EXPERIMENTAL STUDY OF READING

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The investigations which are covered in this review may be grouped as follows: (1) legibility of print; (2) visual apprehension; (3) perception and eye movements in reading. For the most part the studies considered succeed those which were reviewed in the preceding papers of this series (38, 39, 45). No publications appearing later than April, 1932, are included.

Bibliographies, summaries of part of the field, textbook surveys, discussions and comments, and reprinting of material that has appeared earlier will be found in references 2, 3, 4, 12, 13, 20, 21, 24, 27, 38, 39, 44, 45, 54. Several new devices or modifications of previous apparatus have been constructed for use in reading investigations. These are described in references 1, 11, 23, 41, 43, 52. Precautions in methodology are discussed in 29.

LEGIBILITY OF PRINT

The legibility of advertising copy has become an increasingly important problem during recent years with the ever growing use of colored printing. Experimental evidence on the changes in legibility accompanying variations in color of print in a normal reading situation is presented by Tinker and Paterson (47). Employing speed of reading as a measure of legibility and eleven combinations of colored ink and paper they discovered that the combinations providing (1) good legibility were black on white, green on white, blue on white, and black on yellow; (2) fair legibility were red on yellow, and red on white; (3) poor legibility were green on red, orange on black, orange on white, red on green, and black on purple. From this evidence they formulated the rule: “In combining colors (color of ink and-paper) care must be taken to produce a printed page which shows a maximum of brightness contrast between print and background.” While the above order of legibility might not hold in a

Experiments on visual apprehension will be included since the span of apprehension for certain types of material appears to be intimately related to perception in reading.
situation where both letters and background are printed upon white paper with different colored inks, the conclusions concerning the importance of brightness contrast is applicable to both kinds of printing. In another study, and with the same color combinations used by Tinker and Paterson, Preston, Schwankl and Tinker (31) measured legibility by determining the farthest distance from the eyes at which five-letter words could be read accurately. The obtained order of relative legibility of the color combinations is approximately the same as that obtained in the previous study as is shown by the correlation coefficient of +.864 between the two orders. The most marked discrepancy in the two investigations is in the rank of black on white which is 1 (most legible) in the speed of reading experiment and 4 in the distance-perception study. The fact that Luckiesh (45) also found several color combinations more legible than black on white suggests that there is a true difference between the relative legibility of black on white in the normal reading situation and when read at a distance. Employing a distance method, and similar color combinations Sumner (34) arrives at approximately the same conclusions as the above writers concerning the legibility of colored printing. He discovered in addition a correlation of +.54 between order of legibility and preference for the combinations used.

The apprehension of colored letters was found by Tinker (48) to be influenced to a considerable degree by the brightness contrast between symbol to be apprehended and its background. The results will be discussed further under "visual apprehension." Miyake, Dunlap, and Cureton (25) measured the relative legibility of colored (including black and white) numerals on (1) colored and (2) a black background by noting the number of times each combination was read correctly during a very brief exposure. The rank orders of relative legibility show that in general, as the luminosity difference between printed numerals and background decreased, the legibility of the color combination decreased.

A series of reports have been concerned with the influence of brightness contrast between symbol and background on perception of achromatic stimuli. In a carefully worked out series of experiments Ferree and Rand (16) measured the speed of vision in perceiving dark objects on light backgrounds and light objects on dark backgrounds by determining the shortest exposure during which a symbol could be distinguished accurately. Broken circles subtending visual angles of 1 to 3 minutes were used as test objects. Eleven degrees of illumination intensity varying from 1.25 to 100 foot-candles were
employed. The four combinations of brightness used in constructing the test objects were black on white, white on black, white on gray, and black on gray. Almost without exception the rank orders of brightness combinations for speed of vision (i.e., relative legibility) were found to be white on black most legible, black on white next, white on gray next, and black on gray poorest. This rank order corresponds exactly with the degree of luminosity difference between symbols and backgrounds under the conditions of their experiment. In a later report Ferree and Rand (17) have amplified their discussion of the above findings. Employing a somewhat different technique Taylor and Tinker (36) also found that the greater the luminosity between symbol and background, the higher the accuracy of apprehension.

Although the experiments just discussed do not involve a normal reading situation it was possible to maintain normal reading conditions in another study concerned with approximately the same problem. Paterson and Tinker (30), using the two equivalent forms of the Chapman-Cook Speed of Reading Tests with 280 subjects, compared the speed of reading black print on white background with white print on black background. They found a 10.5 per cent difference in favor of the black on white printing arrangement. In another investigation Holmes (22), employing as a measure of legibility the distance from the eye at which a symbol could be read correctly, compared the perceptibility of isolated words printed in black type on white background with words printed in white type on black background. (In both of these studies the white printing was achieved by printing the black background from zinc etchings so that the white letters were produced by the enamel paper showing through as white outlines.) A 14.7 per cent advantage was found for black type on a white background. A consideration of all related studies suggests that factors other than brightness contrast are involved as determinants of apprehension in perceiving printed words and other symbols, especially in approximately normal reading situations. In a study now in progress at Minnesota an analysis of several factors which may influence the perceptibility of black and white print is being made.

In another part of their study of intensity of light and speed of vision, Ferree and Rand (15) investigated the effect of size of object and difference of coefficient of reflection as between object and background. They discovered (1) that increasing size of visual symbol greatly increased its legibility under all degrees of illumination, and
(2) that the effects of increasing the difference in coefficient of reflection (luminosity) between object and background were very similar to those of increasing size of object.

Several other aspects of legibility have received attention. In another of their studies of typographical factors influencing speed of reading Tinker and Paterson (46) investigated the effect of simultaneous variation of type size and line length. The speeds of reading text, printed line for line in 6, 8, 10, 12, and 14 point type were compared. Text in 8 point type with 17 pica line length, and in 10 point with 19 pica line length were read fastest and both at approximately the same rate. Still smaller type with shorter lines and the larger type with longer lines were read slower. Evidently both type size and line length must be properly balanced (with other factors not yet investigated) to produce a printed page of maximum legibility.

After pointing out the lack of conclusive evidence concerning optimum length of line for children's books, Gates (18) presents evidence which indicates that the line length (either short or long) to which the child has become accustomed produces fastest reading. Employing first grade children, speeds of reading test material in short, medium, and long lines were compared. For the experimental group accustomed to reading lines of various length, one length was about as good as another. Where children (control group) had read text principally in one length of line, however, that length produced a greater speed of reading. While these results may not be applied to adult reading, it is obvious that optimum line lengths should not be recommended without sufficient proof that they are optimum.

An unsuccessful attempt has been made by Buckingham (5) to discover which of several typographical arrangements is best for children's texts. The law of the single variable in its traditional sense was rejected in favor of simultaneous variation of several typographical factors. Twelve, 14 and 18 point type; 3, 4 and 5 point leading; and 14½, 21 and 24 pica line lengths were combined in various ways to form 18 typographical arrangements of textual material. Twelve point type in either a short or medium length line and with 3 or 4 points leading respectively appeared to produce fastest reading. Buckingham's results are of no value either to the printer or to the educator for the following reasons: (1) the selections employed were not satisfactorily equated for difficulty according to the sequence in which they were to be read; (2) no account was taken of sampling errors which are apt to be large in short samples of reading performance; and (3) no measures of dispersion of scores
considering both the uncontrolled nature of the experiment and the method of presenting results one cannot be sure that even the largest differences obtained are significant. Indeed, it is questionable to assume that variations in typographical arrangement within rather wide limits produces constant differences in reading performance at any age level at which reading habits have not become stable.

Although Tinker (40) found that Old Style was somewhat more legible (distance method) than Modern numerals when in isolation, and much more legible when printed in groups, the Modern numerals were read under ordinary reading conditions just as fast and just as accurately as Old Style. It is suggested that extensive reading may lead to greater ocular fatigue with Modern numerals because their perceptibility is poorer.

To increase the ease of finding German words in German-English dictionaries and similar word-lists Taylor (37) suggests that all syllables or even letters common to a series of words (as schmelz- of schmelzarbeit, schmelzbar, etc.) be omitted after they have once been given. In mathematical tables of the present day common figures are eliminated to facilitate the finding of numbers. It is desirable to have experimental evidence on this and other factors which may effect the legibility of tabular material and word lists for usually it is not safe to infer the most legible typographical arrangement.

Turner's (51) results showed that manuscript writing has a significant margin of superiority in legibility in comparison with cursive writing. This margin appears to be due to the independence of the letters, good spacing between words, and economy in line space. This finding has important implications for teaching of writing since production of manuscript writing is faster than cursive writing in most elementary grades.

Earlier results are confirmed by Tu (50) who found that Chinese characters were read more rapidly in the vertical than in the horizontal arrangement. Geometric figures, however, were read faster in the horizontal by both Chinese and Americans. Apparently the most efficient typographical arrangement for Chinese readers is largely determined by past reading experience.

Ostwald (28), having noted that there appears to be no orderly plan of determining the size of a printed page for various kinds of subject matter, suggests that each succeeding smaller size of page may be produced by halving the larger sheet; that the different sizes be similar to each other geometrically; and that the two sides of a
page always have the ratio $1: \sqrt{2}$. Such strict uniformity is probably not practical although few would deny that there is room for improvement in methods of deciding the best size for a printed page.

To determine their usefulness as test objects of visual acuity, Gnad (19) determined the relative legibility of numerals and capital letters. ACLDVOU714 were most easily recognized; TPZIGEFKNWR623 were of medium legibility; and HMYXSQB389 of poor legibility. The Snellen E-Test was probably more legible than any of the letters or numbers. An analysis indicated that legibility depended upon (1) visual angle subtended by strokes in test object, (2) distribution of black and white in symbol, (3) characteristic form of symbol, (4) symmetrical distribution of space in objects, and (5) simplicity of form.

**Visual Apprehension**

As part of a more extensive investigation on visual apprehension, Tinker (48) determined the influence on perceptual span of three methods of scoring responses in which accuracy of position in the series as well as correctness of reproduced symbols were considered. In general, it was found that absolute span of visual apprehension changed significantly from one scoring method to another, but size of span in relation to others in the group (relative span) showed little variation with change in scoring method. All methods of scoring had high internal consistency.

In the same investigation Tinker analyzed the influence of letter position on visual apprehension of series of eight letters each and found a definite effect. From left to right there was a decrease in the average number of letters correctly reproduced in each succeeding letter position through the seventh and then a slight increase in the last position. The decrease from the first to the fourth was constant and gradual. There were rapid drops in score from the fourth to fifth and sixth to seventh positions, and always an increase at the eighth position. These produced marked irregularities in the consistency of trend from position to position in the series. Both absolute and relative variability of scores increased consistently from letter position one through eight.

In general, Crosland's (9) findings for influence of letter position on apprehension agree with Tinker's (48). A decrease in score occurred in each letter position until the end position which showed a slight increase. Crosland employed letter series of various lengths (4 through 9). The curves of average scores at each letter position
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for series of 6, 7, 8, and 9 letters, which had few or no entirely correct series, approximated each other closely, but the curve for the 4-letter series is well separated from the others. This was due apparently to the fact that the 4-letter series had 52.1 per cent of correct responses in all 4 positions simultaneously (whole series correct). When only series with one or more errors were included, the curves for all series (4 to 9 letters each) coincide closely (Figure a). Crosland’s results (1) confirm Tinker’s (48) contention that the most adequate measure for influence of letter position is obtained by using a letter series which is just longer than the span of the subjects, and (2) supports the reviewer’s previous suggestion (39) that a high per cent of correct responses for short series tends to influence the shape of the composite curve (showing score in each succeeding letter position) when scores for series of various lengths are averaged all together.

Tinker (48) has studied the influence of color on visual apprehension for (1) homogeneous colored series, and (2) heterogeneous colored series of letters. With the homogeneous colored series there was no relation between span of apprehension and either color preference or attention value of the colors. There was a slight relation to luminosity, however, for in general, the smaller the luminosity difference between letter and background, the less the span. With heterogeneous colored letters there was no relation between apprehension score and color preference, but an appreciable relation between score and both attention value and luminosity of the colors. No marked sex differences appeared. In comparing spans for homogeneous with spans for heterogeneous colored letters it was found that the former were always larger. Employing black, dark gray, and light gray letters in homogeneous and heterogeneous series, Taylor and Tinker (36) discovered that the amount of luminosity contrast between stimulus and background was an important determinant of visual apprehension. As the result of an analysis to discover some of the factors influencing visual apprehension of chromatic and achromatic stimuli Tinker (48) states: “Both direct and indirect evidence from a number of related investigations warrant the following conclusions concerning comparative potency of hue and luminosity of color on visual apprehension and perception of symbols: (a) Hue of color has little or no effect on apprehension and perception. (b) The luminosity contrast between symbol to be apprehended and its background has a large and very important influence on apprehension and perception. (c) Lag of visual sensation, which is due
to brightness contrast between symbol and background, probably explains to a large degree the differences obtained in visual apprehension and perception of symbols varying in color and luminosity.

In a comparative study of visual apprehension in nursery school children and adults Taylor (35) obtained a span of 1.92 items for the children and 6.17 for adults. Inanimate objects were more readily apprehended by adults, and animate objects by children. For the children, size of apprehension score was closely associated with both chronological and mental age.

**Perception and Eye Movements in Reading**

On applying Huey's technique to the reading of Chinese Chou (7) found, as Huey had for reading English, that left and upper halves of Chinese characters are more suggestive of the whole-characters than either right or lower halves. This is probably due to the fact that radicals are on the top or the left, and the characters are mostly written from these directions. In a second report Chou (8) shows that Americans were able to judge true positions of Chinese characters with a fair degree of accuracy, and that most of the errors committed were reversals.

Davidson (10) employed massed forms as an aid in teaching four-year-old (M.A.) children to read. These massed forms duplicated actual word forms and served to generate interest, train discrimination, and improve the use of cues in word perception. There appeared to be a definite transfer to the real reading situation.

Errors made in learning mirror reading were utilized by Tinker and Goodenough (42) to study certain factors influencing word perception. Analysis of errors yielded results similar to those of certain earlier studies: (1) initial letters were of more importance for word perception than either final or intermediate letters; (2) context was frequently utilized to good advantage in apprehending difficult words; and (3) word-length was an important determinant of word form.

Tinker (49) shows that although capital letters are more easily perceived than lower-case letters of the same point size, total word form is more potent in the perception of words in lower-case than in all capitals where perception seems to occur largely by letters. This probably explains the faster reading of text in lower-case type.

Downey's (14) analysis of errors of perception on brief exposure of sentences with many typographical errors showed the three most important types of errors to be (1) supplying omitted letters,
(2) letter substitution, and (3) word substitution. This tendency to proof-readers' illusion appeared to correlate to a considerable degree with intelligence.

In her report of a carefully planned eye movement experiment Vernon (55) points out the chief characteristics of proof-reading in comparison with normal reading. In ordinary reading, reading time, and frequency and duration of pauses were very similar for the two kinds of readers (normal and proof-readers). The variability of reading performance and number of regressions were considerably less for proof-readers than for the controls. In reading material with misprints, however, the reading time and number of regressions increased much less and then remained more constant for proof-readers than for the other subjects. Vernon concludes that this was due to the fact that the proof-readers were able to adopt and maintain indefinitely a more efficient attitude or mental set towards each type of reading material than the normal readers.

In another study Vernon (53) reaches some important conclusions concerning the influence of motor ability of the eyes, and interest and affective reactions on eye movements in reading. Steadiness and accuracy of voluntary fixation and accuracy of voluntary movements appeared to be associated with relatively few fixations and regressions in reading. Lack of attention to meaning led to the most rapid reading and most regular eye movements. With difficulty in comprehension and either high personal interest or strong affective reactions to the printed material the reading was slow and eye movements revealed marked irregularities. Since Vernon employed very few and highly selected subjects these interesting and suggestive results should be accepted as tentative.

According to Butsch (6) fixations of the eye in typing are much more frequent and longer than in ordinary reading. Rapid typists, however, use fewer pauses than slow writers. The eye-hand span was found to vary directly with speed of typewriting, ranging from zero to 13 letter spaces. Most typists tended to keep the eye about 1 to 1½ words ahead of the hand so that there was about one second between seeing a letter and writing it. There was little evidence, even for expert typists, that writing is frequently done by phrases. "Apparently during typewriting the eye does not read at all at its maximum pace or even at the rate which is determined by the requirements of comprehension, but instead reads only rapidly enough to supply the copy to the hand as it is needed."

Rebert (33) photographed eye movements of subjects as they
read chemistry, algebra and physics formulas in context. The formulas were read with unitary fixations (i.e., as words) only when they were quite familiar, very simple and merely contributed to an understanding of the context. In general, formulas tended to be read in an analytical manner and in detail, especially when the context directed attention to relationships between characters of the formulas. This held for both naive and experienced (with formulas) subjects. The fact that the experienced subjects used slightly fewer pauses and regressions than the naive subjects in reading formulas has little meaning since Rebert's groups were small. Longer pauses and relatively more fixations and regressions were employed to read the formulas than the context. Rebert's concluding statement that "familiar chemical formulas tend to be read as units in the same manner as words are read although analytical readings occur" may be somewhat misleading since only the simplest of such formulas, as HCl, were read with single fixations.

In another photographic study of the reading of familiar numerals, Rebert (32) found that, in general, the numerals tended to be read in the same manner as words of the context although in several cases detailed readings involving two or more fixations on the numerals occurred, especially with the numeral 3.1416. Pauses on numerals were longer than on words of the context.

Murray (26) photographed the eye movements of stutterers and normal individuals while they read hard prose, poetry, and light prose. Since there were only 18 subjects in each group the conclusions based on group comparisons can be only tentative. The stutterers used more fixations and regressions, a longer perception time, but shorter pauses than the normal readers. The author's comparison of his results with those of Buswell has no validity whatever since (1) the former use typewritten and the latter printed copy, and (2) the reading material and the length of line in the two studies were different. In his qualitative analysis Murray identifies six eye movement patterns which were classified according to presence and position of regressions in reading a line of print. A similar classification was made for pause duration. The results of the author's comparison of stutterers and normal readers by means of these classifications may be stated in simpler terms by merely saying that the stutterers manifested greater irregularity in sequence of fixations and in pause duration than normal readers.

As part of a more elaborate study of reading Davidson (10) photographed the eye movements of a child three years and seven
months old and found the records superior to those of ordinary children in the third grade.

REFERENCES