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Perception of dynamic information in static handwritten forms

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Handwriting recognition presents a problem for most theories of letter perception. How do people accurately discriminate letters given the variability in handwritten forms? We propose that perceivers detect and capitalize on information relating to production inherent in the static trace of the handwritten letter. In an "implicit detection" task, subjects' ability to detect stroke direction in a series of handwritten characters was found to be influenced by the particular drawing method used to generate the stimuli. Similar results were obtained in an "explicit detection" task in which the subjects were asked to speculate on the drawing method used to generate the samples. Our findings suggest that perceivers are able to extract information relating to production from the static trace. We propose that they can then use this information in conjunction with their knowledge of a common production process, shared by both producers and perceivers, to aid character recognition.

Handwriting recognition presents a problem for most theories of letter perception. How can people accurately discriminate letters given the variability in handwritten forms? How might one design a machine that could successfully segment the written line into meaningful letter units and separate informative strokes from spurious marks on the page?

Past research has favored "feature-analysis" theories of letter perception (for a review, see Gibson & Levin, 1975). According to such feature-analytic theories, the perceiver recognizes a given letter by its "distinctive features," such as whether a curve is open or closed, whether the letter is symmetric or asymmetric, or whether it has a left-diagonal or intersecting cross-stroke. Although these theories work for machine-produced (especially uppercase block) letters, they do not generalize well to handwritten script in which "features," at least as they have been conceptualized, are often distorted or missing entirely. For example, consider a developmental study by Gibson, Gibson, Pick, and Osser (1962) often quoted as support for feature-analysis theories. In this study, children were asked to discriminate artificial and real uppercase machine-produced block letters and four transformations

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on them: perspective, rotation and reversal, line to curve, and break and close. Visual discrimination improved with age; older children were better able to *reject* distortions critical for differentiating letters. The authors claimed that older children were thus more able to extract distinctive features. However, these conclusions are problematic when one attempts to extend them to the recognition of handwritten forms, for it is precisely such transformations (line to curve, and break and close) that one must *allow* in recognizing handwritten letters. Indeed, to effectively recognize handwritten letters, one must be able to generalize and accept variations on a single letter, not discriminate between slight distortions on the same form.

According to Wing (1979), variability in handwritten characters is evident: A given letter may be written in several forms by a single writer depending on its physical contextual location; connections between letters often distort the characteristic shapes of letters; different letter forms are often indistinguishable because writers use similar forms for different letters; and random variation often results in considerable distortion in a given letter or feature despite the equivalence of the surrounding letter context. Because of this diversity, traditional feature-analysis models alone seem unparsimonious for the recognition of handwritten letters, for to apply such models adequately, one would need to assume countless feature clusters for the definition of a given letter that would vary with the particular writer, the letter's physical context, and even situational factors.

Because feature-analysis theories, at least in their present form, do not generalize well to the perception of handwritten letters but do seem to account for the perception of machine-produced letters, one might speculate that separate processes are responsible for the recognition of the two types of forms. Corcoran and Rouse (1970) present evidence in support of separate processing systems. They measured the probability of recognizing tachistoscopically presented words in blocked and mixed trials. The procedure was repeated for three stimuli comparisons: typed versus handwritten words, two words handwritten by different writers, and typed uppercase versus typed lowercase words. Only the typed versus handwritten comparison produced a decrement in the mixed trials. The authors claim that this reflects the time needed to establish the appropriate strategy for each presentation, thereby supporting separate processing strategies.

If readers do apply different strategies, how might we characterize the recognition process for handwritten letters? Freyd (1983b) proposed an alternative to the feature-analysis theories: Handwriting recognition makes use of information about how the letters are formed. Specifically, perhaps perceivers infer the underlying dynamics of the production process used for a particular handwritten letter by applying their own knowledge of the drawing method to its static trace. For instance, perhaps perceivers capitalize on knowledge of dynamic construction that is shared by both producers and perceivers.

Discussion of related studies may clarify this conception of detecting and representing "dynamic information" in static stimuli. Freyd (1983a) demonstrated that snapshots taken of objects in motion may be encoded in terms of the implicit motion inherent in the picture. Subjects saw static representations, but apparently spontaneously extracted information relating back to the original dynamics of the captured event, which was then included in their representations of the static stimuli. A recent study by Zimmer (1982) further suggests that dynamic information may also be relevant to handwriting recognition. Zimmer asked subjects to visualize characteristics of letters while forming different types of mental images. He found that subjects were more accurate in describing configural aspects of the letters while forming an image of the letter being drawn in real time than while forming an image of the static, already drawn character. This suggests that the most facilitative representation of handwriting is one that involves knowledge of production method.

The theory of handwriting recognition that Freyd (1983b) proposes implies two claims: the *knowledge* and *sensitivity* claim. The former proposes that the perceiver has knowledge of the dynamics of the handwriting process represented in the mind in a form that can be used by recognition processes. The latter proposes that the perceiver is sensitive to variations in the static handwritten trace that indicate the order and direction in which the components of the letter were produced.

Freyd (1983b) presents evidence in support of the knowledge claim: the perceiver's tacit knowledge of the writing system influences recognizability of distorted characters. In Freyd's experiment, subjects watched characters being drawn according to one of two methods on a graphics display screen. Both methods resulted in the same final forms. They then viewed static characters distorted consistently with one of the two drawing methods. The distortions included connecting lines, sloppy lines, or both. Subjects found inconsistently distorted characters harder to recognize than either consistently distorted or nondistorted characters. Furthermore, one type of distortion, "sloppy" lines, actually facilitated character recognition. This suggests that there was useful information in the distortions, and that tacit knowledge of a common production system facilitated recognition of the distorted forms.

Freyd (1983b) demonstrated that perceivers are sensitive to dynamic

information presented in static form when the production process is observed. Can they likewise detect the drawing method based on static examples of the characters alone? This is the question raised by the sensitivity claim. In this study, we investigate the ability of the perceiver to extract the underlying production process used to create a series of unfamiliar letters. Although several sources of information pertaining to production could be assessed, this study concentrates on the perception of stroke direction in static examples. Stroke direction appears to be highly relevant to letter recognition, for as Macleod and Proctor (1979) state in their discussion of a dynamic approach to teaching handwriting skills, incorrect stroke direction leads to a progressive deterioration from the model, thereby impairing recognizability.

EXPERIMENT 1

Are observers sensitive to information specifying production method in static handwritten patterns? Handwritten samples of nine novel characters were first collected from two groups of subjects who learned to write the characters according to two different methods. A subset of handwritten samples from each group was used as training stimuli for two additional groups of subjects. Subjects' detection of dynamic information from the static forms was assessed through two tasks. In the first, the implicit detection task, subjects translated a series of arabic numerals into the characters that they had memorized. If subjects were sensitive to production information in the distortions and included this information in representations of the characters, we predicted they would subsequently reproduce the characters in accordance with the rules used to generate the training stimuli. Furthermore, we predicted that judgments concerning production method could also be accessed explicitly. Therefore, in the second task, the explicit detection task, subjects were asked to reproduce the characters in the same manner in which they thought the original writer had drawn them.

Unfortunately, the implicit measure of the dynamic information extracted by the subject at the time of encoding is indirect. Even though subjects may detect information in the handwritten characters that indicated how the particular examples were produced, they may choose to follow a set of familiar drawing rules when asked to generate the characters themselves. Nevertheless, we felt it was important to include a measure of the subjects' implicit inferences about the underlying dynamic production of the handwritten characters because people often have been shown to have knowledge at some level of processing, yet no conscious access to that knowledge (cf. Polanyi, 1966; Shanon, 1976).

METHOD

Subjects

Participants were 40 volunteer Cornell undergraduates. Of these students, 12 generated the stimuli, and the remaining 28 subjects participated in both an *implicit detection* task and an *explicit detection* task. Eight of these 28 subjects were left-handed. Handedness was distributed equally between the two experimental groups.

Stimulus creation

To create a stimulus set of handwritten characters that contains "natural distortions" (sources of production information assumed to be important for the recognition of handwritten letters), we collected samples of nine unfamiliar characters drawn according to one of two production systems. The two sets of production rules were identical in terms of stroke order and stroke direction in all but the last stroke. For one group, the *up* condition, all last strokes were consistently drawn upwards. In the *down* condition, all final strokes were consistently drawn downwards. Although unfamiliar, these characters contain elements common to the Roman alphabet such as intersections, open and closed segments, diagonals, parallel segments, and nonintersecting joints (Figure 1).

In the initial collection stage, each subject was given a set of nine instruction cards. On these cards, the production rules for each character were diagrammed stroke by stroke, showing the proper sequence and direction (Figure 2). Subjects practiced drawing until they were comfortable with the method (typically one pageful or about 50 examples of each character). The subjects then participated in a speeded copying task in which they were instructed to copy duplicates of the same nine characters according to the production rules they had just learned. Subjects were told to copy the cards as quickly as possible, and that a proportional amount of time would be added to their score for each character they drew improperly. By using the time-pressured task, we hoped to maximize natural distortions consistent with the particular production system. Instructions for the up production system were given to 5 subjects, and 7 were given instructions for the down method.

From the speeded-copy samples, the experimenter chose one subject from each group (up and down) whose handwriting was highly distorted. These distortions included connecting lines, hooks, trailing lines, variations in line thickness, exaggerated or missed intersections, and straight-to-curve segment transformations (see Figure 2). By selecting samples from only one subject from each group we hoped to capitalize on the internal consistency in the types of distortions that one writer creates. Six different examples of each

character were selected so as to expose the perceiver to several similar distortions of the given character consistent with the writing procedure, and not just to features of a particular distorted character. From these selected samples, two sets of flashcards were created for use in the training session, one being a set of static examples of the characters drawn from the up method by a right-handed subject, the other, a set of examples drawn from the down method by a left-handed subject. The samples were produced with

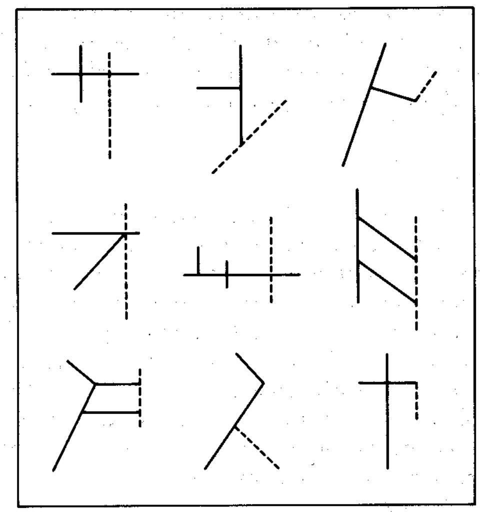

Figure 1. The nine characters used in Experiment 1 (the final stroke on each character is indicated by a dotted line)

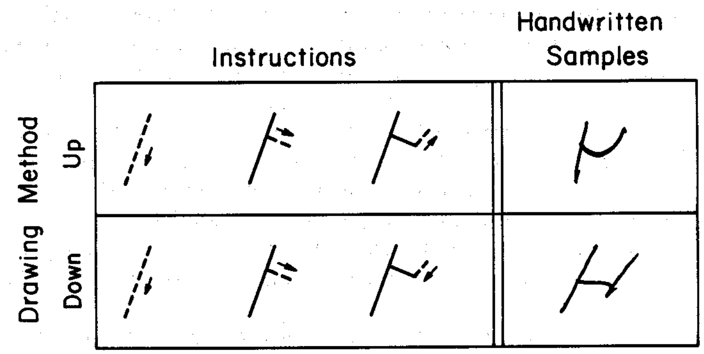

Figure 2. Illustration of the two drawing methods (up and down) for a character used in both Experiments 1 and 2, and examples of the distortions each method produces (handwritten samples are from the set of training stimuli used in Experiment 1; up examples are on top; down examples are on the bottom)

a roll-tip pen on plain white paper. To approximately equate size and therefore visibility of the cues in the two groups, the down samples were enlarged 57%, making the characters in both cases approximately 2 × 2 cm. All samples were then photocopied and mounted separately on 3 × 5-in. index cards. The appropriate corresponding digit, 1 through 9, was written on the back of each of the 54 flashcards in each of the two groups.

Training session

The remaining 28 subjects were tested individually. They first underwent a training session. The experimenter laid out nine flashcards, one example of each character (selected randomly), and told each subject that they represented the Arabic numerals 1 through 9 in proper sequence. The subject was told to memorize the character associated with each numeral. Fourteen subjects learned from up method exemplars, and 14 subjects learned from down method exemplars. After the subject had studied the characters, the cards were removed, and the subject was presented with a stack of 54 shuffled flashcards (six examples of each character) all drawn by one of the two production rules (up or down). The subject verbally indicated which number the character represented. This was repeated until he or she could progress through all 54 flashcards without error.

Implicit detection

After training, each subject completed the "translation" task. The subject was presented with a series of 36 triplets of the Arabic numerals 1 through 9, which were selected and arranged in a random order (a total of 108 numerals). Subjects were asked to translate these triplets from memory into the characters that had been learned. As the subject wrote down the characters, the experimenter noted the direction of the final strokes. Direction was defined in terms of consistency of starting and ending points of the stroke with one of the two drawing methods.

Explicit detection task

The final task involved the subject's explicit deduction of the drawing method used by the original writer. Subjects were told that the writer had been instructed to draw the strokes in a particular direction and order, and that their task was to look closely at the cards and attempt to extract this information. By placing numbered arrows next to the strokes, they then diagrammed the stroke order and direction they thought the original writer had used to create each of the nine characters.

RESULTS AND DISCUSSION

Implicit detection task

The percentage of final strokes drawn upwards was calculated for each of the 28 (14/group) subjects' handwritten samples of each of the nine characters. If a subject did not recall a character or produced

a character with a final stroke that was neither appropriate nor discernible, that subject's data on that particular character were not included in the analysis; 20 such instances (of 252) were omitted from the analysis. The mean percentage of upward final strokes was calculated for each subject and for each character. Despite a strong bias to draw all final strokes downward, there was a significant difference between the two groups of subjects and drawing method (Figure 3). The subjects in the up training condition drew 22% of their final strokes in an upward direction; those in the down condition drew only 8% of their final strokes in an upward direction. This difference is highly significant, $t(26) = 3.44$; $p < .005$, two-tailed.

Explicit detection task

In the explicit task, in which subjects were asked to speculate on the particular production method used by the writer to create the flashcards, there was a significant difference between the two groups of subjects (Figure 3), $t(26) = 2.61$; $p < .015$, two-tailed. Those subjects who saw the up-drawn samples indicated that the last stroke was drawn in an upward direction in 26.2% of the cases; those subjects who saw the down-drawn sample indicated that the last stroke was drawn up in only 7% of the cases.

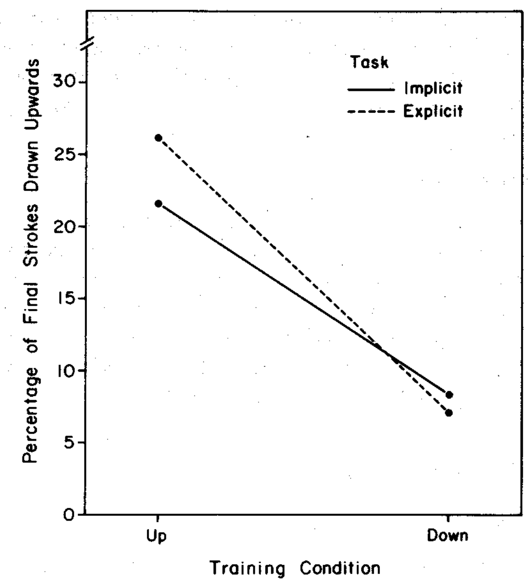

Figure 3. Results of Experiment 1

Items analyses for the implicit and explicit tasks

An analysis by characters showed only a marginal effect of the method used for the static examples in the implicit task, $t(8) = 1.42$, $p < .10$, one-tailed. This seems to be because a limited number of characters were especially conducive to revealing different dynamic cues that allowed inferences about the underlying production process. In particular, the characters associated with the numerals *2* and *3* (the second and third characters in the top row of Figure 1) showed highly significant effects of the writing method used to create the stimuli: for *2*, $t(21) = 3.38$, $p < .005$, two-tailed; and for *3*, $t(22) = 10.70$, $p < .0001$. Subjects in the up condition drew the final stroke upwards in 88% of the samples of character *2* and in 98% of the samples of character *3*, compared with 36% and 14%, respectively, of the instances being drawn upward for the same two characters by subjects in the down condition.

For the explicit task there is a significant difference between the up and down conditions tested across items, $t(8) = 2.60$, $p < .05$, two-tailed. Again, the characters associated with the numerals *2* and *3* showed the largest difference between the up and down conditions, even though there was the predicted difference between up and down conditions for eight of the nine characters. Not surprisingly, given the similarity of the overall results on these two tasks, there is a highly significant correlation between the difference scores for items (up minus down condition) for the implicit and explicit tasks, $r = .94$.

Individual differences

Although both right- and left-handed subjects participated in this experiment and handedness may be of theoretical interest here, we were unable to analyze the effects of handedness because of an insufficient number of left-handed subjects.

In observing the training session, the experimenter noted that 10 of the 28 subjects spontaneously drew the characters in the air as an aid for committing them to memory. Because it appeared that these subjects might be more sensitive to dynamic information, their performance on both the implicit and explicit detection tasks was compared with that of subjects who did not spontaneously draw in the air. The performance difference was not significant in either the up condition, $t(12) < 1$, or the down condition, $t(12) < 1$, suggesting that the use of dynamic information is not dependent on conscious application of an explicit decoding strategy. This is consistent with the lack of correlation found across subjects between their performance on the implicit and explicit tasks in both the up group ($r = .05$) and the down group ($r = -.26$).[1] Perhaps a qualitative difference exists between the information relating to production extracted from static presentation and that extracted during kinesthetic manipulation. Nonetheless, both forms of dynamic information may have a cooperative effect in the recognition of distorted handwritten letters as Zimmer's (1982) study implies.

EXPERIMENT 2

The first experiment suggests that the perceiver can indeed detect production information from a set of static examples of handwritten characters. The results of the implicit detection task illustrate that the perceiver's representation of a character is influenced by the dynamic information relating to production that he or she extracts from the static examples. When the handwritten samples were drawn according to up production rules, learners were significantly more likely to draw the final stroke upward than if they had learned from handwritten samples produced according to the down method. Furthermore, the detection of dynamic information appears to be spontaneous, because subjects were not instructed to apply any particular mnemonic strategy. Likewise, in the explicit detection task, subjects analyzing the up stimuli were significantly more likely to predict an upward final stroke (consistent with the static exemplars' production) than were those analyzing the down stimuli in which an upward final stroke would be inconsistent with the production of the handwritten samples.

A comparison of the results of these same subjects on the implicit translation and explicit detection tasks strengthens the argument that the ability to utilize dynamic information is not dependent upon the subjects' conscious application of task-specific strategies sensitive to the extraction of dynamic information. Whereas one might expect a high correlation between performance on these implicit and explicit tasks, which would indicate that certain individuals are merely more sensitive to dynamic clues in graphic stimuli, the lack of any such correlation suggests that the significant effect of drawing method of the exemplars on the subjects' subsequent production of the characters is not due to conscious, task-dependent strategies nor to a subset of particularly "dynamics-sensitive" individuals.

Subsequent analysis showed that the significant effects in both the implicit translation and explicit detection tasks were due mainly to a particular subset of characters. Because the most successful characters for revealing dynamic information in Experiment 1 were those that contained diagonals, the characters in Experiment 2 were designed specifically to investigate the effect of the presence of a diagonal on the subject's ability to extract information about stroke direction in the implicit detection and explicit detection tasks. By manipulating the presence of diagonals in both the early and final strokes of the eight characters, we sought to determine whether the presence of diagonals intrinsically affords easier detection of the underlying dynamics of the character's overall production, or whether subjects are perhaps more likely to reveal their detection of the dynamic information in the final stroke when it is diagonal. Because we do not believe that the extraction of dynamic information is limited to a particular category or subset of strokes, it was expected that the presence of diagonals in the early strokes would not significantly affect the probability of the subjects' drawing the critical stroke consistent with the method used to generate the training stimuli. On the other hand, it was predicted that diagonal final strokes would result in a significantly higher probability of subjects' revealing their detection of direction in the implicit detection task than would vertical strokes, because of the lower susceptibility of diagonal strokes to a strong directional drawing preference.

If perceivers use the dynamic information that they detect by comparing it with their *own* handwriting production, left- and right-handed writers might be differentially sensitive to certain dynamic clues specific to their particular production system. In Experiment 2 we hoped to avoid the possible effect of different general production systems on the subjects' interpretation of the dynamic clues detected in the handwritten stimuli; we used only right-handed subjects.

Finally, to avoid any possible effects of experimenter bias, we introduced an observer into the experimental testing session who was blind to the condition of each subject's training session to record the direction of the critical strokes. The presence of this observer was explained to the subject by a cover task.

METHOD

Subjects

Participants were 35 volunteers who were Cornell students or residents of the Ithaca area. Of these subjects, 14 generated the handwritten stimuli. The remaining 21 subjects participated in both an implicit detection and an explicit detection task.

Stimulus creation

The stimulus set of handwritten characters was created according to the procedure described in Experiment 1, with the exception that a different

set of eight artificial characters was used. The character set included the two most successful characters from the first experiment, those representing the numerals *2* and *3*, and six novel characters. The eight characters were designed specifically to investigate the effect of diagonal strokes on the probability of detecting stroke direction. The stimuli were created according to a 2 × 2 design, Early Strokes (at least one diagonal vs. no diagonals) × Final Stroke (diagonal vs. vertical), with two characters in each cell (Figure 4).

Seven subjects completed the speeded-copy task in the up condition, seven in the down. All characters were copied with a roll-tip pen. One subject's samples from each of the two drawing conditions was chosen as stimuli for the experiment proper. To enhance visibility, the chosen samples from both groups were enlarged 57% (making the characters approximately 3.5 × 3.5 cm in both conditions) for mounting on flashcards. Two sets of 48 flashcards each (six samples of each of the eight characters) were created for use in the training sessions.

Training session

Subjects learned the eight characters according to the procedure described in Experiment 1. Ten subjects learned from the up-method exemplars, and 11 subjects from the down-method exemplars.

Implicit detection task

Subjects underwent the same procedure for the implicit detection task as described in Experiment 1 with the following modifications. Each subject translated 40 triplets, 15 examples of each of the 8 characters, a total of

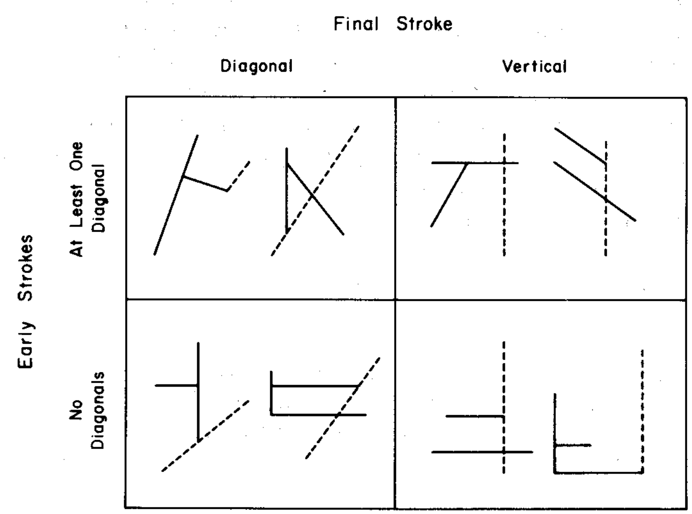

Figure 4. The eight characters used in Experiment 2 arranged by condition (final strokes are indicated by dotted lines)

120 numerals. During the translation task, a blind observer, who was absent during the training session, recorded the production direction of the critical strokes. The blind observer's presence was explained by a cover task. At the beginning of the experimental session, the principal experimenter informed subjects that a trained observer would later enter and record their "inter-character pause interval," which was said to be a relative measure of response time, unaffected by their overall pace through the translation task. During the translation task, the blind observer held a stopwatch and feigned to record these times while in actuality stroke direction was recorded.

After completing the translation task, each subject was given a blank sheet of paper and asked to draw the characters, one through eight, in order. This sheet was later used as the basis for an acceptance criterion for subjects' data.

Explicit task

All 21 subjects completed the explicit task as described in Experiment 1.

RESULTS AND DISCUSSION

A criterion for acceptance of subjects' data was established. If, when asked to reproduce the characters upon completion of the translation test, a subject failed to recall a character or produced more than one character with an inappropriate or indiscernible final stroke, that subject's data on the two detection tasks were not included in the analysis. Only one subject's data were rejected on this basis, leaving 10 subjects' data from each of the two training conditions for analysis. If a subject appropriately produced all but one of the eight characters, that subject's data were included in the analysis, with the exception of those data from the inaccurately produced character; four such instances (of 160) were omitted from the analysis.

Implicit detection task

The mean percentage of upward final strokes was calculated for each subject and for each character. A three-way analysis of variance (ANOVA) was performed on these mean percentages. Training condition (up vs. down) was a between-subjects factor, and early strokes (at least one diagonal vs. no diagonals) and final stroke (diagonal vs. vertical) were within-subject variables.

In accordance with our first experiment, despite a general bias to draw all final strokes downward, there was a significant main effect of the training condition on the drawing method subsequently used by the subject in the translation task. Whereas subjects in the up condition drew 33.0% of their final strokes upward, only 15.5% of the final strokes by subjects in the down condition were actually drawn

upward. This difference is highly significant, $F(1, 18) = 9.18$, $p < .008$.

The ANOVA revealed a significant main effect of the presence of a final diagonal on the probability of the subject's drawing the final stroke upward, $F(1, 18) = 17.09$, $p < .001$ (Figure 5). The effect of early diagonals on stroke direction, however, was completely nonsignificant: $F < 1$. The ANOVA also revealed a trend of an interaction between the condition of the training session (up or down) and the presence of a final diagonal on the subjects' ability to detect stroke direction. There was no interaction between training condition and the presence of diagonals in the early strokes: $F < 1$. This was expected, given that the presence of diagonals in the early strokes had no significant effect on the subjects' subsequent method for drawing the critical strokes.

As Figure 5 illustrates, the ratios of the percentages for the two training conditions are approximately the same for vertical and diagonal final stroke conditions, suggesting that diagonality appears to reduce the "bias" for downward strokes but does not appreciably alter sensitivity to information in the training stimuli that indicates the method of production. This is consistent with the lack of an effect for early diagonals on stroke direction.

Explicit detection task

An ANOVA of the same design used in the implicit detection task was conducted on the data from the explicit detection task. No sig-

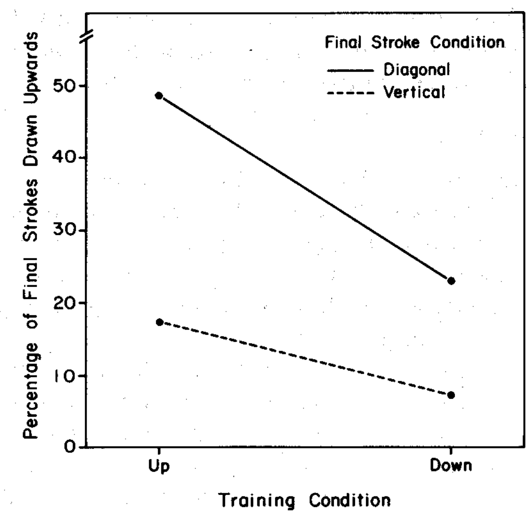

Figure 5. Results from the implicit detection task used in Experiment 2

nificant main effects or interactions were revealed, although the significant results from the implicit detection task (the training condition main effect and the final stroke main effect) were replicated as trends in the same direction. Subjects in the up training condition drew 28.8% of the final strokes upward compared with subjects in the down training condition, who drew only 18.8% of the final strokes upward. Perhaps the particular handwritten samples used as training stimuli in Experiment 2 contained fewer clues salient for the explicit detection of dynamic information; we interpret the fact that the training condition trend is in the same direction as supportive for the explicit detection findings of Experiment 1. In any case, the results from the implicit task suggest that these characters nonetheless contain other types of information regarding production which may be extracted implicitly. It may even be that implicit tasks are better estimators of dynamic information extracted by the perceiver than are explicit detection tasks, a finding consistent with Shanon (1976).

GENERAL DISCUSSION

These two experiments demonstrate that perceivers are sensitive to information in the static traces of a series of handwritten characters that relates to original construction of the characters and that the information subsequently affects the way they produce the characters. We believe that the present results together with the findings reported by Freyd (1983b) support the hypothesis that perceivers spontaneously infer the underlying dynamic pattern of motor movements used to produce handwritten characters by utilizing knowledge of common production processes.

Although we have argued that traditional feature analysis theories are not sufficient to account for handwriting recognition, we would like to point out two ways that modified feature analysis theories might be combined with the theoretical position presented here. The first way involves the notion of complementary recognition mechanisms. In particular, a process that capitalizes on the production information inherent in the handwritten trace may operate concurrently with more traditional feature analytic processes that analyze configural information. Or perhaps the first mechanism is primarily used when reading handwritten letters, whereas the second is used for machine-produced letters. The extent to which each mechanism is used may be dependent on the character's consistency to static configural models or to the presence of distortions that are characteristic of the production method used for that character.

The second way in which a modified feature analysis theory may

be applied involves the perception of dynamic information. We see two fairly distinct issues in handwriting recognition theories: (a) feature analysis versus template matching (see Neisser, 1967), and (b) the use of static versus dynamic or production information. In this paper, we have been concerned with the second issue: the ability of perceivers to utilize dynamic, production-dependent information beyond their use of the more traditionally studied configural information. Our data do not directly address the first issue. Indeed, either the feature analytic model or the template matching model might facilitate extraction of dynamic information. For example, perceivers might use a feature model that emphasizes the presence of certain "dynamic features" (e.g., a hook on the end of a stroke) or a template model that uses overall dynamic continuity (e.g., the continuous gradient of line thicknesses throughout a stroke).

One might argue that our stimulus selection procedures (using characters drawn by only one subject for each experiment) decrease the generality of this study. However, the aim of the current investigation was to *demonstrate* that in the case of characters that are clearly "distorted" (compared with perfect configurations), perceivers are sensitive to information indicating the means of production. Thus we selected examples of handwritten characters that were clearly "distorted" and consistent with one another (all drawn by the same person). We have some evidence as to the generality of the result despite our selection procedures, because the stimuli were generated by different subjects for Experiments 1 and 2. However, in future research it would be important to use characters drawn by a variety of people.

Our findings may actually underestimate the amount of production information the reader normally extracts and utilizes while reading handwritten characters. First, the study limited its analysis to the detection of stroke direction, although other types of dynamic information including temporal characteristics may equally facilitate handwritten letter recognition. For example, further sources of dynamic information might allow the detection of acceleration patterns through the perceiver's sensitivity to changes in line thickness. From these acceleration patterns, the perceiver might again infer the underlying production process and use this knowledge to facilitate letter recognition.

Second, the training stimuli in this experiment may be less conducive to revealing production information than normal handwritten Roman letters. Because the characters are unfamiliar, those subjects asked to create the stimuli might have been less likely to allow normal distortions. Furthermore, creators and perceivers of unfamiliar characters did not share a common production system as do readers and writers of the Roman alphabet. In normal handwriting recognition, perceivers perhaps test dynamic information that they extract against the production process of the hypothesized letter, and therefore less salient cues are sufficient for discrimination. Moreover, the dynamic information in normal handwriting is amplified by the interconnections between adjacent letters, physical contextual factors that were not applied in this study.

Third, a strong directional preference might have concealed subjects' extraction of production information from the static examples. In particular, subjects may have detected information concerning the production of the characters, yet were also influenced by a set of familiar drawing rules in actually producing the characters. For example, subjects often failed to show detection of stroke direction, but nonetheless demonstrated detection of the temporal continuity between adjacent strokes, producing appropriate stroke flow, but in reverse. Although one might expect the problem of directional preference to be avoided in the explicit detection task, if the production preference were strong enough subjects might distort their interpretation of the dynamic cues so that the cues would be consistent with their own preferred drawing methods. Indeed, subjects' spontaneous comments during the explicit tasks suggest that this may be the case. For example, in their attempts to extract the writing method from the static examples, several subjects commented that hooks and lightening of line weight suggest the endpoint of a stroke, but then failed to use this information when diagramming their prediction of stroke order and direction. In terms of natural letter recognition, however, the problem of a preferred production system should rarely have deleterious effects, because most writers share a common production system and directional preferences.

One might argue that some aspects of the handwritten strokes per se may determine how subjects subsequently produce them, and that this may not necessarily depend on extraction of information about production during the initial encoding of the characters. Instead, subsequent production might depend on static figural characteristics, such as the distance between adjacent strokes. The findings reported by Freyd (1983b) suggest, however, that detection of dynamic information in the static handwritten character produces more profound effects on a perceiver's representation of the character than can be accounted for by drawing preferences for particular configurations of strokes. In future research, we hope to determine which possible sources of information (such as variations in line thickness and connecting lines, etc.) in the drawing sample are most informative about the underlying production method. We could then directly compare

the effects on recognizability of sources of dynamic information that make relatively large or small configural differences.

This study suggests several topics for future research. By systematically varying the types of distortions (i.e., hooks, connected strokes, line thickness, degree of concavity), one might isolate the cues most indicative of the production method. Investigations into the effects of handedness might reveal whether the two groups are indeed differentially sensitive to certain patterns of distortions; a result, if obtained, that would suggest perceivers rely heavily on knowledge of their *own* production processes. Finally, it might be interesting to assess both the production and recognition processes involved in illegible handwriting. Perhaps illegible writing is created by an aberrant production process that would impair recognizability because perceivers would be unable to capitalize on their own knowledge of the generally shared production rules.

Further research investigating predictions raised by the information and sensitivity claims may be useful for developing improved computer technology. Better understanding of the types of information actually used by the perceiver could aid in designing accurate and efficient letter-recognition machines for static handwritten samples and in increasing the legibility of machine-produced letters. For example, continued research in this area could aid in developing a handwriting recognition machine that takes static input (such as a handwritten manuscript, check, or memo) and applies decoding algorithms that determine the way in which the handwritten letters were originally produced. These decoding algorithms would use distortions and other sources of information in the static input and then look for matches between the common rules of formation for a given letter and the deduced rules of formation for the input letter. Presumably, this approach would be used in conjunction with the more traditionally studied "feature analytic" approaches to letter perception which work so well for typewritten or machine-produced letters.

The finding that perceivers spontaneously extract production information from static handwritten forms may have implications beyond handwriting recognition. We see this finding as consistent with a general theory of perception that emphasizes the importance of dynamic information even when the stimuli are static (Freyd, 1987). In a related study, Freyd (1983a) demonstrated that snapshots taken of objects in motion may be encoded in terms of the implicit motion inherent in the picture. Thus, it may be that the spontaneous extraction of dynamic information during the perception of static stimuli is not limited to the domain of handwriting recognition.

As a final comment, we wish to point to a connection between the present study and the teaching of handwriting. In Teulings and Thomassen's (1979) discussion of a dynamic approach to teaching handwriting skills, they claim that the process itself should be emphasized over adherence to a strict templatelike shape prescription. They argue that the dynamic approach provides a "better basis for further development of handwriting as a personal and efficient means of communication than is any uniform set of letters, each of which is practiced to a criterion of maximum fit to a standard" (p. 231). This suggests that the invariance of the common production process itself is more informative than static figural "features." In concert, our study suggests that the dynamic process can be communicated to the perceivers through their perception of information in the static trace.

Notes

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1. Correlations were computed separately for up and down groups of subjects to avoid artificially inflating the value of r due to overall group differences.

References

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

Freyd, J. J. (1983a). The mental representation of movement when static stimuli are viewed. *Perception & Psychophysics, 33,* 575–581.

Freyd, J. J. (1983b). Representing the dynamics of a static form. *Memory & Cognition, 11,* 342–346.

Freyd, J. J. (1987). Dynamic mental representations. *Psychological Review, 94,* 427–438.

Gibson, E. J., Gibson, J. J., Pick, A. D., & Osser, H. (1962). A developmental study of letter-like forms. *Journal of Comparative and Physiological Psychology, 55,* 897–906.

Gibson, E. J., & Levin, H. (1975). *The psychology of reading.* Cambridge, MA: MIT Press.

Macleod, I., & Proctor, P. (1979). A dynamic approach to teaching handwriting skills. *Visible Language, 13,* 29–42.

Neisser, U. (1967). *Cognitive psychology.* Englewood Cliffs, NJ: Prentice-Hall.

Polanyi, M. (1966). *The tacit dimension.* Garden City, NY: Anchor Books.

Shanon, B. (1976). Aristotelianism, Newtonianism and the physics of the layman. *Perception, 5,* 241–243.

Teulings, H. H. M., & Thomassen, A. J. W. M. (1979). Computer-aided analysis of handwriting movements. *Visible Language, 13,* 218–231.

Wing, A. M. (1979). Variability in handwritten characters. *Visible Language, 13,* 283–298.

Zimmer, A. (1982). Do we see what makes our script characteristic or do we only feel it? Modes of sensory control in handwriting. *Psychological Research, 44,* 165–174.