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## *Behavioural Studies of the Handwriting Skill*


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# *Introduction to This Special Issue*

This special issue of *Visible Language* is dedicated to the empirical study of handwriting. The papers that follow were chosen to show the wide range of studies related to mechanisms of handwriting production. Their authors' fields of specialisation are as diverse as psychology (including developmental and educational branches), motor skills, forensic science, engineering (waveform analysis, pattern recognition), and artificial intelligence but all have a common interest in characterising the behavioural aspects of handwriting. To ease the uninitiated into this fascinating area, authors were encouraged to make their accounts comprehensible to the non-specialist.

One major area of endeavour that is not represented in this issue concerns the relation between handwriting and the personality characteristics of the writer. However, there has been a very large amount of research on graphological questions such as what traits determine choice of handwriting style or the converse, what features in handwriting are reliable indices of personality? It would thus seem more appropriate to hope there will be a future issue of *Visible Language* devoted to this area rather than try to include only one representative paper.

Finally, I would like to acknowledge the efforts, both of the authors who contributed the papers, and of those who helped the production of this issue by reviewing the submitted papers.

A.M.W

# *Facility of Handwriting Using Different Movements*

R. S. Woodworth

R. S. Woodworth is best known among psychologists for his text *Experimental Psychology*. However, early in his career he produced a research monograph on the accuracy of voluntary movement which included a section on different ways of producing handwriting movements. We reproduce this section here for two reasons: on the one hand it is an early example of a psychologist's interest in handwriting, which he followed up with careful observation; on the other hand it provides a basis for comparison to show the extent to which current work on behavioural aspects of handwriting is not only concerned with measurement but has progressed to possible theoretical interpretation.

In previous experiments it was found that a side-to-side swing of the wrist and forearm was likely to be made longer than it should be in comparison with a movement of the fingers or of the full arm perpendicular to that. The reason seemed to be that the side-to-side movement was freer and easier. In following up this suggestion, it was found that the movement was also more rapid, more steady and accurate in direction, but somewhat less accurate in extent. Since these facts led to the query whether this movement could not be profitably used in writing, a more complete study was made of the ease, speed, and accuracy in extent and direction of this movement, and of two that are commonly used in writing. One of these is the finger-and-thumb movement, as usually taught to children; and the other a movement of the full arm from the shoulder, which is also sometimes taught under the name of "forearm motion."

The experiment consisted in making series of movements, back and forth like a string of small *u's* or *m's*, such as may be seen in Figure 1. For the finger and full arm movements the paper is held as in ordinary writing. For the wrist movements it is best to let the top of the paper slant over to the right (in case of right-handed persons), so that the direction of the series as a whole shall be

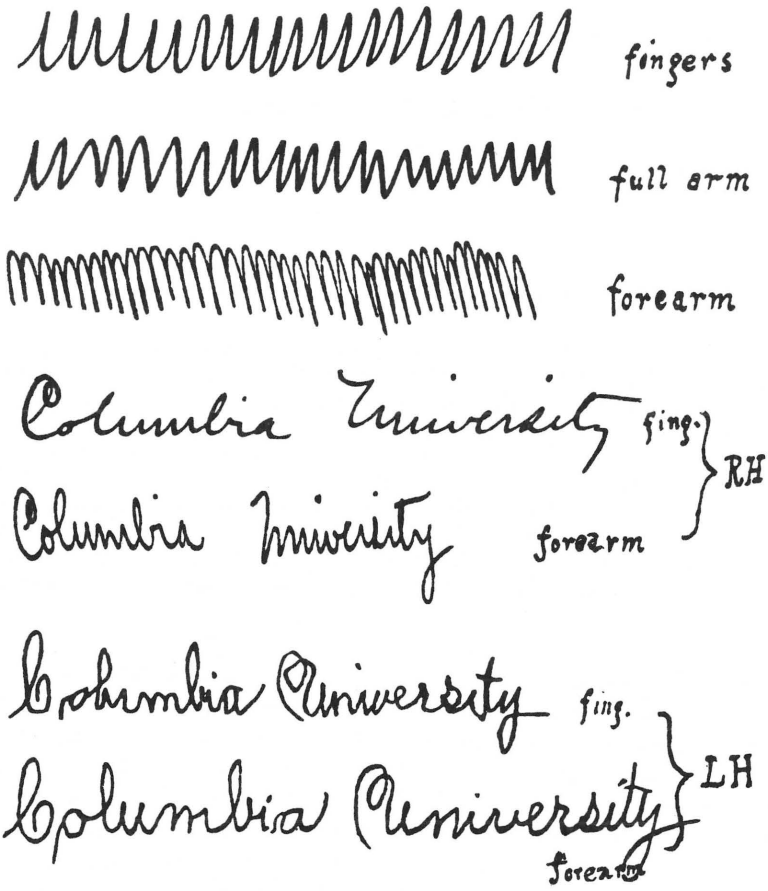


Figure 1. Different movements in writing. RH = right hand, LH = left hand. Reduced to 7/10 original size.

nearly toward the body, or, more exactly in line with the forearm. In this last movement a backward motion of the whole arm carries the hand along the line, while the side-to-side motion of the wrist and forearm makes the separate strokes. The results obtained are as follows:

1. As regards ease, the full arm movement, if hastened, is by all means the hardest. It requires the expenditure of the most energy and shakes the whole body. As between the other two, different persons give different judgments. Some prefer the side-to-side

movement, others the more practised finger movement. There is little doubt that, aside from practice, the side-to-side movement is easier. It is instinctively chosen for such movements as erasing. It is made with a much simpler coordination than the finger-thumb movement. The latter, as has been shown by the researches of Duchenne[1] and of Obici,[2] is a complicated affair. It requires, for instance, the simultaneous extension of the first joint of the forefinger and flexion of the second and third joints, and vice versa. The full-arm movement has no firm fulcrum, and so shakes the trunk. The forearm movement is the simplest, and resting the elbow provides a firm fulcrum. One can see approximately how the three will appeal to an unpractised hand by trying them with the left hand. Besides being the simplest in coordination, the forearm movement has over the finger movement the advantage of being made with comparatively large muscles. The ordinary writing movement is made largely with the little muscles in the hand itself[3] (interosseal and lumbrical). The continued use of the small muscles is more liable to lead to cramp than the continued use of the large muscles. It is found that writers who use the full arm motion are much less subject to writer's cramp than those who use the ordinary motion.[4] The muscles concerned in the side-to-side motion, though not so large as those that make the full arm motion, are large enough. On the whole, therefore, the forearm motion would doubltess be, after practice, the easiest of the three.

2. As regards speed, the forearm is demonstrably the best. Make three series of movements like those in Figure 1 at the fastest possible rate, and time the series. It will probably be found that more back-and-forth movements can be made in a given time by a forearm motion than by either of the others, and that the separate movements of the forearm are also more extensive. Such, at least, has been my observation. Out of 21 persons whom I have tested in this way, there were but four exceptions, none of which was at all marked. The average number of movements per second (double movements, including both back-and-forth) was:

1. G. B. Duchenne, *Physiologie des mouvements*, 1869, pp. 173-175.
2. Recerche sulla Fisiologia della Scrittura; *Rivista di Freniatria*, XXXII, 625-643, 870-893.
3. See Duchenne, loc. cit.
4. See Dana, *Text-book of Nervous Diseases*, 4th ed., 539-548.

Finger movement, 5.3, with a mean variation of 0.8.
Full arm movement, 5.4, with a mean variation of 0.7.
Forearm movement, 6.5, with a mean variation of 1.2.

As between the finger movement and the full arm movement there is no advantage in point of speed. But the forearm movement averages 23% faster than the finger movement.[5]

The left hand gives the same general result. I have tested only four persons, three of whom showed the greatest speed in the forearm movement. The averages were: fingers, 4.0 movements per second; full arm, 4.5; forearm, 5.2. The forearm, therefore, averaged 16% better than the full arm, and 30% better than the fingers. As a matter of fact, the so-called "finger movements" of the left hand are not true writing movements. The left hand cannot make those movements without practice. In trying to make movements of the fingers one finds himself using his wrist, flexing and extending it, and holding the fingers stiff.

It may, perhaps, occur to the reader as an objection that the extremely rapid side-to-side movement of the forearm is a mere muscle trembling, a sort of clonic contraction, and therefore of no use for writing. Inasmuch, however, as the most rapid movements give the same sort of tracings as the more moderate movements of the forearm, inasmuch as the highest rate may be approached without break from the moderate rates, and inasmuch as a certain degree of control can, even without practice, be exercised over the very fastest side-to-side movements, the conclusion must be that these are not muscle trembling, but bona fide voluntary contractions, subject to improvement and voluntary control the same as any other rapid movements. It must be admitted, indeed, that the most rapid forearm movements produce fatigue rather quickly. But very much can here be expected of practice. And, besides, this maximum rate is not much faster than a really comfortable rate which can be kept up for a long time. If one sets out to make movements of three kinds, not at maximum speed but simply at a comfortably fast rate, one generally makes the forearm movement not slower, and very likely even faster than the much more familiar finger movement.

5. This result agrees well with that of Bryan, who found that the fastest series of taps on a telegraph key could be made with wrist or elbow, never with shoulder or finger. *Amer. Jour. of Psy.*, V, 123-204.

Table I.

| | MM. | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 |
|---|---|---|---|---|---|---|---|---|---|
| Subj. G. | Fingers | 0.24 | 0.39 | 0.71 | 0.84 | 0.79 | 0.93 | 1.09 | 1.22 |
| | Full arm | 0.21 | 0.46 | 0.70 | .79 | 0.93 | 0.53 | 1.44 | 0.71 |
| | Forearm | 0.19 | 0.38 | 0.86 | 0.97 | 1.10 | 1.35 | 1.06 | 1.07 |
| Subj H. | Fingers | 0.14 | 0.25 | 0.69 | 1.54 | 1.81 | 2.45 | 2.19 | 2.41 |
| | Full arm | 0.21 | 0.61 | 0.74 | 1.02 | 1.63 | 1.95 | 1.90 | 1.74 |
| | Forearm | 0.22 | 0.48 | 1.02 | 1.91 | 1.11 | 1.74 | 1.63 | 2.17 |
| Subj. Sp. | Fingers | 0.64 | 1.04 | 1.14 | 1.52 | 0.83 | | 1.05 | 0.94 |
| | Full arm | 0.43 | 0.75 | 0.97 | 1.79 | 0.71 | | 0.96 | 1.49 |
| | Forearm | 0.32 | 0.71 | 1.03 | 1.77 | 1.68 | | 1.25 | 1.42 |
| Subj. W. | Fingers | 0.20 | 0.39 | 0.40 | 0.42 | 0.55 | 0.52 | | |
| | Full arm | 0.41 | 0.35 | 0.42 | 0.45 | 0.51 | 0.70 | | |
| | Forearm | 0.24 | 0.48 | 0.48 | 0.44 | 0.40 | 0.61 | | |

Accuracy in extent of three different writing movements. The "normal" was 1 cm. The average errors are given in mm. Error of each average $1/12$ thereof, except in case of subject W, where it is $1/25$

There is then no room for doubt that if the forearm movement should be found feasible in other respects, it would be of decided advantage in the matter of speed.

3. As regards accuracy there are several points to be considered. In uniformity of direction or slant the forearm movement is easily the best of the lot. This may be seen in Figure 1 or better still in a tracing of the reader's own. There is a smoothness and grace of movement about the work of the forearm that is entirely lacking in the others. The spacing is also fully as uniform as by the other methods. The alignment is, however, inferior to that of the finger movements; the forearm movements do not stick to a straight line very well. And there is more variability in the lengths of the single strokes. These two points of inferiority are probably due simply to lack of practice. We can easily remember the difficulty we had as children in both the alignment and the heights of our letters. In order, however, to see how considerable this inferiority was, an experiment was devised in imitation of the simpler parts of learning to write. A series of movements like those of Figure 1 was made, except that they were required to confine themselves be-

Table II.

| | MM . . . | 40 | 80 | 120 | 160 | 200 | 240 | 280 | SUM |
|---|---|---|---|---|---|---|---|---|---|
| 1 | dist. | .3 | .6 | 1.3 | 1.7 | 2.9 | 3.2 | 4.1 | 14.1 |
| | dir. | .3 | 1.2 | 2.1 | 2.2 | 5.3 | 4.3 | 5.6 | 21.0 |
| 2 | dist. | .2 | .9 | 1.5 | 3.2 | 3.8 | 4.3 | 5.7 | 19.6 |
| | dir. | .1 | .5 | 1.2 | 2.4 | 2.4 | 5.0 | 4.3 | 15.9 |
| 3 | dist. | .3 | .9 | 2.2 | 2.9 | 4.0 | 5.3 | 6.1 | 21.7 |
| | dir. | .2 | .9 | 1.7 | 2.7 | 2.4 | 4.5 | 3.3 | 15.7 |

Three-target experiment. Subject W. The error due to faulty direction of the hit is separated from that due to faulty extent. This was accomplished by measuring the distance of each hit, not from the target itself, but from two axes passing through the target, one in the normal direction of the movement toward that target, the other perpendicular to the first. Any hit which fell on the first axis was perfect in direction, any which fell on the second was perfect in extent. The distance of each hit from the first axis gave its error in direction, while its distance from the second axis gave its error in extent. The errors recorded in the table are the averages obtained from fifty hits at each of the three targets. The "error" of each average is one-tenth of that average.

tween two parallel lines a centimeter apart (lines of ruled note paper), and to extend just up to the lines. The experiment was tried at different speeds and the errors in extent measured — that is, the distances by which the separate strokes overran or fell short of the boundary lines. The average errors are given in Table I.

It will here be noticed that while the forearm movements show on the whole the greatest errors, yet there are frequent exceptions. The forearm movement averages the least accurate in only two of the four subjects. In one the full arm movement gives the least accuracy, and in one the finger movement. In the general average of the four subjects the full arm gives the least error, the fingers next, the forearm most, in the ratio of 100, 106, and 118 respectively. The forearm gives 18% greater error than the full arm, and 11% greater than the fingers. When we take account of the much greater practice of the fingers in this sort of movement, this result points to the probability that, given equal amounts of practice, either forearm or full arm would surpass the fingers in accuracy. As between the forearm and the full arm, these averages would show that the full arm gives somewhat greater accuracy in extent.

This view is confirmed, in case of movements of 15-20 centimeters, by similar experiments on the blackboard, and by the analysis of the error in hitting at a target (three-target method) into an error of distance or extent and an error of direction. This is done in Table II.

The result is that the error in distance is less at target number 1, the movement to which is a full arm movement (a pushing forward of the arm), than at targets numbers 2 and 3, the movement to which is largely made by the forearm. The error of direction, on the other hand, is greatest at number 1, being here decidedly in excess of the error of distance, whereas at the other targets it is smaller than the error of distance. The full arm movements are therefore more accurate in extent, the forearm movements in direction. But as far as concerns writing, there can be no doubt that either movement would with practice attain sufficient accuracy for all ordinary purposes.

Careful comparison of the three movements available for writing leads then to the discovery of certain points of superiority on the side of the forearm movement. It is easier, made with good-sized muscles, capable of greater rapidity, more uniform in direction, and only slightly inferior in accuracy of extent and of alignment. Some of these points of superiority it shares with the full arm movement, which seems even to be somewhat more accurate in extent. But the great inferiority of the full arm movement in point of ease and rapidity puts it out of comparison with the forearm movement.

It is freely admitted that purely analytical results of this sort are not sufficient to establish the practical superiority of any way of doing a thing. The suggestions gained in the laboratory need to be tested in actual practice before being adopted. I have not had the opportunity of teaching children by the suggested method, and observing their success. That lies beyond the scope of my work. I have, however, tried the suggested mode of writing on myself, not spending time in special practice but simply using the new method in part of my ordinary writing.

The first difficulty to make its appearance when one who has been brought up to write with the fingers starts to write with the forearm movement is that the paper needs to slant over toward the right rather than to the left, and the unusual appearance of the line to the eye leads to extreme backhandedness. This may be avoided by crooking the arm in closer to the front of the body and allowing

the paper to slant only a trifle, if at all, to the right. This is not the best position for the forearm movement, but it does very well and makes the writing look right as it is being written. Undoubtedly one who had never learned to write would experience no difficulty in learning with the slant which to us is unfamiliar. A second difficulty in writing with the forearm movement is that the hand is carried along by a new movement, which at first is awkward. This awkwardness, however, soon passes away.

The first advantage that appears in the new movement is that there is no longer that strong tendency in rapid writing to flatten out the letters until the vertical strokes are mere rudiments of what the copy books teach. This tendency is almost unavoidable in both finger and full arm writing; but it disappears in forearm writing on account of the great ease and freedom of the movement that produces the vertical strokes — that same ease and freedom which make it difficult at first to make the letters of equal height and to keep the alignment. Another advantage which appears in the new method as soon as the first awkwardness has worn off is that rapid writing is easier and less tiring. On the whole, I have found the possession of the new way of writing of advantage to me. A change from one method to the other affords sometimes a very welcome rest.

Besides using the new movement in my right-handed penmanship, I have also practised both it and the finger movement with the left hand. As the left hand had never been used for such purposes, it was somewhat in the condition of the child's right hand when the child is first learning to write. The adult's left hand soon reaps the benefit indeed of the long practice with the right. But at the beginning the left hand is very awkward, and probably gives us an insight into the difficulties that confront the child in first learning a new movement. On trying with the left hand the different modes of writing, it became at once clear that the finger movement was a hard one to get. At first it is quite impossible to get the proper coordination. The forearm movement, though awkward, is ready from the start. The principal difficulty with it is that the hand is carried along the line by pushing it in the direction of the forearm, instead of pulling it as in the right hand; and this pushing of the forearm as it rests on the table is at first very jerky. The finger and the forearm movements were practised exactly equal amounts. Improvement was fairly rapid in both cases. The finger movement came to be the better in uniformity of height and

in alignment, but it remained subject to little jerks and angularities due to imperfect coordination. The forearm movement was somewhat hard to restrain, but it was always freer and more rapid. The degree of practice finally attained was not at all high. Specimens of both methods in their present state are given in Figure 1, which contains also specimens of rapidly written work with the right hand by each method.

The apparent outcome of these practical experiments is that the forearm movement is entirely practicable. And if it be practicable, we may justly infer from our more analytical experiments that it will be in certain important respects an improvement on the modes of writing now in vogue. It will be freer, easier, and less liable to cramp than the finger movement; it will be more rapid; it will not tend to the extreme flattening out of the letters, such as results from rapid writing by either of the other methods; it will be more regular in the direction of the strokes. Whether it will surpass the present methods in the accuracy of height or of alignment is a matter of doubt. It will undoubtedly be perfectly adequate in this respect. And there seems little room for doubt that it will be more readily learned.

Reprinted from *Psychological Review Monograph Supplements,* 1899, 3 (3).

# *Computer-Aided Analysis of Handwriting Movements*

Hans-Leo H. M. Teulings
and Arnold J. W. M. Thomassen

The paper attempts to demonstrate that writing movements — once recorded on a suitable xy-digitizer — can be processed and analyzed by means of a computer for many different purposes. This method is used in the authors' laboratory to study the human writing apparatus and, to a smaller extent, the reading of handwriting. From the writing movement certain time and frequency functions are derived and the kinds of information that may be obtained from these functions are briefly indicated. Some feasible practical applications are discussed, and the paper concludes with a suggestion on a new kind of writing instruction.

## 1 *Introduction*

At Nijmegen we are analyzing handwriting to discover by which mechanism the human writing apparatus is able to perform the complex movements required for this task. We are particularly interested in the development of graphic abilities in children and in the nature of grapho-motor dysfunction in certain groups of patients with well-specified neurological disturbances. We are also involved in the investigation of reading handwritten words. It will become clear that there is some relation between those two topics when viewed from the methodological side of our study.

When studying handwriting, one may merely look at a static sample of produced handwriting, as when one inspects a piece of somebody's writing. The fact that we are interested in motor control, however, implies that we have to study the actual movements being performed during the production of handwriting. Handwriting is brought about by the combined activity of muscle systems in hand, arm, and shoulder. A complete description would imply that all this muscle activity should be recorded, and that the relative movements of every limb of the human writing apparatus should likewise be registered. We have recognized that it is not

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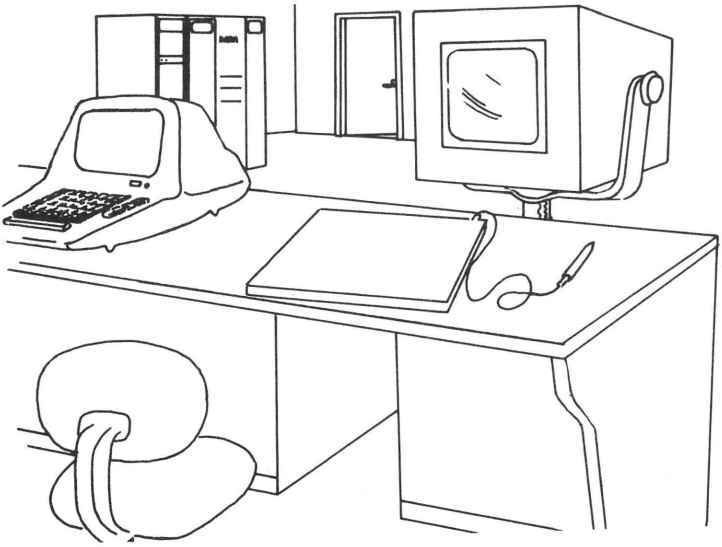


Figure 1. Arrangement of the xy-digitizer with computer and display.

feasible to record all these components. Since the aim of the handwriting act is to produce a well defined static writing trace, it seems reasonable (at a certain level of analysis) to confine ourselves to looking at how the stylus tip moves over the paper.

The purpose of the present article is to show that, by using a digital computer, the movement of the pen may provide us with extremely valuable information for the investigation of motor control in the self-paced movements involved in handwriting. We also wish to indicate that it is possible by means of the computer to transform the graphic product in various ways that are useful in the study of the reading of handwriting.

## 2 *Apparatus*

To record handwriting in our laboratory we use a so-called xy-digitizer, in the shape of a flat board, which is covered by a sheet of ordinary writing paper (Figure 1). The subject writes with an electronic pen that is connected to a control unit by a flexible wire. The pen is ordinary in appearance and has a simple ball-point refill. The position of the tip of the stylus on the xy-digitizer is registered in terms of the horizontal (x) and vertical (y) distance

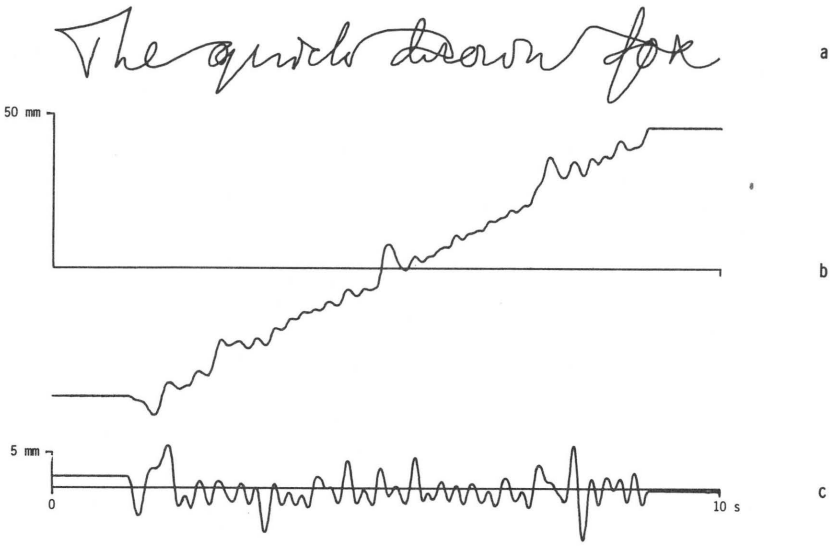



Figure 2. Sample of a handwriting signal as represented in the computer, depicted in two ways: the static writing trace (a), and the x and y coordinate as a function of time (b and c, respectively).

from a fixed point. These distances, or coordinates, may be sampled with a frequency as high as 200 per second and with an accuracy of better than 0.2 mm. It will be clear that a writing movement — even if it lasts only a few seconds — usually contains a very large amount of information. Therefore, the coordinates are fed to a laboratory computer to store the data and to process them. A written word consisting of only a few letters occupies about 2,000 characters in the computer if no data reduction is applied.

These x and y coordinates, which vary with time, will be referred to as the writing signal. The latter comprises all the static and dynamic information of the writing movement that we are going to use in our analyses. The set of positions defined by the simultaneously obtained x and y coordinate values yields the static writing result (Figure 2a). Of course, the writing movement includes also the up and down movements of the pen. Because one may regard these movements above the paper also as part of the writing movement, we can project them onto the two-dimensional writing plane. The dynamic aspects, which can be made visible by plotting the x and y coordinate separately against time, are also retained (Figure 2b, c).

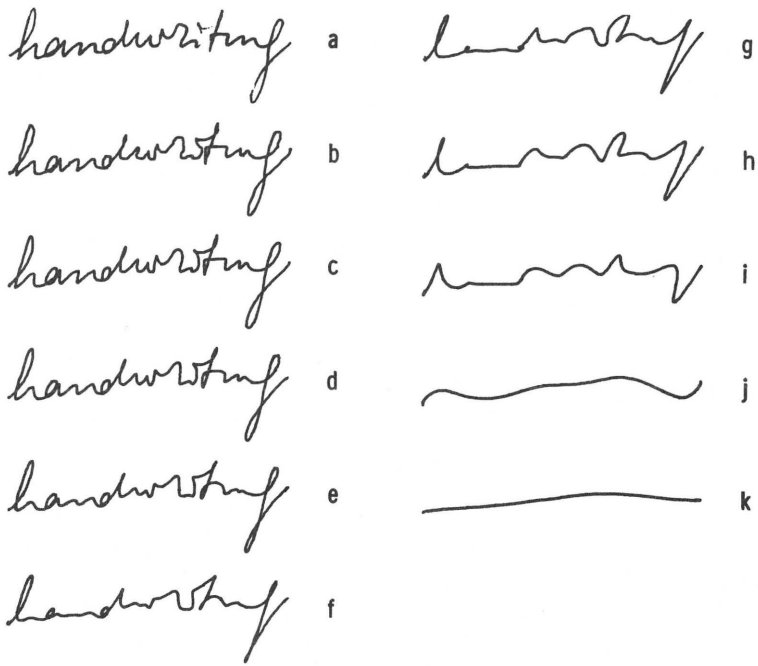



Figure 3. The original writing trace (a) compared with the raw writing trace as stored and displayed by the computer (b) and compared with the writing signal after filtering the raw signal according to low-pass cut-off frequencies of 10, 7, 6, 5, 4, 3, 2, 1, 0.5 Hz respectively (c to k).

## 3 *The Raw Writing Signal, Noise, and Filtering*

The way in which the writing movement is represented in the computer differs in two ways from the original writing movement. First, the position of the pen (i.e., the coordinates) are specified only at certain moments in time. From signal analysis theory we know, however, that the position at all intermediate moments can be estimated exactly, provided that the sampling frequency is high enough. Second, because the accuracy of measurement by the digitizer is limited, the coordinate values are only an approximation; positions of the pen tip intermediate with respect to the resolution of the digitizer are rounded-off to the nearest position that can be identified by the digitizer. The raw writing signal looks jagged relative to the trace left by the pen (Figure 3a, b). This form of distortion we call noise. Noise will often interfere when the signal is processed further. The effects of noise must therefore be reduced by some preliminary processing.

In order to remove noise from the writing signal we must define suitable criteria for separating these. We may state that writing takes place with slow movements relative to the sampling frequency, which implies that the writing signal should be smooth. The contribution of noise results in unpredictable differences between the coordinates as sampled and the true coordinates. Noise appears as fast waves (i.e., high frequencies) in the writing signal. The effects of noise may be reduced by removing these fast waves, which obviously do not occur in real writing movements; this is called smoothing, or low-pass filtering. This type of filtering is commonly encountered in acoustics where it can be done by means of hardware filters. We will perform an analogous manipulation with the writing signal by means of a computer algorithm, which makes use of the Fourier transform. The Fourier transform decomposes the writing signal into a set of sine waves with different amplitudes and frequencies. Plotting the amplitude of all sine waves against their frequency yields the frequency spectrum. By applying the Fourier transform to our writing signal, no information is lost; if we apply the inverse transformation afterwards, we once again obtain the original writing signal. Low-pass filtering, now, is concerned with the following three stages: applying the Fourier transform, setting the high-frequency components to zero, and applying the inverse Fourier transform. Beside the fact that extremely efficient Fourier transform algorithms (called fast Fourier transform) for computers are available, this method possesses some attractive aspects which make fast processing possible. First, other calculations (like determining velocity or acceleration) can be done together with low-pass filtering. Second, the Fourier transform can handle two independent time functions (e.g., x and y coordinates) simultaneously. The described method of removing noise from the writing signal is, of course, just one method among various other methods available, each with their own advantages.

It is difficult to determine a priori at which frequency one should filter; in fact, it depends upon the specific situation. The resemblance between Figure 3a and Figure 3c suggests that we obtain a good approximation to the writing movement if we apply a low-pass filter which removes frequencies higher than 10 Hz. Of course, filtering out frequencies which are important in writing movements will cause distortions (Figure 3d, e, etc.). Filtering at a very low frequency will even lead to the complete removal of all

letters from the writing signal (Figure 3k). What is left is merely the slow displacement movement.

## 4 *Spectrum*

We shall now pay some further attention to the frequency spectrum or, for short, the spectrum.[1] The question as to what frequency components are produced by the writing movement and what components are produced by noise can be answered in a more analytical way by using the spectrum.

From the spectrum of an example of handwriting we can see that most of the frequency components produced by the writing movement are found between 1 and 6 Hz (Figure 4). That these frequencies are essential for easily readable writing may be directly inferred from Figure 3e, f, etc. It appears, moreover, that in some cases one can discern significant frequency components of approximately 10 Hz. If one does not want to remove essential parts of the writing signal one should use a filter cut-off frequency of 10 Hz or higher.

There is also a difference between the horizontal and the vertical component of the writing movement. The vertical component of the writing movement does not comprise slow movements. In other words, nearly immediately after an upstroke, a downstroke will follow since all letters should be aligned according to the base line. As a consequence, if we determine the spectrum of the vertical component of the writing movement, the part of the spectrum between 0 and 0.5 Hz is nearly zero (Figure 4d). We can use this information when we want to estimate the horizontal progression movement according to which writing takes place, including the small vertical variations of the base line. For this purpose we simply filter the complete writing signal with a low-pass filter frequency of about 0.5 Hz (Figure 3k).

Another feature of the spectrum is the possibility of detecting temporal periodicity of the writing movement. If, for instance, a

1. For the sake of accuracy we must distinguish between spectrum and energy spectrum. The spectrum still contains all the information of the writing signal. However, when we are only interested in the relative strengths of the different frequency components, we may use the energy spectrum, which lacks specific information about the phases of the individual frequency components. In this section, spectrum must be interpreted as energy spectrum. Furthermore, the energy spectrum is calculated from the velocity time function — instead of from the positin time function — in order to prevent the very low frequency components from becoming predominant.

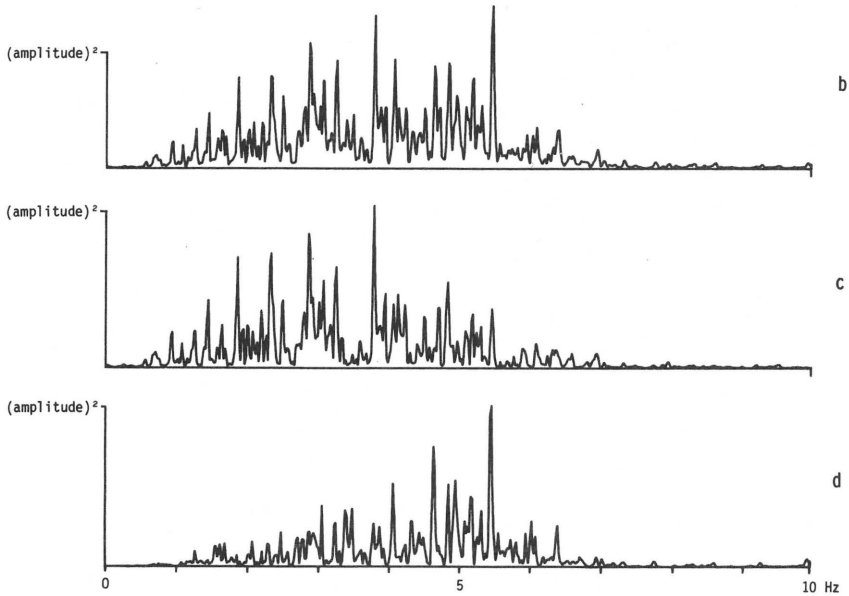



Figure 4. From a sentence of normal writing (a) the frequency spectrum is depicted of the two dimensional movement (b) and for the horizontal and vertical component of the writing movements separately (c and d, respectively). (See footnote).

writing movement contains a stable rhythm or if the writer has some specific tremor, one may expect a strong peak at the corresponding frequency. In general, the spectrum of real writing movements does not contain very high peaks, which indicates that the various strokes in the writing movement take a variable amount of time — depending upon the specific demands of every stroke — or that the writing movement is performed in a rhythm which varies.

5 *Velocity*

For certain purposes one might be interested in the velocity with which the pen moves over the writing surface. Velocity is calculated by determining the change of the position of the pen per unit of time. Velocity, in complex and variable tasks such as handwriting, is itself again a function of time. Velocity must be calculated for changes in the x and y coordinates separately, thus yielding the velocity components in horizontal and vertical directions respectively (Figure 5d, e). Together, the two velocity components define the velocity vector. Absolute velocity or speed can be calculated by determining the size of the velocity vector (Figure 5f).

There is a large amount of data which can be calculated using velocity as a function of time. Imagine that we want to decompose a sample of handwriting into smaller elements. If, for instance, two letters are connected horizontally by a concave-up linking stroke, one way to separate these two letters is to choose the lowest point of the linking stroke. This can be done most accurately by using the vertical component of the velocity over that connection. At its lowest point the vertical velocity component in the linking stoke changes sign from negative to positive.

Often the experimenter wants to know exactly when a writing movement starts, stops, or is disrupted. For that purpose we use absolute velocity as a function of time. In normal, smooth handwriting absolute speed within a word is seldom close to zero for more than 30 ms. We found, however, that this duration may be prolonged drastically, depending upon the demands of the next pen stroke. If, for instance, the subject wants to make the next stroke in a new direction as straight as possible (which is not very common in normal writing) a pause as long as 100 ms is made prior to producing the straight line.

Another function to be mentioned here is the cumulative length of a curve drawn (Figure 5g). This time function can be found by integrating absolute velocity. The time needed to draw a certain pattern appears to be relatively independent of the total length of its trajectory, which is proportional to its size. In an earlier study performed by us, an increase of writing size by a factor of 16 resulted in an increase of the time required by a factor of only 1.6 approximately.

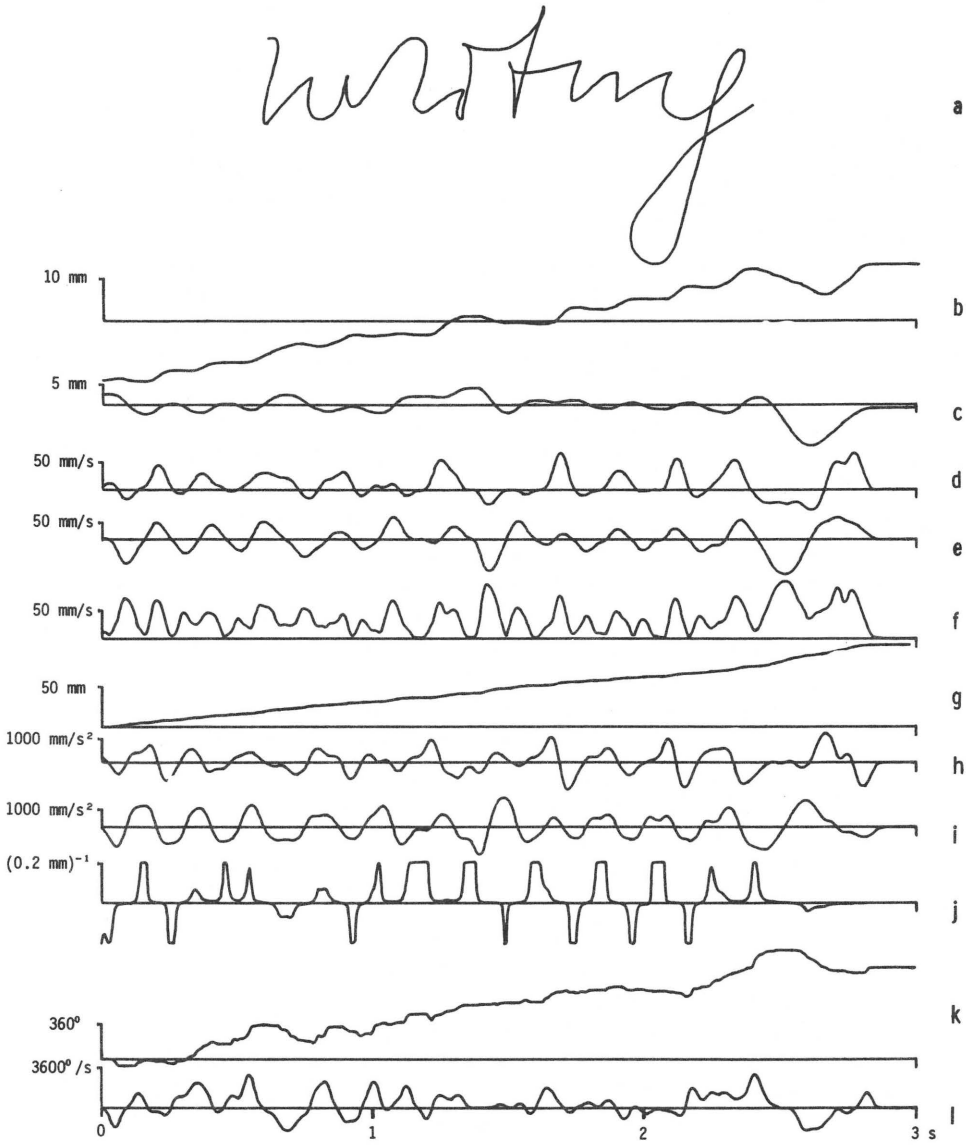



Figure 5. Overview of all time functions discussed in this paper: writing trace (a), x coordinate (b), y coordinate (c), x velocity (d), y velocity (e), absolute velocity (f), cumulative curve length (g), x acceleration (h), y acceleration (i), inverse curve radius (j), running angle (k), and angular velocity (l).

6 *Acceleration*

For certain purposes, acceleration as a function of time is of particular interest. Acceleration is calculated by determining the change of the x and y velocity of the pen per unit of time, thus yielding the acceleration components in horizontal and vertical directions respectively (Figure 5h, i). Acceleration may be called deceleration when acceleration and velocity have opposite directions, i.e., when the movement is slowing down.

The occurrence of acceleration indicates that a force has been applied to the pen. The net force applied is the sum of muscle force and the friction forces of the pen tip and the hand. One might hypothesize that friction helps to stop the pen moving in a certain direction and that muscle force is applied to start the pen moving in another direction. Indeed, in slow writing one can sometimes conclude from the acceleration pattern that the force burst starts just after the friction force has almost stopped the movement. In normal handwriting, however, this effect can be seen only in a few strokes (e.g., see Figure 5d, i). As a first approximation one may say that in normal handwriting the acceleration pattern may be equated to the net force pattern produced by the muscles, because friction levels are in general low as compared to the force levels that apply.

The acceleration pattern often looks very repetitive even though the original writing contains different letters and therefore lacks such a repetitive appearance. The various letters are produced by only tiny variations in duration and amplitude of the individual positive and negative phases in the x and y acceleration and by variations in phase between x and y acceleration.

7 *Functions Related to Form Characteristics*

There is also a class of functions that expresses certain structural features, or form aspects, of a sample of handwriting. We shall look at two simple examples of these functions, to which we refer as curve radius and running angle (Figure 5j, k). One can imagine that a writing trace is represented by a concatenation of small segments of circles, each of them having a specific radius. This radius is, in fact, continuously changing with time. The radius at a certain moment in time can be calculated from the momentaneous velocity and acceleration (or from the running angle, see below). The time function thus calculated we have called the curve radius.

The curve radius may be positive or negative, depending upon whether the curve makes a counterclockwise or a clockwise turn (Figure 5j). For practical purposes the inverse curve radius is plotted so that a small radius is represented by a big deviation from the zero line. A large radius, which always occurs at transitions between counterclockwise and clockwise turning direction, will be represented by a point close to the zero line. In Figure 5j we also restricted the range of values in the graph of the inverse radius because the exact values of the high peaks — representing very small curve radii at the points where the movement reverses — are not of great interest. An attractive application of the curve radius is to use it as a means of reducing the number of data points necessary for displaying a natural looking sample of handwriting, which is in general less easily obtained if the data points are connected by straight lines. For that purpose we approximate the curve radius function by a step function having constant levels at the time intervals during which the curve radius is approximately constant. In other words, we fit the writing trace with segments of different circles, each segment having a certain radius and length of arc.

We now come to our second example function: the running angle. If a writer makes, for instance, one complete loop in counterclockwise direction, the total sum of length of arc covered, irrespective of the curve radius, will be 360 degrees. The cumulative sum of length of arc — which we have called running angle — will thus increase by 360 degrees after each complete counterclockwise loop. Analogously, a complete loop in a clockwise direction will cause the running angle to decrease by 360 degrees. When only a part of a loop is produced, the running angle will change by the amount of the length of arc covered. The running angle is, in fact, a continuous time function which can be calculated from the velocity (Figure 5k). In normal handwriting a counterclockwise curvilinear movement seems to be more frequent than a clockwise one. This may be demonstrated, for example, by showing that the running angle often has a counterclockwise value for a specimen of handwriting, like the one depicted in Figure 5. An application of the running angle procedure may be found in one of the tasks discussed in the paper by Thomassen and Teulings in this issue.

As with any time function, we can calculate the time derivative of the running angle. This function is termed the angular velocity

(Figure 5l). The peaks appear to reach a constant maximum and minimum value for the counterclockwise and clockwise movements, respectively. This is in agreement with the interpretation in terms of the maximum angular velocity, which is limited for counterclockwise and clockwise circular movements. As we found in an earlier study, the maxima are often somewhat higher for the counterclockwise than for the clockwise direction.

## 8 *Transformations of the Handwriting Product*

For certain psychological experiments (e.g., on factors involved in the reading of handwritten words) various manipulations of the handwriting product are of interest. The simplest manipulation is a linear axes transformation. This allows us, for example, to change the slant of a sample of handwriting. There are algorithms available which determine the slope of a person's handwriting. These, combined with linear axes transformation, enable us to change the handwriting of one person into the same person's handwriting with another person's slope or to alter the handwriting of many different writers, each with their own slope, such that they have a single uniform, standard slope (Figure 6a, b).

A different manipulation allows us to vary line width as a function of certain parameters. One may, for instance, choose the width to be proportional to the overlap between the pen movement direction on the one hand and the downward direction on the other. The latter manipulation adds extra "natural" appearance to a piece of handwriting (Figure 6c).

## 9 *Some Practical Applications*

There are a number of obvious, or at least feasible, applications of the algorithms developed for the purpose of our analysis of handwriting. Certain dynamic properties of the writing movement can be used to verify whether the producer of a signature is its real "owner." Such a method should work well because these dynamic properties are totally absent in the static result of handwriting, so that they cannot be forged as easily as the mere appearance of the signature can. One of the main problems in identifying the producer of a signature is how to reduce the amount of information in the writing movement to those parameters that, on the one hand, have maximum constancy for the same signature produced under widely varying conditions by the same person and that, on the other, show maximum variability when that signature is attempted

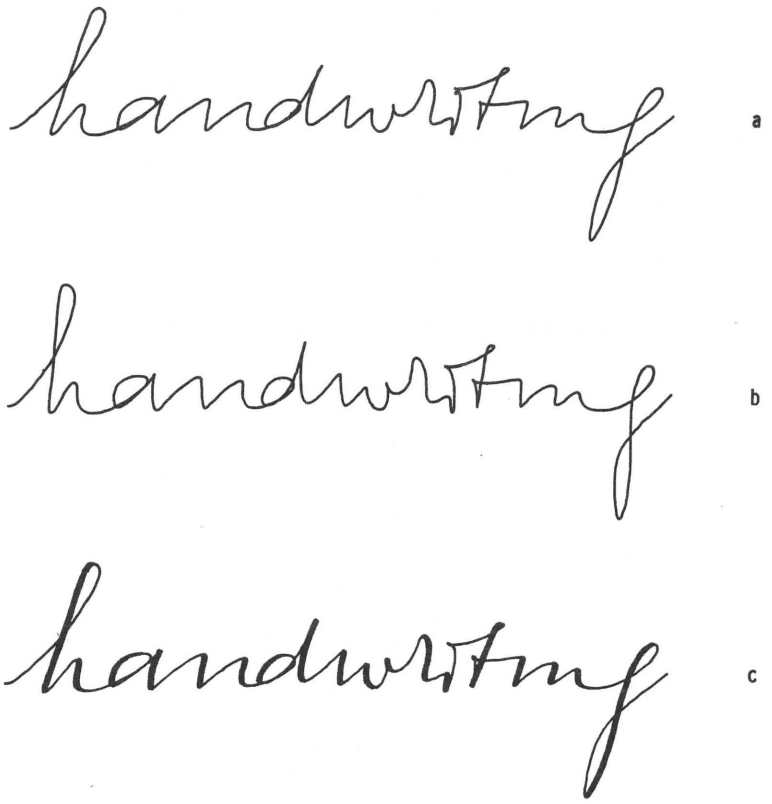



Figure 6. Two examples of the visual transformation of a writing trace (a): a linear axes transformation, where the new vertical axis is chosen parallel to the slant, while the horizontal axis is unchanged (b), and variation of line width (c).

by other persons. Suitable parameters may be the relative durations involved in producing certain elements in writing movements, since it is known that these relations are fairly constant within one person irrespective of overall speed or size variations. Methods like this have been developed, using the pen pressure pattern rather than the writing signal.

Further possible applications include the development of training procedures employing feedback on the writing movement. A simple example of these is the task that may be called track reproduction. One can imagine the experimenter writing a certain track on the xy-digitizer. This track is recorded and stored by the computer. Subsequently, the subject is asked to trace the track accu-

rately. While the writing movement by the subject is being performed, the computer determines, for example, the time needed for any part of the track and the instantaneous distance of the pen from the original track. If the subject takes too much or too little time on a certain part of the track or if the distance is larger than a predetermined value, a buzzer may sound. Thus, the subject is given feedback on the speed and the accuracy of his attempt. He may in the same way be taught to write rhythmically when the same or similar parts are repeatedly written. The maze running test used as an assay of spatial learning ability is, in fact, a rigid precursor of the above procedure. Other examples of providing feedback which can likewise be achieved by real-time processing are, for example, concerned with transformed information of a writing movement with or without delay.

More ambitious applications for instruction purposes are concerned with handwriting as a liberal, expressive means of communication. As such, handwriting is directly tied neither to strict starting and finishing positions nor to template-like shape prescriptions, but instead it allows large amounts of freedom within certain structural or "topological" bounds. A grapheme or a word may be written in as many varied ways as can be recognized. If the purpose of writing instruction is to produce readable but also rapid, natural, and individual handwriting, one must admit that to regard learning to write as a kind of tracking task is totally inadeqate. If for the purpose of writing instruction, descriptions of letters and perhaps letter combinations were prepared in terms of their structural properties such as loops, crossing points, and ratios, programmes could be made available to give beginning writers the appropriate immediate feedback, irrespective of the individual size, slope, curve radius, etc., which constitute precisely the personal features of their own handwriting. This is presumably a better basis for the further development of handwriting as a personal and efficient means of communication than is any uniform set of letters, each of which is practised to a criterion of maximum fit to the standard.

# A Computer to Check Signatures

R. S. Watson and P. J. Pobgee

A growing need to check people's identity automatically — as a safeguard against crime — has led to the development of a computer that verifies signatures by the speed and sequence of pen movements as well as by the finished sample.

Modern technology has, ironically, increased the opportunities for crime and its rewards. Easier and more widespread facilities for getting goods on credit and the introduction of electronic fund transfer systems have made it possible to make money directly by fraud.

Nowadays, too, there are many places where people cannot be allowed to enter unless they are authorized. These may house stocks of valuable or dangerous material or stores of confidential information, often in the form of computer records. Providing guards to check people's identity costs a lot of money so there is a need now for some automatic system of checking that people are, indeed, who they are supposed to be.

There are two ways of tackling the problem. First is the method of providing tokens, such as credit cards or pass cards or even secret codes. But, of course, tokens can be lost or stolen and, on occasions, lent to other people. The second method is to make use of some human property such as fingerprints, body weight, or other physical dimension. Unfortunately, people often object to such things being used. In any case, measurement can be expensive to automate, and together with voice prints these visible attributes can still be imitated.

### *Pen Movements*

Signing is the traditional method for authorizing documents, and signatures represent a well practised human behaviour pattern. In the Computer Science Division at the National Physical Laboratory (Teddington, England) we realized that, although the visible

mark can be easily copied or traced, the way in which it is written is also characteristic of the writer. This means that additional information can be obtained by measuring the speed and sequence with which the pen is moved across the paper.

It followed that in any automatic system for recognizing signatures as they were written the first requirement was for an economic way of obtaining this hidden information without upsetting the writer's natural rhythm. This was obtained by inventing a simple electronic notepad that produced a sequence of electrical signals corresponding to the signing action without being connected to the writer's pen. This pad has been further developed commerically and is marketed by Quest Automation (Dorset, England) as a data entry device under the name Datapad.

The second stage was the study of a great number of signatures to choose a method of measurement that could ignore minor variations between samples from the same writer, while preserving his distinguishing features. Over 10,000 signatures were collected from more than 500 writers from all walks of life. When we examined these with a view to isolating the variables, four rather obvious factors emerged. These were *name*, *style*, *context*, and *noise*.

The *name* forms the basic structure. It may be short, such as B. Nye, or long with 30 letters or more — Sir Frederick Marmaduke Bertwhistle. The name may be written in different languages or scripts such as Russian, Arabic, Japanese, Hebrew, or for that matter any well practised group of symbols. In some cases a person's initials are acceptable.

By *style* we mean the variations about the name form. Many people have a repertoire of styles which they use on various occasions. A number of common examples which we met were a "working or everyday use" style, a "cheque book" style and what might be called an "impress the boss" style.

*Context* is the modification to a given style caused by what the individual is doing at the time. The rhythmic properties of a person's signature can vary according to his attitude to the transaction. The signing of an important document will affect the way he writes more than a trivial event such as the receipt of articles worth a few pence.

All the other influences that may affect the signing behaviour we have called the *noise* factor. The weather may be included in this category and a number of signatures were collected from peo-

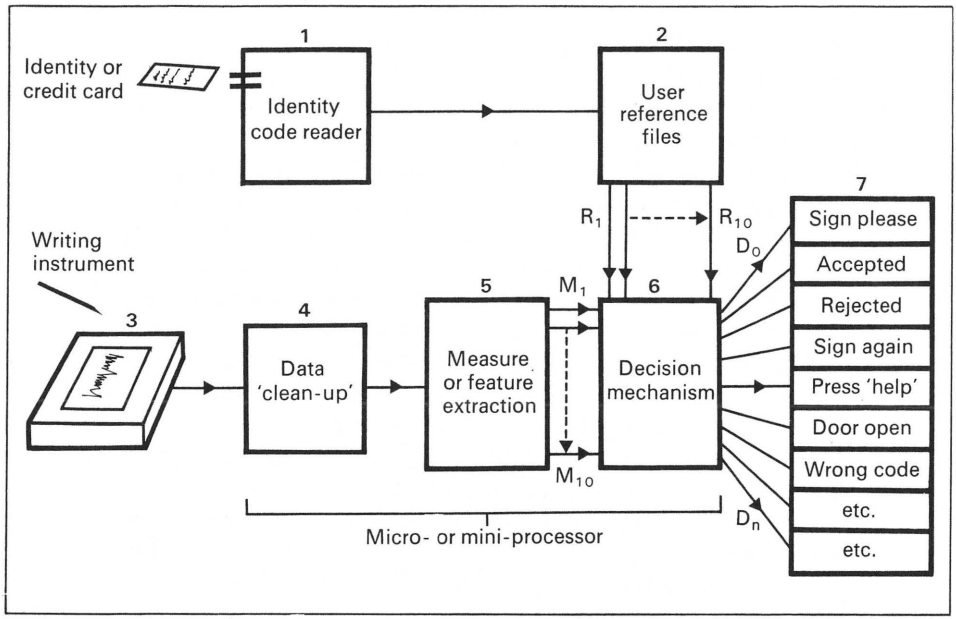



Diagram 1. Basic signature validation machine.

ple arriving at the laboratory in midwinter. Other samples were obtained from people in various states of health. In one case drugs were being taken to alleviate the symptoms of a nervous condition. Then, of course, there is always the "after business lunch effect" which can influence the signing rhythms!

Our large data bank of signatures was supported by other experience from NPL research into interaction between man and machine. This enabled a team led by J. Parks of NPL to develop powerful techniques to overcome many of the difficulties.

Peter Hawkes of the UK's National Research Development Corporation and Stephen Dennis of Inter-Bank Research Organisation had been following our progress with interest, and a joint venture was formed between NRDC, IBRO, and NPL to construct a prototype machine for VERIfication of SIGNatures (VERISIGN).

Diagram 1 illustrates the basic building blocks of the Verisign machine. A user first enters his personal identity code either through keyboard or badge reader (1). The code, which in our case is a four digit number, is used to extract the user's reference file (2) containing a set of ten reference parameters (R1-R10). These are passed to the decision mechanism (6) and a request flashed to

the output display (7) for the person to sign his name on the notepad (3).

The notepad has an electro-sensitive surface on which movements of the writing stylus are converted into a string of interleaved x, y co-ordinates. This data string is then processed (4) to remove artifacts such as marks made accidentally by the user.

Analysis of the cleaned up data occurs at (5) in which measurements are made on certain properties which characterize the signing pattern. Examples of possible measurements are the number of crossings made by the x or y co-ordinates over a datum line or the total time spent in writing. Many other functions of position and time may be chosen.

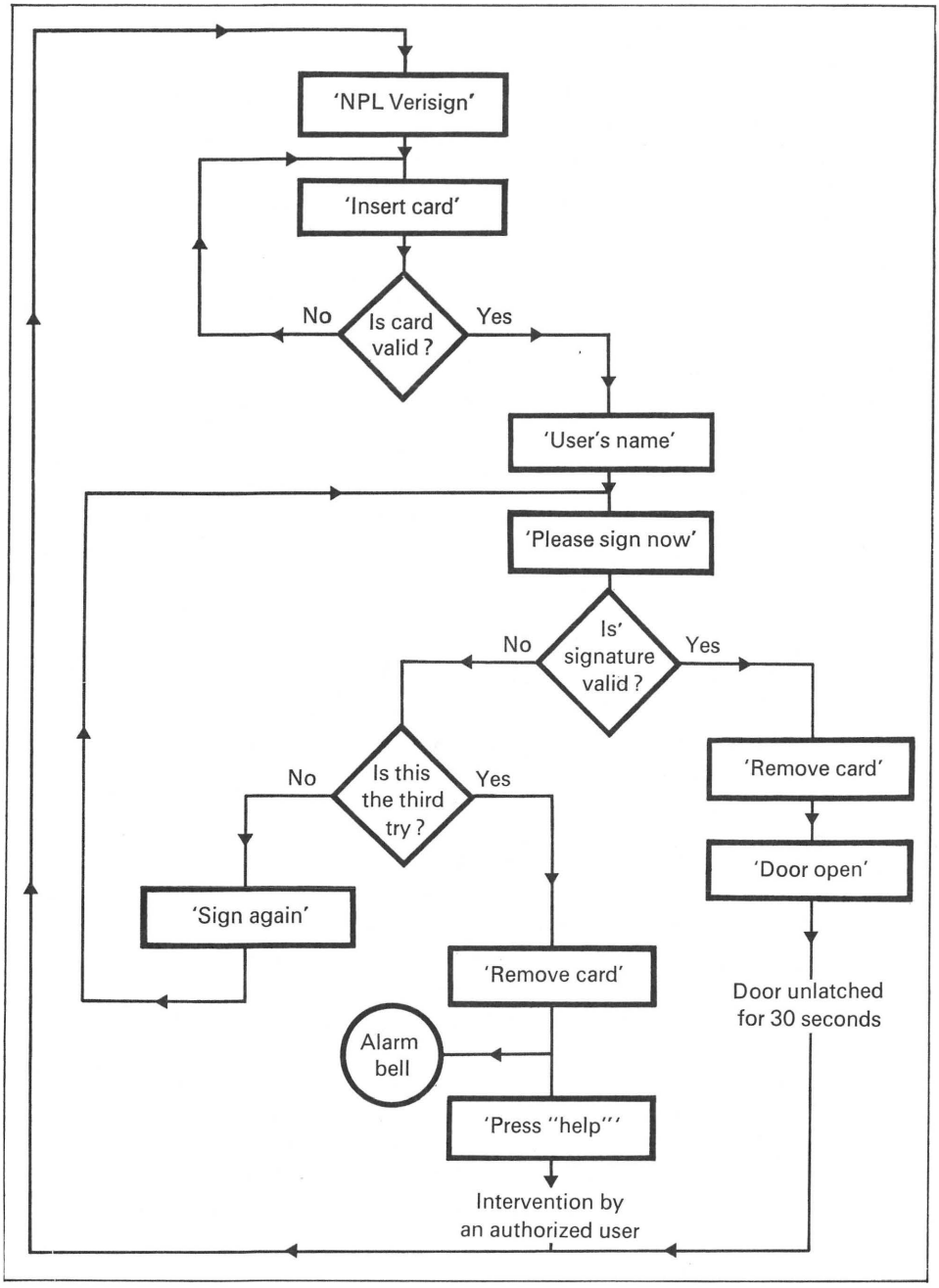
The properties or parameters can be selected locally, that is within certain areas, or globally, with the measurements taken over the whole signature.

Over 100 measures were tested for their ability to discriminate between writers, while remaining insensitive to each person's own variation. From these ten measures were selected and used to generate the values M1-M10 which are passed to the decision mechanism (6). Here a comparison is made with those obtained from the claimed reference set (R1-R10). The degree of similarity or closeness of fit in relation to a set threshold value determines one of number of decisions (D1-Dn). A close fit, that is below the threshold value, is accepted. A poor fit causes the signature to be rejected and displays a request for further samples.

A heirarchy of decision procedures is used allowing context factors such as customer importance or the value of the transaction to be incorporated. The decision mechanism can be easily organized in a number of different ways to suit individual requirements.

Establishing a set of measures to use as a reference for one person is a vital part of the smooth functioning of the machine. Security against impersonation, without the rejection of genuine attempts, will depend on how well the reference measures characterize the writer.

Anyone who will be using the machine is first asked to submit five specimen signatures. The spread of this group is then examined by the machine for any gross inconsistencies. Signatures that lie outside a given tolerance band are rejected and further samples requested to make up the number. The variation in the reference group (variability factor, VF) provides a useful means of assessing what the chances are for successful impersonation by


'NPL Verisign'
'Insert card'
No
Is card valid ?
Yes
'User's name'
'Please sign now'
No
Is' signature valid ?
Yes
No
Is this the third try ?
Yes
'Remove card'
'Door open'
'Sign again'
'Remove card'
Door unlatched for 30 seconds
Alarm bell
'Press ''help''
Intervention by an authorized user

unauthorized users. The lower this factor the higher the security and, of course, the reverse is true.

Knowledge of the degree of security is unknown to either the user or impersonator, and in any case the rating value together with the reference list is updated each time a test signature is accepted. This updating mechanism can also keep track of long-term variation in the way a person writes his signature.

The basic flow chart of the Verisign machine is shown in Diagram 2. Three attempts at writing a signature are permitted before some form of alert is given.

The computer program, apart from a few modules, is written in standard Fortran IV language and occupies about 12,000 words of core store. 20 words are required for each person's reference parameters plus an extra 10 for performance logging.

We used a 16k mini-computer which provided reference file space for up to 120 people. The time to verify a signature was less than 100 milliseconds. This meant that a complete transaction, including the entry of a personal identity code, could be completed inside 20 seconds.

*Tests*

The system was tested in various situations including remote operation over public telephone lines. In addition, two full-scale experiments were carried out. For the first, in the entrance hall at our laboratory, the participants identified themselves as they entered and left the building. The 71 people who took part included typists, security officers, members of the services, professional engineers, and scientists. Out of 2,000 attempts made at identification by signing, 96% were successful.

The second experiment controlled entry to the computer room of a different government establishment. Here, the 47 passholders, often carrying equipment or trays of cards, used the Verisign terminal over a period of several weeks. The results of this experiment were similar to the first.

It is, of course, one thing to ensure that the genuine person is identified correctly with the minimum fuss or bother. It is another to prevent the less scrupulous artist practising his art! With this in mind, at the end of both experiments we displayed a number of

Diagram 2. Simplified flow chart of operations.

target signatures and invited everyone to try his hand at copying them. With the first experiment at NPL, although one or two came very close, no-one was able to obtain a "signature valid" signal. A lower threshold was used for the second experiment and the decision scores were displayed as an incentive. No limit was placed on the number of attempts allowed and under these less rigorous, unrealistic conditions a few people were eventually successful.

No security system is perfect but the hierarchy of this one allows the degree of security to be balanced against the possibility of rejecting an authorized user.

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# *Handwriting Classification in Forensic Science*

Michael Ansell

Recent methods of classification of features in handwriting for use in the forensic examination of documents are described, including the computerized system of classification. Developments in the statistical analysis of the way people construct numbers and lay out their writing are reviewed. The potential usefulness of these systems in quantifying the current document examiners' scale of probability for attributing questioned writings to particular authors is examined.

## 1.0 *Introduction*

In the past so-called experts have reached erroneous conclusions about handwriting classification often because they have studied overall similarities in style of writing rather than the detailed construction of letterforms. Fortunately, the current scientifically trained document examiner arrives at a more statistically justifiable conclusion. However, the science of document examination has advanced mainly as a result of developments in the chemistry and physics of documents, which can be applied to any document whether handwritten or not. The technique of electrostatic detection, for example, is used to recover hitherto invisible indented impressions of writing, or the technique of infra-red luminescence is used to recover obliterated writing. Only recently has significant progress been made in putting on a scientific basis the evaluation of authenticity in handwritten documents in terms of the handwriting per se.

Approaches to forensic handwriting comparison in general may be divided into the Osborn (1929) approach and the European approach. The European approach can be considered to be graphological. It requires an analysis of the psychological and medical condition of the writer of one document as compared with the writer of another. This leads to propositions such as: The writer of document A is a young woman in good health and that of

*Visible Language*, XIII 3 (1979), pp. 239-251.
Author's address: Metropolitan Police Forensic Science Laboratory, 109 Lambeth Road, London SE1 7LP, England.
0022-2224/79/0700-0239$02.00/0 

document B is an old man, feeble, and suffering from brain damage. Therefore document A could not have been written by the writer of document B.

The Osborn (see also Harrison, 1966) approach is that practised by document examiners in the United Kingdom. It involves analysis of the physical result on paper caused by the writing process, without excursion into possible psychological or medical causes of unusual strokes or characters (except possibly for disguised writing). This paper is generally concerned with the latter approach. A direct comparison is made by the examination of writing on the questioned document and of writing on one or more samples of known authorship (control documents). This comparison is based on sets of features present in the handwriting that the examiner believes to be relevant to differences *between* individuals. At the same time the features chosen should not be likely to display variation from occasion to occasion *within* the writing of any one individual (this could lead to the inappropriate conclusion that two samples of writing by the same person — but taken at different times — were not of common authorship). To be practical the features chosen must also be easily identified and measured.

In the next two sections I consider systems for the classification of handwriting features; following that a section is devoted to problems involving statistics for the results of such classification. Such statistics are relevant to the efficient presentation of handwriting evidence in court.

## 2.0 *Classification Systems*

Whether as a result of differences in education, culture, and/or personal preference, people develop individual styles of writing. However, a general statement about overall style is usually not enough to discriminate between the writing of different people. Account must usually be taken of the details of construction of individual letters. Various sets of features or classification systems have been proposed for this purpose (for a review see Baxter, 1973). In this section we consider two illustrative studies.

2.1 *Ansell and Pritchard.* In collaboration with H. Pritchard at the Metropolitan Police Forensic Science Laboratory (London) I have used eighteen parameters to classify samples of normal block capital writing of 134 writers. Only three pairs of writing samples

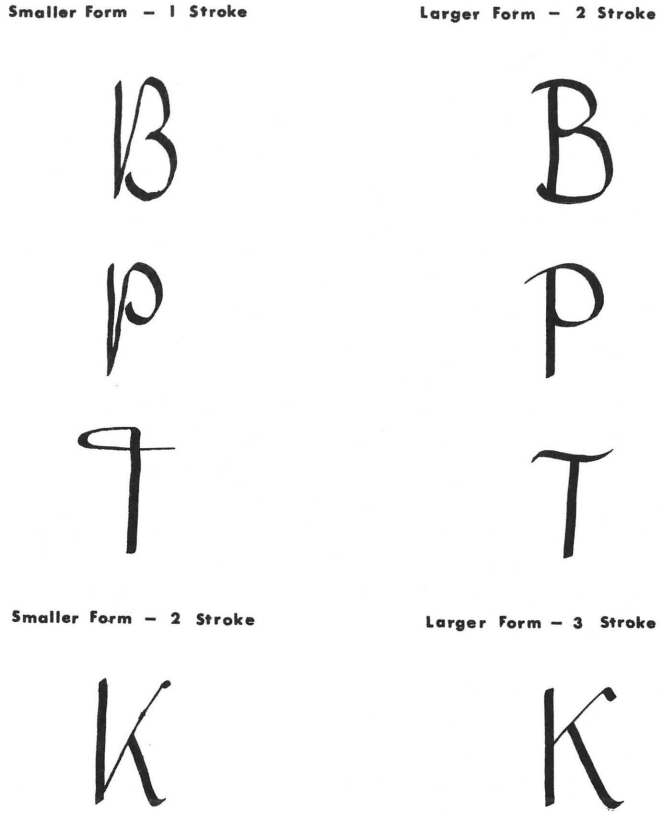


Figure 1. Comparison of the number of strokes required for regular (left) and very large handwriting styles.

emerged as being indistinguishable in respect of all the parameters. These parameters may be summarised:

A Angular or Broad?
A, B, D, etc. Do they start with a downstroke or not?
G Does it have a tail?
K Is it made with 2 or 3 strokes, are they radial?
M Is the centre short or long?
W Is the centre short or long?
U Does it have a tail?

We then used this system to consider the effects of writing on a vertical or horizontal surface. Cases occur in which an offence

such as obscene writing on a wall is committed where, understandably, the offending "document" cannot be conveniently submitted to the laboratory. A further problem arises that control samples based on the same instrument and surface are rarely submitted by the investigating officer! It is within our normal field of experience to consider and assess the significance of resemblances between such questioned documents and control samples of normal horizontal writing on paper. However, where there are differences, are they due to different authorship or are they due to variations that arise when one and the same person writes on different surfaces and in different planes?

An experiment was run with fifteen people who were asked to provide two samples of the phrase BUS PARKING PROHIBITED in block capital letters. One sample in large writing with black felt-tip pen was written on a card placed at a convenient height on the wall. A ballpoint pen was used to provide the second sample written normal size on a card placed on a desk top. We found that only 17% of letter pairs differed in construction between the two samples. The difference was almost always the use of a letter in large writing which increased the number of strokes required (Figure 1).

It may, therefore, be concluded that with appropriate choice of features it is possible to devise handwriting classification schemes that are sensitive to differences between individuals. Moreover they can give consistent results within individuals even where the writing situation is significantly changed from one sample to the next.

2.2 *Hensel, Khan, and Dizon.* The study discussed above involved block capital handwriting which is often contrasted with cursive (or joined-up) writing and numerals. Disconnected or script handwriting is not encountered quite as often in adults as in children and may be classified in a similar manner to cursive writing or individual letters with no need to consider the method of joining successive letters.

Hensel, Khan, and Dizon (1973) considered the problem of classification of non-roman script. If the document examiner whose native language is English has to examine writings in Cyrillic script (such as Russian or Serbo-Croat) where some letters are similar to roman but others are quite different, a typed or block capital transliteration is essential. This is because in the examina-

tion of unfamiliar cursive words it is difficult to establish where one letter ends and another begins, or how many letters there are in each word. As an example, in English the word minimum can be written with fifteen joined identical curved segments. If the word were not recognisable in the context of a sentence, the individual letters — not to mention strokes — could not be identified. Scripts such as Arabic (far removed from roman writing) present much greater problems to a document examiner whose native language is English. Although the identification of individual letters is very difficult, the fact that the writing reads right to left presents no additional difficulty.

To compare two or more Arabic writings to establish common authorship a document examiner without any knowledge of the language or the script needs to be sure that he is comparing like with like. He will also want to know the variations that are likely to occur between different people's writings and which letter forms are common or rare.

When this has been done, he can then apply the scientific principles of observation and deduction with which he is familiar, whatever the language. Hensel, Khan, and Dizon used the method of comparison of an "intelligent illiterate" who uses the criminalistics techniques commonly employed with toolmarks, firearms, and footmarks. They also encountered complications introduced by the illiteracy of native writers. In such cases a scribe or professional letter writer will, for a fee, prepare applications, write petitions, and fill in forms which are then "signed" by a thumbprint. The authors examined one fraud case involving 104 documents bearing 147 signatures of illiterate labourers. All these documents had been written by a single clerk!

### 3.0 *Computers and Handwriting Classification.*

The computer offers the means of storing a large amount of information about handwriting features. This information may then be rapidly scanned for statistical purposes such as those discussed in the next section or for direct comparisons of individuals' writing (after classification).

A system in use at the Zurich Kantonspolizei Laboratory (Angst and Erismann, 1972) employs a large number of features. A one-paragraph sample of writing is copied by the individual concerned and later classified by a document examiner. Classification takes at least an hour, but once the results are entered into the computer,

comparisons with a large data bank may be made very rapidly to select other entries with varying degrees of correspondence. Each sample is classified according to the broad class of writing skill, line quality, slope, size, width, angularity, type and degree of connection, position of accents, and detailed construction of various cursive and block capital letters. Unlike systems where the classifier has to indicate which type of any particular letter or digit is present (e.g., Ansell and Strach, 1975), the Zurich system depends upon a series of "yes" or "not present" answers; e.g., "Is A angular?" if so, check item 53; "Is A broad?" if so, check item 54. This works well in practice for the Swiss-German letters encountered.

4.0 *Statistics and the Presentation of Handwriting Comparison Information*

Following comparison of questioned and control documents, a document examiner will usually be able to express his degree of certainty in his conclusions at one of four levels:

1 Definitely written by the same person.
2 High probability that they were written by the same person.
3 Could have been written by the same person.
4 No evidence that they were written by the same person.

These expressions have implications that are appreciated by document examiners, but may not be fully comprehended in the courtroom. Indeed, members of the legal profession would probably be very happy to see the introduction of a sixteen-point system such as used in fingerprint examination. In this section we consider the difficulties in the reliability of documentation of any particular piece of forensic handwriting comparison. The underlying interest in the following studies is to what extent they tell us about questions such as: What is the likelihood that two different people will write the same way? or How unusual in the population is a particular distinctive handwriting feature or set of features?

4.1 *Livingstone.* Livingstone (1959, 1963) described a system of "pen printing" classification which included cursive writing. In the later work he describes some statistics drawn from 200 samples stored in his collection of edge-punched cards. As well as layout he treated features or groups of letters such as g, y, and z.

Table I. Classification of letter features. Livingstone (1963)

| | *System A* | | *System B* | |
|---|---|---|---|---|
| | *Complete tail* | *Abbreviated tail* | *One or more angles* | *Without angle* |
| Letters g, y, z | 82% | 18% | 30.5% | 64% |

He considered in particular their tails, and divided these into complete or abbreviated (that is, without lower loop) on one system (A) and incomplete plain loop without angle or with one or more angles in another system (B) (Table I).

Some care must be exercised in applying a system developed in one country to nationals of another. For example, Livingstone considers the features of dating layout in the United States; e.g., 23 November 1962 is the dating style used only 4% of the time in the USA but is in frequent use in the United Kingdom.

4.2 *Harvey and Mitchell.* In the case of the murder of Nicola Brazier, Harvey and Mitchell (1973) were faced with a protracted examination and elimination of suspect writings from a large number of people. (The author has on occasion been faced with a similar problem involving 4,000 writers.) Their questioned document was a cheque for five pounds, four shillings, and ten pence dated 7th September 1970. They chose six characteristics from the cheque and scrutinised each of 1,046 samples for these features only:

*Layout*

1 Presence of double dashes in the sum of money £5 = 4= 10 (38 out of 1046)
2 Position of the "th" in the "7th" of the date. High (366) Low (166) Absent (514)
3 Presence of indentation of the word "five" following the printed word "pay" (883)

*Letter Design*

4 Short staffed g (4)
5 The "ce" in pence with the e larger than the c (15).
6 The "x" in Essex having bottom left to right stroke longer (36)

Table II. Frequency of joint occurrence of double dash and indentation. Harvey and Mitchell (1973)

| | *Double dashes* | *Not double dashes* | *Total* |
|---|---|---|---|
| No indentation | 11<br>[ 5.92] | 152<br>[157.07] | 163 |
| Other | 27<br>[32.07] | 856<br>[850.92] | 883 |
| Total | 38 | 1008 | 1046 |

They then considered the hypothesis that the features Double dashes/No indentation were independent. This required determination of the frequencies of joint occurrence of double dash and indentation (Table II). If two features are independent, row and column totals may be used to give expected frequencies of the joint occurrences (in brackets).

The chi square statistic may then be used to determine the statistical reliability of departures in the data from the theoretical predictions based on the assumption of independence,

$$\chi^2 = \sum_{I=1}^{K} \frac{(O_I - E_I)^2}{E_I}$$

O being the observed result, E the expected result, and K the number of cells in the table. The value $\chi^2 = 5.345$ obtained indicates a reliable degree of dependence. The rejection of independence in this case may be contrasted with application of the test to "low th" versus "no indentation." There $\chi^2 = 0.00018$, indicating no signs of dependence. This kind of information is useful to the document examiner who doesn't want to spend extra time evaluating another possible feature, if that feature provides information depending strongly on a feature already assessed. On the other hand, if two features that in the population are highly dependent diverge in both questioned and control documents, this information is evidence for common authorship.

4.3 *Ansel and Strach.* Ansell and Strach (1975) concentrated on the apparently simple task of classifying the methods of writing numbers (Figure 2). The manner of writing 0 and 8 by 993 people is summarised in Table III. Consider classes 2, 3, and 4 in Table

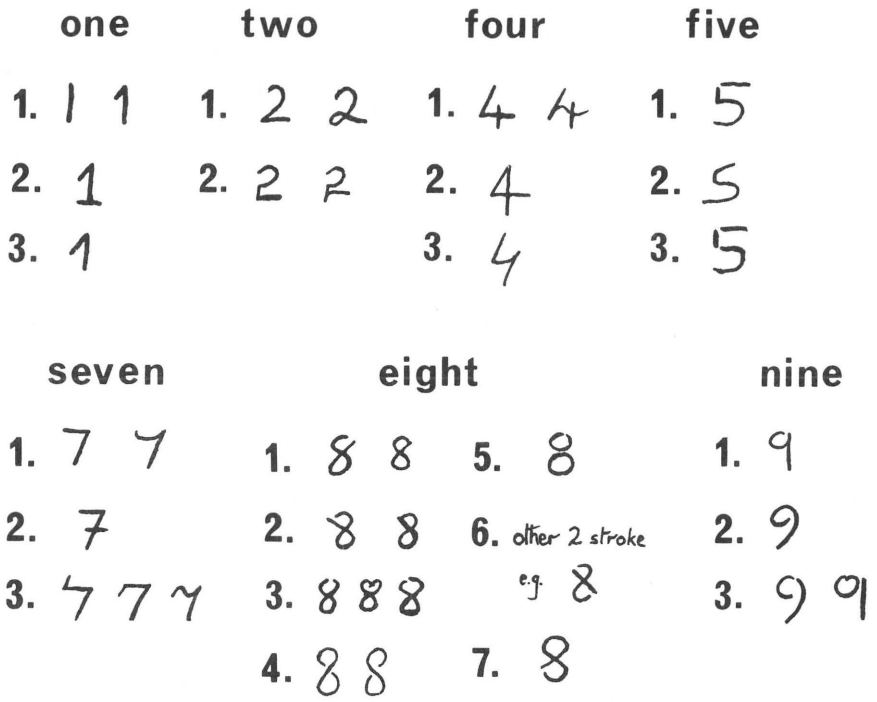


Figure 2. Classification of methods used to write the numbers 1, 2, 4, 5, 7, 8, and 9. Ansell and Strach (1975)

III where 0 and 8 are classified according to the position of any opening, join, or discontinuity.

The number of people writing a particular class of number 0 in combination with a particular class of number 8 is given in Table IV. For example the entry in the bottom right-hand corner of the table means that 43 people joined both the 0 and 8 at the top. The (35) indicates the frequency expected on the basis of Table III assuming independence of class assignment. For these data $\chi^2 = 30.01$, which indicates a reliable departure from independence in manner of construction of these two digits.

Further research on these lines has shown that classification of the numeral 0 is unsound because many people write several or even all classes of this number. Taking into account the fact that people wrote several classes of each number and adjusting the classification to be more discriminating, we can see the results of the modified classification of 8 in Table V. We considered 90 peo-

Table III. Classification of the manner of writing the numbers 0 and 8 according to position of any opening, join, or discontinuity. Ansell and Strach (1975)

| *Number 0* | | | *Number 8* | | |
|---|---|---|---|---|---|
| Class 1 | Join ambiguous | 34% | Class 1 | Join ambiguous | 18% |
| Class 2 | North West | 36% | Class 2 | North East | 51% |
| Class 3 | North East | 7% | Class 3 | North West | 14% |
| Class 4 | North | 26% | Class 4 | North | 14% |
| Class 5 | Two stroke forms | 0.8% | Class 5 | Middle | 1% |
| Class 6 | Other forms. | 0.9% | Class 6 | Separate circles | 0.6% |
| Class 7 | | | Class 7 | Other two stroke forms | 0.5% |
| Class 9 | | | Class 9 | Others | 1.2% |

ple who wrote five examples of this number (but of unknown handedness), 140 people who wrote two examples of this number (also of unknown handedness), 833 people who were right-handed and wrote one example of this number, and 101 left-handed people writing one example of this number. Unfortunately this system is still limited in that about 14% of writers would have their numbers (1, 2, 4, 5, 7, 8, and 9) assigned to the highest frequency class for these digits.

Table IV. Classification comparison of people writing the numbers 0 and 8. Ansell and Strach (1975) (See Table III)

| *Classes of number 0* | *Classes of number 8* | | | |
|---|---|---|---|---|
| | 1,5-9 | 2 | 3 | 4 |
| 1,5-9 | 78(66) | 157(166) | 51(48) | 42(48) |
| 2 | 65(67) | 154(170) | 64(49) | 53(49) |
| 3 | 15(14) | 45(35) | 4(10) | 5(10) |
| 4 | 37(48) | 137(121) | 22(35) | 43(35) |

Table V. Modified classification of handwriting number 8 according to position of any opening, join, or discontinuity. Ansell and Strach (1975)

| | *90 people 5 examples Unknown handedness* | *140 people 2 examples Unknown handedness* | *833 people 1 example Right-handed* | *101 people 1 example Left-handed* |
|---|---|---|---|---|
| 1. North East | 55.8% | 63.87% | 46.74% | 58.4% |
| 2. North West | 5.1% | 14.24% | 12.29% | 3.0% |
| 3. North | 36.4% | 15.69% | 36.88% | 33.6% |
| 4. Middle | — | 2.18% | 1.44% | 2.0% |
| 5. Separate Circles | 1.1% | 1.82% | 0.48% | — |
| 6. Other two stroke forms | 1.1% | 0.74% | 0.84% | — |
| 7. South West | 0.21% | — | 0.84% | 2.0% |
| 9. Other | 0.25% | 1.46% | 0.48% | — |

4.4 *Allan, Pearson, and Brown.* In a recent experiment Allan, Pearson, and Brown (1978) used 52 people each writing a short length of prose. Eight measurements were taken:

1 Number of lines.
2 Margin width.
3 Paragraph indentation.
4 Length of last ten spaces.
5 Length of last eleven words with spaces.
6 Length of first ten spaces.
7 Length of first eleven words with spaces.
8 Ratio of relative height of letters with ascenders.

It will be noted that none of these involve details of method of letter formation. They then used a measure

$$D \star \sqrt{\sum_{i=1}^{n} \frac{(x_i - y_i)^2}{m_i^2}}$$

to characterise the difference between control and questioned samples, where $x_i$ and $y_i$ are the measurements in the "i" the dimension, m is the mean value over subjects for that dimension, and n is the number of dimensions. A computer program was used

to compare measurements. The program calculates the "distance" between the measurements on the known and questioned samples in the dimensions required. Comparisons were made of a person's handwriting with other samples of that person's writing that had been disguised or had been written after an interval of one year. Only 5% of writings by other people were computed to be closer to the known person's writing than were his time lapsed or disguised samples.

It may be expected that work such as that of Allan, Pearson, and Brown and of Ansell and Strach will in future lead to a clear statement in the statistical confidence of handwriting evidence given in court. At present it is limited to suggesting a reply to questions such as: Is this a common letter T? Is this a common style of writing or layout? The answers would be in the form: No, it occurs to an extent of less than x% in samples submitted for examination.

In practice the work of Ansell and Strach is used in a negative sense if the defence claims resemblances between the writers of, say, a questioned 2 and 4 of a particular person as being important, but the resemblances can be shown to be statistically not significant.

*Conclusion*

In this short review a limited selection of the available work has been considered to give some idea of the range of forensic handwriting research. It ought, however, to be mentioned that in the field of forensic science it is normal to refer to the person carrying out handwriting examinations and comparisons not as a "handwriting expert" but as a "document examiner." Only rarely can comparison of handwriting be carried out without wider examination of the writing materials or instruments used, or perhaps needing to clarify or restore the writing before it can be compared.

So what of the future? More detailed statistics are needed as to letter construction, style, dimensions, and letter and word spacing; also more work on the dependence of construction of a particular letter upon the method of construction of other letters by the same author. I would like to see the document examiner being able to make statements in court of the kind: only x% of the population's writing bears the same number of resemblances to the control writing as does the suspect's.

Finally, although experienced document examiners often possess subjective (but hopefully reliable) ideas of the effects of disguise, illness, infirmity, wrong-handedness, duress, alcohol, or drugs on a person's handwriting, little objective statistical work has been done (although Allan, Pearson, and Brown make a start on the effects of disguise and of time lapse). A helpful approach could be for a psychologist to classify a subject's writing using one or more of the systems mentioned in this review (or a modified version of the system) and a statistician to assess the usefulness of the results.

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# A Competence Model for Handwriting

John Hollerbach

It is proposed that handwriting production is fundamentally an oscillatory process arising from two orthogonal joints. Letter shapes emerge from an oscillation train by a process of constrained modulation. The choice of underlying oscillation and modulations limits the diversity of letter shapes and gives rise to a common writing style. The model was tested by synthetic production of human-like cursive script with a mechanical arm under computer control. In this simulation the vertical joint acts as the driving joint, the horizontal joint as the shaping joint. Various force constraints on the oscillations and modulations are proposed.

One approach towards understanding handwriting is to attempt to produce handwriting artificially with a mechanical device. Artificial production serves to test models of handwriting and to hit upon insights into the handwriting process not readily obtained by measurements on humans.

In the present study a six-degree-of-freedom computer-controlled mechanical arm — the VICARM of the MIT Artificial Intelligence Laboratory — was used to synthesize handwriting (Figure 1). The VICARM is a commercially available mechanical arm designed by Victor Scheinman while at MIT. A rapid ballistic movement comparable in speed to human speeds can be produced by controlling currents to torque motors at each joint. Position and velocity sensors at each joint allow the computer to monitor the movement, although this feedback was not used to correct the open loop handwriting trajectories. Other work on simulation has used primarily graphics displays to generate handwriting according to a computational model of the handwriting process (McDonald, 1966; Yasuhara, 1975); Koster and Vredenbregt used a mechanical device similar to a chart recorder.

The emphasis in my research has been to determine if there is an underlying control strategy in the production of diverse letter shapes. One alternative explanation is that each letter has an iso-

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Figure 1. The VICARM, a six-degree of freedom manipulator used in the mechanical writing.

lated motor program — idiosyncratically formed by each individual — that is combined with other letters by a general linking process. Is handwriting a sequence of isolated letters strung together, or do superficially different letters share common production features? Eden (1962) developed a stroke vocabulary by decomposing letters into sequences of straight strokes and corner strokes; while different letters are related in this scheme by sharing strokes from the vocabulary, there is some question as to whether his decomposition is a good model for how people form letters or whether it is a formal artifact. Other past research, while not necessarily adopting the position that letters have isolated motor programs, has focused for the most part on duplicating human written letters or words as precisely as possible without concern for underlying meaning to the parameter values to their equations (Mermelstein, 1964; McDonald, 1966; Yasuhara, 1975).

It will be proposed that handwriting be viewed as the constrained modulation of an underlying oscillation pattern. Letter shapes are superimposed on the oscillation pattern and are subjected to the operation of the oscillation as a whole. Seemingly different letter shapes have the underlying oscillation pattern in common, as well as the same constraints on force patterns. The rest of this paper explores constraints to the oscillation pattern and their implications for producing letter shapes.

There is precedence for postulating oscillatory mechanisms in locomotion research (Grillner, 1975). More subjectively each of us

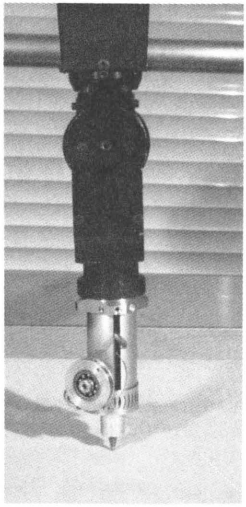


Figure 2. A spring loaded cartridge attachment to the VICARM keeps the pen on the writing surface.

can feel a steady rhythm in fast fluent handwriting that varies little from letter to letter. There is also a simplicity of control of oscillating mechanisms which may literally be responsible for letting us write and think at the same time.

This model of handwriting rests more on adequacy and simplicity criteria than it does on experimental evidence, mainly because the measurement apparatuses in past experimental work have not provided accurate enough measurements of position, velocity, and acceleration during writing. Parallel to this mechanical arm project I have designed and built an apparatus for more precise measurements; this research — that would allow assessment of the model against human performance — is still in progress. Therefore, this model of handwriting should be viewed as a competence model rather than as a model that performs exactly as humans do. The model represents a simple motor control strategy that has few parameters (and hence is testable) and that captures some of the complexity of handwriting.

The only letter shapes dealt with here are lower-case cursive script. No claim is made about the formation of capital letters, about dotting *i's*, or crossing *t's* and *x's*. Nor do we consider gross movements of the hand and arm between words or between lines of script. The problems of pen grasping and pen-paper contact have also been finessed in this research by design of a special spring-loaded pen attachment to the VICARM (Figure 2).

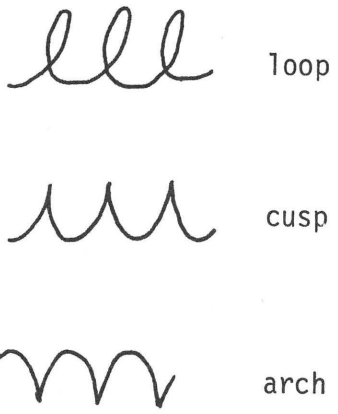



Figure 3. The three basic top corner types in handwriting.

Within these limitations the production of handwriting has been ascribed to two joints, a vertical joint and a horizontal joint in the plane of the paper (Denier van der Gon and Thuring, 1965). For human writing these joint roles are normally fulfilled by fingers and wrist, respectively. The best joints in the VICARM for this purpose are the wrist joint for vertical movement and the shoulder joint for horizontal movement; the disparate size of the joints was found unimportant for the production of realistic writing.

*An Underlying Oscillation*

The underlying oscillation pattern in the VICARM writing is fundamentally a down-up movement traveling from left to right. The vertical joint plays the role of oscillator: it drives the movement with rhythmic down-up movements. The horizontal joint acts as the shaping joint: by carrying the writing from left to right at different speeds and at different points in the vertical oscillation, it produces letter shapes.

Over a background of repetitive down-up motion, the horizontal joint shapes the top and bottom turning points into various types of corners suitable for particular letter shapes. There are three basic corner types: loop, cusp, and arch (Figure 3). Unless expressly stated otherwise, all samples of writing in the figures were produced by the VICARM. All letters can be decomposed into a sequence of these corners. Within each corner type there is considerable leeway in shaping: loops can be large or small, arches can be rounded or angular. An "individualistic" writing style can be obtained by a consistent interpretation of corner shape.

As an example of the letter formation process, Figure 4 indicates the transition between an oscillation pattern and a VICARM rendering of *vial*. The oscillation pattern couples repetitive down-up movements in the vertical joint with rightward start-stop movements in the horizontal joint. Different horizontal patterns at the bottom of the vertical oscillation would give a different shape to the underlying oscillation; this figure represents just one example of such a pattern. In (b) the vertical joint modulates force amplitude for letter height; the second down-up movement has been shortened for the connection between *v* nad *i*, and the sixth up-down movement has lengthened for the letter *l*. In changing letter height in an oscillation train, one has the choice of either modulating the amplitude or the frequency; in the present model the formation of tall letters is assumed to occur by a process of amplitude modulation without changing frequency. In (c) the horizontal joint overlays a rightward corner pattern at the bottom of the *a* and a leftward corner pattern at the top of the *l* to produce the *vial*. Although letter height and top and bottom corner shape adjustment were accomplished at different times in this example, they are not necessarily independent processes.

*Force Constraints*

A motor program corresponding to a particular corner type is a single acceleration-deceleration pattern. Loops come from leftward accelerating patterns, arches from rightward accelerating patterns, and cusps from patterns that decelerate to a halt exactly at top or bottom turning points. In the following, positive accelerations will be considered upward for the vertical joint and rightward for the horizontal joint.

Within this framework there is still considerable leeway in forming corner patterns and in setting up the vertical oscillation. A number of force constraints have been applied that limit the number of possible corner patterns and oscillations but preserve the ability to produce a sufficiently diverse set of letter shapes. The first two constraints restrict the vertical oscillation patterns; the last three contraints restrict both horizontal and vertical patterns. As mentioned earlier, these constraints are derived mainly from simplicity criteria.

1 *Strict rhythmicity.* Cycles of an oscillation always have the same duration. Thus tall letters are written as fast as short letters.

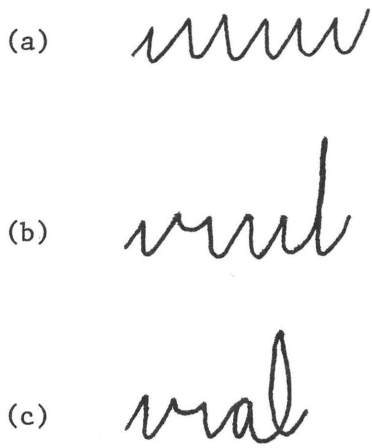



Figure 4. Conceptual process of letter formation beginning with the oscillation train (a), and ending with the cursive rendering of *vial* in (c). In (b) the vertical joint modulates for letter height. In (c) the horizontal joint applies various corner patterns at appropriate points in the oscillation.

2 *Symmetric oscillation.* Downstrokes and upstrokes of the same height have the same duration; within a downstroke or an upstroke the acceleration and deceleration periods have the same duration.

3 *Constant force tendency.* The force amplitude stays at a constant plateau during an acceleration or deceleration period.

4 *A fixed time quantum.* Time is quantized into a series of fixed steps. During a time step, force is held constant; at the end of one step and the beginning of the next the force may change amplitude. The time quantum stays the same for all writing speeds and sizes.

5 *Synchronous joint activation.* The time quanta have the same size for different joints. The beginnings and ends of the time quanta occur at the same time.

To illustrate the effects of these constraints on the motor patterns, the force patterns for two cycles of the writing of Figure 4 are diagrammed in Figure 5. Focusing first on the bottom left plot, which represents the vertical force pattern for two cycles of the top writing in Figure 4, the abscissa has been divided by the ticks into single quantum units. Changes in force amplitude are seen to occur only at integral units of the time quantum, satisfying constraint 4. The time quanta for the horizontal and vertical joints

have the same duration and their onsets are synchronized, satisfying constraint 5.

Following constraint 1, the two cycles represented in Figure 5 have the same duration, namely four time quanta; this oscillation pattern produces the fastest possible writing under the constraints. Each quantum acts to accelerate or decelerate the pen in a given direction. The net amount of acceleration must of course be balanced by an equal amount of deceleration, assuming no losses in the system. For example, the vertical quantum 1 causes a downward acceleration from the top corner. Quantum 2 decelerates the pen exactly to a halt at the bottom corner. Quantum 3 then accelerates the pen upwards, and quantum 4 decelerates the pen to an exact halt at the top corner. This process continues for each cycle of the oscillation.

According to the symmetric oscillation constraint 2, the downstrokes are required to take the same amount of time as the upstrokes; in this example each such stroke requires two time quanta. Moreover, the acceleration and deceleration periods in the downstrokes and upstrokes are of equal duration: quantum 1 matches quantum 2 for the downstroke, quantum 3 matches quantum 4 for the upstroke. Constraints 1 and 2 are trivially met in this example, but for longer cycled oscillations there are more possibilities. Constraint 3 requires that the two quanta 5 and 6 in the rightward acceleration of the horizontal joint have the same force amplitude.

In the bottom right diagram in Figure 5 the vertical force profile for the two down-up cycles going into the production of the *l* show different amplitudes between deceleration from the downstroke to acceleration for the upstroke. Since the constraints prevent duration scaling, force amplitude scaling is required to produce the taller letter *l*.

Slower oscillation patterns allow the horizontal actuator more time to shape letters, in particular more time to incorporate leftward movements. With an 8-quantum cycle, a garland chain with leftward movement and more rounded bottoms can be obtained (Figure 6). When modified, the garland chain becomes the *vial* below. A feature of this modification is hesitation at sharp corners such as the *i*, where the top loop of the garland is aborted. The hesitation is required to keep the writing in phase with the oscillation.

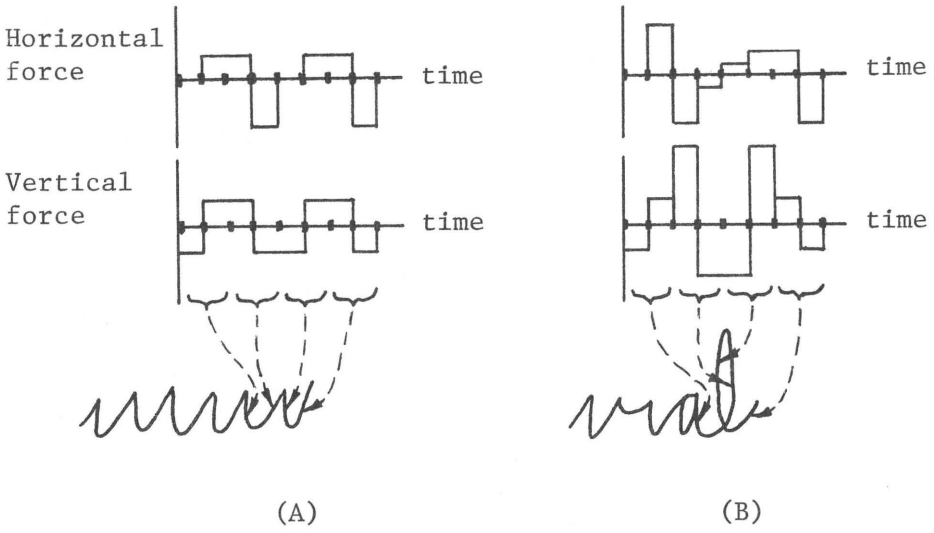



Figure 5. (A) Horizontal and vertical force patterns by the actuators produce the smoothed sawtooth below. Two cycles of the oscillation are shown in the force patterns. The correspondence of downstrokes and upstrokes with portions of the vertical force pattern are indicated by dashed lines. The ticks represent single time quantum units. (B) Modulation of the force pattern in (A) produces *vial;* the two cycles forming the *l* are shown in the force diagram.

Figure 6. An eight-quantum cycle allows the production of a rounded pattern of *e's*. Modulation of this pattern yields the *vial* rendering below.

*Horizontal Motor Programs*

The horizontal joint, which does not oscillate as does the vertical joint, may have different amplitudes and durations in adjacent acceleration-deceleration periods. The only constraint is that the negative deceleration brings the movement exactly to a halt. Additionally there can be a quantum of coasting or zero acceleration between positive and negative accelerations for reasons of shape production. Thus all corner patterns are either of the form $a^m b^n$ or $a^m 0 b^n$; where $a_m^m$ means m quanta of positive acceleration amplitude a, and $b^n$ means n quanta of negative acceleration amplitude b, subject to the constraint ma = nb.

Once a horizontal corner pattern has been selected, its onset must be synchronized relative to the vertical joint movement. This synchronization is specified with respect to the vertical top or bottom turning point. Depending on how one shifts, or overlays, this pattern relative to the turning point, different corner shapes are obtained. In practice there are two overlays that produce the most generally useful shapes: (1) the acceleration ends precisely at the turning point; (2) the acceleration ends one quantum after the turning point. In addition useful shapes are obtained only if the acceleration is about the same length as the deceleration; otherwise strongly asymmetric shapes result. This restriction may be expressed as limiting the difference between acceleration and deceleration durations to no more than one quantum.

The important features of the horizontal patterns can be summarized in terms of a simple motor program vocabulary. The elements of this vocabulary that go into the making of a "word," or motor program, are presented in Table I.

A "word" in this vocabulary thus has three "letters"; for example a 7SD word represents a pattern with a total of seven time quanta symmetrically arranged about a coast quantum (i.e., an $a^3 0 b^3$ pattern) overlayed so that the last acceleration quantum a ends at the vertical corner. The existence of a coast quantum can be deduced from 1 and 2; for example, a 4L corner pattern has a coast quantum, a 5L pattern does not. Table II gives some examples of horizontal corner patterns and a rough description of the shapes produced. The corner patterns are diagrammed in Figure 7 and their shapes appear as bottom corners in Figure 8.

An association library can be formed that contains horizontal corner patterns formed according to the vocabulary of Table II and

Table I. Corner Shape Vocabulary

| | | | | |
|---|---|---|---|---|
| 1 | Total number of time quanta | | | |
| 2 | Symmetry | S | symmetric | $a^n(-a)^n$<br>$a^n0(-a)^n$ |
| | | L | asymmetric left | $a^{n+1}b^n$<br>$a^{n+1}0b^n$ |
| | | R | assymmetric right | $a^nb^{n+1}$<br>$a^n0b^{n+1}$ |
| 3 | Overlay | A | accelerating through corner | |
| | | D | acceleration stops at corner | |

a qualitative shape description corresponding to each pattern. Each horizontal corner pattern is a ready to use motor program that needs only the amplitude values for instantiation. To produce a desired letter shape, the letter is broken down into a sequence of qualitative corner shapes and the appropriate horizontal motor programs can be retrieved from the library. The breakdown of letter shapes themselves can be kept in a separate table.

This restricted repertoire of corner patterns is adequate to capture many of the shape variations seen in human handwriting. As an illustration an attempt was made to duplicate four *a's* as drawn by different human subjects, taken from Koster and Vredenbregt (1971). These *a's* appear paired with their VICARM facsimilies in Figure 8, the former the smaller writing on the left and the latter the larger writing on the right. The *a's* as represented in the figure are actual size; the larger writing is favored for the VICARM for mechanical reasons. Appearing to the right of each VICARM letter is the horizontal pattern for the bottom corner in the language of Table II. The output current to the horizontal torque motor corresponding to each of these patterns is diagrammed in Figure 7.

As is evident from the figure the duplication is fairly good, especially considering the differences in mechanics. The process

Table II

| | |
|---|---|
| Rounded | 7SD |
| Sharp cornered | 4SD |
| V shaped | 5SA |

12 quantum

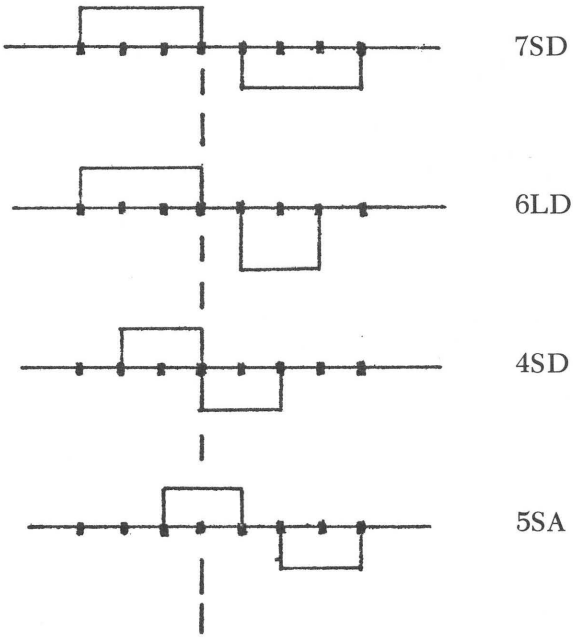
7SD

6LD

8 quantum

4SD

5SA




bottom corner

of manufacturing these shapes was accomplished first by choosing an appropriate oscillation speed and then selecting appropriate corner patterns. The first two *a's* are rather rounded, and a relatively long twelve-quantum cycle was required for correct shaping. The last two *a's* are more angular, calling for a faster eight-quantum cycle.

*The Inherent Simplicity of Handwriting*

Though human handwriting may be executed under a different set of strategies from the VICARM writing, the VICARM results suggest that handwriting is an inherently simple task. The simplicity arises because superficially different letters share in the VICARM writing common production features. Once an oscillation is set up under the various constraints, a limited number of corner types suffices to produce most letter shapes. In a sense these strategies may be viewed as a trick to minimize the complexity of handwriting.

As a rough numerical estimate to indicate the complexity of the VICARM writing, the number of required corner types is in the vicinity of twenty. The number of force levels found necessary in the VICARM writing to cover acceptably the variety of letter shapes is also small because casual observation shows writing to fall naturally into letters of three or four different heights and perhaps ten different widths. The implication of this small number is that there need be only limited control in handwriting in shaping letters.

Of course, the more exact a duplication of particular corner shapes is required, the larger must be the number of different corner types. This number also does not take into account personal idiosyncracies such as peculiar letter shapes, combined printing and writing, and drastic changes in the style of writing. By writing slowly, it is possible to produce a much greater variety of letter shapes than by writing fast; it is not clear, however, that fast and slow writing are produced by humans in the same way. Nevertheless, for a regular style of writing such as the VICARM's, relatively few corner types suffice to produce acceptable writing.

Figure 7. Diagram of force patterns by the horizontal actuator corresponding to Table II and to the bottom corner patterns of Figure 8.

Figure 8. Four *a's* from different human subjects (Koster and Vredenbregt, 1971) on the left are paired with their VICARM fascimiles on the right. The top two *a's* were produced with a twelve-quantum cycle, the bottom two *a's* with an eight-quantum cycle.

We have only touched on earlier the ideation process involved in converting the mental image of a word into a sequence of handwriting strokes. It was suggested that letters are decomposed into a sequence of qualitative corner shapes that can index into an association library of motor programs. The connections between letters are also just different kinds of strokes and corner shapes, and are treated similarly. It may be the case that context effects interfere in this process; for example, by an unlikely juxtaposition of letters such as jz. The real issue here is what the elementary unit in handwriting is: is it the letter, the syllable, or the word? An unusual combination such as jz may cause difficulty in writing because it is not an elementary unit or a composition of elementary units. The resolution of this issue is beyond the scope of the present work.

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# *Slips of the Pen*

Andrew W. Ellis

A corpus of the author's own slips of the pen is analyzed. Four processing levels — lexical, graphemic, allographic, and graphic — are postulated with different types of error being assigned to different levels in the production of handwriting.

Throughout the history of psychology human error has provided a fruitful source of information concerning the processes mediating skilled performance. Nowhere is this more true than in the domain of the psychology of language and especially the skill of speech production which remained relatively uninvestigated until psycholinguistic analyses of naturally-occurring slips of the tongue carried out by Boomer and Laver, Fromkin, MacKay, and others showed just how much could be learned from this rather obscure facet of human behaviour (See Fromkin, 1973, for these and other papers on speech errors; also Fromkin, in press). Hence a psychologist interested in the production of handwriting — and I feel no compulsion to justify such an interest in this context — may undertake a study of writing errors with a reasonable hope that his labours will be rewarded with a deeper insight into the processes underlying the graphic production of language.

Recent analyses of slips of the pen in normals (Hotopf, 1968, 1971; MacKay, 1969a; Van Nes, 1971, 1972; and Wing and Baddeley, 1979) or in individuals with either developmental or acquired disorders of writing (e.g., Lecours, 1966; Chedru and Geschwind, 1972) have begun to provide descriptions of some of the predominant varieties of writing error together with observations on their distributional and other characteristics. In fact, as with so many aspects of modern cognitive psychology, the study of writing errors (and indeed of writing in general) experienced an earlier flowering between the years of, roughly, 1890 to 1930 (see especially Bawden, 1900; Douse, 1900; and Wells, 1906. Spache, 1940, provides an overview). As is so often the case, the results of these

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studies lay neglected until the revival of interest in the subject within the last decade.

Before progressing any further, it is necessary to draw a distinction between two different sorts of writing error, namely errors of knowledge and errors of performance. Errors of knowledge arise when a person mis-spells a word through total or partial ignorance of the word's correct, standard spelling. Errors of performance, in contrast, are genuine, unintentional[1] slips of the pen which the writer recognizes, either immediately or subsequently, to be erroneous deviations from the intended product. It is these latter, correctable lapses with which the present paper is concerned.

The errors which will be discussed here are taken from a corpus of the author's own slips of the pen, collected over a period of approximately eighteen months. The corpus currently contains 766 errors. My strategy has been to record any writing error as it occurs, noting the intended (correct) form together with as much of the context as appears necessary to explain the lapse. Care has been taken to record as accurately as possible the precise graphic form of each error (the various examples given in this paper are, therefore, copies of copies of handwritten errors). Having collected a corpus of errors, the task then becomes an exercise in taxonomic natural history, describing in detail the different species of lapse and the different habitats they characteristically occupy. Classification must precede exposition.

What follows is thus an analysis of the errors produced by a single individual. This method has its dangers, but it also has its advantages. The dangers are those inherent in any attempt to generalize to a population from a sample of one, particularly the possibility that individual differences exist such that another writer might produce quite different sorts of error. The author happens to believe that the processes revealed in the error analysis conducted here will hold true for all writers (of English, at least), and he is reinforced in this belief by the degree of congruence between the present analysis of his own errors and other analyses of individual or group data, but a degree of interpretative caution is called for until more corroborative stidies are available.[2]

1. The possibility of unconscious motivation in writing errors as discussed by Freud (1901/1960) will not be dealt with here. The author has expressed doubts elsewhere as to the "psychological reality" of Freudian speech errors (Ellis, in press), doubts which are equally applicable to Freudian slips of the pen.

The advantages in basing one's investigation on one's own corpus accrue from the unique access which a writer has to his own intentions at the time when a slip occurs. Unlike collectors of speech errors, the collector of slips of the pen is rarely in a position to interrogate his subjects as to their intentions and impressions when an error occurs. Some categories of error (particularly the switch — see below) depend critically upon the introspections of the writer for their sure diagnosis. Other lapses would almost certainly have been misclassified had they been encountered in text produced by another writer. For example, on one occasion I wrote "no a," deleted the "a," and altered the text to read "no reaching towards sounds." This suggests either anticipation of the "a" of "reaching" or an incomplete one-apart reversal of "a" and "r," terminated after anticipating the "a." In fact neither of these interpretations is correct as the error was due to my having begun to write "no *attempt* at reaching towards sounds" before deciding upon an alternative wording.

Most errors involve omission, intrusion, or re-arrangement in sequences of discrete elements (letters, words, punctuation marks, etc.). The literature on errors in domains such as writing, typing, speech production, or memory contains a plethora of terms to describe what are, in fact, formally identical types of error. Table I shows the set of terms which will be used here where possible; the terminology is designed to be applicable wherever errors of intrusion, transposition, or omission occur.[3] The system will not extend to errors where items undergo complex modification, e.g., blends in speech (MacKay, 1973) or switches in writing (see below).

2. The generalisations proposed here are not based upon a statistical analysis of the corpus. The reasons for this are partly to do with the small numbers of errors in some of the subcategories and partly to do with the considerable difficulties inherent in attempting to formulate appropriate statistical tests (see MacKay, 1970, and Garrett, 1976, for discussions of this problem in the speech error literature). Where empirical claims are supported by other analyses of writing errors, this is indicated in the text.

3. For example, classes A and C of Table I on the one hand and class B on the other correspond to the distinction commonly drawn between item errors and order errors respectively in studies of short-term or long-term memory for serial lists of items (Ellis, in 1979). There are interesting parallels to be drawn between the types of error which occur in a variety of areas of human serial ordering behaviour (Lashley, 1951; Shaffer, 1976).

Table I. A terminology for errors in linear sequences of discrete elements. In all cases the target (intended) sequence is taken to be 1 2 3 4 5.

| ERROR SEQUENCE | DESCRIPTIVE TERM |
|---|---|
| A *Intrusion errors* | |
| 1 2 3 *X* 4 5 | Addition |
| 1 2 *X* 4 5 | Substitution |
| B *Transposition errors* | |
| 1 2 *3* *3* 4 5 | Immediate repetition |
| 1 2 *4* *4* 5 | Anticipation with replacement (adjacent) |
| 1 *4* 3 *4* 5 | Anticipation with replacement (1-apart) |
| 1 *5* 3 4 *5* | Anticipation with replacement (2-apart), *etc.* |
| 1 *4* 2 3 *4* 5 | Anticipation with addition |
| 1 2 *2* 4 5 | Perseveration with replacement (adjacent) |
| 1 2 3 *2* 5 | Perseveration with replacement (1-apart), *etc.* |
| 1 2 3 *4* 2 5 | Perseveration with addition |
| 1 2 *4* *3* 5 | Reversal (adjacent) |
| 1 *4* 3 *2* 5 | Reversal (1-apart), *etc.* |
| C *Omission errors* | |
| 1 2 4 5 | Omission (1-item) |
| 1 4 5 | Omission (2-item), *etc.* |
| D *Ambiguous errors* | |
| *1* *2* *4* | *Either* Omission |
| | *Or* Incomplete transposition |

In the corpus, letter errors outnumber lexical (word) errors by about seven to one — the amount of space in this paper devoted to these two classes of error will reflect this disparity. A number of punctuation errors, word space errors, etc., have been recorded, but these are not discussed here.

*Lexical Errors*

Lexical substitution errors come in a number of different forms. One variety involves homophone substitution — that is, substitution of one word by another which is phonologically identical through semantically and orthographically different (e.g., *there* →

their; *weak* → week; *too* → two; *piece* → peace).[4] A second variety involves substitution of a word which is related in meaning to the intended word. Such semantic substitutions (e.g., *speaking* → reading; *last week* → next week; *semantic targets* → syntactic targets) are relatively few in my corpus, but their occurrence has been attested independently by Hotopf (1971) and they may be placed with reasonable confidence in a category of their own.

A third, and rather odd, category of lexical substitution error is exemplified by lapses such as *worms* → words; *the case* → the cause; *R.S. Woodworth* → R.S. Woodwork; and *Waugh and Norman* → Waugh and Normal. It is my conjecture that these errors, which I have termed completion errors, arise as a by-product of the writer (myself) monitoring the written output. A fragment of a partially-completed word may suggest another, different word (in the way that the word fragment "Hippo" may suggest the word Hippopotamus although the intended word was *Hippocrates*), causing that word to be (somehow) translated into writing.

Were it not for the existence of visual completion errors, one would be tempted to diagnose errors such as *postulating* → postulate; *relative* → relating; *possibly* → possible; and *discussion* → discussing as morphological substitutions, and errors such as *of* → or; *by* → be; *an* → as; and *is* → in as function word substitutions. However, all these examples are open to an alternative diagnosis as completion errors, and until such time as the corpus contains sufficient examples of unambiguous derivational errors (e.g., **dislike* → unlike)[5] or function word errors (e.g., **if* → but) the relative importance of these two putative categories must remain in doubt.

As well as lexical substitutions, the corpus also contains lexical transposition errors, but not as yet in sufficient numbers to warrant any confident generalizations. These errors could, in principle and given a larger corpus, provide data on grammatical and lexical planning in writing (cf. the studies on lexical speech errors by Fromkin, 1971, and Garrett, 1975, 1976).

4. In these and all subsequent examples, the correct (intended) form is given in italic to the left of the arrow, and the error form (as written up to the point of detection by the writer) to the right of the arrow.

5. An asterisk (*) before an error denotes a lapse which could occur, but which has not yet been seen to occur.

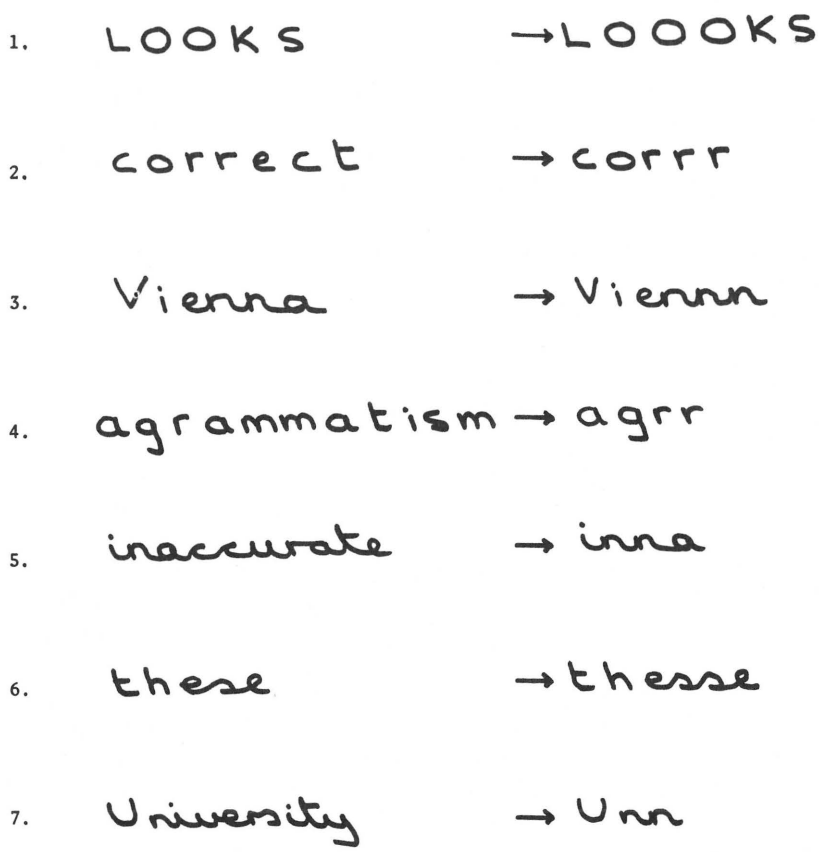


Figure 1. Letter transposition errors involving immediate (false) repetition of letters.

*Letter Errors*

Letter transpositions occur in a number of different forms. Immediate repetition errors — which cannot by their very nature be classified as either anticipatory or perseverative — appear to be of three basic types. The first type, the perseverative switch, will be discussed later. The second type, tripling of a doubled letter, can be seen in Figure 1, examples 1 to 3. The third type of immediate repetition error, doubling of a single letter, is shown in examples 4 to 7. When perseverative switches are excluded, 13 of the remaining 15 cases where a single letter has been repeated in error have occurred in the process of writing words which already contain a

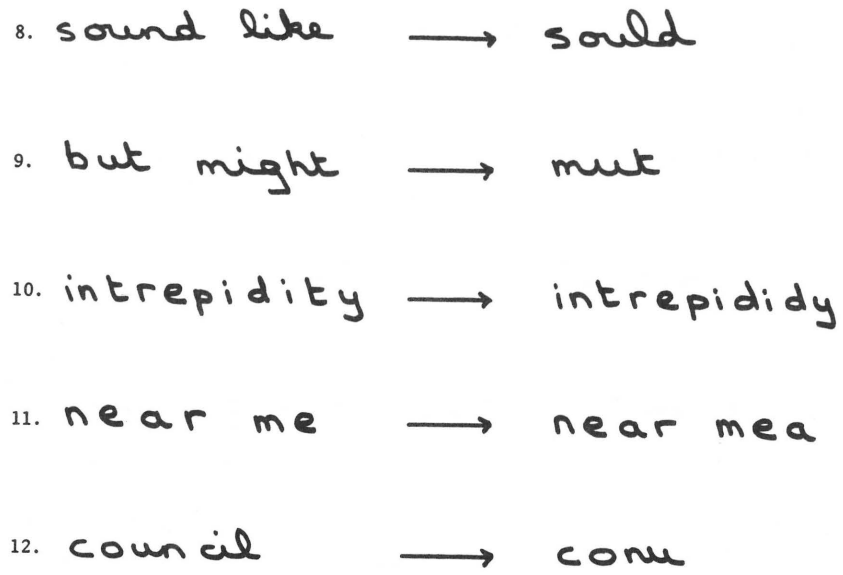


Figure 2. Other varieties of letter transposition error.

(different) repeated letter. The repeated letter in the intended word may take the form of an adjacent pair of identical letters (examples 4 and 5), but this is not an essential prerequisite (examples 6 and 7). The association between false repetition and the presence of other repeated letters in the intended word has been noted by Douse (1900) and Lecours (1966), and a possibly analogous phenomenon in short-term memory for letter sequences was reported by Lee (1976). The implication of this type of immediate repetition error appears to be that the information which specifies that a particular letter is to occur twice in a word can be dissociated from that letter and be erroneously applied to one of the other letters in the word, causing it to be doubled incorrectly.

Other letter transpositions may involve anticipation (Figure 2, example 8 and 9), perseveration (examples 10 and 11) or reversal of letters (example 12) — note that many incipient anticipations and reversals may be noticed and corrected before the "full" error is made (cf. Table I, category D). Perseverative errors have been recorded both within words (example 10) and between words (example 11). All the unambiguous letter anticipations in the corpus occur between words (examples 8 and 9), the possible instances of within word anticipation being open to an alternative

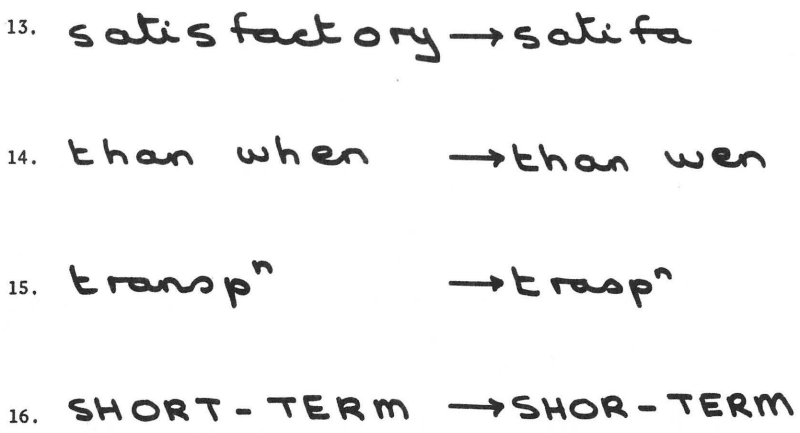


Figure 3. Omission of one of two repeated letters (letter masking).

classification as incomplete reversals. Unambiguous within word anticipations have, however, been noted by other investigators (e.g., Douse, 1900, p. 87; Wells, 1906, p. 82; Lecours, 1966).

Letter omissions fall into at least three distinguishable subcategories. First are errors involving the omission of one of two repeated letters in a sequence. This process, illustrated by examples 13 to 16 in Figure 3, may be termed letter masking by analogy with the similar phenomenon of phoneme masking in speech (MacKay, 1969b). Masking may be forwards, with the second of the two repeated letters being omitted (see examples 13 and 14), or backwards, with the first repeated letter omitted (examples 15 and 16). Masking may occur within words (examples 13 and 15) or between words (examples 14 and 16). Within my corpus, 22 errors may be classified as forward masking and five as backward masking. This predominance of forward over backward letter masking was also noted by Lecours (1966) and MacKay (1969a).

A second type of letter omission also concerns repeated letters, but in this case the error involves omission of one of two repeated letters plus the letters intervening between the repeated pair. The term "haplology," as used in linguistics (e.g., Sturtevant, 1917/1961, p. 54) may be adopted for this type of error. Figure 4 shows examples of haplologies occurring both within words (example 17) and between words (example 18). Omissions of one of two adjacent repeated letters (examples 19 and 20) may be subsumed under this category, but may also be construed as a variety

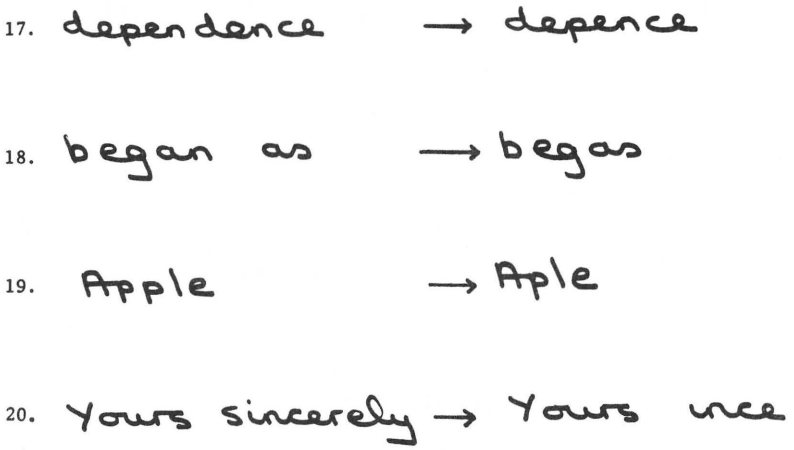


Figure 4. Omission of one of two repeated letters plus any intervening letters (haplology).

of masking error. A third category of letter omission (switches) will be discussed later.

Thus far, in considering letter transpositions and letter omissions, the suitability of the term "letter" has not been questioned. However, the word letter is in some ways an imprecise one. Are the capital (upper-case) "S," the printed (lower-case) "s," and the handwritten "  " the same letter or different letters, and if they are the same letter what term is to be used to distinguish between the various forms? Linguists interested in written language (e.g. Pulgram, 1951; McIntosh, 1956; Hamp, 1959) have proposed a number of sets of terms for describing graphic units. Following these writers, I shall adopt here a three-tier system which recognizes the grapheme as the most abstract unit (hence, the English alphabet comprises 26 graphemes, of which < s > is one[6]). Each grapheme is represented at the next lowest level by a number of allographs: thus, grapheme < s > is represented in my own handwriting by the three allographs { S }, { s }, and {  }. Now, any given allograph will receive perceptibly different realizations in the writing of different individuals or the same individual on different occasions. Hence, the lowest level in the descriptive hierarchy is the concrete graph — the pattern of ink on the paper. (The term "letter" may usefully be retained as a general designa-

6. The bracketing notation (pointed brackets < > for graphemes and corner brackets { } for allographs) is as suggested by Hamp (1959).

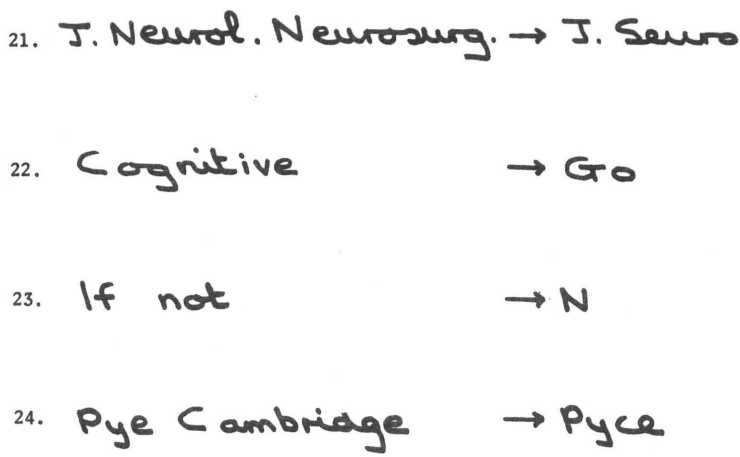


Figure 5. Letter transpositions showing allographic accommodation to the error context.

tion, or for use when the writer wishes to expressly avoid specifying the exact descriptive level involved).

A system of this sort is only of value in a context such as this if its use clarifies the nature of the psychological processes involved in writing. It is my contention that it does; in particular, I wish to argue that letter transpositions are more accurately described as grapheme transpositions, whereas letter masking is, in fact, allograph masking.

The evidence that transpositions are graphemic in nature comes from errors in which a letter is transposed into a position where it is required to adopt an allographic form different from that which it would have displayed in the correct, intended version. Such a process of accommodation has been independently attested by Wells (1906, pp. 90-91), and can be seen in examples 21 to 24 (Figure 5). This process whereby transposed letters change from lower-case to upper-case, or vice-versa, has occurred in all the eleven errors noted to date where change of case is required by the error context. The most parsimonious way of explaining these observations is to propose that transpositions involve abstract graphemes and that allographic form is determined after the level at which transpositions occur.

In contrast, all of the instances of omissions attributable to letter masking in my corpus involve identical allographic variants (see Figure 3). Figure 6 shows errors of the sort which would be indi-

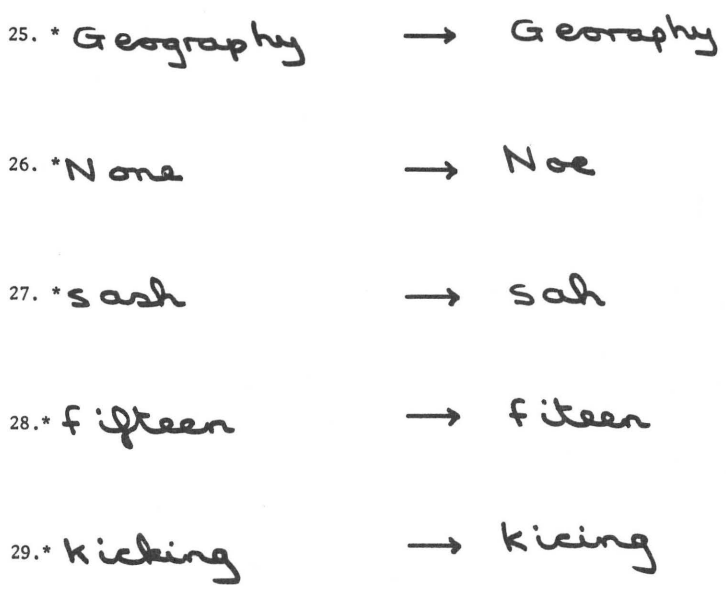


Figure 6. Possible, but non-occurring, examples of grapheme (as opposed to allograph) masking.

cative of graphemic as opposed to allographic masking, but which have not yet been seen to occur. By the same token, haplological errors involving omission of one of two repeated letters plus the intervening letters (Figure 4) also seem to occur between identical allographs.

Substitution (intrusion) errors, whatever the level of analysis, are problematic in that an error is classified as a substitution only by default, i.e., when the intruding item does not occur elsewhere in the nearby co-text (the definition of "nearby" is itself problematic). The probability of mis-classification is obviously greater for small sets of items like letters than for large sets such as words. Nevertheless, some substitutions of letters have occurred in the process of writing single, isolated words or short phrases where the possibility of transposition can be ruled out. Figure 7 gives examples of such letter substitution errors. A characteristic of these errors is an element of allographic similarity between the intruding letter and the replaced letter. Allographs which are similar in appearance will also tend to be similar in terms of the strokes involved in their execution (where a stroke may be

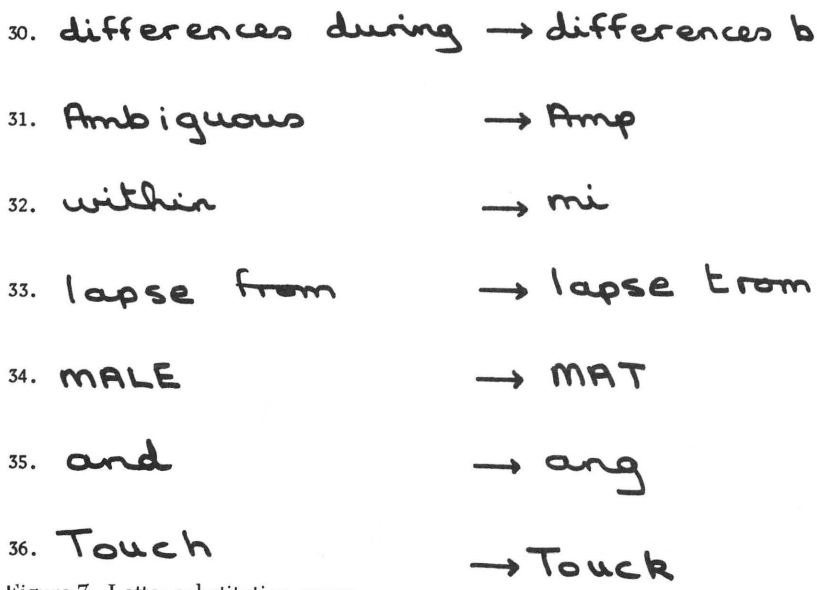

Figure 7. Letter substitution errors.

defined, following Mermelstein and Eden [1964] as a segment occurring between points of zero vertical movement of the pen). It is possible therefore that similarity of motoric (stroke) representation is the causative factor underlying these substitution errors. Thus the substituting letter may be a left-right or up-down inversion of the intended letter (examples 30, 31, and 32, respectively), or may incorporate the same strokes recombined to form a different letter (examples 33 and 34).

Of the three graphic levels (graphemic, allographic, and graphic) discussed earlier, letter substitutions appear to arise during the process of translation from an allographic code to a graphic product. This translation process seems to be implicated in the genesis of two other varieties of error. The first of these is the stroke repetition error (Figure 8). Inspection of these errors reveals certain apparent similarities with the immediate letter repetitions, but once again the corpus is not sufficiently large to warrant any firm generalizations.

The final category of graphic error is illustrated in Figure 9, and most strikingly in examples 41 to 44. This type of error occurs within a particular graph at a point where the execution of the

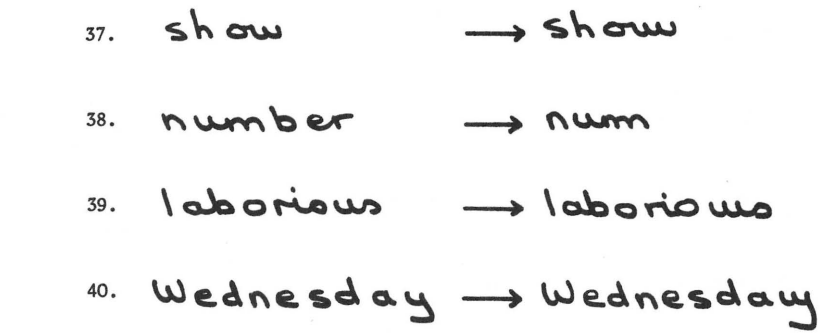


Figure 8. Stroke repetition errors.

graph requires a movement or stroke which also occurs in a contiguous, usually adjacent, graph. What results is a switch in the motor program from the intended graph into the other nearby graph. Thus Hotopf (1971, p. 30) writes of an error *good* → god that "instead of completing the second 'o,' the pen makes an upward movement, converting it into a 'd' " (see also Bawden, 1900, p. 83; Book and Harter, 1929, p. 111; and Van Nes, 1972, Figure 1). Figure 10 attempts to illustrate the process involved when a switch occurs. Although irregular switches like examples 41 to 44 provide the more dramatic cases, it is much more common for a switch to occur when contiguous allographs share an identical initial stroke or set of strokes. By far the most common outcome of a switch is the (apparent) complete omission of the first graph (Figure 9, examples 45 to 48), but five examples of perseverative switches, which result in false letter repetitions, have been recorded (e.g., Figure 9, example 49).

The switch completes the list of discrete categories of error which have emerged from the corpus (Table II shows the frequencies in each of the major categories, together with the frequencies of ambiguous and other errors). This is not to say that other categories will not be discerned; the corpus contains, for example, letter omission errors which resist being classified as masking errors, haplologies, or switches, but which may form the basis of new categories when more errors are collected. The reader will note the large number of ambiguous errors in Table II; such ambiguity is an unfortunate but unavoidable aspect of analyses of naturally occurring slips.

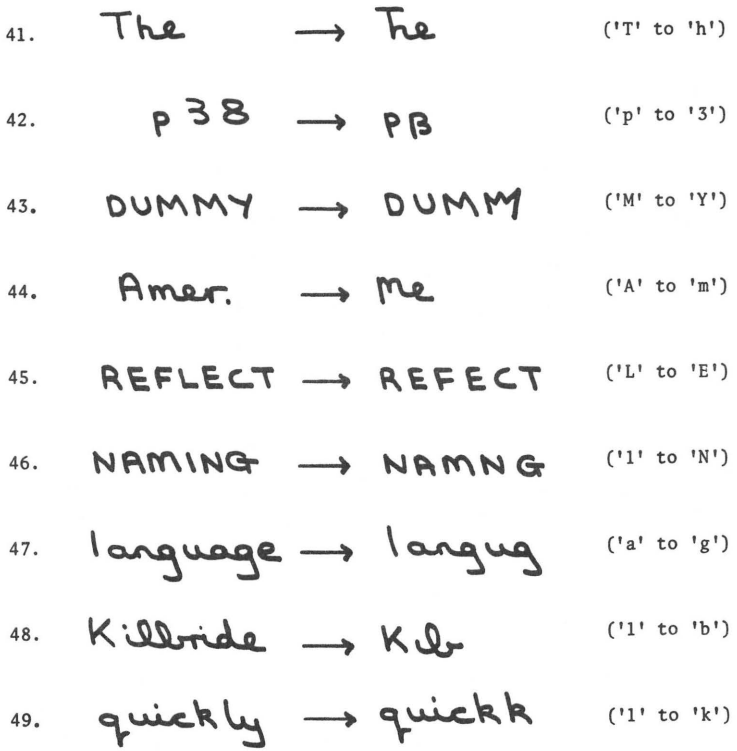


Figure 9. Switch errors.

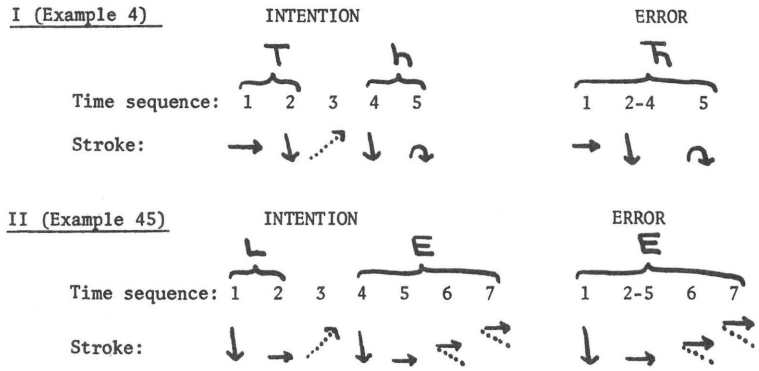


Figure 10. Analysis of two switch errors.

Table II. Frequencies of errors in each of the major categories in the corpus (N = 766)

| | *Frequency* | *Category* |
|---|---|---|
| LETTER LEVEL | | A Letter intrusions |
| | 19 | Letter substitutions |
| | | B Letter transpositions |
| | | Immediate repetition of 1 letter |
| | 11 | — tripling of a doubled letter |
| | 5 | — perseverative switch |
| | 15 | — others |
| | 8 | Immediate repetition of more than 1 letter |
| | 5 | Anticipation with replacement |
| | 30 | Perseveration with replacement |
| | 23 | Reversal |
| | | C Letter omissions |
| | | Omission of 1 letter |
| | 135 | — switch |
| | 19 | — 1 of 2 adjacent, repeated letters |
| | 22 | — forward mask |
| | 5 | — backward mask |
| | | Omission of more than 1 letter |
| | 14 | — switch |
| | 28 | — haplology |
| | 7 | — others |
| | 151 | D Ambiguous |
| WORD LEVEL | | A Lexical substitution |
| | 9 | Semantic |
| | 9 | Homophonic |
| | 11 | Completion |
| | 8 | (morphological) |
| | 18 | (function word) |
| | 11 | Others |
| | 7 | B Lexical transpositions |
| | | D Ambiguous |
| | 6 | Omission or transposition |
| | 54 | Ambiguous letter(s) or lexical error |
| OTHER SLIPS | 41 | Irregular switch |
| | 9 | Stroke repetition |
| | 86 | Punctuation, spacing and misc. |

Clearly there is much information of value still to be gleaned from the study of writing errors. It is the author's opinion that the way forward lies with the development of functional models of writing performance (though it is not my intention to articulate such a model here). Functional models (e.g., Morton, 1970; Ellis, 1979,) seek to unify and explain particular domains of human performance by describing the various ways in which information must be encoded, stored, and translated in order for tasks involving that domain to be successfully accomplished (Garrett, 1975, 1976). Thus, on the basis of the preceding analysis of slips of the pen, a model of writing performance must incorporate facilities for storage and inter-translation of (minimally) lexical, graphemic, allographic, and graphic information. A model for writing must also attempt to characterize the nature of the inter-relationship between the production of speech and of writing (thus, it seems a reasonable assumption that the two modalities of language production share common mechanisms at least at the semantic and syntactic levels). With a developed model, disorders of writing (Lecours, 1966; Chedru and Geschwind, 1972) should be explicable in terms of impairment affecting one or more functional subsystems within the total system.

Whatever the future directions of research, it is gratifying to see that writing — the neglected modality — is once again receiving its due share of psychological attention.

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# *Variability in Handwritten Characters*

Alan M. Wing

Two aspects of the variability of handwriting are considered. In the first part there is a discussion of the effects of variability in the shapes of letters on their legibility. An experiment to compare the relative advantages of cursive and block capital writing is summarised. The second part summarises experiments concerned with the time taken to prepare handwriting movements and with the variability of the timing of movements in the execution of handwriting.

To a psychologist handwriting is a particularly fascinating subject for study; several different sub-skills must be temporally coordinated if coherent output is to result. In addition to the control of movement, letters must be placed in the correct sequence to form words, and words chosen to convey the desired meaning must be placed in grammatically acceptable constructions. Elsewhere I have considered what may be termed the higher levels of processing with an analysis of errors in letter sequencing in handwriting (Wing and Baddeley, 1979; see also Ellis' paper in this issue). In this paper I consider variability in the forms of handwritten letters. The function of handwriting is primarily one of communication. I therefore start with a consideration of the efficiency of handwriting as a means of communication. I then turn to the control processes underlying individual handwriting movements and review work on the timing of these movements.

## *Handwriting as a Form of Communication*

The efficiency of handwriting as a communicative device refers both to its production and to the subsequent stage of reading. With respect to handwriting production, the normal concern is that of speed and, unfortunately, this must in general be traded-off against neatness. While this has consequences for the aesthetic quality of writing, in this paper I will be concerned not with the general visual impression but rather with the legibility of the writ-

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Figure 1. Several common forms of the letter *f*.

ing. A useful legibility measure is the speed of reading, and this may be assessed, for example, by the time taken to find target words in a body of text or by the time taken to read the text to achieve some level of comprehension.

A number of factors may be involved in slowing down the identification of handwritten letters. Here I consider these with specific reference to cursive (joined-up) handwriting since this is the form commonly employed to maximise speed of writing.

1 Across the writing of a number of people most letters display a number of forms (see, for example, Figure 1). Until the reader has become familiar with the particular forms a writer uses, unusual letter forms can make reading difficult. In the general population there is a wider range of forms for some letters than for others. These might be expected to cause more difficulty in reading, although they may play an important role in the identification of authorship of a sample of handwriting (see Ansell's article in this issue).

2 Handwritten letters may be hard to read because different letter forms are indistinguishable (Figure 2). This point is perhaps less relevant to reading the writing of one individual than to reading small amounts of writing from a large number of different people. In order to be able to read their own writing, most people will try to avoid ambiguities created by using similar forms for different letters but are unable (or unwilling) to take account of the letter forms used by others.

Figure 2. Confusable forms of *i*, *r* and *b*, *f*.

Figure 3. Joins can make segmentation into letters difficult.

3 The joining of letters in cursive handwriting aids fast writing but can be a problem for reading. For example, the joins may change the appearance of the letter or make it difficult to tell one letter from the next (Figure 3).

4 In handwriting several different forms may be used for a particular letter. This may lead to reading difficulty until the reader develops familiarity with the different variants. The examples in Figure 4 show that multiple letter forms may be associated with:

a Position in the word. Often the shape of letters at the ends of words will differ from that of the same letters written at the beginning of words. In Figure 4(a) quite different forms of *s* arise due to the contrasting requirements of joining the letter with the preceding or with the succeeding letter.

b Surrounding letter context. The particular letters that are joined with a letter can change its form. In Figure 4(b) the join of the *s* with the *t* by means of the crossbar gives the *s* an open, printed form by comparison with the *s* joined with the *d* from the level of the writing line. A letter occurring in a letter combination that has a high frequency of occurrence in the language may also have a form distinct from that when the letter occurs in other contexts. This may take the form of slurring letters together, such as the *ing* of the example in the figure. In such cases the letter group concerned should probably be considered not as separate letters but as a single character. An extreme example of this point may be found in the signatures of many people where a pattern rather than a sequence of individual letters is produced. For this reason there may be little point in taking signature validation by machine through preliminary stages based on letter identification (for example, see Watson and Pobgee's article in this issue).

c Random variation. Even if the surrounding letter context and position in the word remains unchanged, there may be considerable variation in the shape of a particular letter or one feature of a letter. The examples in Figure 4(c) show that relatively

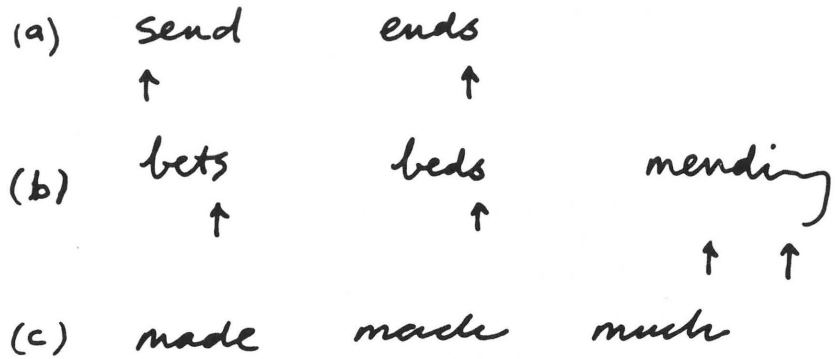


Figure 4. Multiple forms of letters as a function of (a) word position, (b) letter context, (c) random variation.

small variation in closure of the *a* and *d*, combined with the effect of letter joins, can qualitatively change a word. Such quantitative variation in form may be attributable to the inherent unreliability of the neuromuscular system in making fine motor movements. Moreover, the motor system is not only limited in accuracy of repetition but it is also limited in speed. Trying to write too fast is a well-known cause of bad writing and also tends to produce incompletely formed letters. In the second half of this paper I take up the timing of handwriting movements and relate this aspect of motor control to letter formation. However, at this point it is worth noting that in addition to speed having effects on writing, external factors such as time of day, stress, or simply distraction from the task of writing can also have effects on writing (Glenville, Broughton, Wing, and Wilkinson, 1978; Christie and McBrearty, 1979; Wing and Baddeley, 1978; Schouten, Kalsbeek, and Leopold, 1962).

An alternative to cursive writing, often chosen on grounds of improved legibility, is writing in block capitals. In block capital writing any particular letter has fewer common variants and in the writing of one person one does not usually find multiple forms of a particular letter (except that arising from random variation). Perhaps most important is the general lack of joining lines between block capitals. In principle at least, each letter stands in a clearly defined space of its own so there need be no difficulty for the reader in segmenting words into letters.

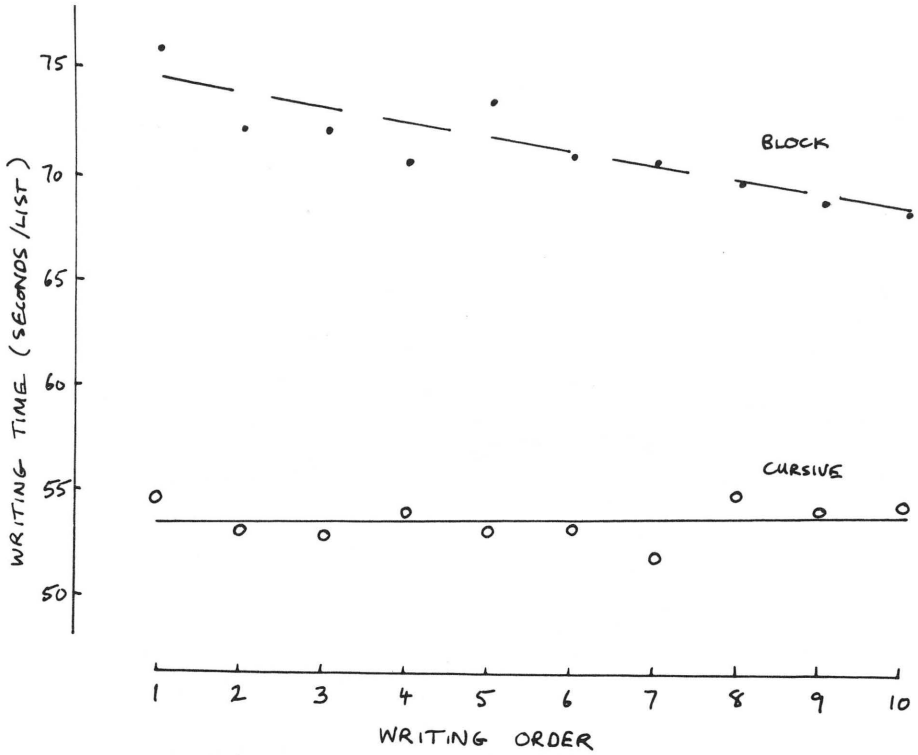


Figure 5. The speed of writing in block capitals or cursively as a function of amount written.

In an unpublished experiment I evaluated the supposed benefits of block capital writing and, at the same time, considered the "costs" from the point of view of the writer. Two groups of ten subjects copied, at a "comfortably fast" speed, ten lists of twenty words each arranged in column fashion. One group was instructed to write cursively, the other in block capitals. Two points about speed of writing may be made on the basis of the results shown in Figure 5. There is a time cost associated with writing in block capitals. This cost reduces over the period of writing (about ten minutes), but even then block capitals are of the order of 50% slower to write.

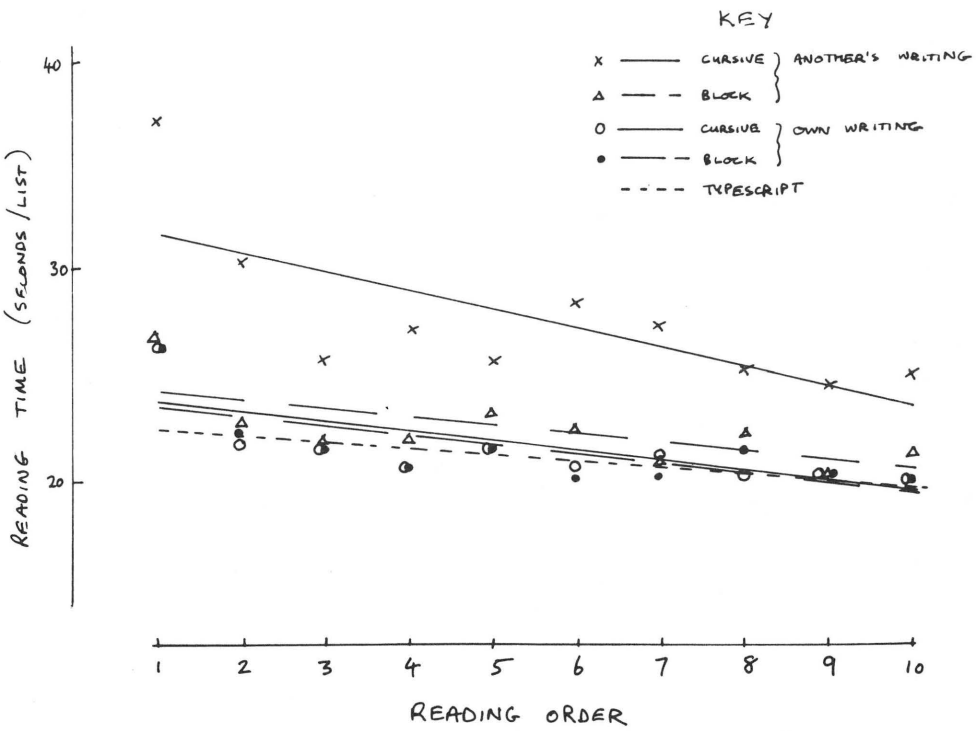


Figure 6. Reading speeds for typescript or written word lists where the writing is in block capitals or cursive and was written by the reader or another person.

A second part of the experiment was to determine the legibility of the handwriting. The same twenty subjects together with twenty new subjects were asked to search through the handwritten lists and put check marks against words falling into various, predefined categories. The order of reading through the lists was random with respect to the order in which they had been written, and there was no significant effect of writing order on reading time. The reading time per list is plotted against reading order in Figure 6 as a function of whether or not the subject was reading his or her own writing. There is no real advantage to block capitals when reading one's own writing (and the reading rate is as fast as that of people searching through the same word lists in typescript). When someone other than the writer has to read through the lists, it is clearly easier to do so if the writing is in block capi-

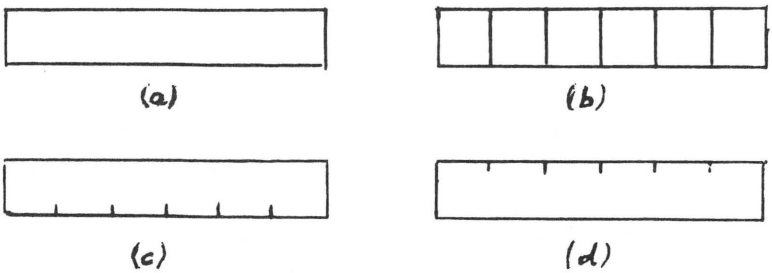


Figure 7. Response formats to encourage letter separation.

tals. However, the advantage to block capitals in reading is less than their elevation of writing time.

Particularly interesting are the changes in reading time with number of lists read (the lists were randomly re-ordered with respect to the original order in which they had been written). Reading performance on the search task improves over the ten lists by an approximately equal amount in all cases but one. The general improvement is a practice effect on searching through word lists. However, people reading the cursive writing of one other person showed an additional reduction in time taken. This probably reflects adaptation of the reading mechanisms to the particular difficulties imposed by reading cursive writing. This relates to the finding of Corcoran and Rouse (1970) that it takes longer to read single words in cursive writing or typescript when they are presented in alternation than when the reader is given a series of words in one form or the other. They suggested that operations specific to reading a particular form must be retrieved each time before the word can be read under conditions in which successive words are alternately cursive and typewritten. Extra time is needed for retrieval and this makes reading slower.

Even though block capitals are relatively restricted in letter forms, casual observation shows that they are often written with joins between letters. Morever, the spacing between letters is rarely even. Figure 7 shows various methods of subdividing a line of writing that might be expected to separate letters and give a more even spacing. However, a series of studies (Barnard and Wright, 1976; Barnard, Wright, and Wilcox, 1978; Wing, 1979a) have shown that not only is there an increase in writing time associated with spacing the letters in the formats b, c, d but also the

writing in these formats takes longer to read. It thus seems hard to justify such formats unless segmentation of the letters is of paramount importance as, for example, in the context of machine reading of handwriting.

*Handwriting Movement Control.*

Movements of the pen in the plane of the paper during handwriting are effected by three muscle/joint systems that are physiologically capable of independent operation. Flexion and extension of thumb, index, and second fingers is usually used to give letters their height. Radial abduction and ulnar abduction of the wrist joint are commonly used in giving letters width. (In the case of left-handed writers it should be noted that those writing with the hand in a hooked position above the line of writing exchange the roles of thumb/finger and wrist movements, so that the latter is responsible for letter height.) Movement of the upper arm about the shoulder joint relative to the body is largely responsible for gross movement of the pen across the page.

Questions concerning movement control may then focus on the control of any of these systems. In the studies that I summarise below I limited my attention to the control of up/down movements during the writing of single letters or of single words. In these cases it is probable that the left-to-right translation is effected by wrist movements since casual observation indicates that movements of the whole arm are deferred to word boundaries where possible.

In the experiments that I summarise, observations on the timing of handwriting were made using a computer coupled to a x/y digitiser. This permitted recordings to be made and the movements to be subsequently amplified and displayed as a function of time for x- and y- axes separately.

Typical handwriting speeds are in the region of four letters per second. Since most letters comprise several segments between reversals of pen direction, the direction changes — and thus the adjustments to muscle activity that produce the direction changes — occur at short intervals of time. Data are shown in Figure 8 for two subjects who wrote one of the letters *v, n, w, m* on each of a number of trials. On the right of the figure are shown representative samples of their writing. On the left the up-down component of the movement (vertical displacement) is plotted as a function of time for the successive minima and maxima of each letter. (The

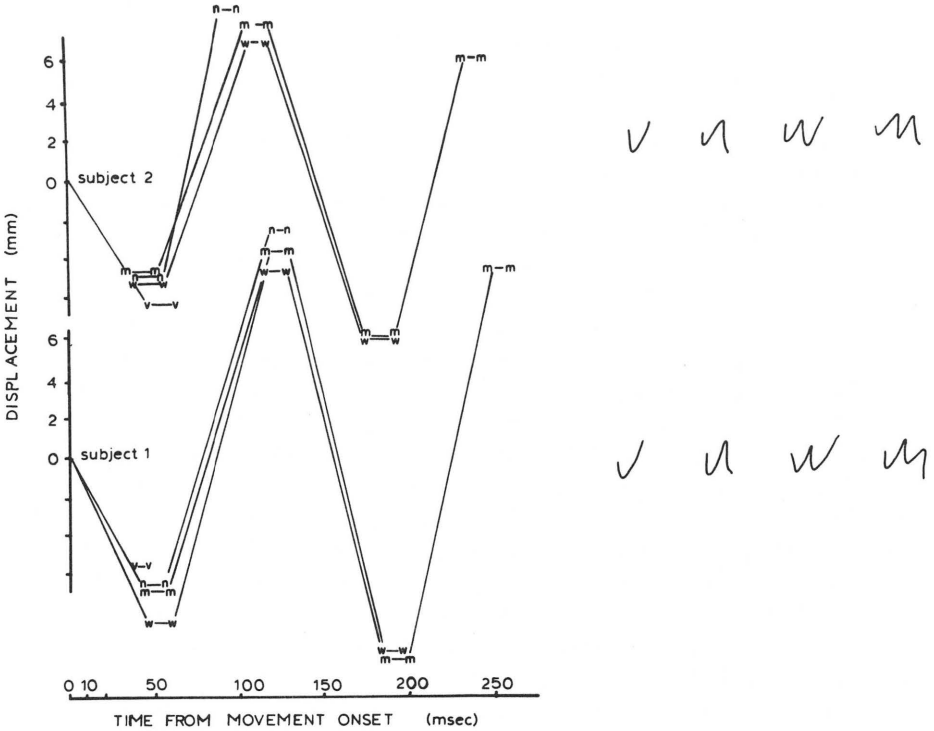


Figure 8. Displacements and times of direction changes for the letters *v*, *n*, *w*, *m* written singly, 50 observations for each letter; typical samples for each subject are shown on the right.

final segment of each letter is not included in the figure.) Durations of successive segments are in the region of 40 to 70 msec. This is very much shorter than the time it takes to make a decision, for example, about the length of a line presented in a reaction time task. The conclusion, therefore, is that the endpoint of one writing movement is not determined on the basis of the writer making a judgment about the length of the immediately preceding movement. There is not time for the writer to make visual reference to the endpoint of the preceding movement and adjust the ongoing movement accordingly. Even the endpoint of the movement before that occurs so close in time that the relative slowness of visual judgment would render it of little use in terminating the current movement. At least at the beginning of a letter, command

signals that modulate activity in the muscles to cause a termination of a movement segment by a change of pen direction must be set up independently of feedback.

If commands to control a sequence of movements are not contingent on feedback, they may be prepared in advance of any movement. In the case of handwriting we may ask whether operations that translate an intended letter into a "motor programme" (a set of commands specifying activity levels and timing appropriate to the relevant muscles) are performed prior to the initiation of the command sequence. One approach to this question about the preprogramming of a movement sequence is to compare the initiation latencies of two sequences of movements that differ in complexity. The preprogramming idea would receive support if the latency to initiate the more complex movement were greater than the initiation latency for the simpler movement that required preparation of only a subset of the commands used in the more complex case. The latency difference would be taken as reflecting the extra preparation time that results from increased command complexity.

Initiation latency data were collected in the experiment using the letters *v*, *n*, *w*, *m*, since in the writing of the two subjects the letter forms differed simply in the number of up-down segments. On each trial the latency of movement initation following an auditory signal to start writing (the imperative signal) was measured, the subject having been warned in advance which letter was to be produced. However, no increase in the reaction time to start writing was found with increase in number of segments across the four letters (Wing, 1978).

Because subjects knew before the imperative signal which response they were to make on each trial, it is possible that subjects preprogrammed the movement prior to the imperative signal. If so, differences in preparation time associated with the different degrees of complexity of the response would not have been revealed by the reaction time. In another unpublished experiment a choice situation was used to look for evidence of preprogramming. On each trial the subject had to write out a fixed-length, ascending sequence of consecutive digits starting at 2 or 6. The imperative signal indicated which sequence was to be written out and the computer checked that the initial movement was made in the direction appropriate to that digit. (Error rates averaged 5% of trials and did not change over different sequence lengths.) Under these conditions it is reasonable to assume subjects could not prepro-

Figure 9. Writing latency data for the ascending digit sequences starting at 2 or 6. The straight lines are the best fits to the average at each sequence length. Subjects 1, 2 also took part in the *v*, *n*, *w*, *m* experiment and are identified consistently with Figure 8.

gramme the movement for any trial in advance of the point from which reaction time was measured. Sequence length was changed at the end of each block of 100 trials. Three subjects were tested on four blocks per session over a number of days, and the results for the last three consecutive sessions are summarised in Figure 9 With each additional digit the time taken to write the sequence (movement time) increases by an amount approximately equal to the movement time for one digit. However, there is no consistent effect of sequence length on response latency and so the data provide no evidence for preprogramming. This state of affairs contrasts strongly with that for speech where the latency of initiation of an utterance increases reliably with increase in length of the utterance, (Sternberg, Monsell, Knoll, and Wright, 1978). Thus, for handwriting it appears that preparation of the motor programme temporally overlaps at least the onset of movement itself.

In the experiment that used the letters *v*, *n*, *w*, *m*, I found that the variability of timing as a proportion of the duration of the various movements was high. The standard deviation was as much as one quarter of the mean movement duration. However a correlation analysis showed that the variation of duration of successive segments in these letters was not random. In particular the duration of the second movement (up) correlated strongly and positively with the duration of the third movement (down). This was in contrast to small negative correlations found between other adjacent segments. On the basis of the pattern of correlations obtained, I suggested this was evidence for grouping of segments into strokes reflecting an underlying psychological structure to the sequence of movements (Figure 10). While the two subjects' data were in very good agreement on the correlations, this work obviously requires extension. On the one hand, there is the question of

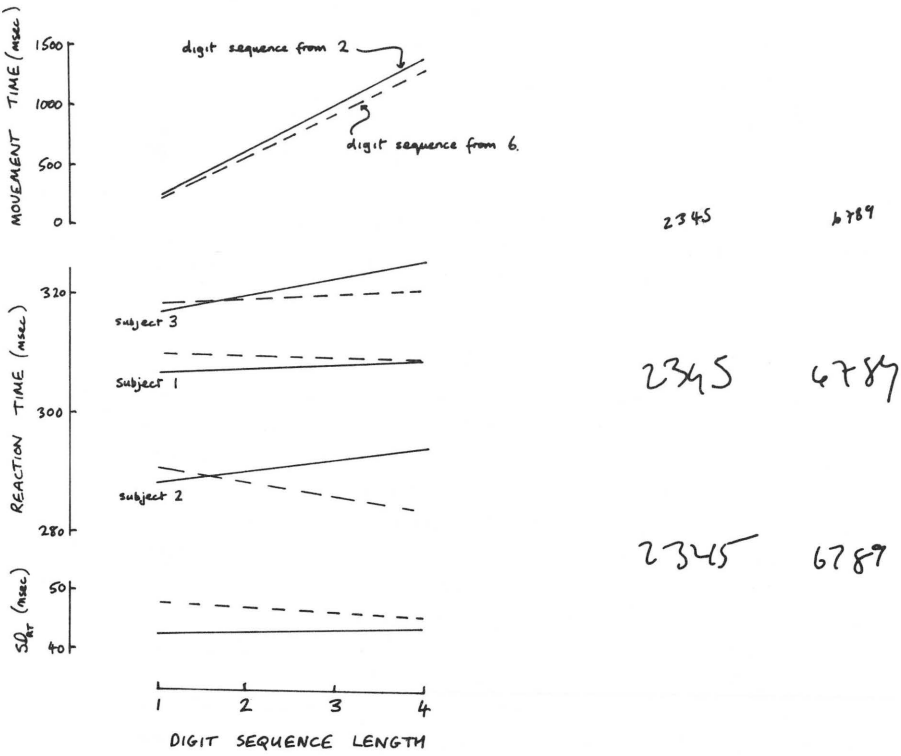


Figure 10. Segmentation of *w*, *m* into strokes based on correlation data of Wing (1978).

whether the result applies to other writers or if there is perhaps a division between those whose writing tends more toward garland or toward arcade styles of writing, for example. On the other hand, it is also important to determine whether the result — based on a particular subset of letters having no retrograde movements — generalises to other letters and to letters in word contexts.

So far I have written about the effect of timing variation on the variability of letter shapes. Inconsistency of handwritten letter forms may be a result of poor timing in the patterning of the underlying muscle activity. A particular movement may be relatively too large, for example, if the muscle activity that halts (or reverses) the direction of movement occurs late in time relative to activity in the muscle that produced the movement in the first place.

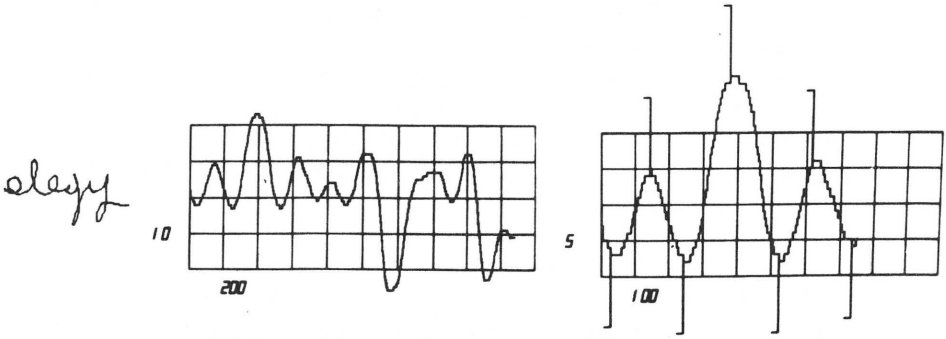


Figure 11. Measurement of the duration and amplitude of the first three letters of the word *elegy*. Photograph of a computer display generated by the programme that was used to display the vertical displacement (3.6 units/mm) as a function of time (msec) and to pick out coordinates of direction changes.

As well as distorting letter shape, changes in timing may underlie overall changes in size of writing. An important characteristic of handwriting movements is that their size can be adapted to suit the circumstances. This may involve a small change — perhaps to fit writing into narrow lined paper — or it may be as gross a change as writing on a blackboard so that people some distance away are able to read the writing. In the latter case very different sets of muscles must be responsible for producing the movements of chalk over the vertical surface of a blackboard, yet the handwriting remains remarkably constant in style. Such motor constancy is often put forward as an argument for non-specificity of encoding movements in the central nervous system (for example, see Pew, 1974). Different muscles (controlling the whole arm rather than the fingers) have to produce movements of a different writing implement (chalk rather pen) in a vertical rather than a horizontal plane. The timing and relative amplitudes of muscle forces must also be drastically revised, for example, to take account of the effects of gravity acting with or against the direction of a particular movement. Yet we can switch from writing on paper on a table to writing on blackboard without noticeable change of writing.

The case of changes in size of writing is perhaps less dramatic, but it may also be revealing with respect to how our movements are encoded by the brain. In a recently completed experiment (Wing, 1979b) I asked twenty people to write out single words, either normal size or larger than normal. Figure 11 shows how I measured the durations of the vertical movements in the letters *e*

and *l*. I found that when people increased the overall size of their writing by 25%, the size increase of the up and the down movements in these two letters was in proportion to observed increases in duration. This is consistent with the idea that changes in size of handwriting are based on an overall rescaling of the timing of muscle activity. If all movements are allowed to proceed further by a certain proportion of their original durations, all movements will be longer in proportion to each other. One point should be noted about this result. Other workers have found that writing larger is not accompanied by changes in duration of the movements (Denier van der Gon and Thuring, 1962). However in their case one set of writing was 600% larger than the other set. Very large overall amplitude changes may require changes in the muscles involved. In that case one might expect changes in force so that timing changes would be redundant.

In my experiment, the words written included the letters *e*, *l*. In most people's handwriting these two letters have a similar form and differ only in height. However, I found that the difference in height expressed as a proportion of the height of the *e* was considerably greater than the proportional difference in duration. I therefore concluded that a different mechanism for height control operates to determine letter height within words, one that includes changes in applied force.

*Conclusion.*

Much of the variability evident in handwritten letter forms may be attributed to style. Different shapes are often used to represent the same letter by different people, and this reflects educational and cultural influences as well as personal choice. Within the writing of one individual a range of shapes for a given letter may also be observed as a function of the particular letter context in which it occurs. This may also be considered an aspect of style, though more likely attributable to idiosyncratic development of the writing of the particular individual than a function of educational influences. The conventionally accepted range of block capital letter forms is smaller than that for cursive letters, and material written in block capitals is generally easier to read than if written cursively. For this reason block capital writing is often requested on application forms and the like. In such cases if legibility is critical and the amount of material to be written is reasonably small, the time penalty associated with this form of writing may not be con-

sidered serious. These points were considered in the first half of this paper under the general heading of the efficiency of handwriting as a form of communication.

Outside the variation in the shape of letters resulting from stylistic differences are the apparently random distortions that occur over repetitions of the same letter at different times. These distortions reflect the operation of the mechanisms that control handwriting movements. In the second half of this paper I discussed these from the point of view of the timing of movements. I also considered the question of planning of handwriting movements but found no strong evidence in favour of preparation of sequences of handwriting movements in advance of the first movement.

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# *The Development of Directional Preference in Writing Movements*

Arnold J. W. M. Thomassen
and Hans-Leo H. M. Teulings

The paper looks into the origin and the development with age of the preference to make either clockwise or counterclockwise curves and contours in writing and drawing. Twenty-six subjects of four age groups performed four writing and drawing tasks. Two of these were writing single symbols and accurately copying patterns; the other two were free scribbling and drawing repeated circles at a high rate. The developing directional preferences that were observed between four years of age and adulthood suggest that two semi-independent motor systems are involved in writing: one, more primitive, for rapid non-figurative tasks evolving from flexion-first to extension-first; the other, which occurs later but more rapidly under a higher degree of cognitive control, for precision and symbolic functions, favouring counterclockwise curves, irrespective of the writing hand.

## *Introduction*

One may regard the production of any piece of handwriting as the production of a sequence of curved line segments. The direction in which a segment is curved will to a large extent be determined by the general shapes of the letters and the script used in formal writing instruction. Although in some cases, such as in closed circles, the segments could in principle be drawn either clockwise or counterclockwise, it is likely that learning to write induces a certain preference for one direction over the other. At the same time, however, it is obvious that the scripts in use must to some degree reflect the most natural movements, not only in terms of slant and size, but also in their direction of rotation.

We have recently obtained data which indicate that there is a systematic difference between clockwise and counterclockwise writing movements. By some of the subjects in these experiments, the counterclockwise versions of continuous loops as well as of repeated circles (Figure 1) were produced more rapidly than their

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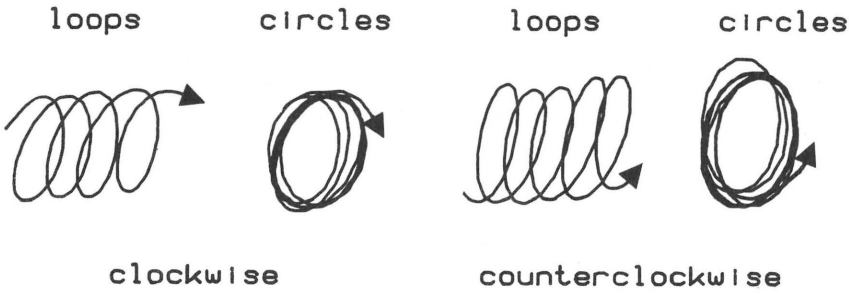


Figure 1. Clockwise and counterclockwise versions of sets of loops and repeated circles, the dynamic properties of which may display directional preferences.

clockwise counterparts; in other subjects this relationship was reversed. We shall refer to that direction of rotation which is apparently the easier one to produce as the preferred direction. This concept may also be used in drawing tasks. If, for instance, a subject copies simple geometric patterns, he may systematically draw the patterns following a specific sequence, e.g., building them up in a clockwise fashion. The cause of such an apparent preference must — just as in the case of writing — be located within the subject's history, in his motoric disposition, or in both.

The research to be reported in the present paper is concerned with a further establishment of the preferred direction in writing and drawing and with finding out whether they have a common basis. Our specific aim is, furthermore, to investigate to what extent directional preference is caused by merely neuromuscular properties of the motor system in its successive stages of development, and to what extent it is determined by higher, cognitive processes which are, in turn, subject to influences such as those of writing instruction.

In the literature on writing and drawing behaviour in children a number of observations have been reported which seem to indicate that a counterclockwise build-up occurs most frequently in children over the age of six. In younger children there is a somewhat less obvious preference, or even a preference for a clockwise sequence of segments. Ames and Ilg (1951) distinguish four developmental stages characterized by the way in which the child is most likely to draw a circle, starting either at the top or at the bottom and continuing in a clockwise or counterclockwise direction. Their findings may be summarized as in Table I.

Table I. Four developmental stages characterized by the manner of drawing circles. Data from Ames and Ilg (1951).

| *Stage* | *Age (years)* | *Starting point* | *Direction of rotation* |
|---|---|---|---|
| 1 | 3 | top | counterclockwise |
| 2 | 3.6 | bottom | clockwise |
| 3 | 4 - 5.6 | top | clockwise |
| 4 | over 6 | top | counterclockwise |

More recently Goodnow and Levine (1973) have proposed a set of selection rules describing the sequence following which a geometric pattern is drawn. Of the patterns employed by these authors, the ones that are relevant for the present study are the three patterns having an apex: rhombus, triangle, and inverted V (Figure 2). Two rules describe how these patterns are copied: (1) the starting rule states that the apex will be selected as the starting point; (2) the progression rule states conditionally that if rule (1) is satisfied, the first line to be drawn will be in a left-downward direction. According to these authors, there is a particular relationship between age, on the one hand, and the degree to which the two rules predict copying behaviour on the other. This relationship is summarized in Table II. The age groups 4.5, 6.2, 6.11, and adults follow rule 2 with the very high probabilities of approxi-

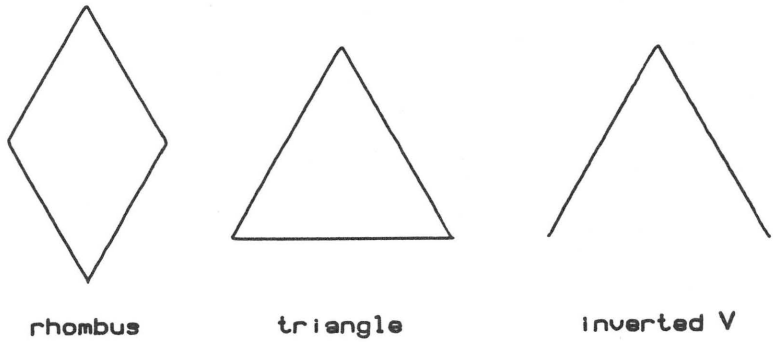


Figure 2. Three of the patterns employed by Goodnow and Levine (1973) which were adopted as copying examples in Part B of the present study.

Table II. Probability of graphic behaviour by five different age groups according to two rules. Data estimated from Goodnow and Levine (1973).

| *Group* | *Age (years)* | *P (rule 1) (start)* | *P (rule 2) (progress)* |
|---|---|---|---|
| 1 | 4.5 | 0.69 | 0.88 |
| 2 | 5.2 | 0.53 | 0.43 |
| 3 | 6.2 | 0.59 | 0.92 |
| 4 | 6.11 | 0.77 | 0.94 |
| 5 | adults | 0.75 | 1.00 |

mately 90 per cent or higher. Now, if drawing a line from the apex towards bottom-left is similar to drawing the first segment of the counterclockwise production of a circle, these data imply that these age groups display an ever increasing counterclockwise preferred direction. The five-year-olds, however, deviate strongly from these numbers. They stick to rule 2 only just below chance level (43 per cent), which shows that these children probably do not possess a preferred direction; they certainly lack the preference of the other age groups.

A clinical approach to preferred direction in writing has been followed by Blau (1977). He presented his subjects with a standard task consisting of drawing six circles, three with the right hand and three with the left. The proportion of subjects doing this consistently in a counterclockwise direction again appears to be related to their age, as may be concluded from Table III.

From the age of five there appears to be a monotonic increase of the number of subjects drawing counterclockwise circles only. It is of interest to note that these data were obtained by observing right *and* left-hand writing, so that at least here a simple motoric preference rule such as "flexion precedes extension" does not suffice, for the sequence of these mechanics is inverted when a circular pattern is performed in the same direction but with the other hand.

The motor system may in a greatly simplified fashion be viewed as consisting of two antagonist pairs, of which the muscles are denoted as (1:2) and (3:4) respectively. Circular writing movements, irrespective of their direction, are always performed by these four

Table III. Probability of drawing all of six circles in a counterclockwise direction. Data estimated from Blau (1977).

| *Stage* | *Age (years)* | *All counter-clockwise* |
|---|---|---|
| | 5 | 0.18 |
| 2 | 6 | 0.29 |
| 3 | 7-8 | 0.53 |
| 4 | 9-10 | 0.63 |
| 5 | 11-12 | 0.71 |
| 6 | 13-16 | 0.76 |

muscles. If the order of contraction is 1-4-2-3, 1-4-2-3 . . . in one direction, it will be 1-3-2-4 . . . in the other (Figure 3). The direction of rotation is thus dependent on the sequence of the various muscle contractions. It may be that the neuromuscular processes involved in the sequential innervation of the muscle system play an important role in the origin of directional preferences. This seems likely in view of the fact that the human writing apparatus (arm, wrist, and hand) has an asymmetrical anatomy. A critical prediction would be that directional preferences are hand-dependent, because the left hand is the mirror image of the right. But as we noted above, at least in certain cases preferred direction is independent of the hand used for writing.

Graphic behaviour (i.e., writing and drawing tasks of various kinds) may be considered to be located on a continuum ranging from (1) an accurately copied complex pattern or even the calmly written, orthographically correct product of creative thought on one extreme to (2) making non-figurative, arbitrary scribbles at a very high speed on the other. It is very likely that along this continuum there is a decrease in the relative weight of higher cogni-

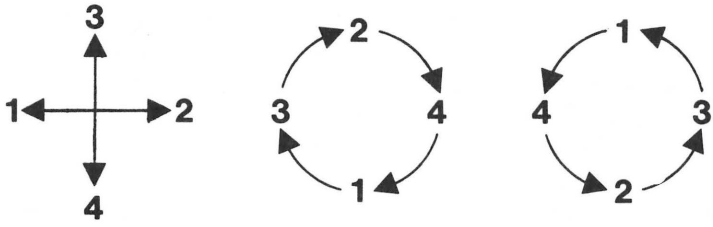


Figure 3. Simplified representation of the two antagonistic muscle pairs involved in the execution of a circular writing movement in two opposed directions.

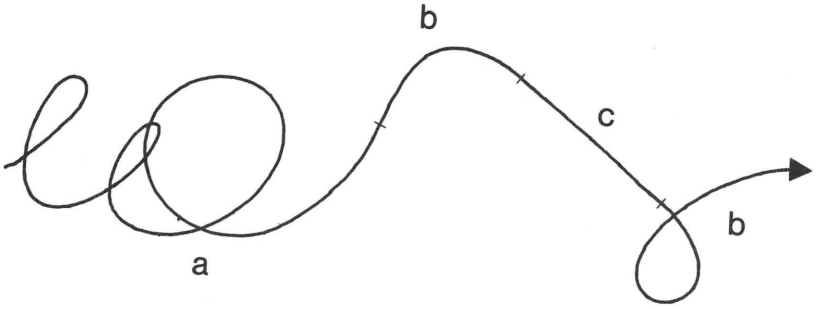


Figure 4. Hypothetical fragment of scribbling with sections of counterclockwise (a), clockwise (b), and effectively no curve direction (c).

tive control, also over the motor side of graphic performance. It may be assumed, perhaps, that if in a continuous mechanical writing task of the latter type a directional preference is present, this preference finds its origin in the motor system itself rather than in its cognitive control.

The present study will investigate to what extent the basis of the direction preference reported in the literature and observed in our own earlier experiments is to be found in the executing motor system or in its higher cognitive control. In tasks where the latter control is strongly reduced (e.g., by requiring a very high writing speed and non-figurative writing products) any pure motor preferences should become more obvious. If they remain similar to the ones observed under higher-control conditions, there is reason to postulate their common origin in the "peripheral" motor system. If, however, rapid non-figurative writing displays a different directional preference, or shows a lack of it altogether, the reported preferred direction in drawing and writing may be due to factors at more central levels.

Rapid non-figurative graphic behaviour may, for example, involve drawing repeated loops or circles in two directions. We found, however, that such tasks are hard to perform adequately by children under the age of six. But it remains possible to let the children scribble freely and to collect samples of "handwriting" reflecting the preferences that we are after. Now, if the child (or the adult, for that matter) is urged to scribble freely at maximum speed, he will, as a result of the instruction as well as of the continuous character of the task, perform writing movements which are to a large extent determined by any obtaining peripheral preferences among the various motoric alternatives.

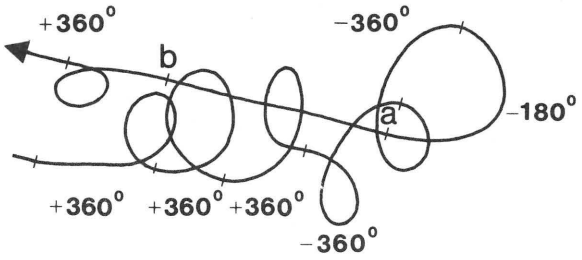


Figure 5. Imaginary scribbling fragment in which markers indicate the places where a complete rotation (360 degrees) has been completed in one direction, or where direction changes occur. Counterclockwise direction is denoted by a positive sign. The net running angle for the presented fragment is 360 + 360 + 360 − 360 − 360 − 180 + 0 + 360 degrees = 540 degrees. The straight section ab does not contribute to the running angle.

In prolonged scribbling various patterns may successively occur. In the present context it is relevant to distinguish, in terms of rotation direction, between patterns with counterclockwise rotation, with clockwise rotation, and those virtually without rotation (Figure 4).

In order to determine any preference differences between counterclockwise and clockwise rotation in scribbling, the movements of the pen during a scribbling trial may be recorded by means of the xy-tablet discussed in the paper in this issue by Teulings and Thomassen. The quasi-continuous coordinate values of the writing signal are entered into the calculation of a time function which states for any moment the number of rotations — or the total angle over which the pen has rotated — in either direction since a predetermined moment in time. This function we have named "running angle." An example in the form of an imaginary scribbling segment in Figure 5 will clarify the procedure.

The running angle is calculated separately for clockwise and counterclockwise rotations. By attributing a negative sign to the former and a positive sign to the latter, the net running angle, after a specified interval, will reflect any directional preferences.

*Experiment*

On the following pages an experiment is reported in which subjects of four age groups performed on four writing and drawing tasks. Of these tasks two were regarded as being of a precise, symbolic nature requiring substantial cognitive control (A and B);

the two other tasks involving rapid, non-figurative movements were considered to represent, to a large extent, pure-motor performance (C and D). The experimental results are analyzed in terms of the above theoretical considerations with respect to the origin of directional preference in these two types of graphic behaviour.

*Subjects.* Four groups of subjects took part in the experiment: two groups of kindergarten children (N = 6, N = 7), primary school children (N = 6), and students (N = 7). The two youngest groups with age ranges from 4.4 to 4.11 and from 5.1 to 6.2 (median ages were 4.5 and 5.10, respectively) were recruited from the kindergarten belonging to the psychological laboratory; these children have some experience in participating as subjects in studies of various kinds. They had not had any formal writing instruction. The primary school children were from the first form of a local primary school. They had received instruction in writing for approximately eight months. Their ages ranged from 6.9 to 7.6 with the median at 7.3. All subjects were right-handed, except for one child of the youngest and three of the next youngest group.

*Apparatus.* All the tasks were performed on an xy-writing tablet (Vector General Data Tablet) connected to a computer. The writing surface of the tablet is 44 x 44 cm. The attached stylus has a ball-point tip; its diameter is 11 mm and its weight 25 g. The stylus is connected to the top of the tablet by a flexible wire. The stylus also contains a press switch. The automatic recording of the writing movements was employed only in parts C and D. The position of the pen was determined at a frequency of 200 Hz with an accuracy of better than 0.2 mm. The subjects were seated on an adjustable chair at a comfortable height.

*Procedure.* The experiment consisted of four parts, as follows.

A Drawing circles and crosses
B Drawing a rhombus, a triangle, and an inverted V
C Prolonged, rapid scribbling
D Continuously drawing circles at maximum speed

Part D was not performed by the two youngest groups. The parts were presented to the subjects in a random order; each part was

entirely performed twice, once with the left hand and once with the right, also in a random order.

The materials for part A were six sheets of paper with three diagonal crosses with a line-length of 15 mm, surrounded by a circle with a diameter of 30 mm. On each sheet there was either a cross or a circle missing. The subject's task was to complete the sheet after indicating where the cross or the circle was missing. The task implied drawing three circles and three crosses, alternatingly. The subject drew on a new, semi-transparent sheet of paper which was placed over the stimulus sheet for each trial. The experimenter noted starting point and rotation direction of each circle and the starting points and sequence of execution of the lines of each cross. He counted the number of circles drawn in a counterclockwise direction and the number of crosses built up following a counterclockwise strategy. The latter was considered to apply if the transition from the end of the first line to the beginning of the second line of the x followed an imaginary counterclockwise curve.

The materials for part B were three sheets of paper on which were pictured a rhombus, a triangle, or an inverted V respectively (Figure 2). The apex was always 60 degrees. The length of the lines of the rhombus was 5 cm, that of the other patterns was 7 cm. The sheets were presented once in a random order. The subject's task was to copy the pattern on a separate sheet on every trial. The starting point and the sequence of the lines were noted for each pattern drawn. The number of patterns was counted where the starting point was at the top and where, given this starting point, the first line was drawn towards bottom-left. Moreover, it was counted how often a pattern was built up following a counterclockwise strategy. The latter was considered to apply if the first line drawn had a counterclockwise direction with respect to the imaginary centre of the pattern.

The scribbling task of part C was performed on a plain sheet of paper, size 21 x 30 cm, placed in a horizontal position. (This was also the size and the position of all the other sheets of paper in this experiment). Scribbling was introduced to the subject by means of a long woollen thread which was tangled by the experimenter. The subject was asked to draw such a tangled thread after having been shown an example of a drawing of the type required. During his attempt, the subject was encouraged to continue at a high rate and to use the whole sheet for his drawing. The subject

Table IV. Proportion of circles and crosses of Part A drawn in a counterclockwise direction.

| *Age group* *Md. years* | *Left hand* *circles* | *crosses* | *Right hand* *circles* | *crosses* |
|---|---|---|---|---|
| 4.5 | 0.67 | 0.22 | 0.50 | 0.28 |
| 5.10 | 0.38 | 0.43 | 0.52 | 0.52 |
| 7.3 | 1.00 | 0.33 | 0.94 | 0.39 |
| adults | 1.00 | 0.43 | 0.81 | 0.57 |

was required to continue scribbling in this way for 47 s. During that period, ten continuous 4 s samples were taken, separated by intervals of 700 ms. For every 4 s record the net running angle was computed automatically. The algorithm designed for this purpose neglected segments of scribbling in which the speed of the stylus remained below $^1/_{30}$ of its maximum speed during that 4 s interval. Subsequently, the number of records was counted where a counterclockwise movement was predominant, as shown by a positive value of the net running angle.

The materials for part D were sheets of paper on which were drawn two parallel horizontal lines, 5 mm apart. The subject was instructed ten times to draw as fast as possible a continued repetition of circles, staying on the same spot and fitting them approximately between the lines. He could himself determine the moment of recording his writing attempts by pressing the pen. The record was begun 1 s after initiating the first subsequent writing movement and lasted 4 s. The ten trials involved five clockwise and five counterclockwise attempts. The pertaining instructions followed a random order. For each trial the mean time needed to complete one circle was computed. The algorithm designed for the purpose calculated the time intervals between the successive moments at which the pen position was at its lowest position.

*Results*

Part A *Circles and Crosses.* The proportion of circles and crosses drawn in a counterclockwise fashion according to the described criteria is given in Table IV, which presents the data for each age group for the left and right hand separately. The results for the

Table V. Proportion of patterns of Part B copied in a counterclockwise direction, together with the observed probability of obeying the starting and progression rules.

| *Age Group Md. Years* | *Left hand* | | | *Right hand* | | |
|---|---|---|---|---|---|---|
| | *counter-clock-wise* | *P (rule 1) (start)* | *P (rule 2) (progress)* | *counter-clock-wise* | *P (rule 1) (start)* | *P (rule 2) (progress)* |
| 4.5 | 0.56 | 0.56 | 0.80 | 0.56 | 0.28 | 0.60 |
| 5.10 | 0.62 | 0.71 | 0.60 | 0.19 | 0.76 | 0.19 |
| 7.3 | 0.77 | 0.77 | 1.00 | 0.83 | 0.83 | 1.00 |
| adults | 0.38 | 0.38 | 0.50 | 0.29 | 0.29 | 1.00 |

circles indicate that, indeed, there is an increased overall tendency with age to draw in a counterclockwise direction, and that, more specifically, the strong increase in this directional preference between the ages of 5 and 7, which has repeatedly been reported in the literature, is replicated in the present study. The left-hand results of five-year olds in fact provide an exception to the almost monotonic relationship observed for circles. There are, furthermore, no striking differences between the hands. The results for the crosses follow the same trend. There is an increasing counterclockwise preference, which is approximately the same for the two hands.

The proportions of counterclockwise crosses are, however, in general somewhat lower than in the case of circles. Moreover, the strongest increase now seems to occur between the ages of 4.5 and 5.10, i.e., around the age of five.

Part B *Rhombus, Triangle, and Inverted V.* The proportion of patterns copied in a counterclockwise direction following the criterion described is given in Table V, for the four age groups and for each hand separately. The table also presents the proportion of attempts adhering to the starting and progression rules mentioned above. If the adults are left out of consideration, the other groups show an increase in counterclockwise directional preference also in these patterns. Similarly, there is an increasing tendency to behave according to the two rules. As in Part A the five-year olds once more provide an exception in places by deviating from the

Table VI. Proportion of 4 s periods during which counterclockwise curves prevailed in the free scribbling task of Part C.

| *Age group Md. years* | *Left hand* | *Right hand* |
|---|---|---|
| 4.5 | 0.30 | 0.62 |
| 5.10 | 0.57 | 0.40 |
| 7.3 | 0.48 | 0.40 |
| adults | 0.63 | 0.24 |

trend. There are, again, no further big differences between the hands. Puzzling are the copying attempts by adults. They tend to draw neither counterclockwise nor following the grammar rules. Only with their right hand (which was the preferred hand in all these subjects) did they obey conditional rule 2 at the high probability reported by Goodnow and Levine (1973).

Part C *Rapid Scribbling.* Table VI presents the proportion of the sampled periods in which counterclockwise curves prevailed. The most striking feature of the scribbling data in the table is that the direction of the strong age effect depends entirely on the hand performing the scribbling task. If a young child's right hand preferably makes counterclockwise scribbles, his left hand seems to prefer exactly the opposite. Similarly, if an adult's right hand tends to scribble in a clockwise direction, this preference will be in the opposed direction for the left hand.

Part D *Circles at Maximum Speed.* The results of this speed task — which could only be offered to the oldest age groups — are presented in Table VII. The data represent the proportion of subjects in which counterclockwise rotations were faster than clockwise rotations. In some cases, these differences were significant within subjects. It seems as if the results of part C are here replicated on another scale. The younger subjects show a tendency to make rapid counterclockwise movements with their right hand, whereas this tendency is reversed in adults. Thus, again, there is an interaction between age and hand.

Table VII. Proportion of subjects performing repeated counterclockwise circles at a higher speed than clockwise circles in Part D.

| *Age group* | *Left hand* | *Right hand* |
|---|---|---|
| 7.3 years | 0.00 | 0.50 |
| adults | 0.86 | 0.29 |

*Discussion*

The results of our experiment, which was limited in many respects, may tentatively be summed up in the following dichotomy.

1 Writing tasks which require or allow careful planning (on every trial there is a single, different letter or pattern to be written or copied, such as in Parts A and B) show little difference in directional preference between the two hands. The preferences themselves become increasingly counterclockwise with age, and with age they follow more and more the rules specified in the "grammar of action" by Goodnow and Levine. Five-year olds form an exception in some respects, but a specifically strong increase tends to occur between the ages of five and seven. The strange adult behaviour on the apex patterns of task B can in part be explained by pointing out that these subjects nearly always wrote the inverted V (or the capital lambda for them) without pen-lifting and starting bottom-left, which is scored clockwise and in conflict with the rules. Also in the other patterns, however, there appears to be a tendency to start at the left rather than at the top and to continue in an upward direction.

2 In contrast to the above are tasks which do not require, or even allow, careful planning, such as the fast arbitrary scribbles (which yielded on average approximately 100 cm distance per 4 s period) of Part C and the rapidly repeated circles of Part D where the subject's maximum speed was required. In these tasks there was a strong hand-effect, the direction of which was dependent on age. Thus, a finding of great importance is that in these tasks most of our adult subjects show a clockwise preferred direction with their preferred (right) hand. This means that, although a fully developed counterclockwise preference has been shown to exist in drawing single circles accurately, the latter turns into a clockwise preference when more liberal and rapid movements are per-

formed. It is in line with our earlier discussion to hold the more peripheral mechanics of the motor system responsible for movements of the latter type and to predict strong hand effects for these. These hand effects were indeed observed; their direction implies that in adult writing the motor system at its "lower" levels tend to favour "extension first." In young people this peripheral mechanism appears to be developing from an initial tendency towards "flexion first," which results in a counterclockwise preference in the right hand of the youngest children.

The latter situation may also explain the results of the five-year olds, which show up as an exceptional group in various studies, including ours. If a primitive flexion-first preference (which in right-hand writing appears as a counterclockwise preferred direction) is present in the youngest children of, say, four and younger, that preference will determine all their graphic behaviour, irrespective of its required precision or its possible symbolic nature. Now, suppose the later development of a higher-order writing motor system — dealing with the more precise and perhaps symbolic functions — implies the development of different, complex innervation patterns (which follow more abstract grammar rules and which are less dependent on the performing hand) and suppose this development starts at the age of four or five. This would be especially disturbing to the five-year olds, because in them the old system, which is at that age developing towards an extension-first strategy, would tend to confound with the recently developing new system. Especially the right-handers among them would be in great difficulty because of the fact that the new motor system happens to favour counterclockwise movements which their initial motor system, developing toward extension-first, has just left behind. The two underlying systems themselves may be entirely different, but still their interaction in writing at this critical age may be extremely disturbing.

We are now in a position where the main questions of our research can be answered in a speculative way. There are, conceivably, two motor systems: one for rapid and non-figurative tasks, the other for accurate and symbolic purposes. The former, then, may be described as a more primitive system, "pure motor" in character and concerned with an early neuro-muscular tendency towards flexion-first, which from the age of four or five slowly develops into an extension-first tendency. Description of the resulting writing movements in terms of preferred direction would for

this system result in the hand effects that we observed, especially in the youngest and the oldest subjects. The latter motor system in these considerations follows a different development under a higher degree of cognitive control, taking place especially rapidly between the ages of five and seven and being less dependent on the performing hand. It would be biased towards a counterclockwise preferred direction which is perhaps, but not necessarily, induced by educational influences starting at that age. These intriguing suggestions, of course, need further exploration in greater detail. As a first step we shall in a following study scrutinize the individual data on a larger set of tasks, obtained from selected right-handed and left-handed subjects. Although this has not affected the present results in any systematic way, their numbers were unequally divided over the age groups in the above experiment. We will need the results of further experiments if we are to arrive at firm conclusions on the issue of handedness and individual performance on the two types of graphic behaviour tentatively distinguished here.

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# Some Instructional Parameters Related to Children's Copying Performance

Nils Søvik

Copying is a common technique for training perceptuo-motor skills such as handwriting. An experiment is described in which stimuli to be copied were presented dynamically or statically close to or distant from children seven and ten years old. The implications of the results for teaching handwriting are discussed.

## *Theory and Problems*

Various researchers have stated that psycho-motor skills, including handwriting, can be explained by a cybernetic theory (Coleman, 1969; Smith & Smith, 1966; Søvik, 1974, 1975). The theory considers learning and performance of such skills to be a direct function of human factors of the performer related to learning situation, instruction, tools, and social interactions. Information on developmental trends of children's dynamic control of perceptual environment is therefore of significance for research into the learning and instruction problems in copying, drawing, and writing skills. Thus great attention is paid to the development of perceptual orientation through infancy and childhood. Controlled comparisons between dynamic and relatively static conditions of social interaction have indicated a progressive development of the social orientation of children between one and three years of age. The level of orientation was significantly greater for the dynamic than for the static images (Smith, 1972). Moreover, several studies on maturation of social tracking accuracy and psycho-motor abilities in general have disclosed a rapid and progressive increase in accuracy of such function between three and nine years, and some further increase between nine and fifteen years (Heinonen, 1957; Søvik, 1975). Although the studies described can be viewed as part of a more comprehensive social-educational program to test the validity of the cybernetic principles, it is important to note that the first stages of copying, drawing, and writing are much based on *dynamic imitation.*

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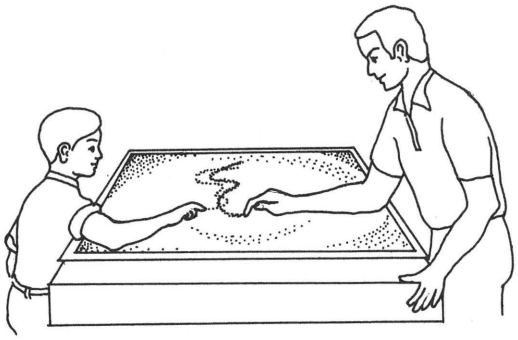

Figure 1. Dynamic, persisting, imitative tracking. Note: Figures 1-4 have been reproduced from Smith (1974) with kind permission of the author.

Cybernetic theory — stressing social tracking/dynamic imitation in connection with children's learning and performance of psycho-motor skills — also considers feedback to be important in development of skills. It should be noted that the information a child receives from his teacher's instruction during and after a copying task at school can improve the effects of the related feedback systems. Developmental trends of skills, including copying and writing, have been found by Fleishman (1969), Heinonen (1957), and Søvik (1975). But the interaction which may occur between the sensory feedback mechanisms operating in the copying activities related to the age-variable and the specific parameters associated with instruction of this skill is still an open question. Exploratory studies of the interaction are therefore motivated by the implications for instruction of handwriting. This aspect of the present work I will identify as Problem 1; further specifications are dependent on the main factors raised in Problems 2-4.

As the present study was concerned with the effect of different instructional conditions, further information on social tracking in copying activities and related feedback control are needed before formulating the hypotheses under investigation. Recent studies of the various modes of feedback control of social graphic behavior have disclosed many possible types of dynamic imitation in reproduction of letters and in tracing and copying these forms (Romanova & Feigenberg, 1975; Søvik, 1975, 1976). Some of these principles of social interaction and communication in learning graphic skills are indicated in Figures 1 through 4.

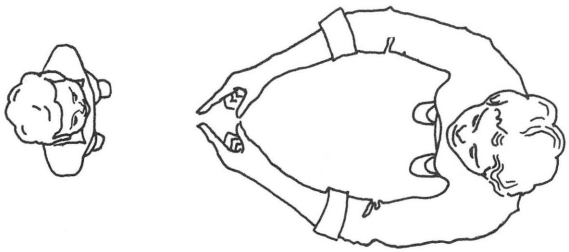

Figure 2. Perceptual, dynamic tracking.

In addition to the principles of dynamic tracking described above, these patterns of behavior include the following:

1 Dynamic displaced imitation
2 Dynamic delayed imitation
3 Dynamic persisting tracking
4 Static tracing
5 Copying static models
6 Delayed or non-persisting static copying

These forms of copying or tracing involve guidance of movements based on *visual tracking*, which is used as the basis of projecting and guiding manual movements in drawing or writing. Also, it has been confirmed that sensory feedback has a more positive effect on the child's copying performances when he can compare his own copying product with the model display (Hertzberg, 1926; Søvik, 1975). At school, however, the principle of copying from static models is followed as often as copying from dynamic ones when children are practicing handwriting exercises. Previous research in this area is very limited, and no guidelines are available for handwriting instructors whether dynamic presentation of the models (numbers, letters, or sentences) should be preferred to static models or vice versa. We thus would like to know how children's use of feedback develops with age and if dynamic structuring of tasks helps because this is supposed to provide extra feedback (Problem 2). A presentation of dynamic models seems to be more closely related to the verbal and motor demonstrations given by the instructor in teaching elementary handwriting, therefore we may hypothesise:

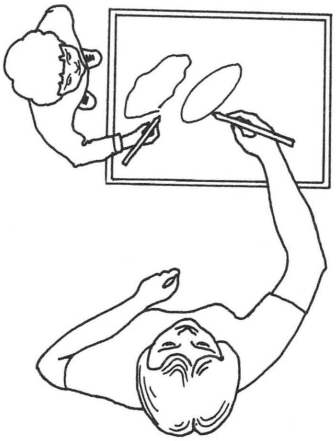

Figure 3. Displaced, reactive, persisting, social tracking.

> Assuming learning-instruction conditions to be equal, where the instruction is based on both motor and verbal explanations of the copying tasks, a presentation of dynamic designs in general will give higher accuracy-scores in copying performances of seven- and ten-years-old subjects compared with a presentation of static designs. (H1)

Little research has been carried out for studying the effects of presenting copying models at different distances and angles to children in a classroom with regard to their graphic performance. The findings of a previous study showed that the accuracy-scores of copying/writing performances deteriorate if normal feedback control is changed spatially for copying from normal table control to TV-monitor control, and even more if the feedback control is reversed or inverted spatially in the TV-monitor (Søvik, 1974). However, the displacement problem in handwriting instruction has not been solved, and further research is needed. To simplify the problem it was decided to concentrate on the distance phenomenon only in this study (Problem 3). Since children usually are supposed to copy models from books placed at their desks rather than models presented on blackboard, it was reasonable to expect the highest accuracy-scores from children's copying performances when models were presented in accordance with the close working situation. A second hypothesis may therefore be stated:

Figure 4. Perceptual, dynamic, persisting, social tracking.

> Assuming learning-instruction conditions to be equal, with the instruction based on motor and verbal explanations of the copying tasks, a close presentation of the copy designs (2 feet) in general will give higher accuracy-scores in copying performances of seven- and ten-year-old subjects compared with a distant presentation (12 feet) of the same designs. (H2)

An interesting question attached to Problems 2 and 3 is whether the expected effects of the dynamic/static variable and the distance variable would be additive or not. Although these trends were likely to appear while testing H1 and H2, the theoretical background for formulating a hypothesis with regard to this interaction effect seemed to be weak, and only preliminary explorations could be done (Problem 4).

## *Method*

### *Design*

An experiment organized as a three-way (2x2x2) factorial design was conducted. The three independent variables were: chronological age (two levels, CA 7 and 10), dynamic vs. static presentations of copying models (two experimental treatments), and different distances of presenting the copying models (two experimental treatments, i.e., close and distant). The dependent variables were the accuracy of copying and the time taken to complete the tasks.

To follow a more thorough procedure in testing the effects of the two experimental variables, the study was later split into two separate studies (designs) each of which corresponded to the two age-groups under examination. These studies were organized as two-way (2x2) factorial designs with two covariates: Scores of subjects (Ss) on Bender Gestalt Test (visuo-motor integration) and teacher-ratings of Ss with regard to attention/concentration on school work, whereas the two experimental variables and the dependent measures remained the same. Product-moment (PM) inter-correlations were calculated between measures of mental age (MA), visuo-motor integration (BGT), ability to concentrate on school work, quality of handwriting, and the two dependent variables in order to have different measures of Ss' capacities for selecting some adequate covariates.

Ss were sampled according to the principle of equal cell frequencies. The 32 Ss were randomly chosen from the population of children in the Trondheim (Norway) public schools and stratified on chronological age. The Ss were randomly assigned to each of the cells in the design.

*Tests and Assessments of Ss*

Before the experiments started, each S was tested by Sandven's Modenhetsprøve (maturity test) (Series I & II) which is a group test of intelligence, standardized for Norwegian children aged six to eleven years, and by the Bender Gestalt Test (Koppitz's version and norms). BGT is supposed to measure children's ability of visuo-motor integration. Data concerning reliability and validity of the two tests are considered satisfactory (Sandven, 1962; Koppitz, 1968). In addition, the teachers were asked to rank each S on a scale from 1 (low) to 5 (high) with respect to quality of handwriting and ability to concentrate on ordinary school tasks.

*Equipment*

Each S was tested individually on a 18 x 20 foot section of an audiovisual laboratory (Figure 5). A special writing desk was constructed of a metal frame 2 x 2 feet in which plate glass ½-inch thick was placed. The writing surface was tilted 30° from the horizontal, and a white sheet of paper for data collection was taped on the lower part (#7 in Figure 5). The upper half functioned as a window through which the copying models were presented when S was given the experimental treatment of close display of the

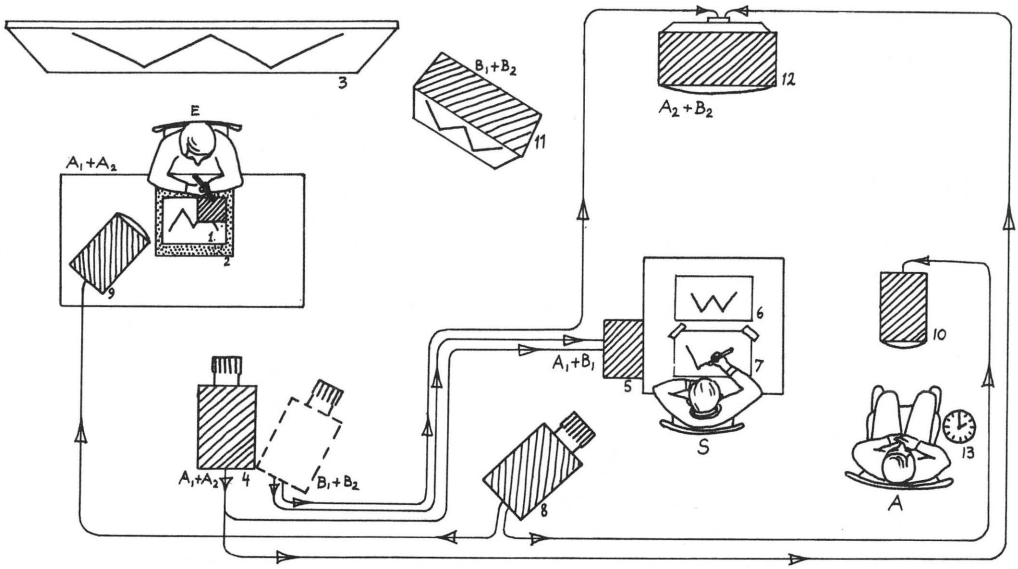


Figure 5. The experimental design and instrumentation.

models (#6). A Penol 200 felt-tip pen was used by S. Figure 5 shows that the experimenter (E) sat at an ordinary writing desk 12 feet to the left of S. On E's desk a 3M 088 over-head light projector was placed (#2). E also used a Penol 97 felt-tip pen when demonstrating dynamic copying models to S. Moreover, on E's desk there was a 12-inch TV-monitor (#9) so that S's copying behavior could be watched by E. Similar equipment (#10) was available at an assistant's desk (A), such that A could also monitor S's copying. The camera (a Philips plumbecum LDH 150) was located to the left of S and close to his desk (#8).

Behind E a white screen (5 x 5 feet) was placed (#3) for the projection of the writing signals produced by E. Another Philips plumbecum LDH 150 camera, placed in front of E and the white screen (#4), could transfer the experimental tasks (copying models) via the related cord system to the optic instruments placed on the floor below S's writing desk (#5). These instruments consisted of (a) an 11-inch TV-monitor, (b) a Leitz episcope combined with (c) a lens-system taken from a Lara over-head light projector. This combined optic system, constructed for this experiment specifically, would then transfer the copying models through the S's tilted glass-table. A stopwatch was used by A to time S's copying performances.

The above equipment was used when Ss were given the experimental treatment of *close display* of the task variables (dynamic persisting imitation). When Ss were supposed to copy from static models under the condition of close display of the task variables, the models were written on white sheets of paper and placed (one at the time) on a tilted box placed to E's left (#11). In this case, the over-head system at E's desk and the big screen behind him were disconnected from the experimental system, and the TV-camera in front of E was turned in the direction of the box with the models. Pictures were then taken by the camera and transferred to the TV-monitor below S's desk.

Finally, a TV-monitor with screen size 20 x 20 inches placed 15 feet in front of S and 4 feet above floor (#12) was used instead of the optic devices below S's desk whenever the experimental treatment of *distant display* of the models was introduced.

*Task Variables*

In previous research (Beery, 1967; Bender, 1938; Søvik, 1975, 1976) on children's copying ability, both geometric and non-geometric forms were used as task variables or items in the applied tests. Two designs consisting of simple two-dimensional forms were chosen for training in the present study. Although letter-like copying models would be preferable for handwriting instruction at school, the six geometric forms shown in Figure 6 were chosen as task variables in the experiment. The main reason why these forms were preferred to more letter-like materials (e.g., the twelve Gibson figures) was the greater advantage at scoring Ss' copying performances of the designs in Figure 6.

*Experimental Treatments*

Ss were assigned to one of the specific combinations of experimental treatments. Before taking part Ss were given an oral orientation of the experimental procedure and they received a short period of training; Ss copied the two figures designed for this purpose (Figure 7). The training was organized with exactly the same instrumentation and experimental method as used in Ss' experimental treatment to ensure that the equipment would function in accordance with the experimental conditions and to familiarize Ss with the experimental situation. During training and experimentation Ss were asked to do the copying in a relatively slow and exact way. In other words, they were permitted to spend the time they

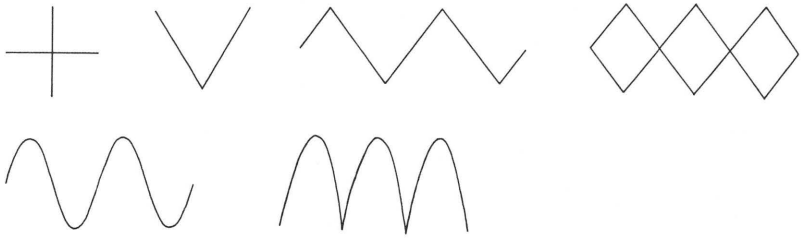

Figure 6. The six designs used as task variables.

Figure 7. The two designs used as training variables.

needed for the execution of the imposed tasks. The experimental treatments were as follows:

1 ($A_1$) *Dynamic persisting imitation (copying) with close display of task variables.* E presented each of the six copying models (one at a time) by demonstrating the drawing of the figure on the over-head projector placed on his desk. The forms were simultaneously transferred by camera (#4) to the upper half of S's writing desk (#5, 6). E gave detailed oral instructions while he demonstrated the drawing. Ss subjected to this treatment were asked to observe E's hand while he demonstrated the figure and listen carefully to E's verbal explanations how the figure should be correctly drawn (i.e., where each of the separate strokes in the figure started, the direction of the line, and where it ended). Having finished his drawing on the copying model, E asked S to copy it.

2 ($A_2$) *Dynamic persisting imitation (copying) with distant display of task variables.* This experimental condition was exactly the same as in $A_1$ except for the presentation of the task variables which now appeared at the big TV-monitor (#12) in front of S. As the copying models under the $A_2$ treatment were shown at a distance from S six times the corresponding distance given under $A_1$, the objective sizes of the models at the TV-screen (#12) were enlarged proportionally.

3 ($B_1$) *Copying from static models with close display of task variables.* This treatment was the same as $A_1$ with one main alteration: The task variables were presented as static (completed) figures on the box located to the left of E, such that the camera (#4) had to be turned clockwise some 30° to catch the figures. (Before S started his copying work E pointed to the figure and gave his explanation/demonstration).

4 ($B_2$) *Copying from static models with distant display of task variables.* The fourth experimental treatment corresponded with $B_1$, but the copying signals were not presented through the upper half of S's writing desk. They appeared at the big TV-screen (#12) (cf. $A_2$).

In each treatment the copying model remained on the desk/screen as long as Ss were copying. Thus no time limit was set in the experiment. The total time spent on the series of experimental treatments for one S varied from 12 to 18 minutes.

*Scoring of data*

The main output produced by Ss in the experiment were their copying performances drawn on sheets of writing paper. In addition, time-scores corresponding to the total amount of time spent by Ss in executing each figure were available. The graphic products were rated by two raters trained in advance for the specific task. While scoring Ss copying products the two raters tried to work in accordance with some rules established before the rating procedure commenced. As a general rule three main sources of errors were emphasized: (a) errors caused by deviations from correct proportions of central components of the model, (b) "errors" related to the quality of the copying performance, and (c) frequencies of errors found for each copying product. That is to say, the higher the total error-score was for each of the graphic products (and for the whole series of the six figures) the lower was the accuracy-score of this performance. Inter-correlation data for rating of Ss copying products thus ranged from $r=.27$ to $r=.85$ for the separate figures. The coefficient of correlation between the ratings made by the two raters for total copying accuracy-scores (used for further data analyses) was .67.

*Data analyses*

Intercorrelation coefficients were first computed among Ss'

Table I. PM-correlations among Ss' abilities and visuo-motor performances for the 16 first-graders.

| | *MA* | *BGT* | *CON.* | *WRIT.* | *COPYING* | *TIME* |
|---|---|---|---|---|---|---|
| MA | 1.0000 | .2402 | .8386 | .2536 | .4940 | –.1227 |
| BGT | .2402 | 1.0000 | –.0200 | .2137 | .5754 | –.1603 |
| CON. | .8386 | –.0200 | 1.0000 | .5517 | .5156 | –.0680 |
| WRIT. | .2536 | .2137 | .5517 | 1.0000 | .5021 | .0491 |
| COPYING | .4940 | .5754 | .5156 | .5021 | 1.0000 | –.1654 |
| TIME | –.1227 | –.1603 | –.0680 | .0491 | –.1654 | 1.0000 |

Correlation coefficients should be at least .35 to be considered significant.

testscores, ranking of some related personality traits, and data from the experiments. Then a three-way fixed effects model ANOVA was used to analyze the accuracy- and time-scores of the experimental data. Finally, the experimental data were re-analyzed as two-way fixed effects model COVAR with two covariates.

*Results*

Table I presents PM-correlations among six variables: mental age (MA), visuo-motor integration (BGT), ability to concentrate on school work (CON.), quality of handwriting (WRIT.), accuracy-score in experiment (COPYING), and time-scores of copying performances in experiment (TIME) for the 16 first-graders who constituted one half of Ss in the present experiment. The BGT scores and accuracy-scores in copying in Tables I and II have been converted from original scores on the test, i.e., the higher the BGT-scores the better the individual performances (0-point was set for the lowest BGT-score).

Data in Table I show significant correlations between mental age and ability to concentrate on school work, and also between mental age and accuracy-scores in copying. Furthermore, visuo-motor integration correlates even stronger with copying (r=.58) than does mental age (r=.49). The significant correlation found between ability to concentrate on school work and handwriting performances (r=.55) is, of course, of great interest. The CON.-ability also correlates significantly with COPYING (r=.52). The relatively

Table II. PM-correlations among Ss' abilities and visuo-motor performances for the 16 fourth-graders.

| | MA | BGT | CON. | WRIT. | COPYING | TIME |
|---|---|---|---|---|---|---|
| MA | 1.0000 | .7185 | –.1499 | .1332 | .2653 | –.0707 |
| BGT | .7185 | 1.0000 | –.0163 | .4639 | .2670 | .4360 |
| CON. | –.1499 | –.0163 | 1.0000 | –.0490 | .4742 | .1112 |
| WRIT. | .1332 | .4639 | –.0490 | 1.0000 | .4185 | .8333 |
| COPYING | .2653 | .2670 | .4742 | .4185 | 1.0000 | .2397 |
| TIME | –.0707 | .4360 | .1112 | .8333 | .2397 | 1.0000 |

Correlation coefficients should be at least .35 to be considered significant.

close relationship which could be expected from previous research between accuracy-scores of copying and handwriting performances (r=.50) has again been confirmed by these data. Finally, it is worth noticing that the time-scores of copying performances in the laboratory correlates close to zero with each of the other variables.

The corresponding correlation data in Table II represent the 16 fourth-graders who belonged to the other half of Ss in the experiment. It can be seen that the correlation between mental age and visuo-motor integration is considerable (r=.72), whereas the corresponding data for MA and copying is non-significant (r=.26). BGT-scores correlate significantly with handwriting performances (r=.46), but not so with COPYING (r=.27). As far as CON. is concerned, this ability correlates substantially with COPYING also at this age level (r=.47). Similarly, a significant correlation finding shows up between handwriting and COPYING again (r=.42). Moreover, it is noteworthy that the PM-correlation coefficient between quality of handwriting and time-scores during experimentation was as high as r=.83. A general difference between data in Tables I and II can be observed with regard to the time variable which correlates from r=.27 to r=.83 in Table II, whereas all the corresponding correlations in Table I were close to zero. The correlation findings in Tables I and II are in line with previous research (Koppitz, 1968; Søvik, 1975).

Methodological assumptions for use of analysis of covariance could hardly permit more than two covariates for the experimental

design and sample under investigation. As variables chosen for covariates ought to correlate substantially with the main dependent measure and simultaneously be relatively independent of one another, BGT and CON. seemed to satisfy these requirements. On account of data in Tables I and II these two variables were therefore chosen as covariates in further covariance analyses of data. Three-way ANOVA on accuracy in copying (with age, figure-type, and distance as factors) was performed. Reliable main effects of age ($F [1,24] = 3.81$, $p=.06$) and distance ($F [1,24] = 3.17$, $p=.08$) were found. No other significant effects were found. ($p<.10$ is considered significant. Complete ANOVA-tables can be obtained from the author on request.) Multiple classification analysis of the data showed that the significant difference between the two age-groups under study favored the older Ss, whereas the significant difference between close and distant display of models went in favor of the younger Ss. The beta-values of the three independent variables (age, figure-type and distance) were .61, .10, and .56. $R^2$ equalled .20. The results seemed to make further data analyses a necessity. (cf. the COVAR).

A three-way analysis of variance of the second dependent measure, time-scores in relation to Ss' copying performance, was also done. No significant findings were disclosed, except for the two-way interaction effects between figure-type and distance ($F [1,24] = 3.21$, $p=.08$). In consequence, no multiple classification analysis of the main effects with respect to Ss' time-scores seemed to be necessary. However, it is noteworthy that no significant findings regarding differences between treatments were revealed as far as time spent on copying the models was concerned.

To throw more light on data presented above analyses of covariance were carried out for each of the two age-groups separately. A regression approach has been used during each COVAR, i.e., all effects — including main effects, covariate effects, and any interaction effects — were assessed simultaneously as in multiple regression. (Also, each effect is the additional contribution to the explained variation after adjusting for all other effects).

As to data from the analysis of covariance for first-graders with accuracy-scores of copying as dependent measure, reliable findings were disclosed for both covariates used in the analysis, i.e. ($F [1,10] = 6.53$, $p=.03$) for visuo-motor integration (BGT), and ($F [1,10] = 12,34$, $p=0.1$) for ability to concentrate on school work (CON.). The strong relationships between the two covariates and

accuracy in copying appeared likewise in the two beta-coefficients of −5.93 (BGT) and −14.21 (CON.). Further, a significant difference was found between close and distant display of copying models (F [1,10] = 5.46, p=.04), close presentation being the most effective. No other significant effects were found. $R^2$ for this analysis of covariance equalled .63 which means that variance of accuracy in copying seems to be explained mainly by the two covariate-measures introduced in the specific data analysis for seven-years-old Ss.

Data from the analysis of covariance of the second dependent variable, copying-time, for the sample of first-graders, gave a significant effect of figure-type (F [1,10] = 4.87, p=.05). According to data, most time was spent on copying static figures. Furthermore, significant interaction effects between figure-type and distance were disclosed (F [1,10] = 6.09, p=.03). The finding indicates that the treatment effects have had different effects for the level of the experimental variables with regard to time. $R^2$ equalled .32 for these statistical analyses of the time-variable.

Besides data presented from analyses of covariance at the first-grade level, findings from corresponding analyses at the fourth-grade level also became useful information on our explorations related to the problems. As far as data from the analyses of covariance effect was found for ability to concentrate on school work (CON.) (F [1,10] = 4.79, p=.05), the regression approach used in this analysis of covariance gave the following beta-coefficients: −2.31 (BGT) and −9.07 (CON.). No other significant results were found in this analysis. However, information presented by the multiple classification analysis seemed to favor dynamic vs. static and close vs. distant display of copying models. The difference between figure-types was considerable when dependent measure was adjusted for independents and covariates. $R^2$ equalled .43 which was much lower compared to $R^2$ for the first-graders (.63).

Concerning the analysis of time spent in copying task variables neither the covariates nor the main and interaction effects gave significant findings. The information is of interest when results presented above are to be interpreted.

### *Discussion and Conclusions*

Previous research has found a close relationship between perceptuo-motor abilities and sensory feedback systems function-

ing spatially and temporarally during the execution of a psycho-motor skill. Consequently, improved copying and writing performances have been disclosed between ages seven and sixteen (Harris & Rarick, 1959; Søvik, 1975). According to the cybernetic theory, the feedback mechanisms thus play an important role in learning and performance of all kinds of psycho-motor behavior, and as a consequence they affect the dynamic social tracking and children's copying performance. The present work is a study in a series of experiments designed to investigate how instructional circumstances may affect the feedback phenomena related to children's copying performance. The study was designed to investigate the effect of varying the graphic model on copying performance combined with an assessment of age effects.

In general, significant correlations were found between accuracy-scores in copying and other variables under study, whereas no significant relationships seemed to exist between time-scores and the same variables. The findings were in line with earlier studies (cf. Koppitz, 1968; Townsend, 1951), and made a control of the ability and time variables related to children's copying performances a necessity for data-analyses of the experiment.

Without changes in writing speed, data from the study indicated that older children (ten years) were more accurate in their copying performances than younger children (seven years). Furthermore, the age factor interacted with neither the proximity of the copying model nor the dynamic/static characteristics of the experimental tasks. The findings might be expected as they are in accordance with the developmental trends of the perceptuo-motor abilities and psycho-motor skills reviewed above. The explorations done so far in response to Problem 1 seem clear with respect to the age and instruction variables under investigation.

According to Problem 2 and H1, presentation of dynamic designs was expected to surpass static ones regarding Ss' copying performances. This trend was detected both at first and fourth grade-levels, but the findings were not statistically reliable. However, the comparable analyses of time-scores confirmed the fact that Ss, first-graders in particular, spent more time on completing copying tasks from static models, although the accuracy of these reproductions was lower then for dynamic models. A reasonable interpretation might be that feedback mechanisms operate more effectively when younger school children copy from dynamic display, or to be more specific: children seem to assimilate information given by dynamic copying models in a better way than infor-

mation associated with static models. On account of the available data, however, no final conclusion can be drawn with regard to H1, except for the fact that further work on Problem 2 seems to be necessary.

As to Problem 3, it was hypothesized that copying under close model display would give higher accuracy-scores than under distant condition (H2). Without changes in writing speed, close graphic models gave better copying performances in the present study, and the hypothesis could be accepted. However, the verification of H2 does not mean that Problem 3 has been completely solved. Two fixed treatments were the only ones tested in the experiment, and both represented different forms of displacement. Future work, therefore, should consider (a) effect of using modes of presentation other than TV; (b) distances other than two and twelve feet. Also, children of ages other than seven and ten years (especially children from age-levels below seven) should be used as subjects for further testing of the cybernetic theory in this field. Dynamic tracking may help the very young where there are no established motor sequencing strategies to decide where copying should start. This point of view may also be applicable to school children having severe learning problems because of dysfunctions in visuo-motor integration.

Only one significant interaction was disclosed in the present study: interaction between figure-type and distance variables when time-scores were taken into consideration (cf. Problem 4). In ordinary copying/writing instruction at school, children's accuracy-scores are supposed to be of greater interest to teachers than the time-scores. Although final conclusiveness and advice for copying/writing instruction concerning model display have to be postponed, *the findings of the experiment seem to support teaching that emphasizes relative close, dynamic presentations of the copying models.* In teaching handwriting, however, effects of ability to concentrate on schoolwork and visuo-motor integration with regard to copying should be noted. This effect suggest the need for individualized instruction which means further investigations of interactions of human factors related to tools, books, audio-visual aids, learning materials, and other instruction parameters. As the principles of *tracing* and *tracking* are emphasized in the cybernetic theory as well as in copying/writing instruction at school, the next studies in our attempts at finding a scientific foundation of efficient handwriting instruction are planned to throw more light on these phenomena.

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# *Handwriting Ergonomics*

Henry S. R. Kao

The purpose of this paper is to suggest a conceptual framework for the handwriting system, consisting of three elements: the hand, the writing instrument, and paper. Within this system the hand control mechanism, the writing instrument design, and their integration in the dynamic writing on the paper are discussed relative to efficient, legible, motivating as well as fatigue-reducing handwriting performance. Based on this systems framework, an overview of relevant studies and a proposal for needed areas of research are presented. Designs of the writing instruments (in terms of penpoints, shanks, and other physical characteristics), the reduction of writing fatigue, and comparisons of various instruments are analyzed.

## 1 *Introduction*

Man's handwriting ability has evolved over thousands of years, and in that time he has developed all kinds of writing instruments. But improvements aimed at efficient handwriting have been given little attention. In western civilization the ease of writing was greatly improved in the seventh century when religious scribes adopted the quill pen, and several centuries later when the Chinese method of making paper from rags became known in Europe. Not until the eighteenth century was the split steel-point pen introduced. The use of "black lead" or graphite for writing was discovered accidentally in England during the days of Elizabeth I. Subsequent to the development of steel pens and lead pencils, no change in handwriting equipment appeared until the ballpoint pen was introduced in 1940. The most recent innovation is the felt-tip pen, first introduced as a marking device.

Although pens, pencils, and paper have formed the primary bases of education, little systematic attention has been given to the design of writing instruments until fairly recent times. Aside from technical improvements in writing pens by manufacturing firms, systematic ergonomic investigations began only in the last

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ten years or so. This paper seeks to provide a conceptual framework for an ergonomic system of handwriting behaviour from which certain important design as well as performance considerations for handwriting may be derived.

## 2 *The Handwriting System*

Ergonomic analysis involves the study of those aspects of human sensory-motor control relative to design and construction of writing equipment as well as their interactions that affect the efficiency of the writing operation. Typically, we investigate how movements of the human body guide the writing instrument and how the instruments should be designed for particular individuals and for particular writing tasks, for training as well as for the practice of penmanship.

The handwriting system consists of three main components: the hand, the writing instrument, and the paper. Ergonomic considerations of design and improvement in the acquisition of writing skills and performance should, therefore, center around these elements and their interactions for the purpose of writing comfort, legibility, efficiency, and motivation. Essential to these elements is the sensory-motor feedback in the operation of the handwriting system.

Three sources of feedback about writing may be identified: from the hand itself, from the action of the writing instrument, and from the resulting handwriting traces on the paper. They are referred to respectively as reactive, instrumental, and operational feedback (Smith 1966). The most important of the three is the operational feedback from the focal action of the penpoint movement on the paper.

### 2.1 *The Hand Control System*

Systematic writing movements are achieved by coordinating distinct motions: those of the arm with hand-supporting functions, travel or transport movements, and the articulated movements of the thumb and fingers. The hand is positioned for postural support and pressure control. Muscles acting at the shoulder, elbow, and wrist periodically move the hand between words or bring it back to start a new line of writing. Meanwhile, wrist-hand movements and opposed or complementary thumb-finger movements hold the pen and drive the writing point to form the letters. Efficient writ-

ing depends on precision in coordinating the various movement systems of the arm, hand, and fingers.

### 2.2 *The Writing Instrument*

Modern writing instruments — whether pen, pencil, or other forms — are usually designed and produced for mass consumption with very little systematic improvement. This may be due to slow realization of the potential contributions of ergonomics and the general lack of clear direction in the various design considerations. Several indicators of whether a writing instrument is efficient may be seen in the relative smoothness of writing, writing legibility, pace of writing, control ease of the instruments, reduced error rate, cleanliness of writing, as well as subjective variables such as writer interest and satisfaction. In addition, the writing comfort and reduced fatigue effects in using certain types of poorly designed writing instruments are important factors. On a comparative level different types of writing instruments or various designs of the same type of instrument may be examined to provide certain guidelines for their choice and use by writers.

### 2.3 *The Writing Paper*

The third component of the handwriting system is the writing surface, usually in the form of paper or parchment. This element seems to have been taken for granted and has received the least attention in handwriting research. In its static characteristics paper varies in texture, smoothness, glare, thickness, surface configurations, size, as well as ink absorption. For normal writing use most paper is in the form of plain white sheets. Little work is available on the design of the paper surface configuration for facilitation of the user's hand and arm movements and for accuracy in positioning letters and words in either vertical or horizontal dimensions (depending upon the language used) by designing ruled sheets or boxed lines for specific writing purposes.

## 3 *Ergonomic Aspects of Handwriting Performance*

### 3.1 *Handwriting Control and the Measurement of the Hand*

Individuals differ in both the static and dynamic anthropometric measurements of the human hand. In theory, writing instruments should be compatible with individual hand configurations for optimal writing performance. Since there is nothing we can do to

change the hand, we must look at various groups of people with distinctive writing requirements where general designs of instruments are inadequate. These groups include children at the kindergarten and early grade-school level, left-handers, and the manually handicapped. Kao (1974) reported one ergonomic study on writing performance by ten-year-old children using shank diameters of ¼, ⅜, and ½ inch. While the thickest pen was found to be the most effective for boys, the girls wrote equally well with the three sizes. Obviously, the lack of coherence between the size of children's hand and fingers and the size and design of their writing instrument may contribute to their difficulties in producing legible writing.

### 3.2 *Hand and Writing Pressure*

In writing, the hand typically is positioned at two points on the writing surface — at the side of the heel and on the lower side of the curled little finger. These two resting points provide a stable platform from which the fingers, thumb, and hand can control the action of the writing instrument and writing point pressure. The pressure exerted varies with the stability of the hand platform. The efficiency of the hand platform varies with the type of writing instrument as well as with the size and other anthropometric characteristics of the hand.

### 3.3 *Ergonomics of Writing Instrument Design*

The writing instrument as a component of the writing system is a passive tool of operation; the instrument itself can affect writing efficiency by causing discomfort, the need for increased visual-motor coordination in the writing process, the obscuration of written traces of the pen tips, etc. These become more pronounced in the acquisition of handwriting skill. The different types of writing instruments in use today give quite different visual, tactual, and kinesthetic feedback whch affects the dynamic process of letter formation.

Specific ergonomic design research should examine both the physical and the operational characteristics of the writing instrument. The former should include investigation of the size, weight, shape, and length of the instrument; the shape, surface texture, and hardness of the shaft for the requirements of hand control; and the size, shape, and loci of the point relative to the shaft axis. Operational characteristics should be analyzed in terms of writing

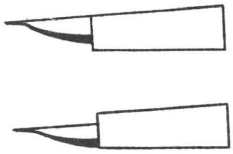

Figure 1. Comparison of centered and off-centered penpoints.

smoothness, ink flow, conspicuity of writing traces to serve as visual feedback, gravitational point, and point pressure of the instrument in action. Both types of characteristics must be coordinated for tasks different in nature and requirements; characteristics should always be considered relative to the manipulator of the writing instrument: the human hand.

3.3.1 *Penpoint Designs.* Kao, Smith, and Knutson (1969) investigated the locational variations of penpoints relative to the axis of the shank of fountain pens. With two different penpoint loci — centered and off-centered straight tips (Figure 1) — the subjects'

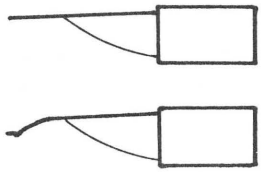

Figure 2. Comparison of straight and curved penpoints.

performance was measured in terms of the time taken in writing English letters and drawing small triangles. The off-centered penpoint design, providing generally a better visual feedback of the marking action, resulted in superior writing task performance compared to the centered tip. Another study (Smith, Kao, and Knutson, 1967; Kao, 1977) compared the designs of straight and curved penpoints relative to their visual feedback properties in writing tasks (Figure 2). Due to the obstruction of visual feedback of the writing traces with curved penpoints, as measured by task time the straight pen tips were found superior in writing efficiency.

A third study on the design of penpoints (Kao, 1973a) compared penpoints tilted at an angle from the straight axis with normal straight pentips (Figure 3). It was hypothesized that because of

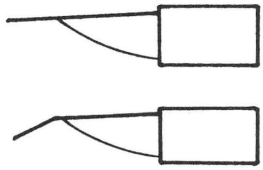

Figure 3. Comparison of straight and tilted penpoints.

their enlarged exposure of visual feedback the tilted penpoints would tend to result in higher writing efficiency than regular straight penpoints. The findings were as predicted; writing time was considerably shorter with the tilted pen tips. A fourth experiment (Kao, 1979a) focussed on the effects of differential levels of pencil tip hardness on handwriting performance. "Black," "hard-black," and "hard" pencils represented three levels of tip hardness. With both task time and task pressure as measures of writing performance, the "hard-black" pencils took significantly less writing time than the "black" pencils; the "hard" pencils did not differ significantly from either the "hard-black" or the "black" ones. No difference was found in the task pressure for the three types of pencils.

Other interesting studies along this line of investigation may include, for example, research on differential hardness of the pen tips in affecting grip pressure, and tip deterioration in relation to writing time and the legibility of pencil writing.

3.3.2 *Pen Shank Designs.* The pen shank affects handwriting in a number of ways: hand grip, pen movement, muscular fatigue, writing task pressure, as well as writing time. A recent study (Kao, 1979b) has investigated the differential weights of ballpoint pens in adult handwriting performance. Using 5-gram, 10-gram, and 15-gram weights separately attached to three identical ballpoint pens, the subjects' performance was measured with respect to the effect of shank weight on their writing pressure and writing time. Results showed a general advantage for the heaviest shank in producing shorter writing time and reduced point-tip pressure. This may indicate that increased shank weight alleviates both the grip pressure exerted on the shank and the point-tip pressure on the writing surface requred with the use of lighter instruments. Of course, individual differences play an important part in the optimal match between the pen and the hand.

3.3.3 *Ergonomic Comparisons of Writing Instruments.* Kao (1976) used a questionnaire-and-practice technique to study user preference for ballpoint pens, pencils, fountain pens, and felt-tip pens. Assessing such variables as writing ease, legibility, and control comfort, the survey revealed the ballpen to be the most favored writing tool, followed by the pencil. Fountain pens were considered by adult users as the least effective in writing practice. Another series of experiments (Kao, 1978) compared the writing efficiency of pencils, ballpoint, fountain, and felt-tip pens by measuring writing time and pen-tip pressure. The results confirmed the overall superiority of the ballpoint in requiring the least time when performing identical writing tasks. The research also confirmed the findings of the previous study on user preferences among writing instruments.

Comparisons are needed to differentiate the various types of instruments for different user groups. Although best for adults, ballpoints may not be best for very young children. Certain instruments may yield greater legibility due to minimal point deterioration. Ergonomic considerations should make efforts to differentiate instruments for different writing purposes and for different groups of users.

3.4 *Ergonomics and Writing Fatigue*

Individuals write differently at different times not only because of the variations in writing instruments but also because of emotional and physiological tension in writing control. Under strain, the pressure imparted to the pen becomes greater, degrading the focal or basographic feedback effect of the pen on the writing surface and causing a tendency toward increased size and reduced legibility. As a result, individuals may like one type of writing instrument when they work under pressure and a different type when they are relaxed. Some individuals write for long hours during the day most of their lives, but most people use a pen or pencil for only a limited time. Careful observations have suggested that writing fatigue as well as writing interest and motivation are closely related to the design of different parts of the writing instrument and do not depend entirely on the person.

Unduly small writing shafts or poor writing points tend to induce increased pressure in holding the instruments, increased point pressure, poor legibility, discomfort, dissatisfaction, fatigue — and writer's cramp, the painful muscular contraction of the arm

and the hand. Many people develop callouses on the working side of the second finger or the tip of the index finger, making writing painful and interfering with the control of the writing instrument. Although a study has shown that moderate or even exhaustive short-time manual exercise helps increase writing pace at no sacrifice of writing accuracy (Kao, 1973b), prolonged muscular contraction in handwriting may create an extreme case of physical accumulation of exhausted muscles.

The ergonomic answer to writing fatigue, writer's cramp, and calloused fingers is the better design of writing instruments. Writing points that are friction-free — soft-lead pencils, fiber-tip pens, and well-designed metal points — are the starting points of investigation. Smooth paper is another consideration. The size and design of pen shafts should fit the writing hand in order to minimize the holding pressure. A pencil or pen wrapped with thin strips of plastic foam covered with masking tape to provide a bulging grip position, prevents callouses and can reduce or even eliminate writing fatigue or discomfort.

## 4 *Conclusions*

In this age of mechanization the view is often expressed that handwriting in time will become obsolete as a human skill. I believe this to be an unlikely possibility. Handwriting appears to be a necessary activity in the organization of human thinking. Special types of writing such as typewriting might be a substitute for penmanship, but mechanistic constraints are imposed on the expressive movements of handwriting by keyboards.

This paper has suggested a framework for the handwriting system within which the component elements are specified and analysed to identify the needed areas of concerted research. It has also provided an overview of the kinds of practical design applications currently in progress. It is expected that future research on handwriting will encompass more exact studies of the ergonomic principles in penmanship, legibility, learning and training of handwriting, development of handwriting skills, design of writing instruments, the proper integrations of hand, instrument, and paper, and the role of writing in the development of individuals. Ergonomic research of this nature can turn the study of handwriting from the limited investigations using legibility tests or personality correlates to more fundamental research on writing and

human behavior. However, an expanded science of writing skills and instrument design needs the combined and enhanced efforts of ergonomists, educators, and industry for research and development of efficient new instruments as well as motivation toward expressive graphic activities in human handwriting and penmanship.

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# *Kurzfassungen der Beiträge*

Übersetzung: Dirk Wendt

Computer-unterstützte Analyse von Schreibbewegungen *von Hans-Leo H.M. Teulings und Arnold J.W.M. Thomassen*

In diesem Aufsatz wird versucht zu zeigen, das Schreibbewegungen, wenn sie einmal auf einem geeigneten x-y-Digitalisierer aufgezeichnet sind, mit Hilfe eines Computers verarbeitet und für vielerlie Zwecke analysiert werden können. Diese Methode wird im Labor des Verfassers benutzt, um den menschlichen Schreibapparat zu untersuchen und, in geringerem Umfang, das lesen von Handschriften. Aus der Schreibbewegung werden gewisse Zeit- und Häufigkeitsfunktionen abgeleitet, und die Art der Information, die aus diesen Funk tionen erhalten werden können, wird kurz angedeutet. Einige mögliche praktische Anwendungen werden diskutiert; der Aufsatz schliest mit einem Vorschlag zu einer neuen Art Schreibunterricht.

Ein Computer zur Unterschriftsprüfung *von R.S. Watson und P.J. Pobgee*

Ein wachsendes Bedürfnis zur automatischen Überprüfung der Identität von Personen — als Sicherheitsmasnahme gegen Verbrechen — hat zur Entwicklung eines computers geführt, der Unterschriften sowohl auf Grund der Gerschwindigkeit und Abfolge der Schreibbewegungen als auch auf Grund der fertigen Schriftprobe überprüft.

Handschriften-Klassifikationen in der Forensik *von M. Ansell*

Es werden neuere Methoden zur Klassifikation von Merkmalen der Handschrift bei der forensischen Untersuchung von Dokumenten — sowohl für lateinische wie auch für nicht-lateinische Schriften — einschlieslich eines computerunterstützten Systems zur Klassifikation. Es wird über die Entwicklungen der statistischen Analyse der Methoden berichtet, die Leute benutzen, um Zahlen und die Anordnung ihrer Schrift zu konstruieren. Die mögliche Nutzanwendung dieser Systeme zur Quantifizierung der gagenwärtigen Wahrscheinlichkeitsskala des Gutachters bei der Zuordnung fraglicher Schriften zu bestimmten Schreibern wird untersucht, und einige Vorschläge hinsichtlich des möglichen Nutzens dieser Statistiken gemacht.

Ein Kompetenz-Modell zur Handschrift *von John Hollerbach*

Es wird vorgeschlagen, das Schreiben mit der Hand grundsätzlich als oszillatorischen Vorgang zu betrachten, der von zwei zueinander rechtwinkligen Gelenken ausgeht. Die Buchstabenformen erwachsen aus einem oszillierenden Grundrhythmus durch einen einschräkenden Modulationsprozes. Die Entscheidung für eine zugrundeliegende Oszillation und Modulation beschränkt die Vielfalt der Buchstabenformen und läst einen gemeinsamen Schreibstil entstehen. Das Modell wurde durch synthetische Produktion menschlicher Handschrift mit Hilfe eines computergesteuerten mechanischen Arms überprüft. Bei dieser Simulation wirkte das vertikale Gelenk als Antriebsgelenk, das horizontale Gelenk als formendes Gelenk. Es werden verschiedene Intensitätsbeschränkungen für Oszillation und Modulation erwogen.

Schreibfehler *von Andrew W. Ellis*

Der Verfasser analysiert eine Reihe von eigenen Schreibfehlern. Es werden vier Ebenen der Verarbeitung vorgestellt — die lexikalische, graphemische, allographische und graphische — wobei diesen verschiedenen Ebenen unterschiedliche Fehlertypen zugeordnet werden.

Variabilität bei handgeschriebenen Buchstaben *von Alan M. Wing*

Es werden zwei Aspekte der Unterschiedlichkeit von Handschriften betrachtet: Im ersten Teil steht eine Diskussion der Auswirkungen der Verschiedenheit der Buchstabenformen auf ihre Lesbarkeit. Es wird ein Experiment zum Vergleich der relativen Vorteile von Kurrentschrift und Blockschrift zusammengefast.

Im zweiten Teil werden Experimente zusammengefast, die sich mit dem Zeitaufwand zur Vorbereitung von Schreibbewegungen und mit der Variabilität der zeitlichen Folge der Bewegungen bei der Ausführung der Handschrift befassen.

Die Entwicklung einer Richtungs-Bevorzugung in der Schreibbewegung *von Arnold J.W.M. Thomassen und Hans-Leo H.M. Teulings*

Der Aufsatz beschäftigt sich mit dem anfang und der Altersentwicklung der Bevorzugung von Kurven und Konturen mit oder gegen den Uhrzeigersinn beim Schreiben und Zeichnen. Sechsundzwanzig Versuchspersonen in vier Altersgruppen führten vier Schreib- und Zeichenaufgaben aus. Zwei davon bestanden darin, Einzelzeichen zu schreiben und Muster genau abzuzeichnen; die anderen beiden waren freis Kritzeln und wiederholtes Kreisezeichnen mit hoher Geschwindigkeit. Die sich entwickelnden Richtungsbevorzugungen, die zwischen dem Alter von vier Jahren und dem Erwachsenenalter beobachtet wurden, legen die Vermutung nahe, das zwei fast unabhängige motorische System am Schreiben beteiligt sind: ein primitiveres für schnelle, nicht figürliche Aufgaben, die sich aus dem Beugen und Strecken entwickeln, das andere tritt später, aber kommt schneller unter ein höheres Ausmas an kognitiver Steuerung, dient der Genauigkeit und symbolischen Funktionen, und bevorzugt Kurven gegen den Uhrzeiger, un abhängig von der Schreibhand.

Einige Parameter der Instruktion bei der Abschreibe-Fertigkeit von Kindern *von Nils Søvik*

Das Abschreiben ist eine gebräuchliche Technik zum Einüben sensumotorischer Fertigkeiten wie das Schreiben. Es wird ein Experiment geschildert, in dem die abzuschreibenden Reize dynamisch oder statisch aus geringer oder gröserer Entfernung sieben und zehn Jahre alten Kindern dargeboten wurden. Es werden Folgerungen der Ergebnisse für den Schreibunterricht diskutiert.

Handschrift-Ergonomie *von Henry S.R. Kao*

Zweck dieses Aufsatzes ist es, ein begriffliches Rahmensystem für Handschrift-Systeme aufzustellen, das aus drei Elementen besteht: die Hand, das Schreibinstrument, und das Papier. Innerhalb dieses Systems werden Mechanismen der Beherrschung der Hand, der Gestaltung von Schreibinstrumenten und ihre Integration im dynamischen Schreiben auf dem Papier in Bezug auf wirksames, lesbares, anregendes (wie auch ermüdungsarmes) Schreiben diskutiert. Auf diesem Rahmensystem aufbauend wird ein Überblick über wichtige Arbeiten und ein Vorschlag für notwendige Forschungsgebiete dargelegt; die Gestaltung des Schreibinstruments, Verminderung der Ermüdung beim Schreiben und Vergleiche verschiedener Instrumente werden analysiert.

# *Résumés des Articles*

Traduction: Fernand Baudin

Les mouvements de l'écriture étudiés par ordinateur *par Hans-Leo H.M. Teulings et Arnold J.W.M. Thomassen*

Si l'on enregistre les mouvements de l'écriture sur un ordinateur approprié, ces données peuvent être traitées et étudiées en vue de plusieurs utilisations. L'auteur s'en sert dans son laboratoire pour étudier la physiologie de l'écriture et, accessoirement, la lecture de l'écriture. Il montre comment on peut isoler les fonctions temps et fréquence ainsi que ce que l'on peut déduire des informations ainsi obtenues. Il examine enfin d'autres applications possibles: notamment en ce qui concerne l'enseignement de l'écriture.

Un ordinateur pour contrôler les signatures par *R.S. Watson et P.J. Pobgee*

Pour prévenir la criminalité, il devient de plus en plus urgent de pouvoir vérifier automatiquement les signatures. Aussi a-t-on construit un ordinateur qui examine la vitesse et le dectus du tracé aussi bien que l'aspect général de la signature.

La classification des écritures manuelles à l'usage des tribunaux *par M. Ansell*

L'article décrit les méthodes actuellement en usage pour la classification des écritures (latines et autres) à l'usage des tribunaux, y compris la méthode par ordinateur. Il décrit la mise en statistiques des formes que les gens donnet aux chiffres et la manière dont ils font la mise en page de leurs écrits. Il est question également des applications pratiques éventuelles de ces méthodes pour l'attribution de tel ou tel document à tel ou tel scripteur; et de l'utilisation possible de ces statistiques.

Pour mesurer l'efficacité d'une écriture *par John Hollerbach*

Ecrire consiste essentiellement en un mouvement oscillatoire né de la jointure de deux orthogonales. Les lettres naissent d'une série d'oscillations par voie de modulation délibérée. Le choix des oscillations et des modulations est ce qui impose des limites à la diversité des formes des lettres et donne lieu à un style d'écriture déterminé. Une simulation d'écriture cursive a été réalisée à l'aide d'un bras mécanique dirigé par ordinateur. La jointure verticale gouverne le mouvement; la jointure horizontale gouverne la forme. L'auteur propose plusieurs types d'inflexions imposées aux mouvements oscillatoires et modulatoires.

Les variantes dans l'écriture manuscrite *par Alan M. Wing*

Les variantes dans l'écriture manuscrite sont examinées sous deux aspects. D'abord, dans quelle mesure la lisibilité en est-elle affectée ? dans l'écriture cursive, d'une part ? et, d'autre part dans l'écriture dite en capitales d'imprimerie ? Deuxièmement, combien de temps prennent, d'une part, les mouvements préparatoires ? et, d'autre pat, l'écriture proprement dite ?

Comment se forment les habitudes directionnelles dans l'écriture *par Arnold J.W.M.Thomassen et Hans-Leo H.M. Teulings*

L'article décrit l'origine et l'évolution au cours des années des habitudes que nous prenons, en écrivant et en dessinant, de former les boucles et les lettres dans le sens de l'aiguille d'une montre ou autrement. Vingt-six sujets répartis en quatre groupes d'âge ont eu à faire quatre exercices dont deux consistaient à écrire des symboles isolés et a faire des ronds très vite. Les différences observables dans la direction des mouvements entre l'âge de quatre ans et l'âge adulte suggèrent que l'écriture mobilise deux systèmes-moteurs quasi indépendants. Le premier, originel, commande les mouvements rapides et non figuratifs dont l'évolution passe de la flexion initiale à l'extension initiale; l'autre, plus tardif, mais dont l'évolution est plus rapide en raison d'un degré supérieur de contrôle conscient, et qui commande les fonctions de précision et de symbolisation tout en favorisant des mouvements qui vont dans le sens de l'aiguille d'une montre quel que soit le scripteur.

Quelques paramètres concernant l'exercice de la copie chez les enfants *par Nils Søvik*

Copier est une technique très répandue pour l'entraînement de certains mouvements perceptuo-moteurs tels que l'écriture. L'article est consacré à une expérience où des stimuli fixes et mobiles, éloignés ou rapprochés sont présentés à des enfants de 7 à 10 ans. Les résultats sont examinés en vue des conclusions qu'on peut en tirer dans l'enseignement.

L'ergonomie de l'écriture *par Henry S.R. Kao*

L'auteur propose d'aborder l'écriture selon un schéma conceptuel composé de trois éléments : la main, l'outil, le papier. Selon lui, la main gouverne le mécanisme, l'outil gouverne la forme; tandis que le tout se traduit en écriture sur le papier. Celle-ci peut être examinée sous l'angle de l'efficacité, de la lisibilité, de la motivation (et de la fatigue). Partant de ce schéma, il évoque les études pertinentes, et suggère quelques recherches utiles. Il compare différents outils et examine les mayens de réduire la fatigue.

# *Resumenes de los Artículos*

Traducción: Ana Fisch

Clasificación de la letra en la ciencia forense *por M. Ansell*

Se describen los métodos recientes de clasificación de las características de la letra — tanto en la escritura romana como no romana — para el uso en el examen forense de documentos. Se hace revista a los desarrollos del análisis estadístico de los métodos que la gente utiliza para construir números y la disposición de sus escritos. Se examina la utilidad potencial de estos sistemas para cuantificar la escala de probabilidades del actual documento de examinadores para atribuir a autores determinados escritos en cuestión. También se hacen algunas sugerencias sobre la utilidad potencial de tales estadísticas.

Un modelo de competencia para de letra *por John Hollerbach*

Se propone que la producción de la letra es fundamentalmente un proceso oscilatoria que se origina de dos junturas de octogonales. Las formas de las letras emergen de un tren de oscilación por un proceso de modulación constreñida. La elección de oscilación básica y de modulaciones limita la diversidad de las formas de letras y hace nacer un estilo común de escritura. Se ensayó el modelo por la produccion sintética de escritura

Análisis de los movimientos de la letra con la ayuda de la computadora *por Hans-Leo H.M. Tuelings y Arnold J.W.M. Thomassen*

Este artículo trata de demostrar que los movimientos de la escritura una vez grabados en una adecuada digitadora xy, pueden procesarse y analizar por intermedio de una computadora para muchos propósitos diferentes. Se usa este método en el laboratorio de los autores para estudiar el aparato de la escritura humana y, en menor grado, le lectura de la letra. Ciertas funciones de tiempo y frecuencia se derivan del movimiento de la escritura y se indica brevemente los tipos de información que se pueden obtener de estas funciones. Se discuten algunas aplicaciones prácticas factibles; el artículo concluye con una sugerencia sobre un neuvo tip de instrucción de la escritura.

Una computadora para verificar firmas *por R.S. Watson y P.J. Pobgee*

Una creciente necesidad de verificar la identidad de gente automáticamente — como un resguardo contra crimenes-ha conducido al desarrollo de una computadora que verifica firmas por la rapidez y la sucesión de los movimientos de la pluma asi también como por la muestra completada.

cursiva casi como-humana con un brazo maquinal bajo control computador. En esta simulación la juntura vertical actúa como la juntura impulsada y la horizontal como la formadora. Se proponen varios constreñimientos de fuerza en las oscilaciones y modulaciones.

Faltas de la pluma *por Andrew W. Ellis*

Se analiza una colección de faltas de la pluma del autor mismo. Cuatro niveles de procesamiento — léxico, grafémico, alográfico y gráfico — son postulados con diferentes tipos de errores atribuídos a los diferentes niveles en la producción de la letra.

Variabilidad en los caracteres de la letra *por Alan M. Wing*

Se consideran dos aspectos de la variabilidad de la letra. En la primera parte se discuten los efectos de la variabilidad de las formas de las letras sobre su legibilidad. Se sintetiza un experimento para comparar las ventajas relativas de la letra cursiva y la escritura en letra mayúscula. La segunda parte resume los experimentos referentes al tiempo tomado para preparar los movimientos de la letra y a la variabilidad de la regulación de los movimientos en la ejecución de la letra.

El desarrollo de la preferencia direccional en los movimientos de la escritura *por Arnold J.W.M. Thomassen y Hans-Leo H.M. Tuelings*

El artículo examina el origen y el desarrollo con el tiempo de la preferencia de hacer curvas y contornos en la escritura y el dibujo ya sea con movimiento circular a la derecha o a la izquierda. Veintiséis sujetos de cuatro grupos de edades ejecutaron cuatro tareas de escritura y dibujo. Dos de ellos escribían símbolos únicos y copiaban diseños exactamente; los otros dos garabateaban y dibujaban librement círculos repetidos a gran velocidad. Los preferencias direccionales que se observaron desarrollarse entre los cuatro años y la edad adulta sugieren que dos semi-independientes sistemas motores intervienen en la escritura: uno, más primitivo para tareas rapidas no-figurativas que se despliegan de primero-flexión a primero-extensión; el otro que se da mas tarde pero más rapidamente bajo un mayor grado de control cognitivo para funciones simbólicas y de precisión favoreciendo las curvas de movimiento circular a la izquierda independientes de la mano que escribe.

Algunos parámetros de instrucción relacionados con la función del copiar en los niños *por Nils Søvik*

El copiar es una técnica común usada en el entrenamineto de habilidades perceptivo-motoras tales como la letra. Se describe un experimento en el cual los estímulos a copiarse eran presentados dinámica o estáticamente próximos a, o distantes de niños entre 7 y 10 años. Se discuten las implicaciones de los resultados de la enseñanza de la letra.

Ergonomía de la escritura *por Henry S.R. Kao*

El propósito de este artículo es sugerir un marco conceptual para el sistema de la escritura que consiste en tres elementos: la mano, el instrumento de la escritura y el papel. Dentro de este sistema se discuten el control maquinal de la mano, el diseño del instrumento de la escritura y su integración en la escritura dinámica sobre el papel, relativos a la función eficiente, legible y motivadora (asi también como reductora de fatiga) de la letra. Basado en este marco de referencia se presentan una vista general de los estudios relevantes para los campos necesarios de investigación; también se analizan el diseño del instrumento de la escritura, la reducción de la fatiga en la escritura y comparaciones de los distintos instrumentos.

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The designer of this special issue of *Visible Language* is Geoff Green. He is the designer for the Cambridge University Press, Printing Division, Cambridge, England. One reason for his choosing the ampersand to decorate this issue is because the ampersand has remained the one device used by scribes to show their calligraphic inventiveness within their more formal writing. The ampersand used on each article opening is Eric Gill's Perpetua, and the ones shown on the front cover are by Cooper, Dwiggins, Fairbanks, Johnston, Mercator, Morison, Palatino, Shelley, and Wyss.