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-

Visible Language, XIII 3 (1979), pp. 283-298.
Author's address: MRC Applied Psychology Unit, Cambridge CB2 2EF, England.

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.

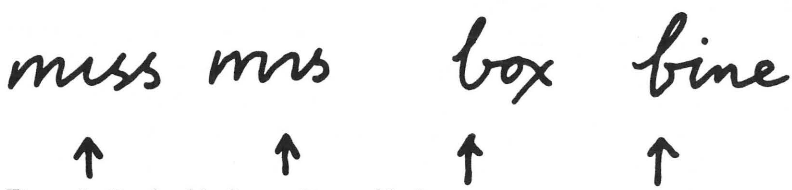

Figure 2. Confusable forms of *i*, *r* and *b*, *f*.

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

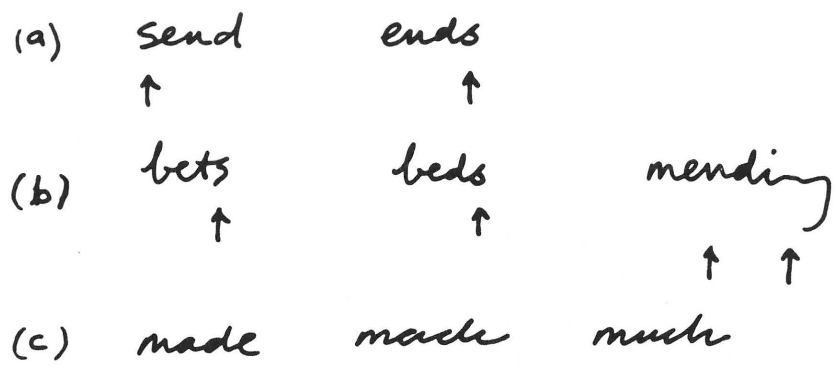

Figure 4. Multiple forms of letters as a function of (a) word position, (b) letter context, (c) random variation.

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.

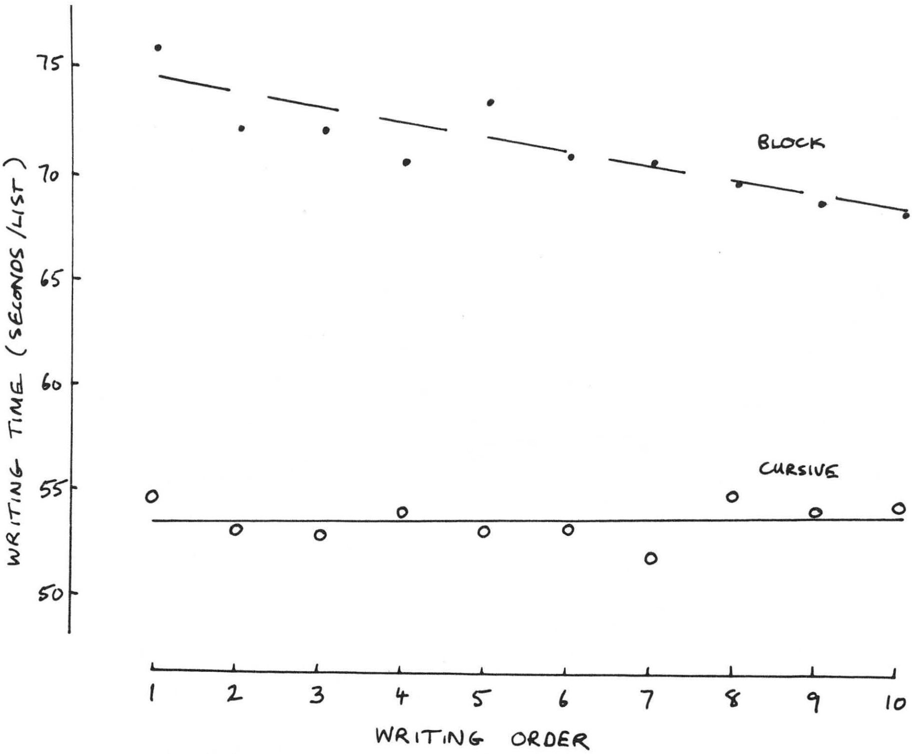

Figure 5. The speed of writing in block capitals or cursively as a function of amount written.

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.

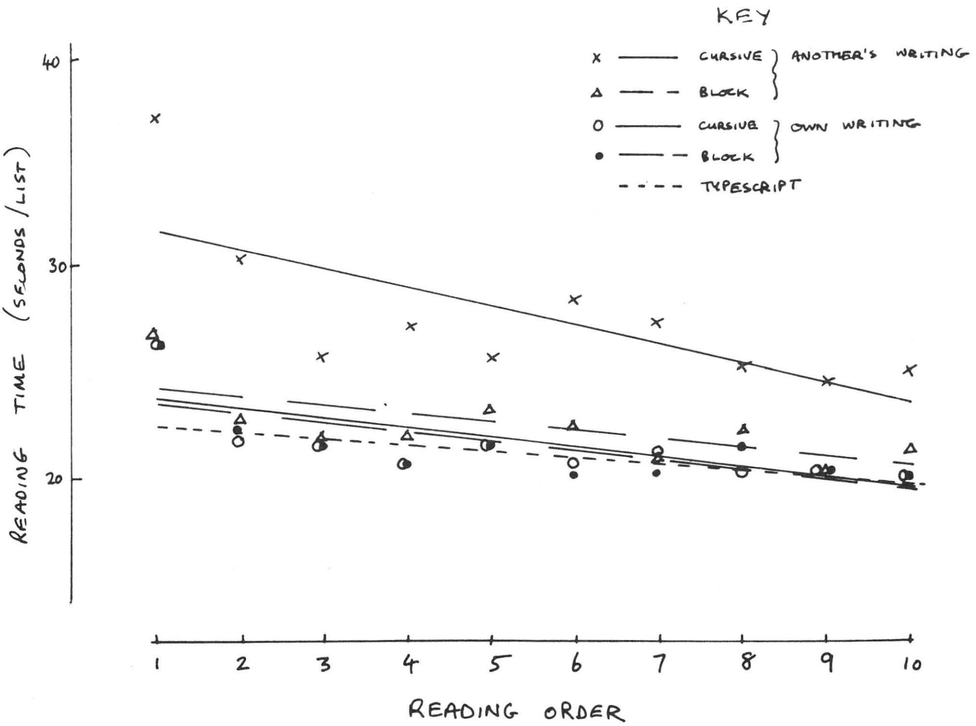

Figure 6. Reading speeds for typescript or written word lists where the writing is in block capitals or cursive and was written by the reader or another person.

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-

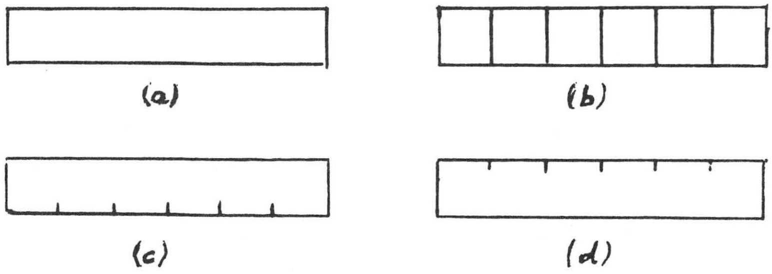

Figure 7. Response formats to encourage letter separation.

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

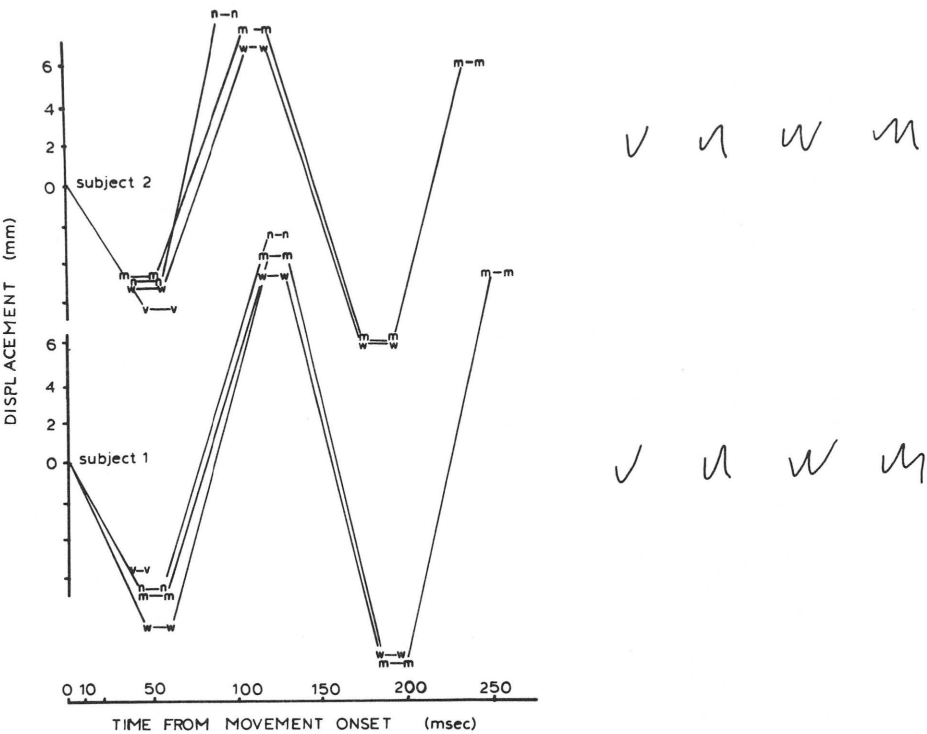

Figure 8. Displacements and times of direction changes for the letters *v*, *n*, *w*, *m* written singly, 50 observations for each letter; typical samples for each subject are shown on the right.

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

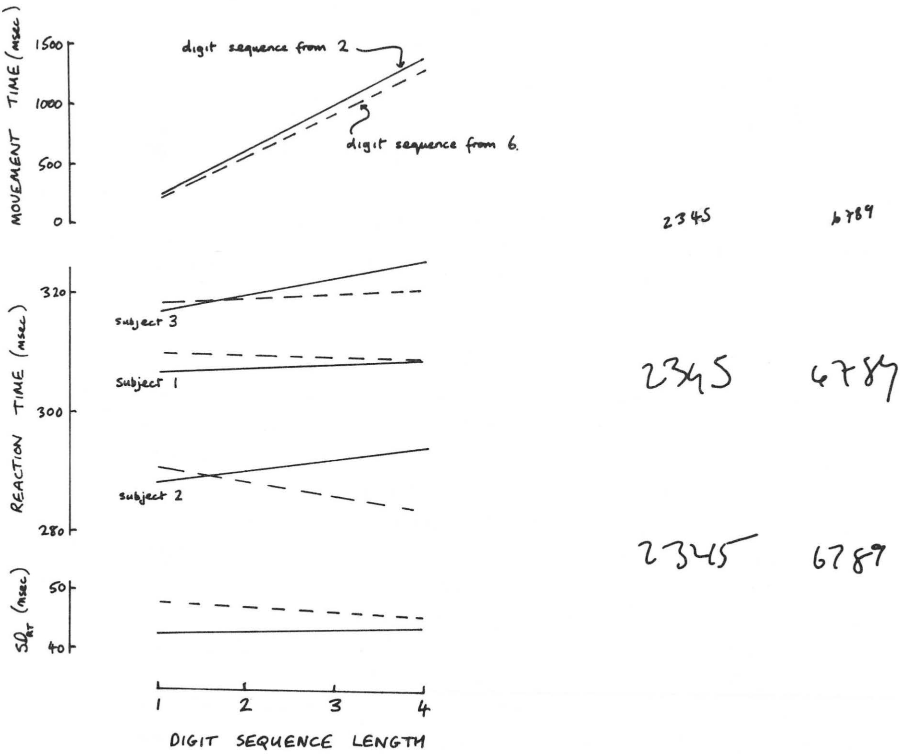

Figure 10. Segmentation of *w*, *m* into strokes based on correlation data of Wing (1978).

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.

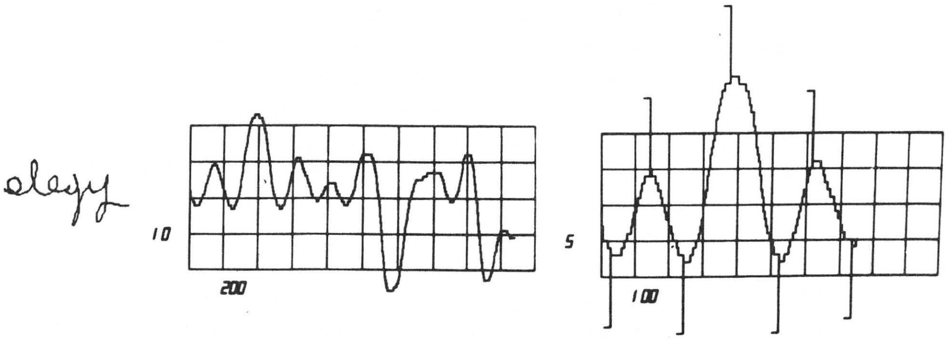

Figure 11. Measurement of the duration and amplitude of the first three letters of the word *elegy*. Photograph of a computer display generated by the programme that was used to display the vertical displacement (3.6 units/mm) as a function of time (msec) and to pick out coordinates of direction changes.

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 considered 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.

References

Barnard, P., & Wright, P. The effects of spaced character formats on the production and legibility of handwritten names. *Ergonomics*, 1976, *19*, 81-92.

Barnard, P., Wright, P., & Wilcox, P. The effects of spatial constraints on the legibility of handwritten alphanumeric codes. *Ergonomics*, 1978, *21*, 73-78.

Christie, M.J., & McBrearty, E.M.T. Psychophysiological investigations of post lunch state in male and female subjects. *Ergonomics*, 1979, *22*, 307-323.

Corcoran, D.W.J., & Rouse, R.O. An aspect of perceptual organization involved in reading typed and handwritten words. *Quarterly Journal of Experimental Psychology*, 1970, *22*, 526-530.

Denier van der Gon, J.J., & Thuring, J. Ph. The guiding of human handwriting movements. *Kybernetik*, 1965, *2*, 145-148.

Glenville, M., Broughton, R., Wing, A.M., & Wilkinson, R.T. Effects of sleep deprivation on short duration performance measures compared to the Wilkinson auditory vigilance task. *Sleep,* 1978, *1*, 169-176.

Pew, R. Human perceptual-motor performance. In B. Kantowitz (ed.) *Human Information Processing: Tutorials in Performance and Cognition.* Potomac, Maryland: Erlbaum, 1974.

Schouten, J.F., Kalsbeek, J.W.H., & Leopold, F.F. On the evaluation of perceptual and mental load. *Ergonomics,* 1962, 5, 251-260.

Sternberg, S., Monsell, S., Knoll, R.L., & Wright, C.E. The latency and duration of rapid movement sequences: Comparisons of speech and typing. In G.E. Stelmach (ed.), *Information Processing in Motor Control and Learning.* New York: Academic Press, 1978.

Wing, A.M. Response timing in handwriting. In G.E. Stelmach (ed.) *Information Processing in Motor Control and Learning.* New York: Academic Press, 1978.

Wing, A.M. (a) The slowing of handwritten responses made in spaced character formats. *Ergonomics,* 1979, *22*, 465-468.

Wing, A.M. (b) The height of handwriting. *Acta Psychologica,* 1979, in press.

Wing, A.M., & Baddeley, A.D. A simple measure of handwriting as an index of stress. *Bulletin of the Psychonomic Society,* 1978, *11*, 245-246.

Wing, A.M., & Baddeley, A.D. Spelling errors in handwriting. In Frith, U. (ed.) *Cognitive Processes in Spelling.* London: Academic Press, 1979.