to light to show that vertical reading is intrinsically less efficient than horizontal.