EXPERIMENTAL ANALYSIS OF THE WRITING MOVEMENT¹

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The experiment here reported consisted in an analysis of the handwriting movement of adults and of children by measurements of the size, speed and pressure of writing. By an interpretation of the results some of the psychological factors in the writing process and in its development have been determined. Writing is characterized by a decided rhythm which is more pronounced in the developed than in the undeveloped movement. In this as well as in other ways the movements by which the successive parts of a complex letter or series of letters are produced are united in such a way as to indicate that writing psychologically is not a succession of separate acts, but is an organized process in which individual elements have their place in the larger units of letters, words or groups of words. The component elements in the process come to be treated not as individual strokes or movements but rather as stages in the progress of the organized whole. The writing of children stands, however, in contrast to more developed writing in that it is less rhythmical, less organized and less automatized. That the child gives more continuous attention to the details of the writing movement is inferred from the fact that the movement is more uniform in speed throughout the different parts of the letter.

I. THE PROBLEM

The writing movement may be analyzed in two ways. In the first place the number of component movements—finger, hand, arm, etc.—may be determined and their nature investigated as in the experiments of Judd (**11**) and Obici (**17**); and in the second place the characteristics of the total resultant movement may be investigated. The present report deals with an investigation of the second type. The characteristics of the writing movement which are here studied are the speed, pressure and size of writing, and their relations to each other. Taken together

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they furnish a good objective characterization of the writing movement. Such a study was made in order to determine the stages and course of development of the writing movement. A characterization of writing has often been sought in terms of the external form. The latest use of external form as a basis for study has been made by Thorndike (**19**) and Ayers (**3**) in their construction of scales for the measurement of the excellence of handwriting.² The present investigation, however, aimed to determine the differences in writing at different stages of its development in terms of the motor coördination by which it is produced. In this report a method for such a study is described and some comparative results of its application to the writing of adults and of children are given in order, as just stated, to ascertain the course of development of the movement. The application of the method to the study of the development of the writing movement is by no means complete and the writer plans to continue this study, and to present further results in the near future.

II. HISTORICAL SKETCH

A report of the experiments may be prefaced by a brief discussion of previous investigations in the experimental analysis of the writing movement by methods of the same type as the one here used. The discussion may be divided into two parts, concerning first, the investigation of the speed of writing, and second, of the pressure and speed together.

A study of the speed of finger and hand movements of different degrees of complexity, including the writing movement, was made by Jack (**10**). The movements had three degrees of complexity: first, simple flexion and extension of a single finger; second, a straight movement with the pen involving several fingers; third, an ordinary writing movement. The distinction between the second and third types is not altogether clear except, perhaps, that the latter included curves as well as straight lines. The method was to require the subject to trace the lines on a piece of smoked glass carried on one prong of a

² The writer has also prepared for publication in the near future a scale to be included in *The Teaching of Handwriting*, Houghton Mifflin Co., Boston.

vibrating tuning fork. The problem was to discover the modifications in the different types of movement with differences in age, education and manual skill. The result in general was that old age, lack of education or of manual skill, as well as certain pathological conditions, affected unfavorably the complex movements to a far greater extent than the simpler ones. The simple flexion and extension movements were made with practically the same rapidity by all classes of subjects and also with the right and left hands.

The speed of writing movements was more extensively studied by Binet and Courtier (4). These authors used the Edison pen. This is an apparatus by means of which a needle is driven downward by a rotating eccentric at a rate of 1,000 strokes per minute. Thus when one writes with the Edison pen a dotted line is traced, and the distance between the dots indicates the speed of the movement. There are two defects in this method. In the first place the pen weighs about a quarter of a pound and the conditions are therefore not normal. In the second place, there is no record of the time of pauses. The results were as follows. The speed was greater when the writing movements were large and when they were accustomed movements than in the contrary cases. The direction in which the most rapid movements were made was the diagonal from lower left to upper right. The middle of the stroke was more rapid than the beginning and the end, connected writing was faster than disconnected, and intentional increase in speed corresponded to a decrease in size. A change in direction was accomplished by a reduction in speed, the amount of reduction being proportional to the angular change in direction. The more conditions which had to be satisfied by the movement, the slower it was. There was in general found to be a uniformity in speed variations in similar movements.

The relative speed of a writing movement in different directions was studied incidentally in connection with a general investigation of voluntary movement by Woodworth (21). He found that the most rapid movement was a side to side forearm movement and that the vertical finger movement was much slower.

The relative speed of finger, wrist and arm movements in different directions was investigated by McAllister (12). He used two methods. In the first the movements of the finger were recorded by the breaking of an electric circuit at the beginning and the end of the movement. The subject moved with his fingers the upper end of a vertical rod pivoted in the middle, the lower end of which released the contact. By the second method the speed of the movement was recorded by an electric spark produced by an induction coil, which passed from the pen to a metal sheet underneath the paper. The paper was covered with a coat of lampblack and the sparks were recorded as dots on the line of the writing. The defects of this method are first, that the possibility of a shock introduces a distraction; and second, that the time of pauses, as in Binet and Courtier's experiment, could not be recorded. McAllister found that movements in the direction from lower left to upper right and the reverse direction were the fastest, and that the arm movement was somewhat faster than the finger-wrist movement. He also found that the direction of a movement was unintentionally diverted in the direction of the greatest ease.

A piece of apparatus based on the same principle and called a graphometer was constructed by MacMillan (13). This consisted essentially of a small disc containing a groove along one of the radii and pivoted in the center so that the groove could be set in any direction. At each end of the groove were contacts and an electric circuit was made when the stylus touched either of these contacts. MacMillan, like Woodworth, found that the most rapid movements were made by a side to side arm and wrist motion.

The pressure of writing was first analyzed by Goldscheider (8). The method was to record the pressure by means of a tambour upon which the writing surface was supported. Goldscheider found that there is a characteristic form of pressure curve for the different letters and strokes and concluded that the sensations of pressure form an important means to the recognition and control of the writing movement.

Gross (9) analyzed the writing movement as a means to

clinical diagnosis. For comparison he studied a number of normal individuals. The apparatus used was Kraepelin's writing balance (*Schriftwage*). This consists essentially of a small table resting on the short arm of a lever, the other end of which records upon a kymograph. By adding a time line on the drum the total speed and average speed per letter may be measured. Gross confirmed Goldscheider's result that the pressure curves from a given individual for a given letter were uniform and that the corresponding pressure curves from different individuals presented great similarity. The pressure in general was higher on the down stroke than on the up stroke. Exceptions occurred, however, at the beginning and end of a letter or group of letters. The pressure showed a more abrupt release at the end than was the on-set at the beginning. There was a gradual increase during the course of writing of a series of letters or figures. The speed and size of characters had an intimate relation and tended to vary together. In other words, the total time of a character tended to remain constant and the writing manifested a rhythmical character. In the course of the writing the speed, pressure and size increased together. This was attributed to an increasing nervous excitation (*Anregung*). The same fact appeared at the beginning of writing and was attributed to the initial impulse (*Antrieb*). The author found greater variation in the length of the pauses between the strokes than in the duration of the letters themselves. He confirmed the result found by Jack, that there is greater difference between individuals in the complex than in the simpler strokes and that in pathological cases the differences due to education and skill tend to disappear.

The same method and apparatus was used by Diehl (5), who carried on his investigation for the purpose of testing and completing Gross's determination of the normal type. Diehl found in general a similar relation between the three elements, speed, pressure and size, as was found by Gross. An increase in the general nervous excitation or activity (*Anregung*) produced an increase in the speed, pressure and size. An increase in the mental difficulty attending writing, such as writing characters in the reverse order, produced a decrease in the speed and size and an

increase in pressure. Voluntary increase in speed produced a decrease in size and an increase in pressure. The changes in the last two instances are the same except for speed, which in the latter case is subject to voluntary control. An analysis of the two cases shows that an increase in effort produces a decrease in size and an increase in pressure.

This effect of effort upon writing has been determined incidentally in connection with other investigations. Urbantschitsch (20) found that stimulation by a high musical tone produced a crowding of the letters together and a decrease in size, accompanied by a feeling of constraint and inhibition, while a low tone produced the opposite effect. Meyer (16) found that an increased effort of attention produced a decrease in the size of writing and concluded that this was a special instance of a general increase in muscular tension which accompanies an effort of attention. Downey (6) reports an increase in pressure accompanying an increase in the difficulty of the attendant mental operation. The changes in writing with practice and facility consist, on the other hand, according to Diehl, in an increase in speed and a decrease in pressure and size. The author does not attempt to interpret these changes.

A similar investigation was carried on by Mayer (14). Mayer confirmed in general the results of the above-mentioned investigators and in particular the conclusions in regard to the relationship between speed, pressure and size. He attempts to explain the effect of practice upon these elements. He concludes that in the case of practice there is present a high degree of effort and that this effort is directed toward a production of relatively high speed. In the case of unskilled writers this effort does not produce a decrease in size because they are unable to make the required forms in a small compass. With increasing skill this decrease is brought about. This explanation, however, does not take account of the fact, which is well established, that an increase in effort produces an increase in pressure. A more probable explanation would seem to be that with an increase in practice the acquirement of speed is attained with less and less effort. With increasing skill this is accomplished by economizing

on size. In other words, a decrease in size may be due to other factors than increased effort. The decrease in pressure is explained by the greater ease consequent on practice.

The rhythm of writing was studied by Margaret K. Smith (18) and Awramoff (2). Miss Smith used no special apparatus, but Awramoff used one which recorded the pressure by a combination of the registering devices of Goldscheider and Kraepelin, and the speed by a system of contact lines. The pencil in passing over these contact lines successively made and broke an electric circuit. Speed determination by such means is not accurate however, since the number of contacts per unit of length varies greatly with the angle at which the stroke crosses the contact lines.

Both authors found writing to be characterized by decided rhythm. This rhythm, however, is the result of development and is characteristic to a very limited extent of the writing of children. Awramoff describes the difference by saying that adults write a letter or series of strokes with a total unitary innervation (*Gesamttinnervation*), while children write with a separate impulse for each stroke. In terms of pressure the writing of children showed an individual pressure curve for each stroke, while in the case of adults the pressure throughout a letter or word had a single point of culmination to which it rose and from which it fell.

The effect of an imposed rhythm upon writing was found to be an increase in the quantity, usually accompanied by a decrease in the quality, of the writing. That is, each writer has his natural speed at which he can write best. He may learn, however, to modify the natural rhythm to a certain degree. The effect of a well chosen imposed rhythm upon children's writing was to organize it and render it more like the writing of adults.

III. APPARATUS AND METHOD

The apparatus and method utilized in this experiment were the same as those used by the author in a preliminary experiment on writing reactions, already reported in these studies (7). The apparatus was designed to measure the speed and the pressure

of writing or of a graphic movement. The speed was measured by a method based on the kymograph principle. That is, under the sheet of paper on which the reactor wrote there traveled a strip of paper and the record of the writing was taken on this strip through a carbon paper or, in the present experiment, a typewriter ribbon. In order to determine the speed of the strip, an electric marker was made to write tenths of a second on it. By this means the speed of the whole or any part of a letter might be accurately measured, and the duration of pauses in the movement determined.

In order to determine the details of the speed variations of writing, each letter written by the subject was divided into parts 1 mm. in length. This was done by means of a pair of sharply pointed dividers. The method is not strictly accurate but if applied with care will give results sufficiently exact for the present purpose, and the probable error of measurement was not great enough to render uncertain the conclusions which were drawn. This division of a letter gave also a basis for the measurement of size. This element of writing was not, however, treated independently, but only in its relation to the other elements of speed and pressure.

The pressure was recorded by a combination of the apparatus of Goldscheider and Kraepelin. That is, the writing was done over a small table which rested on the short arm of a lever. The movement of the longer arm was transmitted by means of a tambour and was recorded on a long strip of smoked paper which ran with approximately the same speed as that of the speed strip. Upon this pressure strip there was also a time marker indicating the same intervals as that on the speed strip. The advantage of this arrangement in comparison with those of previous investigators is that the pressure record may be accurately correlated with the speed record and thereby with the letter itself. Without this correlation it is a matter of guess work to determine what part of a letter corresponds to any particular part of a pressure curve.

An unimportant change in the author's previous method of driving the apparatus was introduced. This consisted in connect-

ing the driving shaft with the shaft of the machine shop below the experimenting room. This had the advantage of giving a more uniform motion than that which was obtained by the electric motor used in the previous experiment. This regularity of motion made it unnecessary to be particular that the writing movement was directly under the time marker.

The details of the method of measuring the speed records is as follows. The primary record, that is, the paper on which the reactor wrote, is placed over the strip on which the speed record was taken in the same relation in which they were when the writing was done. The records then appear as shown in Figure 1.

Figure 1.

The primary sheet showing the letter as written is indicated by the letter A, the speed strip by the letter B, the time line by CD, one unit of which is represented by the distance EF. The first millimeter length of the letter to be measured is represented by the distance between the points 1 and 2. The points on the time line which correspond to these two points are found by drawing horizontal lines from 1 and 2 respectively until they cross the speed curve. The line from point 1 should, of course, meet the beginning of the speed curve. If we now measure the horizontal distance between the points 1' and 2' we have a distance through which the strip travels during the writing of the first millimeter section of the letter. This, however, is subject to a correction due to the fact that the pencil altered its horizontal position during the writing of the section in question. Since the direction

of movement of the pencil was the same as that of the strip, the amount of horizontal pencil movement must be added to the horizontal distance on the strip in order to obtain the actual distance through which the strip traveled. We now must divide this distance by the distance which represents $1/10$ of a second in order to turn it into time units.

Since these operations require great accuracy of measurement, a piece of special apparatus was constructed for the purpose. This apparatus is shown in Figure 2. It consists essentially of a vertical and horizontal scale which can be applied to the records. The vertical scale consists of a sliding glass plate moved by a micrometer screw by means of which one may read to $1/50$ of a millimeter. This plate, E, is fastened to the metal piece, I, which slides in a tightly fitting groove, J, in the carriage, D. The millimeter distances may be read on the edge of the piece, I, and the fractions of a millimeter on the screw. The horizontal distances are measured by sliding the glass plate with its carriage, D, along the horizontal scale, A. The latter is divided into half millimeter lengths, and by means of a vernier scale, F, divided into twenty-fifths of a centimeter, it can be adjusted to tenths of a millimeter. In order to facilitate the finer adjustment there is a supplementary carriage, G, which may be clamped to the scale. The larger carriage, D, may then be adjusted by means of the screw, H. A magnifying glass set over the scale makes the reading easier.

The primary sheet is held in place by four flat discs which can be raised from the surface of the board, in order to insert the paper, and lowered again by turning the handles, K. These operate two rods upon which are eccentric cams. The cams raise the discs which are drawn down again by springs. The glass plate slides easily over these discs. The strip containing the speed records is adjusted by means of the rod, C, and a similar one at the other end of the board.

The method of operation is as follows. The glass plate is placed above the letter upon the primary sheet. The horizontal and vertical position of the first point on the letter is then determined by reading the horizontal and vertical scales respectively.

FIGURE 2—View of measuring apparatus.

The same is then done for each of the succeeding points of a letter. By means now of the vertical measurements, the points on the speed curve which correspond to the points on the letter may be found. By means of the horizontal readings the corrections for the movement of the pencil out of the vertical line may be determined. Thus, after the letter itself has been gone over, the plate is set at the first vertical reading and the point found on the speed curve which is on the same horizontal line with this. This, of course, is the beginning of the curve. The horizontal reading of this point is then taken. The plate is then set at the second vertical reading and the corresponding point found on the speed curve. The horizontal reading of this point is taken and so on for the rest of the curve. Each successive horizontal reading is subtracted from the one following it, and the differences corrected by the amount of horizontal displacement found in measuring the letter. The length of a unit of time line is then measured and the horizontal differences of the speed curve divided by this unit. The typical series of measurements is shown in Table I.

TABLE I

Illustration of the readings and operations involved in measuring the speed of the first two divisions of a letter

<i>No. of division points</i>	<i>Vertical reading on letter mm.</i>	<i>Horizontal reading on letter mm.</i>	<i>Differences in Horizontal reading mm.</i>	<i>Horizontal measure on strip mm.</i>	<i>Differences in Horizontal measure on strip mm.</i>	<i>Corrected differences mm.</i>
1	15.25	9.43		41.36		
2	14.45	9.38	— .05	43.42	2.06	2.11
3	14.00	9.36	— .02	44.03	.61	.63
			<i>Dist. per 1/10 sec.</i>	<i>Time per mm. in sigmas</i>		
		1		5		
		2	3.80	56		
		3	3.80	17		

In order to present the results of these measurements graphically a curve is drawn, the base of which represents the successive millimeter distances of the letter and the altitude the

corresponding times in thousandths of a second. Such a curve (of the letter "o") is shown in Figure 3. The interpretation of this curve indicates that the reactor took considerable time (105 σ) to get started and to traverse the first section of the letter. The pencil then moved at an average rate of 1 mm. in 17 σ

FIGURE 3—Speed curve of letter "O."

until it came to the curve at the base of the letter. The section at this point took 53 σ —three times as long as the average millimeter on the down stroke. The up stroke was still faster than the down stroke. The turning point at the top of the stroke was slow however, occupying 124 σ . The last outward stroke was rapid. This was the typical record of the speed changes of the movement during the writing of a letter.

The pressure curve from the letter "o" by the same reactor is shown in Figure 8, in the appendix. The pressure curves are to be read from right to left. This curve can be correlated with the speed curve by reversing the process used in measuring a letter. In that case we found the time represented by a given distance on the strip by dividing this distance by the distance for one tenth of one second. Now in order to find the distance on the pressure record which corresponds to the time of

a given section of the letter, the distance for one tenth of one second on the pressure record is multiplied by the fraction of a second which represents this time. We may thus determine the points on the pressure curve which correspond to the successive points of the written letter. In this way, in the present instance, the position on the pressure curve of three points was determined. These are the end of the first millimeter distance, the bottom turn of a letter and the top of the upstroke, corresponding to divisions 1, 6 and 11 of the letter.

From an inspection of the pressure curve it will be seen that the pressure increased during the first millimeter to almost its maximum amount. Upon the down stroke the pressure decreased. It increased again at the beginning of the upstroke but fell to the minimum about the middle of this stroke. It then steadily increased while the readjustment at the top of the stroke and the final outward stroke were being made, reaching its maximum on the latter. The drop at the end is abrupt.

The methods here used for analyzing writing movements may be briefly compared with those which have been previously used. The only other methods known to the writer by which a speed analysis of the writing movement may be made are those of the Edison pen used by Binet and Courtier (4), the spark method described by McAllister (12), and writing over contact lines described by Diehl (5) and Meumann (15). The present method possesses the advantages in comparison with that of Binet and Courtier, first, that the conditions are more normal (since the Edison pen weighs a quarter of a pound and contains machinery in rapid vibration); second, that it permits the measurement of the duration of a pause; and third, that it permits a more exact measurement of the more rapid parts of a letter. The advantages over the spark method are similar to those over the Edison pen with perhaps even greater emphasis on the first point. The defect of the system of contact lines is that the units of distance which are measured by it are not uniform. This criticism was made above.

The only method of analyzing the pressure curve with which the present method may be compared is that of Diehl and of

Meumann. The other methods of recording pressure, for example those of Goldscheider (8) and Kraepelin, furnish no means of determining the correspondence between the pressure and the parts of the letter. The correlation between the pressure curve and the written letter is in any case only as exact as the speed analysis of the letter. Since the latter, in the method of Diehl (5) and Meumann (5 and 15), is inaccurate the correlation of the pressure curve with the written letter is correspondingly inaccurate.

The reactors in the experiment consisted of four adults and ten children. Of the adults, three were graduate students, T. T. G., R. D. W., and F. N. F., and the fourth a college senior, D. H. Of the children, five were boys and five girls. The ages ranged from 9 to 15. C. K., 14 years, was in the second year in high school. H. H., 13 years, was in the first year in high school. M. G., 13 years, and G. B. 15 years, were in the eighth grade. O. B., 14 years, and E. C., 12 years, were in the sixth grade. C. N., 11 years, and A. S., 11 years, were in the low sixth. E. H., 10 years, was in the fourth, and M. H., 9 years, in the third grade. C. K., H. H., O. D., C. N., and A. S. were boys and M. G., G. B., E. C., E. H., and M. H. were girls. For the opportunity of working with the children the writer is indebted to Mr. Harry Houston, Supervisor of Penmanship in the New Haven Schools, who arranged to have the children come to the laboratory and was present himself at several of the experimental periods.

There were first measured two and in some cases three specimens of each letter of the alphabet of the writing of a single reactor, F. N. F. This was done in order to determine the differences and relationships between the different letters of the alphabet and thus to avoid generalizations which might rest on a study of part of the letters. Means was thus furnished also of choosing letters for use with the other subjects which might represent different typical facts in regard to their writing. From each of the remaining subjects then, records of the writing of three or four letters were obtained. In the case of adults there was some variation in the particular letters used, but with the

children the same were used for all, namely, the letters "a," "r," "f," and "h." The word "American" was chosen to test the letters a and r written in combination and each reactor also wrote his own name. Mr. T. T. Giffin made a short investigation of the letters "a," "b," and "c" in his own writing in connection with the course in experimental psychology at Yale. The writer wishes to thank him for the use of the results of this study.

This may appear to be a small number of letters to measure, but the time required in the measurement of the records was so great that it was not practicable to use a larger number. It was therefore thought preferable to make an intensive and exact study of a few letters than an inexact study of a larger number. The writer plans to simplify the method of procedure without sacrificing accuracy and to extend the study over a wider range.

Besides writing in the ordinary manner it was planned that each reactor should write under varied conditions. These conditions consisted in writing much larger than usual and writing between two horizontal lines, in order to test the effect on the writing of differences in size and of the addition of certain external limiting conditions. It was also planned to study the relations between letters written separately and in combination in a word, but this purpose was only to a limited extent carried out. Reactor R. D. W. gave a complete series with the letters "r," "e," and "m" and D. H. a complete series with the letters "a," "e," and "n." Reactor T. T. G. wrote the letters "a," "b," and "c," but only in his natural writing, that is, without variations. F. N. F. gave a complete series except that he did not write between lines. The letters which were written large were "b," "r," "f," and "h," and the letters in combination (in his given name) were "r," "a," "n," and "k."

An effort was made to have all of the subjects write in as natural a manner as possible. This was probably successful in the case of adults and of some of the children. The chief tendency which had to be combated with the latter was one toward slow, painstaking writing, such as one would put in a copy book. Such writing would furnish a profitable subject of study but would be unfavorable to the type of comparison made in the

present experiment. Reactors M. G., G. B., O. D., and E. C. seemed to the experimenter to write in this unnatural manner and the records of the speed of their writings was not measured in detail, only the total speed and the average speed per millimeter being taken.

IV. RESULTS AND DISCUSSION

The discussion of results will be divided into three main parts, taking up first, the average speed per millimeter of the various letters; second, the characteristic changes in speed in the different parts of the letter, which may for convenience be spoken of as the speed curve; and third, the pressure and the pressure curve. The writing of children and adults will be compared on the basis of this analysis. Under these heads also will be made a comparison of the different letters with one another, of letters written larger than usual and of those written between limiting lines.

We will first take up the consideration of the average speed of letters written under different conditions and by different adult subjects. We are dealing with the average speed per millimeter and not with the speed curve. The first result deals with the relation between the size and the average speed of different letters of the alphabet in the writing of F. N. F. The size is measured by taking the length of the line which the pencil traced in making the letter. A comparison was made by putting the letters in two lists, the first being arranged in the order of size and the second in the order of speed. These lists are given in Table II.

It will be seen that, in general, the order of the letters in the two columns is the same. That is, the larger letters are also the more rapid. The degree of correspondence may be worked out by the "r" method of correlation, according to which the degree of correlation is expressed by differences in the gradation from zero to one. The correlation in the present instance is found to be .83, which indicates a close relationship between speed and size of the letters. Some deviation from exact correspondence exists, it is true, but this may be at least partly explained by the differences in the complication of the letter and the

TABLE II

A comparison of the order of the letters on the basis of size and of speed

Letters in the order of their average speed Reactor F. N. F.		Letters in the order of their size Reactor F. N. F.		
	Time in sigmas per mm.		mm.	
1.....	j	15	k	36
2.....	g	17	g	36
3.....	f	18	f	33
4.....	l	20	p	33
5.....	k	21	h	31
6.....	p	21	j	30
7.....	d	22	t	29
8.....	h	22	m	27
9.....	z	22	q	27
10.....	q	23	d	26
11.....	t	23	y	26
12.....	i	24	z	26
13.....	y	25	b	24
14.....	e	27	w	21
15.....	m	28	l	20
16.....	s	30	s	18
17.....	w	30	u	17
18.....	b	31	n	17
19.....	v	32	v	16
20.....	u	33	e	16
21.....	x	33	a	15
22.....	n	35	i	14
23.....	o	37	x	14
24.....	a	38	o	12
25.....	c	42	r	12
26.....	r	42	c	11

consequent difficulty in making it. For example, the "k," which is the largest letter, is especially slow at the last turn and this puts it lower in the speed column. Again, "j," which is sixth in the order of size, is first in the order of speed because of its simplicity. The differences which occur may therefore be accounted for on the basis of other factors and the relation between speed and size comes out very prominently.

This correspondence between the speed and size of writing appears also from a comparison of the same letters written, first, in the ordinary size and, second, larger than usual. The comparison for the three adult subjects is shown in Table III. On the right appears the percentage increase in the size of the letters when they were written large and on the left the percentage decrease in the time per millimeter (or the increase in speed) of the large letters.

There is in these cases a decrease in the time per mm. in each case of an increase in size. The decrease in time ranges

TABLE III

Comparison of the time in sigmas per mm. of letters written normal size and large											
Reactor	Kind of letter	Comparative times per mm.				Comparative size in mm.					
	Normal	31	42	18	22		24	12	33	31	
	Large	15	24	14	16		45	21	51	45	
	% Decrease	52	43	22	27	% Increase	88	75	55	45	
D. H.			a	e	n		a	e	n		
F. N. F.	b		r	f	h		b	r	f	h	
	Normal		40	48	47		17	11	15		
	Large		28	26	30		30	20	26		
	% Decrease		30	46	36	% Increase	76	82	73		
R. D. W.			r	e	n		r	e	n	a	
	Normal		75	44	50		10	15	19		
	Large		22	15	15		31	35	78	40	
	% Decrease		71	66	70	% Increase	210	133	310		

from 22 per cent to 71 per cent and is greater when the normal letter was unusually slow. The decrease in time is also greater the greater the increase in size. See for example, the great decrease in time in case of the reactor R. D. W.

This tendency to increase in speed with an increase of size is also shown by comparison of the total time of the letters of each sort. This comparison is made in Table IV, which refers to the same letters as those in Table III. There are four cases in which there is a decrease in the total time of a letter when the size increases. The increase in total time when it occurs is very small compared with the increase in size.

TABLE IV

Comparison of the total time in sigmas of letters of normal size and written large												
F. N. F.	b	r	f	h	D. H.	a	e	n	R. D. W.	r	e	n
Normal	733	476	587	668		688	524	706		753	664	955
Large	642	487	693	675		844	515	775		679	549	1149
% Inc.	-12	2	18	1		23	-2	10		-10	-17	20

A comparison may now be made between the average speed of normal letters and of those written between lines. Only two adult reactors gave data for such a comparison. The results are shown in Table V. The lines between which the reactor wrote were so placed in the case of R. D. W. that he wrote much larger than usual. The intention of this arrangement was to prevent the reactor from disregarding the lines, but it also introduced another factor, that is, the increase in size. The amount of increase in size is shown on the right-hand side of the table. For R. D. W. this is great enough to necessitate a correction of the

figures; that is, we must calculate the percentage change in time per mm. which would result from the increase in size of the letters (calculated on the basis of Table III) and by subtracting this from the actual percentage change in time get the increase which is due to the introduction of the lines. We have, therefore, in the table, first, the actual percentage change in time per mm., then the percentage change which would be produced by the increase in size and finally the corrected increase in time.

TABLE V

Comparison of time in sigmas per millimeter of letters, normal and between lines, showing increase in time.

<i>R. D. W.</i>	<i>Time per mm.</i>				<i>Size in mm.</i>		
	<i>e</i>	<i>m</i>	<i>r</i>		<i>e</i>	<i>m</i>	<i>r</i>
Normal	45	50	75		15	19	10
Between lines	49	37	41		22	45	25
% Change	+11	-26	-45	% Increase	47	137	150
% Change corresponding to inc. in size	-23	-31	-51				
Corrected change	+34	+5	+6				
<i>D. H.</i>	<i>e</i>	<i>n</i>	<i>p</i>		<i>e</i>	<i>n</i>	<i>p</i>
Normal	48	48	28		11	15	21
Between lines	74	73	44		11	14	32
% Increase	54	52	57				

The increase in time is very pronounced for D. H. and for the letter "e" of R. D. W. The lack of a pronounced increase for "m" and "r" of R. D. W. may be accounted for by the fact that the normal writing of this reactor was unusually slow as compared with the writing of the other reactors and with his own large writing. This then would tend to reduce the effect of lines in decreasing the speed of the writing.

We turn now to a consideration of the average speed of the writing of children. The data for discussion are shown in Tables VI and VII.

Table VI gives the time per millimeter of the normal letters written by the various children and the average for all of the children, as well as the percentage change in time of the letters written large and between lines. The corrected change in time for letters written between lines was calculated by the method already described for R. D. W.

Table VII gives the size of the letters written under the different conditions for the various children. The averages, and

TABLE VI

Time in sigmas per millimeter of the children's writing.

Reactor	Normal			Large			Between Lines			In Name	In word "American"
	a	r	f	a	r	f	a	r	f		
H. H.	65	70	37	40	54	40	55	72	43	41	43
C. K.	74	94	48	44	56	31	44			60	58
M. G.	117	118	92	84		55	117	125	75	105	105
G. B.	117	96	50	100	63	36	92	83	61	78	
O. D.	115	188	103	118	145	89	142	165	86	74	164
E. C.	174	187	184	181	164	117	182	257	125	124	170
C. N.	178	145	102	190	121	87	149	185	93	89	134
A. S.	141	152	116	110	85	52	106	130	60	84	125
E. H.	109	90	70	54	116	54	105	98	64	64	70
M. H.	47	64	42	52	56	36	84	103	64	71	57
Avg.	113.7	120.4	84.4	91.1	95.4	59.7	114.7	135.3	72.3	79.9	102.9
% Change..				20	21	29	+1	+12	-14		
% Change corresponding to inc. in size							-15	-13	-47		
Corrected change in time							+16	+25	+33		

TABLE VII

Size in millimeters of letters of the children's writing.

Reactor	Normal			Large			Between Lines			In Name	In word "American"
	a	r	f	a	r	f	a	r	f		
H. H.	12	8	25	28	16	30	31	20	53	60	51
C. K.	11	12	21	25	20	37	23	16	39	54	43
M. G.	16	11	26	24		38	19	16	37	20	48
G. B.	14	12	25	31	29	50	20	14	45	25	
O. D.	19	11	28	23	11	28	22	19	36	40	42
E. C.	14	12	23	23	25	32	22	19	36	34	34
C. N.	20	16	23	26	26	40	24	16	41	42	41
A. S.	16	11	28	21	17	36	27	17	54	21	16
E. H.	17	12	23	21	14	43	16	14	46	23	24
M. H.	15	12	26	27	18	32	21	17	47	22	13
Avg.	15.4	11.7	24.8	25.3	19.6	36.6	22.6	16.6	44.2		
% Increase				64	68	48	47	42	78	85	

the percentage increase in size of the letters written large and between lines. These figures are used as the basis for the calculation of the corrected change in time for letters written between lines as given in Table VI.

The speed of the children's writing is markedly less than that of adults. The speed of the "r" for example is 42σ per mm. in the case of F. N. F. and 64σ per mm. in the case of the most rapid children's writing. The slowest of the children's writing gives 188σ for this letter. Similarly, the speed of "f" for F. N. F. is 18σ and for the children 37σ to 184σ . For the "h" the corresponding times are 22σ , and 41σ to 156σ respectively. The same relation may be found between the writing of the same letters by the other adults and that of the children; it is not necessary to make a detailed comparison. The only striking exception is the case of the "r" written by R. D. W. This is exceeded in speed by the writing of two of the children, but the large "r" of R. D. W. is more than twice as fast as any of the large "r's" written by children.

There is still a greater difference in speed in favor of adults when the letters are written large. That is, adults show a proportionally greater increase in speed with the increase in the size of the writing.

As a class then the writing of children is much slower than that of adults. There is not found in the present experiment, however, a uniform gradation in speed for the children of advancing age, although the ten children do fall into several fairly well defined groups. H. H., C. K., and G. B., the older children, are comparatively fast writers. M. G., O. D., E. C., C. N. and A. S. write more slowly while, finally, the two youngest, E. H. and M. H., write comparatively fast.¹ This anomaly of fast writing of the younger children is probably due partly to the fact that the children did not all apprehend the problem in exactly the

¹ Other and more comprehensive tests of the writing of children in the elementary school of the University of Chicago and in the public schools of more than fifty large cities have revealed a more regular but not entirely uniform progression in speed. The speed is affected by the quality of the writing and probably also by the style of teaching adopted by the individual teacher.

same way. That is, some evidently aimed very much more at accuracy of form than others. Their writing had almost the appearance of the copy book style. The other children, on the other hand, wrote more fluently and carelessly. This may be due partly to a difference in teaching. A further possible cause of difference lies in the fact that the older children had reached a higher stage of development in which they were able to write a series of letters with a unified movement. Their chief advance then would be represented not by an improvement in the writing of isolated letters but of letters in a series. The present experiment deals almost entirely with the writing of isolated letters. This may not bring out the chief difference between the writing of the younger and the older children.

The difference in speed of the letters of the alphabet due to their normal differences in size is also a factor in the writing of children. If we compare for example, the speed of the "a" and the "r" with that of the "f" and "h," we find that the latter are written much more rapidly. The difference is not so great, however, as in the case of adults. That is, there is not so much tendency in the writing of children to maintain a constant time for letters when the size varies.

The relative decrease in speed of the children's writing between lines is on the whole probably less than that in the writing of adults. It is greater than that of the adult reactor R. D. W., but this is probably, as indicated above, not a fair representative of the average change in the case of adults. In comparison with the other adult reactor, D. H., the writing of children between lines showed very much less decrease in speed.

The discussion thus far has dealt with the average speed of the letters. We now come to the analysis of the speed of the various parts of a letter, represented in the speed curves. The results are not susceptible of presentation in tabular form, but must be given by an analysis of typical individual speed curves. A comparative analysis may first be made of the characteristics of the different curves, and the relation of these characteristics to the forms of the various letters and to the different conditions of writing in the case of one individual. The comparison may

then, secondly, be extended in the same way to the writing of different adults and of children. An attempt will be made in connection with the analysis of the results to make an interpretation of them by relating them to other facts of reaction and movement. The question may be raised, for example, as to how far the changes in speed are due to mechanical or to psychological factors. We will now proceed with the discussion of the writing of the individual subjects.

Figure 4, in the appendix, gives a typical speed curve of each letter of the alphabet as written by reactor F. N. F. An analysis of these curves shows that there is always considerable time consumed in starting the stroke and bringing it to its normal speed. There is also a retardation at the end of the letter. This slowness at the beginning, while characteristic of every letter, showed great variation in amount for the different letters. The duration ranges in the whole series from 51 σ in the case of the letter "j," to 128 σ in the case of "b." The variation in the speed at the beginning is shown even in different cases of the same letter. The slowness at the end is not a uniform characteristic of all of the letters.

No principle which may account for the initial variation is discoverable. If the letters are arranged in order according to the speed of the first part of the letter, this order has no evident correlation with that which is made on the basis of the size of the letter. We cannot say, therefore, that either the average speed or the size of the letter has a noticeable effect on the time of the first part of the stroke, for it will be remembered that there was a correlation found between average speed and size. The complexity of the letter might conceivably have an effect upon the speed of the beginning, and if we allow for this factor, there might be a relation between the initial speed and the size of the letter in combination with the complexity. That is, theoretically we might assume that the retardation at the beginning would be greater the smaller the letter and the greater the complexity. Even with this modification, however, the two series do not show any apparent correlation.

We may ask then what the explanation of the initial delay

may be. There is, doubtless, a slight mechanical inertia which would cause a somewhat gradual increase in speed at the beginning of the letter. The great variation in the initial speed, however, shows that this factor, in the cases before us, accounts for only a small part of the phenomenon. Evidently there are cases in which the writer is prepared to make a stroke as soon as the pencil touches the paper, and in these cases inertia plays but a small part. If we turn to a possible psychological factor, we must exclude any which involves a reaction time. We might conclude, for example, that the initial period represented the time of reaction to the cue furnished by the contact of the pencil with the paper. The time of the first millimeter, however, is less than 100σ in all but three of the letters and this obviously excludes such an interpretation. The assumption that originally such a reaction took place and that the adult habit is a survival of this procedure is probably also excluded by the fact that a time sufficiently long to admit of a reaction is not present in a nine-year-old child. If a reaction to contact-stimulus were the original basis then of this delay, it must have disappeared before that age. We can only say that the initiation of the stroke includes a movement of the pencil down upon the paper and then across its surface. A slight incoördination between the two parts of the act would account for the delay at the beginning of the letter. The lack of accurate adjustment would also account for the variation in the time of this initiatory stroke. Since the initial delay is too short to be interpreted as reaction time, we cannot speak of the initial pressure as an initiatory control, but only as a possible report control, that is, a sensation which reports the completion of an intended movement. This will be again referred to in a discussion of the pressure.

The retardation at the end of the letter is still more variable than the delay at the beginning. In fact, it is sometimes absent altogether. When it is present, however, it apparently indicates that stopping a movement may be as definite an act as starting one. It was found in the preliminary experiment (7), for example, that a reaction by stopping a movement was longer than one by starting. But in finishing the movement of writing a

letter we have not the same sort of reaction as when a movement is stopped at a given signal since in writing a letter the end of the movement is anticipated during the writing. We have, however, on the objective side, as already indicated, and also on the subjective side, a definite fact representing the cessation of the movement. The movement does not merely stop but it is stopped. This is often connected with the consciousness of the "rounding up" of the letter, as though one would say, "so much is finished." This is, doubtless, much more characteristic of some writers than of others.

An examination of the speed curves (Fig. 4) shows that there are other points at which there is a definite retardation of the movement, and a comparison of these points with the letters themselves indicates that they come at places of change in direction of the stroke. We may, for convenience, call these places in the letter "turns," that is, points where the stroke turns a corner. Binet and Courtier (4) and Jack (10) mention these points of retardation and state as a general principle that the retardation is greater the sharper the turn, or that the speed is proportional to the radius of the curve. This rule would hold roughly if the delay in speed were due to mechanical factors. There is, doubtless, some approach to this general principle, but it does not apply in the wholesale fashion indicated by such a simple statement. There are other factors which influence greatly the amount of retardation. A measure of the difference which is due merely to the difference in angular change may perhaps be seen from a comparison of the "l" and the "t." We have here two turns which are radically different in form. The sharp turn at the top of the "t" is, to be sure, slower than the more rounded turn at the top of the "l," but the difference in this case is slight. The difference is much less than many differences in the case of strokes having the same sort of turn. Compare, for example, in this respect the first turns of the "a," "d," and "g," all of which are of the same form. The relative retardation of these is quite different.

The last example shows that we must look to other conditions than the immediate character of the stroke to explain the speed.

The part of the letter which follows any particular part under consideration is of importance. In the present instance, for example, the latter part of the letter "g," that is, the lower loop, doubtless has an effect upon the time of the first turn. This is but an example, of which many others will be found, of the fact that the act of writing a letter is a unitary thing, each part influencing every other part. In particular, the following parts of a letter influence those which precede. This is closely related to some of the results found in the preliminary reaction experiment (7). For example, the time of a reaction was very much lengthened when the stroke which constituted it was required to extend to a certain point, or to follow the course of some geometrical figure. In terms of adjustment, the motor mechanism had a different set according as the later movement was of one sort or another. In psychological terms, the anticipation of a given type of later movement affected the previous attitude.

The same difference as that found in the last mentioned letters is also found in the comparison of the "i" and the "j." That is, with two turns exactly similar the amount of retardation is different.

If we compare the turns in the "m" and "n" with those in "u" and "w," a striking fact appears. Whereas, in the former, the sharp turns (at the bottom of the letters) are much slower than the rounded ones, in the case of the latter this difference disappears or is reversed. The sharp turns at the top are no slower than the rounded turns at the bottom.

The turns represent, therefore, something besides mere points requiring a mechanical readjustment of the stroke. They doubtless represent to a large degree the points of division of the letter from the point of view of the movement and the perception processes. That is, a letter is represented to us, not as a uniform whole, but as composed of certain subordinate units. If the division point between these units occurs at a turn, the mechanical tendency to a retardation will be reinforced. Otherwise, the movement will proceed past the turn with little more retardation than is produced by mechanical conditions. In

the case of the "g," for example, it is very probable that the first enclosed loop, which it has in common with the "a," and the other loop which extends below the line, represents two such units of the letter. The development of these units of movement is characteristic of adult writing, as we shall see later.

In confirmation of the principle that certain turns show a retardation out of proportion to the change in direction of the stroke, we may point to the last turns in the letters "b," "f," "k," "o," "v," "w," and "s." From the point of view of form there is no reason for the extreme retardation of these turns. That is, we cannot assign a mechanical cause for it. They have the common characteristic, however, that they mark the completion of a certain definite part of the letter. In addition to this, most of them demand a rather delicate adjustment of the stroke so as to meet a certain point or line. These two factors together comprise the condition which causes the slowness of the movement. The first factor is the same as that which, according to our hypothesis, caused retardation at the end of the letter, and the second is related to the retardation of a reaction, already referred to, caused by the necessity of a later adjustment. Binet and Courtier (4) refer to this same fact when they state that the more conditions which are set for the movement, the slower it is.

The slowness at the second turn of the "z" may perhaps be ascribed partly to the fact that it completes one section of the letter as well as to the fact that it is immediately followed by another pronounced readjustment in direction. That is, the next stroke consists in a rather abrupt turn and the formation of a loop. The latter condition (a sharp turn followed closely by another) is still more strikingly exemplified in the letter "r." The first turn of this letter is no sharper than the top turns of the "i" and the "j," for example, but it is uniformly an extremely slow stroke. In analyzing the letter we see that this particular turn is immediately followed by two other readjustments in direction. In preparation for these, the movement makes an unusually long pause. Another example is shown in the comparative speed of the last upstroke of the "g" and the "q." In

the latter it shows the delay which is produced by the more delicate adjustment which concludes it.

The effect of the succeeding part of a letter upon that which precedes is well brought out, too, by a comparison of the first turn in the letters "a," "d," "q," and "g." This turn is exactly the same in all these letters from the point of view of its external form. It may be readily seen, however, that it is progressively more rapid in the successive letters, in the order named. This corresponds to the fact that there is also a progressive increase in the size of the letters. Evidently then, the total size of the letter has an influence upon the speed of certain definite parts. The individual parts do not stand by themselves, but are united throughout the whole letter in the total movement which produces them, so that each part is influenced by the others.

We may now turn our attention to a comparison of the speed of the relatively straight strokes of the different letters. Binet and Courtier (4) stated that the longer the stroke, the faster was the movement which made it. This appears to be true in the examples which are before us. In the form of the above statement, however, it is susceptible of an explanation which our curves do not justify. That is, it is clear that from the mechanical standpoint a stroke might gather speed the longer it persisted. We would then have a shorter stroke and a longer one exactly similar so long as we compared identical distances. That is, the longer stroke would increase in speed in the same manner as the shorter one and then continue its increase merely because it lasted longer than the other. This, however, is not the case. The longer strokes reach their characteristic speed in the same space as the shorter ones, and this speed is greater in the former than in the latter. This is shown by the fact that the speed curves for the straighter strokes are practically level, and that those for the longer ones are on a lower level than the others. Compare, for example, the similar strokes of the letters "e" and "l," "i" and "j," "b" and "f," and "u" and "y."

If we compare the smaller and the larger letters with respect to the speed of the turns, we find here also the same relation

as in the case of the straight strokes. That is, the longer letters are faster throughout. This enables us to analyze the difference which we found between the average speed of the large and the small letters. This might possibly have been due to the fact that the longer letters have a greater proportion of straight strokes as compared with the turns, and that they, therefore, have a greater average speed since the straight strokes are more rapid than the turns. This, it is true, must contribute to the difference in speed, but that it is not the whole or even the chief factor, is seen from the present analysis. That is, the elements in the letter which are strictly comparable are made in different time when the letter is large or small. In the large letter there is a quickening of the whole movement, an evident tendency to rhythmical writing in the sense that different strokes, though of differing length, tend to be made in the same time.

We may further compare the speed of the up and down strokes. Awramoff (2) states that down strokes are the faster. In our own preliminary experiment (7) the relation of the speed of vertical lines in the upward and downward direction was studied in the case of the four reactors. There was found to be a large variation. The reactors formed a series. One of them made the up strokes markedly faster, and another the down strokes faster. The two other reactors made the one or the other faster on the average, but the difference was much less. One of the two latter was the reactor whose writing is the subject of this analysis (F. N. F.). In the preliminary experiment he made the up strokes faster than the down strokes in eleven cases out of sixteen. In writing the letters in the present experiment there are some cases in which the same relation holds, but there seems to be no uniform rule. There are many special conditions which affect the speed of the up or down stroke, so that any tendency which may exist toward a greater speed of the one or the other is covered up. For example, the main down strokes of the "d," the "f" and the "p" are the faster, but this difference may be assigned to the fact that these strokes have fewer conditions to meet than the up strokes, or that they are of greater length. On the other hand, the up strokes of the "i," the

"u" and the "z" are the faster. But in the case of the first two letters, these strokes are the longer, and in the case of the last one the up stroke has a freer course. There is therefore no clear evidence that either sort of stroke is more rapid than the other in the case of this reactor.

The relative speed of the strokes in the direction of the two diagonals, the upper left to lower right (represented in back-hand writing), and the upper right to lower left, is shown in the letter "x." In accordance with the principle laid down by Binet and Courtier (4), Woodworth (21), McAllister (12), and McMillan (13), the latter is much the faster.

The letters "x" and "t" furnish an opportunity for a comparison of the speed of the stroke which the pencil traces through the air in making two parts of the letter, with the speed with which it makes the stroke itself. The average time per millimeter from the end of one stroke to the beginning of the next in these two letters was measured, and is indicated in the line which joins the corresponding points on the speed curve. It appears that the average speed of this free stroke is the same as for the part of the stroke immediately preceding and following it. This seems on the face to be a contradiction of the statement of Binet and Courtier that connected writing is faster than disconnected. The facts, however, are too fragmentary upon which to base such a conclusion, and it will be also noted that the parts of the letter which precede and follow the free stroke, are not so rapid as the ordinary straight stroke. This is doubtless due to the fact that there is here a readjustment in direction. We cannot, therefore, in the present case, draw any far-reaching inference.

An examination of the records of the other adult reactors will indicate the variations which may be expected to occur within the adult type and will give a broader basis for comparison of the adult with the child type. A few speed curves from the three other adults are shown as samples in Figure 5 in the appendix: "a" by T. T. G. (curve 68) and D. H. (curve 78); "b" and "c" by T. T. G. (curves 66 and 72); "e" by D. H. (curve 74) and R. D. W. (curve 85); "m" by R. D. W. (curve 87), "n" and "p" by D. H. (curves 76 and 79).

In discussing the differences between the speed curves of the different persons the difference in shape of the letters must be taken into account. Compare, for example, the shape of the "c" as written by F. N. F. and by T. T. G. Aside from the extra stroke, the latter has a sharper turn at the bottom than the former. Compare also the "a" of D. H. with that of F. N. F. and of T. T. G. There are here three degrees of angularity, from the writing of T. T. G. at one extreme to that of D. H. at the other. We should then expect to find, other things being equal, a corresponding difference in the amount of retardation at the turns. If the differences do not correspond, other things, that is the characteristic speed variations of the writers in question, are not equal.

It should be said also in discussing the retardation of the turns of a letter, that we should regard the relative and not the absolute speed of these parts. As a measure of retardation then, we shall take the quotient of the time of a particular slow part of a stroke divided by the time of the adjacent rapid part. In making this calculation we will not use the extremely low points of the curves of T. T. G. since the time these represent is probably too short.

From a glance at the general characteristics of the speed curves of the various reactors, it is seen that they conform to those already pointed out in detail in the case of one writer³. We find the gradual increase in speed at the beginning, the retardation at each change in direction, and in some cases, notably in the writing of T. T. G., a retardation at the end.

If we examine the writing of the four reactors we shall see that that of one, T. T. G., is angular, that of two, D. H. and R. D. W. is rounded, and that of the fourth F. N. F., stands midway between the two extremes. Parallel to these differences there is a difference in the average speed, T. T. G. writing most rapidly, D. H. and R. D. W. most slowly, and F. N. F. at a medium rate. The relative speed of the straight strokes and the turns varies in the same order. There is a relatively greater retardation at the turns in the writing of T. T. G., least in that

³ See p. 13.

of D. H. and R. D. W., and an amount between these two extremes in the writing of F. N. F. That is, so far as we may judge from the the results of these few reactors, the relation between the speed of the straight strokes and the turns and the differences in speed for the different sharpness of the turns are the same when we compare the writing of different individuals as when we compare the writing of different letters written by the same individual. The same rule holds that the sharper the turn the greater the retardation. In regard to the relation between the differences in speed and the amount of retardation, however, the principle appears to be reversed. When we compare the writing of different individuals, the more rapid writing is characterized by greater retardation at the turns. That is, the difference in speed seems to be chiefly in writing the straighter strokes, whereas in the writing of a single individual an increase in speed in rapid writing occurs equally or nearly so in all parts of the letter. In other words, the same writer tends to preserve his characteristic writing rhythm at different speeds, while different writers who write at different speeds have also a different rhythm.

It was remarked above that the writing of T. T. G. is characterized by a marked retardation at the end of the letter. It will also be remembered that this writer has greater retardation at the turns. We may then say that he has a general habit of pausing, or at least slowing down the strokes at the end of strokes and of letters. This may be called a particular type of the writing habit, and goes in this case, at least, with an angular style and with generally rapid writing.

As was found in the case of F. N. F., there is no noticeable difference in the writing of other adult reactors in the relative speed of the up and the down strokes.

In discussing the writing of F. N. F., we have already compared the speed characteristics of letters of different sizes, as for example, the "a" and the "p."⁴ We may also compare the speed of certain letters written by the adult subjects at one time in the usual size and at another time written larger than usual. Two

⁴ See pp. 17-18.

typical records of letters written larger than ordinarily are shown in Figure 6, the letters "r" written by F. N. F. (curve 47), and "n" written by D. H. (curve 82). These show the typical relation of letters written in this way to the ordinary writing. A comparison of these curves with those of the records of the same letters, written by the same subjects, in the usual size, in Figures 4 and 5 shows that the same difference obtains here as was noted between different letters of different sizes. That is, in writing the larger letter, whether we compare different letters of different sizes or the same letter written now small and now large, there is a marked increase in speed throughout the letter, both on the straight strokes and at the turns. In other words, a writer tends to maintain the same writing rhythm.

The records from writing between lines are so meager that general conclusions cannot be drawn from them. The results from the three cases which are at hand are suggestive, however, and are illustrated in the sample record from the letter "n" written between lines by D. H., Figure 6, curve 75. A marked retardation in the speed is here evident, and it is also evident that practically all the excess retardation comes at the turns, that is, at the places where the stroke approaches the limiting line.

An illustration of the effect on the speed of writing a connected series of letters in a word is given in Figure 7. This is the record of the letters "Frank," part of the given name of the reactor. A comparison with the separate letters "r," "a," and "n" may be made by turning to the curves in Figure 4. The striking thing about the connected letters is the great uniformity in the speed changes of the successive strokes as compared with the changes in the same letters written separately. The amount of retardation at the turns in particular, is practically the same for the various turns of the different strokes. This is a good example of a sort of unity or uniformity in connected writing which consists in a marked degree of rhythm throughout. This rhythm is partly independent of the external formal character of the strokes and partly influences the character of the external form by reducing the differences among the various letters.

The pressure changes in adult writing are illustrated by the reduced reproductions of typical pressure curves from F. N. F., D. H. and R. D. W. shown in Figure 8. These curves are to be read from right to left. The dots on the curves represent certain stages in the letter. The first dot on the right represents the end of the first millimeter of the stroke, the succeeding dots represent the various turns, so that the parts between the dots correspond to the different strokes.

A glance at the various pressure curves makes it evident that there are regularly two points of high pressure in the letter, namely, the beginning and the end. There are exceptions to this rule, as at the beginning of the letters "h" and "t" (curves c and f, Figure 8). These are, however, distinct exceptions. The particular curves shown to illustrate the writing of D. H. do not show a marked high pressure at the beginning. The writing of this reactor is not in general, however, an exception to the rule. This high pressure at the beginning and the end of the letter occurs whatever the direction of the stroke may happen to be. It may be an up stroke, a down stroke or a horizontal stroke. It is evidently due, then, to the position of the stroke in the letter. An explanation for the high pressure at the beginning has been suggested in discussing the retardation at this part of the letter. On account of the insufficient time, the retardation and high pressure cannot be regarded as constituting an initiatory cue or control, but are probably due to the fact that the beginning of the stroke constitutes a point of adjustment between the movement toward the paper and one along the surface of the paper. The stroke along the surface of the paper is not a second movement, the initiation of which follows upon the sensation of pressure caused by the contact of the pencil with the paper, but part of a single movement which may be interrupted for a longer or shorter period by the lack of perfect adjustment to the position of the paper. This adjustment may be more or less rapid and perfect. The more rapid and perfect it is, the less will be the retardation and excess of pressure at the beginning of the stroke.

The pressure at the end may be related to the fact that there is

a progressive increase in pressure throughout the letter. This latter fact was noted by Gross (9). There is probably a general heightening of nervous excitation in the course of the writing. There is, however, a special increase in pressure just at the end. We found also that there is often a marked retardation at the end of the letter. The two facts are doubtless connected and are to be interpreted as meaning that ending a letter is a definite act psychologically and physiologically.

The above-mentioned pressure characteristics pertain to the letter as a whole and indicate its unity. There are also certain pressure changes which correspond to particular sorts of strokes. An examination of the pressure curves shows that there is, in general, a greater pressure on the down strokes than the up strokes. This fact was also pointed out by Gross. The rule, it is true, is not universal. There are variations between different letters and between different reactors, and limitations due to the position of the stroke in the letter. So, for example, the last stroke may be an up stroke and still have a high pressure. See the curve for the "h," curve c, Figure 8. Or the first stroke of a letter may be a down stroke but the initial pressure be so great that the subsequent part of the stroke decreases in pressure. Again, while a down stroke may in general be made with a high pressure, the last part of the stroke may decrease in pressure. Or the last part of an up stroke may increase in pressure in the same way. For this reason the division points on the curve do not always come at the crest or the valley. See the two "h's," curves b and c, Figure 8. Further, as was indicated in the preliminary experiment, there is often a slight rise in pressure at the beginning of a stroke, whether its direction be up or down. See, for example, the rise at the beginning of the "o," curve d, Figure 8. These variations are due to the relation of the different strokes to each other in the letter and are evidence of the oft-repeated fact that a letter is not merely a collection of strokes, but possesses a distinct unity.

There are also variations among different individuals in the relation of the pressure to the direction of the stroke. To R. D. W., for example, the rule applies but very slightly. There

is somewhat greater pressure on the down stroke, but not a great deal. This brings us to the query why any such relationship exists and why it varies with different persons. The difference might formerly have been explained as a result of convention. But shading on the down stroke is not now commonly taught or practiced with definite intent in the United States. Such shading might, however, explain the phenomenon among writers in Germany. A probable explanation is to be found in the manner of holding the pen and in the character of the movement from the mechanical standpoint. If we observe the position of the pen as we hold it in the orthodox way, we will see that it makes an acute angle with a down stroke of the writing. A movement made in this position by turning the fingers about the middle joints would, if the pen point were not against the paper, trace an arc of a circle. The chord of this arc would not be parallel to the surface of the paper but would be inclined toward it as we make a down stroke. When the pen moves across the surface of the paper we compensate for this tendency by an extensor movement of the first joints of the fingers and a drawing up of the thumb. The tendency to make the movement in a simpler way, that is, by a simple arc-movement about the middle joint, survives, however, in the increased pressure of the stroke.

Reactor R. D. W. held his hand over on the right side so that the pencil did not make an acute angle with the down stroke, and accordingly we find that he exerts practically the same pressure on the down as on the up stroke. The variation in pressure is then probably the function of the mechanical conditions of writing due to the manner of holding the pen, and to the character of the movement in relation to the structure of the hand.

Pressure changes during writing which have been described in the case of one reactor are characteristic of the others with the exception just noted. There are certain variations in detail, but the general principles hold good.

A pressure curve of a letter written large is shown from the writing of R. D. W. and D. H., and of one written between lines by D. H. (Fig. 8). The effect of the modified conditions is substantially the same for all the reactors. When the letters are

written large there is a greater difference between the maximum and minimum pressure of a letter than when they are written in the usual size. There is also more variation in the different parts. In the case of letters written between lines, the opposite effect may be seen. There is less difference in pressure in the different parts. In the latter case it is evident that greater care and closer attention is given to the form of the writing. In the former case, effort is put forth to write with greater speed, though the effort may be made without conscious attention. We may then assume, perhaps, that the attention is to some degree withdrawn from the form. If this inference is correct we may say that attention to form tends to a lack of differentiation in pressure and conversely that approach to automatic writing tends to differentiation in pressure.

In order to compare the writing of children with that of adults, a single letter is chosen, the letter "f." The speed record of this letter written in the usual way is taken from the writing of H. H., C. N., A. S., E. H. and M. H. (Fig. 9, curves 93, 104, 109, 121 and 115) and the record of the same letter written large and between lines is given for the last four reactors (Fig. 10, curves 105, 111, 123, 117 and 107, 113, 125 and 119 respectively). Pressure curves from the same letter for all five reactors are shown in Figure 11.

The most general facts in regard to the speed changes in adult writing appear also in the writing of children. There is a marked variation in speed in the different parts of the letter. The greatest speed is on the straight strokes and there is a more or less retardation at the turns. When we come to examine the children's writing in detail, however, marked differences appear. An examination of the curves from the children's writing reveals a great deal of irregularity, both between the writing of different children and in the writing of the same individual. Compare, for example, curves No. 104 and 109 from the writing of C. N. and A. S. (11 years of age) and curves Nos. 121 and 115 from the same letter written by E. H. and M. H. (10 and 9 years respectively). Although the latter two children are younger they have written the letters much faster than the first

two. The children, in general, showed in the experiment a tendency to write in what appeared to be an unnatural and unusually slow manner. But in the case of the reactors here under consideration, the supervisor of penmanship, Mr. Houston, was present and encouraged them to write freely until he obtained what he thought was their normal writing. We may assume then that the characteristics of this writing were not the product of the conditions of this experiment. We must seek a more general explanation.

There are three possible explanations for this difference between the writing of the different children. In the first place, it may be due to individual variation. This, however, is improbable, for individual variation is ordinarily greater in the writing of adults than of children, and the variation in the present instance is greater than that which we have found in the case of adults. In the second place, the difference may be due to differences in the stage of development, the earlier stage being characterized by greater freedom and less care for form than the later one. A failure to develop in the direction of increase of speed might also, as remarked above, be due to the fact that attention was being turned to the connection of the letters with one another. The third possibility is that the writing of a child is more variable than that of an adult. The same child may write now slowly and carefully, and now rapidly and carelessly, according as the conditions vary or his attitude toward the situation is different. His habit, according to this view, is not yet settled, and since it is in the plastic state it is much more susceptible to outside influences. Adults are also subject to such influence, but not to the same extent. On the basis of our present knowledge of the child's writing habit the third explanation seems to the writer to be the most probable.

The great irregularity in the writing of the same individual may be seen by comparing (Fig. 9) the speed of the different strokes in the writing of H. H., curve 93 and of C. N., curve 121; and of the first part of the letter with the last part in the case of M. H., curve 115. These examples are illustrations of the fact referred to in the last paragraph, that the same child may have

different types of writing. The extremely slow writing is evidently not due to the inability to make a single stroke more rapidly, but either to the difficulty of combining the strokes in a complex total movement, or to attention on the visual form to be made, thus introducing conditions which we have found to reduce the speed of the movement. These two causes doubtless are combined.

In spite of these variations, the children have, in common, one mark of uniform difference from adults. This difference is concerned with the relative speed of the straight strokes and turns. There is less retardation at the turns in the children's writing compared with the speed of the straight strokes. The form of the curve does not make this apparent; in order to get at the true relations one must compare the distance of the various parts from the base line. The difference between the writing of children and adults in the ratio of the speed of the straight strokes and the turns is then seen to be marked. Children have, then, a greater general uniformity of speed throughout the letter, so far as the influence of different kinds of strokes is concerned. That is, there is less difference on the average, between the speed of the straight strokes and the turns.

The curves 105, 111, 123 and 117 in Fig. 10 are records from C. N., A. S., E. H. and M. H. writing the same letter large. We have here evidence in confirmation of the position that the first two children are to be distinguished from the last two in the type of movement they employed. In writing large the first two modify the speed of their movement radically while the last two do not. The first two reactors, furthermore, modify the type of the movement so as to approach that of adults. That is, there is a greater difference between the speed of straight strokes and turns when the writing is large. The younger children had apparently written at about their maximum speed when they wrote the letter in the usual size. It may also be that the tendency to rhythm is less with them and their writing is therefore less modified by the increase in size.

There is a noticeable difference in the speed changes when the letters are written between the lines. The feature common to all the cases is the increased retardation at the turns where the

letters meet the line or a decrease in speed on the part of the stroke approaching this point or both. In the case of A. S. the approach only is slow. A very noticeable case of the retardation at the turn is seen in curve 107 from C. N. A marked case of retardation on the approach is seen in curve 119, from M. H. The lines were so placed that the letter was written considerably larger than usual. This caused it to be written more rapidly by C. N. and A. S., particularly the latter, and this counteracted the retardation due to the lines.

These results indicate then that a restriction such as limiting lines has a similar effect on the writing of children as on that of adults, that is, a retardation, particularly at and just before the point of finer adjustment.

The pressure of children's writing is illustrated by curves from five reactors, Figure 11. The pressure records of E. H. were too dim to be read. The division points on the curve represent the same points on the letter as in Figure 8. Where there are only three division points the last out stroke of the "f" was too short to be indicated.

The mean pressure of the children's writing is less than that of the adults, as shown in the accompanying table:

<i>Adults</i>			
F. N. F.....	9.5	D. H.	15.0
R. D. W.....	13.5		
<i>Children</i>			
H. H.	2.5—B	E. C.	4.5—G
C. K.	8.0—B	O. D.	14.0—B
M. S.	6.5—G	A. S.	7.0—B
G. B.	7.0—G	M. H.	9.5—G

The units are arbitrary. The letters on the right indicate the sex and show that this was not a determining factor. Too much stress is not to be laid on this difference in mean pressure because the children in these schools were drilled in the avoidance of pressure. The low pressure of H. H., the son of the writing supervisor, is significant in this regard.

In certain respects the pressure changes of children's writing are similar to those of adults. There is a gradual increase in pressure toward the end of the letter. There is usually a rise

in pressure on the down stroke and a fall on the up stroke. The curves from reactors A. S. and M. H. are exceptions to the rule in this respect.

The similarity of the records of some of the children to those of adults is also apparent. The pressure in the writing of H. H., C. K. and C. N., for example, increases and decreases in the same parts of the letter as in the typical adult writing. The entire release of pressure, however, is a mark of difference. In the writing of A. S. and M. H. the maintenance of the same degree of pressure for a continued period of time at the end of the letter is at variance with the adult type. In general then, the pressure of the children's writing varies from that of adult writing chiefly in that it is more irregular. This is evidence that the coördination has not yet attained stability and uniformity.

If we attempt to characterize the writing habit of children in comparison with that of adults, or in other words, if we describe the course of development of the writing habit so far as we may do so on the basis of the results of this experiment, we find in the first place that undeveloped writing is irregular. This irregularity is a matter of easy observation so far as the external form is concerned. We have here defined the irregularity in terms of the coördination. There is irregularity in the average speed and in the distribution of speed throughout the letter. For example, though the ratio between the speed of the straight strokes and the turns is less than in the writing of adults, though there is greater uniformity in this sense, this ratio is less constant than in adults' writing. There is greater change wrought in the coördination by changes in the outward conditions. The yet imperfectly formed coördination is unstable, having not yet acquired its fixed form.

Another characteristic of undeveloped writing which we have been able to define somewhat definitely, is the relative lack of rhythm. There is less tendency than in developed writing to increase the speed with an increase in size, whether of the same letter or of different ones. In writing letters larger than usual the adult increases the speed of the whole letter, while the child increases the speed of the straighter strokes.

We may venture to interpret the greater uniformity in speed in the writing of children as indicating that the writing process is a more continuous one than is the writing of adults. This continuity may be interpreted as giving evidence of more continuous and uniform discharge of nervous energy, or innervation. On the the mental side it doubtless corresponds to the more continuous and greater expenditure of effort throughout each part of the writing stroke; and to the application of a higher degree of attention to the visual aspects of the writing stroke during its production. This latter conclusion is supported by the experiments of Ahrens (1) and the observations of Schubert, whom he quotes, to the effect that the eye movements of children follow the course of the writing stroke more completely than do the eye movements of adults.

With the development of the coördination less attention is given to the visual aspects of the writing. The guidance or control of the movement must then be given over more largely to the kinesthetic sensations. This fact brings the points of motor readjustment in the writing into greater prominence. These are of course the points of division between the successive strokes. Furthermore, the control in developed writing is not only relatively less dependent on the visual and more on the kinesthetic sensations, but the attention is less directed toward controls of any sort. In other words the writing becomes more automatic in nature and comes more under the influence of the mechanical conditions of the movement. One of these conditions is the inertia which brings about a retardation in the speed of an object when the direction of its movement is altered. This factor again brings about a discontinuity in the movement by which the successive strokes are produced.

The results of this experiment, then, lead to the adoption of a point of view regarding the character of the nervous process by which the writing movement is produced which is at variance with the interpretation made by Smith (18) and Awramoff (2) on the basis of their experiments, and by Meumann (15) in his interpretation of children's writing. These authors hold that children's writing is a series of separate impulses or innerva-

tions (*Einzelinnervationen*), whereas in the writing of adults a number of successive strokes or letters is united by the fact that they are produced by a single impulse (*Gesamttinnervation*). On the contrary, the writing of children is less broken up into distinct strokes than that of adults. The fact that the pressure curves give evidence of at least as sustained effort as do the pressure curves of adult writing points to the same conclusion.

As there are characteristics of writing in successive stages of development which point to a breaking up of the continuity of the process, there are other facts which point to a progressive organization or unification. This appears in the more pronounced rhythm of developed writing and in the extent to which the speed and pressure of the individual strokes are modified by their relation to the other strokes which compose the letter or the word. This increase in the organization of the movement may be looked on as the positive result of the change in the object of attention, of which the negative result is the increased mechanization. The attention of the practiced writer is not narrowed to the portion of the stroke which is being made, but includes the word or group of letters of which the stroke which is being made is a part. That this inclusion in the attention of anticipated strokes influences the stroke which is in the course of being made accords with the fact which was discovered in the preliminary experiment (Freeman 8), namely, that the speed of a reaction is modified by the anticipated later course of the movement.

This anticipation of letters and organization into groups accompanies the recognition of them as having meaning—that is, as being language symbols. The organization takes place primarily on the plane of the recognition of meaning, and secondarily in the motor process. This organization affects the series of innervations which compose the writing movement, not by making them into a total innervation, but by introducing modifications into the successive innervations. These modifications take the form of the development of rhythm, and of sundry retardations or accelerations of parts of strokes as the result of the anticipation of other strokes.

The statement that undeveloped writing is not organized into a complex habit so that the separate elements of movement can be relinquished to relative automatism does not mean that the child would not be able to make a single stroke by itself, not in a letter, much faster than he makes the parts of a letter. He could. But it is precisely the ability to make a stroke in a letter as though it were not restricted by its relationship to other strokes, and at the same time adjust it nicely to them, which requires the combination of automatism and control which the child cannot command. He must develop it by long practice, at first under the constant guidance of attention.

It would be out of place to discuss here any pedagogical applications of these principles, but one which follows directly from what has been said may be at least mentioned. It is unquestionably true, as Meumann (15) and Awramoff (2) hold, that since rhythm is one of the chief characteristics of the developed writing habit, to impose an artificial rhythm upon undeveloped writing will give it some of the characteristics of developed writing. It may do so at the expense of external form, however, if the precaution is not taken to suit the tempo to the ability and stage of development of the child.

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FIGURE 4—Reproduction of speed curves from all the letters of the alphabet from the writing of F. N. F.

FIGURE 5—Reproduction of speed curves of letters written by T. T. G., D. H., and R. D. W.

FIGURE 5 (Continued)

FIGURE 6—Reproduction of speed curves of letters written large by F. N. F. and D. H. (curves 47 and 82) and of a letter written between lines by D. H. (curve 75).

FIGURE 7—Speed curve of letters written connectedly in name by F. N. F.

Reactor F. N. F.

FIGURE 8—Pressure curves from the adult subjects, F. N. F., D. H., and R. D. W.

Reactor R.D.W:

Reactor D.H

FIGURE 8 (Continued)

FIGURE 9—Speed curves of letters written by children, in usual manner

FIGURE 9 (Continued)—Speed curves of letters written by children in usual manner

Reactor H.H.

Reactor C.K.

Reactor C.N.

Reactor A.S.

Reactor M.H.

Figure 10.—Speed curves of letters written by children, Nos. 105, 111, 123 and 127 written large, and Nos. 107, 125, 113 and 129 written between lines