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Do We See What Makes Our Script Characteristic – Or Do We Only Feel It? Modes of Sensory Control in Handwriting

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Summary. How does a person produce handwritten letters which are both legible and also show an individuality of script? Three production control models are proposed: 1) Visual control, 2) Kinesthetic control, and 3) Parallel Kinesthetic and Visual control. In Experiment 1 24 subjects wrote text samples by hand under normal lighting, reduced lighting, or in complete darkness. The subjects addressed the samples to themselves, to close friends, or to other students. The handwriting did not degenerate under the reduction of visibility if the subjects addressed the samples to themselves, but it did undergo marked changes if directed at someone unknown. This result rules out the visual control model. In Experiment 2 the same subjects were asked to answer questions about the characteristics of their own handwritten letters while holding an image of the letter in mind. There were four types of imagery instructions: subjects were told to form either 1) a static visual image, 2) a dynamic image, 3) a kinesthetic image, 4) a combined kinesthetic and dynamic visual image. Subjects were able to answer questions about their handwritten letters more correctly with the fourth type of imagery instructions, suggesting Parallel Kinesthetic and Visual control of handwriting, the third of the proposed control models. A closer examination of the results of Experiment 2 reveals that the control processes are interactive; the idiosyncratic letter forms which make up the individuality in handwriting are controlled exclusively by kinesthetic information.

One of the many puzzling aspects of cursive handwriting is that despite the high variability between people's scripts it is possible to decipher an individual's handwritten messages relatively easily. Equally puzzling is that despite the high variability *within* a person's handwriting a writer can be identified through his or her script with high reliability. Any theory that attempts to elucidate the processes underlying the production and recognition of script has to identify invariances and transformations which can account for the variability as well as for the communicability of script. Visual feature analysis, which has been successful in the identification of printed letters (see,

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e.g., Winston 1975; Lindsay and Norman 1977), has not been similarly successful in the identification of handwritten letters (Eden 1961, 1962; Eden and Halle 1961). It seems that features such as symmetry, or whether the letter has a straight or a curved line etc., do not catch the crucial characteristics of script and therefore fail as a model for the identification of handwritten letters. Even if the feature analysis takes into account the contextual information, as in the model by McClelland and Rumelhart (1981), the outlined problems remain approximately the same. An alternative approach concerned exclusively with the production and performance aspect in handwriting starts from the 'near-miss periodicity' in handwriting (Shaffer 1982, p. 116) and describes the dynamics in handwriting as a modulated periodic process in two dimensions (Hollerbach 1979, 1981; Wing 1978, 1980). These rhythmic characteristics reflect well the physical constraints (e.g., the anatomy of an individual hand-arm combination) but they do not account for idiosyncratic context dependent letter variants, which usually are referred to in the identification of an individual script ('That is exactly X's "p"!').

Freyd's (Note 1) theory and experiments provide an alternative to the feature analysis theories of letter perception in handwriting by pointing out that it is not the static forms in themselves, but the dynamic information that can be inferred from them, that is crucial for the identification of the intended form. In her experiment subjects saw artificial characters drawn in real time and were later asked to identify distorted versions of the same characters presented statically. Subjects were faster to identify static characters distorted in a manner consistent with the drawing method they had witnessed than static characters equally distorted but inconsistent with the drawing method. Against the background of this finding the present research poses the question: What is it about the script that is represented; what allows the recognition of dynamic patterns; and what underlies the production of script? It seems plausible to assume that parallel to, but interconnected with, a visual representation of printed letters as a schematic combination of static features, there is a representation of handwritten letters that consists of a dynamic version of the static schemata of printed letters. These static schemata are assumed to be characterized by primitives (e.g., higher-order features) and transformations (for a more detailed discussion of this notion of schema theory see Zimmer 1981 and Note 3).

If people have both static and dynamic knowledge about their own and others' handwritten letters, there has to be a connection between the static information contained in the schema system of printed letters and the use of knowledge about the dynamics underlying the production of handwritten letters. One possible model for the functioning of this connection is the 'grammar of action' as developed by Goodnow (1972, 1977). Simmer (1981) has demonstrated that this model accounts fairly well for the way children start drawing letters, thereby imposing certain constraints on the development of script. However the emergence of highly individualistic, but nevertheless legible, variants of letters cannot be explained by a general grammar of action.

Freyd (Note 1) suggests that the perception and production of letters are governed by some of the same sensory control processes for dynamic forms but she does not specify what these sensory control processes are, except for the constraint that they have to be sensitive to changes in space and time; i.e., they are visual and/or kinesthetic. From these considerations, three different control models can be distinguished.

1. *Visual control.* Although the *control* is visual, this model does allow for distortions in handwritten letters because of the physical characteristics of the motor system, such as the inertia, the bending direction of joints, the contraction patterns of antagonistic muscles (see Wing 1978; Hollerbach 1982).
2. *Kinesthetic control.* Under this model the influence of the visual feedback affects only external constraints such as the format alignment or lines on a sheet of paper. That people are able to write in the dark or while listening to and looking at a lecturer seems to favor this notion of control in handwriting. The perceptual process would then consist of an immediate translation of visible patterns into kinesthetically coded motor memories.
3. *Parallel kinesthetic and visual control.* This model is in line with the results on hand-eye coordination (for an overview see Lee 1978). Freyd's (Note 1) suggestion that handwriting recognition might be a perception/production system like speech perception is also in line with this twofold control process. Furthermore Watt's (1975) attempts to create a system of categorization for the letters of the alphabet have led him to propose that the proper units of handwritten letters are 'kinemes' (static traces of movement) instead of only the traditional distinctive features.

There are at least two possible ways of discriminating between these three proposed models. One possibility is to investigate the influence of reduced visual control on handwriting performance, which should determine how much visual control is used in this performance. The other more indirect way is to probe the mental representation that controls the execution of handwritten letters. That is, the investigation of mental images of handwritten letters might shed light on the control processes of production. For instance, if a kinesthetic image proves to give the subject more access to information about the visible characteristics of his or her own letters than a *visual* image does, it suggests that the kinesthetic control model is more appropriate than its visual counterpart.

Experiment 1

One easy method of reducing the effectiveness of visual control in handwritng is to reduce the lighting. In the first experimental factor (A) there were therefore three levels of illumination: A_1, lighting conditions as required by the norms for secretarial jobs; A_2, reduced lighting which makes control of the alignment possible, but does not allow the writer to detect single letters; and A_3, total darkness. Since it is plausible to assume that contextual requirements influence the mode of control in handwriting too, in the second factor (B) 'shared knowledge with the addressee' was varied.

The contextual variable 'shared knowledge with the addressee' was chosen, because it seems plausible to assume that characteristics of individual script might be affected differently by the control variables, depending on the knowledge the addressee has about the writer's production. The main reason for this assumption is that visual characteristics can be extracted immediately by anyone provided that she or he uses the same kind of script, but that the kinesthetically controlled characteristics are known only by the writer *himself* or *herself* and to a lesser degree by close friends. Therefore the amount of visual control in handwriting may depend on the constraints of 'shareability' (Freyd, Note 2) too, which Zimmer (Note 3) has demonstrated to underlie subjects' behavior in drawing pictures for purposes of communication.

The variation of the lighting conditions and the amounts of shared knowledge require dependent variables which catch legibility as well as performance characteristics which can be assumed to deteriorate under impoverished conditions. In order to determine legibility two variables were measured: the similarity of the written letter with the standard form of this letter and the time it takes a reader to scan the handwritten text for mistakes. Deterioration of visibility can be assumed to be counteracted by writing the words without lifting the pencil in order not to lose orientation. This in turn necessitates that crossbars and i-dots are inserted afterwards; therefore connectedness inside the words and misplacements of crossbars and i-dots can be assumed to mirror the amount of deterioration of visibility.

Subjects

Twenty-four German undergraduate students in psychology, education, and physical education at the University of Oldenburg volunteered to participate.

Method

The subjects were instructed to write notes containing information about campus activities. This information was given to them immediately before each experimental run. The experimental design was a two-way analysis of variance, the independent variables being 'amount of lighting' and 'amount of shared knowledge with the addressee'; each factor had three levels (see above).

The dependent variables applied were: 1) similarity to the standard form of script (as used in German schools), 2) average per-character scanning time for orthographic errors, 3) connectedness of letters inside of word, and 4) misplacement of i-dots and of crossbars for the letters t and f. Variables 1 and 3 are based on ratings by five primary-school teachers, variable 2 was the time these teachers needed for error scanning and variable 4 is the standardized distance of the dots and crossbars from the correct place. The reliability of the ratings was tested by Kendall's coefficient of concordance (W): for the similarity ratings the value of W is 0.87 and for the connectedness slightly lower (W = 0.76).

Each subject wrote nine notes, one for each combination of conditions. The sequence of the 'shared-knowledge' factor was completely balanced, whereas in the 'visual-control' factor the good-lighting condition was always the first condition to give the subjects visual orientation in the experimental surrounding and the sequence of the other two was balanced.

Results

The mean values of the dependent variables are displayed in Figure 1. The results reveal that the role of visual feedback in the control of handwriting is strongly influenced by the contextual effect of the intended addressee. The interaction effects are significant for all indicators, whereas the main effects for the 'lighting condition' factor is significant only for the dependent variables 'similarity to the standard form' and 'mis-

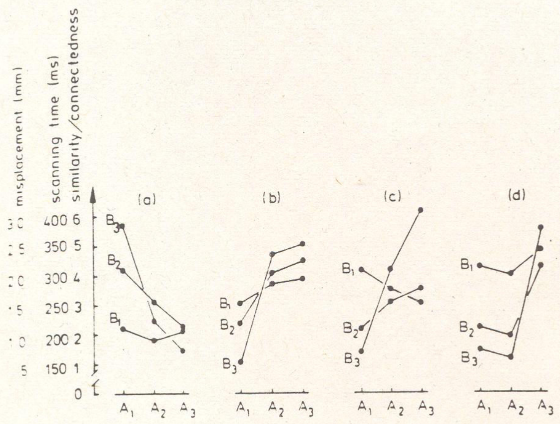

Fig. 1. Mean values for a) similarity with the standard form, b) scanning times per letter, c) connectedness of letters, and d) misplacement of i-dots and crossbars. A_1: writing under good lighting conditions; A_2: writing under poor lighting conditions; A_3: writing in the dark; B_1: writing for oneself; B_2: addressing a close friend; B_3: addressing someone unknown

Table 1. F-values for the ANOVA (2 factors, fixed effects)

Indicator	Visual control	Shared knowledge	Interaction
Similarity to standard form (Table 2)	3.81*	3.21*	2.51*
Scanning time (Table 3)	1.62	3.37*	3.01*
Continuity (Table 4)	1.41	3.57*	4.07*
Misplacement (Table 5)	3.26*	3.42*	3.11*

The stars indicate significant F-values ($P < 0.05$)

placement of i-dots and crossbars'. The F-values for all conditions and dependent variables are given in Table 1; the significant values ($P < 0.05$) are marked with an asterisk.

A closer look at the interaction plots in Figure 1 reveals that the handwriting in notes intended for the writers themselves (B_3) underwent practically no changes that were due to the visual control variable. On the other hand the script in notes intended for unknown addressees was affected most strongly in all cases.

The scanning time data (Fig. 1b) and the misplacement data (Fig. 1d) indicate that the deterioration of visual control affects the handwriting on at least two different levels; the interaction effect on scanning time, which can be interpreted as an index of legibility, takes place between full visual control and reduced visual control; afterwards the slopes are parallel. This level of primary visual control seems to depend on explicit knowledge about standard forms of handwritten letters. For the misplacement variable the deterioration of visual control takes place between the reduced lighting and the blindfolding condition. The reduced visual control condition is apparently sufficient for the spatial control of letter components which are not parts of the continuous flow of writing. These two different points of marked qualitative change can tentatively be interpreted as *breakdown of the visual control of single letter production* and *as breakdown of the visual control of the spacing of words and within words*.

Experiment 1 suggests that the role of *visual* control in handwriting is mostly confined to the modification of each person's individual script for communicative purposes. That is, the less is known about the addressee the more standard the script becomes. Thus the role of visual feedback is especially important for maintaining that standard form. If, on the other hand, the subject is addressing herself or himself, then the handwriting remains about the same independent of the visiblity conditions. This result makes the conclusion plausible that in addressing the handwritten message to oneself, one controls the execution kinesthetically, because later on in perception one will use the visible traces for the reconstruction of the kinesthetic processes. This is in line with Freyd's (Note 1) results that visible traces are interpreted according to the knowledge about their production.

The results from Experiment 1 indicate that *both* visual and kinesthetic control processes are used during handwriting production (although, as we have seen, the relative importance of these control modes depends on the communicative context).

An interesting question emerges: When both control processes are being used, how are they coordinated by the mind? This issue was addressed in Experiment 2; it was assumed that the knowledge that governs the coordination of these two control modes can be accessed if the subjects are asked to imagine their own handwritten letters.

Experiment 2

By varying the role of the control processes used to form a mental image of one's own handwriting it should be possible to estimate the relative importance of the control modes by comparing the imagined letters with the ones produced by real handwriting. This comparison can be achieved by asking subjects to answer specific questions about the imagined letters. In order to be able to produce enough questions it was necessary to select real letters that satisfied the following criteria: 1) the form of the letter must be independent from the conditions under which the letter was written for any given addressee; 2) the letter should differ consistently from the standard form; and 3) the letter should have more than one consistent variant depending on the preceding or following letters. The third criterion was included in order to allow a variety of different questions while probing the imagined letter (otherwise the same questions repeated over and over again might influence the mental image itself).

These criteria were met only by the letters 'b', 'f', and 't' for all subjects. Since 'b' is confused with 'f' under certain conditions (Wing 1979), the final selection of stimuli consisted only of 'f' and 't'. 'f' was chosen over 'b' because in German 'f' is found at nearly any position in commonly used words and is preceded and followed by a greater number of different letters than 'b' is (see Fig. 2 for different context dependent variants for 't'). There were four types of imagery instructions: subjects were

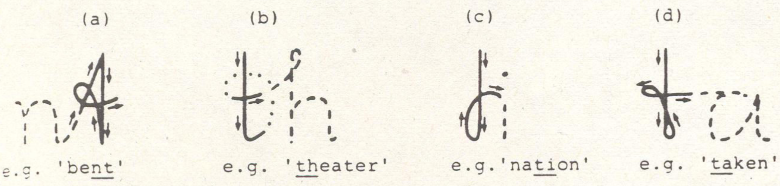

Fig. 2. Forms of the lower-case letter 't' in differentiating contexts (the contextual letters are dashed, the air strokes are pointed, and the arrows indicate the direction of strokes)

asked to form (1) a static visual image, (2) a dynamic visual image, (3) a kinesthetic image, or (4) a dynamic visual and kinesthetic image. Instructions for (1) and (2) were assumed to be consistent with the visual control model; the instruction for (3) with the kinesthetic control model; and the instruction for (4) with the visual *and* kinesthetic control model. Kinesthetic control models are necessarily dynamic in nature, while visual control models could be either static or dynamic. Thus, in order to determine the mode of control it is necessary to make the static vs dynamic distinction (see Freyd, Note 1) and the visual vs kinesthetic distinction.

Subjects

The subjects from Experiment 1 were also used in Experiment 2.

Method

In condition 1 subjects were instructed to build up images of static visual forms, in condition 2 of dynamic visual forms, in condition 3 of kinesthetic dynamic forms, and in condition 4 of forms represented kinesthetically and visually at the same time. The instructions given were: Condition 1 'Imagine yourself looking at a note written by yourself containing the word "Nation." What does the letter "t" in that word look like?' Condition 2 'Imagine yourself watching a TV screen, on which you are shown writing the word "Elephant." What does the letter "t" look like?' Condition 3 'Imagine yourself in the dark. Register the sensations in your hand and arm while writing the word 'enthalten'. What does the letter "t" look like?' Condition 4 'Imagine yourself writing. Observe the movements of the tip of your pen and register the sensations in your hand and arm while writing the word "tanzen." What does the letter "t" look like?'

The experiment consisted of 30 blocks, 15 for 'f' and 15 for 't.' In each block there were four trials in a random order, one for each of the four conditions. The 't' and 'f' blocks alternated. For the letter 't' 12 subjects had three consistent forms, five had four consistent forms, and seven had five consistent forms; for the letter 'f', the corresponding number of subjects are: 10, 7, and 7.

In an attempt to probe the different consistent forms equally often a total of 120 words were used. Typical probes were: 'Is the crossbar connected to the vertical bar some place other than at the crossing points?' (static visual condition); 'Did you lift your pencil in order to cross the "t"?' (other conditions). The probes were made immediately after the subject had pushed a button to indicate that he or she had formed a clear image of the target letter of his or her own script. The times needed to build up a clear image were recorded as well as the answers to the probes.

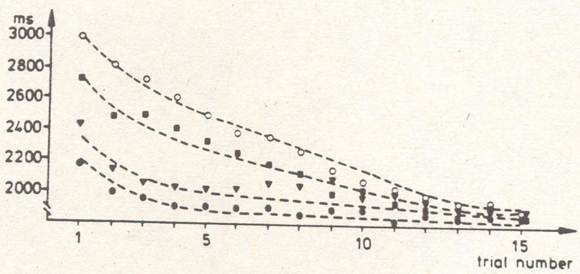

Fig. 3. Imagining times for the different modes as a function of the trial number (● static visual image; ▲ dynamic visual image; ■ kinesthetic image; ○ combined visual and kinesthetic image)

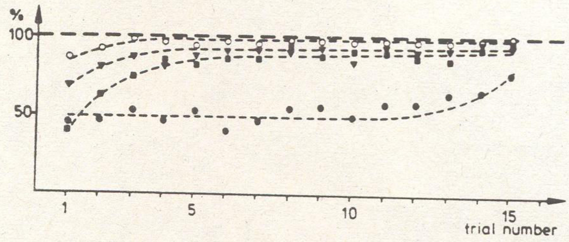

Fig. 4. Percentage of correct answers to the probes for the different modes of imagining (the symbols for the modes are the same as in Fig. 3)

Results

Subjects took a long time to form images at the beginning of the experiment (probably because they were not used to the imagery task), but subjects got faster with practice. The practice curve for 't' and 'f' combined is shown in Fig. 3. The relative frequencies for correct answers to probes about images (that is, answers consistent with the real letters) are shown in Fig. 4. In order to avoid artifacts due to a possible speed-accuracy trade-off only the results of the second half of the experiment were tested for significant differences, because after trial 7 the imaging times were virtually the same for all conditions. There was a statistically significant difference between condition 1 and all other conditions ($t(14) = 3.14; P < 0.001$), a somewhat smaller difference was found between condition 4 and conditions 2 and 3 ($t(14) = 2.07$ and $t(14) = 2.43$ respectively; $P < 0.05$), but there was no significant difference between 2 and 3 ($t(14) = 0.98$). The relative frequencies had been subjected to arc-tan transformations before the statistical analysis in order to remove the effect of different variances. If one takes into account the similarity of the real letters subjects were asked to imagine with the standard form (by dividing them into those above and those below median similarity) then there is a significant difference (F-value for interaction between 'similarity' and 'mode of imaging' $F(1; 1) = 173; P < 0.05$) between the dynamic visual condition (2) and the kinesthetic condition (3). That is, the above median similar letters had a higher frequency of correct answers in dynamic visual imaging whereas kinesthetic imaging led to a higher frequency of correct answers in below-median similar letters.

The moderate improvement in correct responses for the static condition towards the end of the experiment seems to be due to the fact that some subjects disregarded the static-imagery instruction and applied dynamic imagery instead. During the debriefing session after the experiment 10 subjects mentioned that after some time they had no longer been able to image their own script in a static mode.

If these results can be generalized, feature synthesis models of handwriting as implied, e.g., by Gibson et al. (1963), can be excluded as possible candidates for individual script production.

The alternative explanation that the superiority of the dynamic imagery modes is due to a speed/accuracy trade-off can be discarded because of the imaging-time functions in Figure 4. After trial 7 there is virtually no difference any more in the time needed to build up images under the different conditions. Despite this fact the differences in the relative frequencies of correct answers between the dynamic imagery conditions and the static imagery condition are highly significant.

General Discussion

From the results of these experiments some tentative conclusions about the structure of the production system for handwriting can be drawn. On the motor level both kinesthetic and visual control work jointly; both control modes are independently represented, but probably somehow synchronized by a higher-order system, which is apparently not the hypothesized semantic letter system, because the form of handwritten letters is strongly influenced by the preceding and following letters (see Fig. 2). The relative strength of control exerted by the different control modes depends to a high degree on the communicational constraints. For instance, the visual control is dominant if writer and addressee share only the general cultural knowledge about script. On the other side the kinesthetic control prevails if a person writes notes for himself or herself.

The results of both experiments make clear that kinesthetically controlled handwriting is not an exceptional case for adverse situations, but always takes place in handwriting and probably causes the striking individual differences in scripts of writers brought up in the same cultural setting; it is what the mind's hand does not tell the mind's eye.

Note

This paper was written while the author was visiting the Department of Psychology, Stanford University. The development of the theoretical ideas would have been impossible without discussions with Jennifer Freyd on handwriting. The author wishes to thank Gordon Bower not only for the invitation to Stanford but for many helpful suggestions too.

Reference Notes

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