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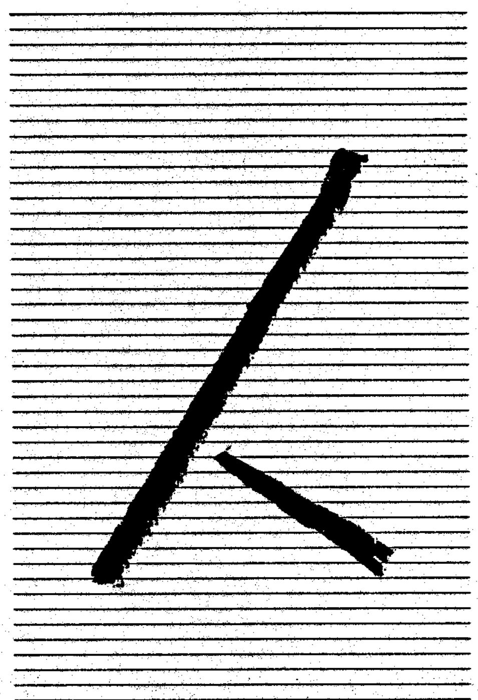




# The Effects of Drawing Method on the Discriminability of Characters

*Michael L. DeKay & Jennifer J. Freyd*

*Three experiments were conducted to investigate the effect of drawing method on the subsequent discriminability of hand-drawn characters. A novel set of eight characters and two drawing rules were developed for use in these experiments. In Experiment 1, angle measurements performed on hand-drawn characters indicated that members of characters pairs drawn using dissimilar stroke directions became more differentiated while members of character pairs drawn using similar stroke directions remained relatively undifferentiated. In Experiment 2, subjects were better able to distinguish between members of differentiated characters pairs than between members of undifferentiated character pairs. In Experiment 3, subjects also appeared to be better at distinguishing between members of character pairs which had been drawn using their own drawing rule, though such a finding may depend on the exact nature of the task.*

Deciphering handwritten script is a task that most of us undertake on a daily basis. In most cases, the writer has encoded the message fairly legibly and we are able to unscramble the complex stimulus material with remarkably little effort. However, if the writer's note is hurriedly scribbled, the task becomes much more complicated. We attempt to piece together the meaning of the passage from the most legible words and use the resulting context to inform our attempts at deciphering the more ambiguous text. Pressing still further, we might focus on the features of troublesome letters or mentally retrace the path of the writer's pen in an effort to uncover the process which led to the distorted traces on the paper. Finally, we may ask for the assistance of others, waiting patiently as they go through a similar sequence of steps.

There are several aspects of this process that are interesting to psychologists. First, there is the process through which the ambiguous script is generated in the first place. Does illegibility result from random distortions of accepted letter forms or are the distortions partially deter-

Department of Psychology, University of Colorado, Boulder, Colorado 80309. *Visible Language* 25:4 Michael L. DeKay & Jennifer J. Freyd, 377-414 © *Visible Language*, Rhode Island School of Design, Providence, Rhode Island 02903

mined by the stroke sequence used to create the letters? Can we predict which letters or letter combinations will become ambiguous by looking at the forms of undistorted characters or the accepted stroke sequences for writing them? Does the use of a nonstandard stroke sequence lead to distortions that are substantially different from those that follow from the standard stroke sequence?

Second, what are the cognitive processes involved in deciphering ambiguous script? Context certainly plays a role, but context alone rarely supplies sufficient information to decipher a truly ambiguous word; more fine-grained perceptual processes are also called upon. How do these processes work? Do we maintain a cognitive catalogue of accepted or familiar distortions for each letter or letter combination or do we consciously or unconsciously retrace the path of the writer's pen? In other words, is the decoding process a static, feature-based approach, or is it more dynamic, like the encoding process of the original writer? In either case, how important is it for the writer and reader to share a common writing method?

In this paper, we attempt to answer three of these questions. First, we ask whether differences in writing methods (e.g., differences in stroke direction) determine the types of distortions that are generated from a set of characters. Second, we ask whether these distortions are important determinants of the ambiguity or illegibility of handwritten characters. Finally, we ask whether familiarity with the method in which characters are created facilitates recognition of ambiguous characters.

### Previous Research

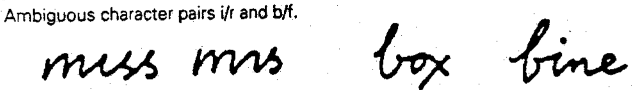
#### *Examples of Ambiguous Characters*

There are several factors which might account for the difficulty of correctly identifying individual letters in handwritten script. According to Wing and colleagues, different writers may use different forms for a given letter (Wing, 1979) and individual writers may use different forms of the same letter depending upon the surrounding letter context and the position of the letter in a word (Wing, 1979; Wing, Nimmo-Smith and Eldridge, 1983). In addition, slight distortions of some common letter forms often render the letters indistinguishable from similar forms of other letters or letter combinations. For example, script forms of the letters i and r or b and f can be difficult to distinguish (see panel A of *figure 1*). Thus, i/r and b/f can be called confusable characters pairs.[1] Sommer (1977) provides a number of other examples in which characters

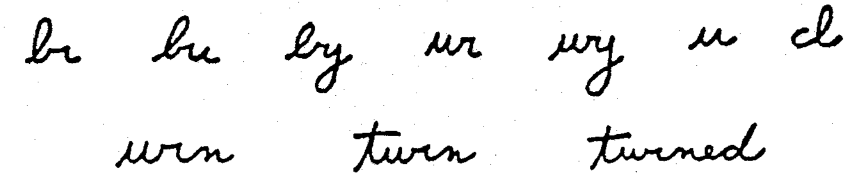


**FIGURE 1.** Examples of ambiguous character pairs and ambiguous words.

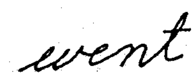
**Panel A:** Ambiguous character pairs i/r and b/f.



**Panel B:** Ambiguous character pairs bi/lr, bu/lri, by/bij/lrj, ur/wi, urj/wy, u/ii and d/cl and ambiguous words win/urn, twin/turn and twined/turned.



**Panel C:** Ambiguous words went/event that results from the ambiguous character pair w/ev.



Panel A examples from "Variability in Handwritten Characters," by A.M. Wing, 1979, *Visible Language* 13:3, 284. Panel B examples from "A Note on 'Graphonyms'" by R. Sommer, *American Journal of Psychology*, 90, 527-528. © 1977 by the University of Illinois Press. Reprinted by permission. Panel C example from "An Interactive Model of Reading" by D.E. Rummelhart. In S. Dornic, ed. *Attention and Performance VI: Proceedings of the Sixth International Symposium on Attention and Performance*, 579. Reprinted by permission, © 1977 Lawrence Erlbaum Associates, Inc.

or combinations of characters are confused with other combinations of characters, sometimes creating ambiguous words (see panel B of *figure 1*). Nash-Weber (1975) provides yet another example in which an ambiguous word results from a simple distortion (the actual script in panel C of *figure 1* is Rumelhart's 1977 adaptation of Nash-Weber's example).

Confusions like those represented in figure 1 occur only if the writer is somewhat sloppy. If the writer properly dots his i's and j's and properly closes his d's, the ambiguities begin to disappear. However, because most of us write in a sloppy manner from time to time, especially when we are in a hurry, it seems reasonable to expect that minor distortions will occasionally result in ambiguous words or letters. Moreover, the examples presented in figure 1 do not exhaust the set of possible ambiguous character distortions. Suen's (1983) confusion matrices for print, manuscript and cursive letters provide evidence for a wide variety of ambiguous letter forms. For example, the most common confusions for cursive script are c/e, c/i, e/i, g/q, g/y, h/b, k/h, n/w, o/a, q/g, r/i, v/u and w/u, few of which are represented in figure 1. One can imagine the number of confusable letter *combinations* that might arise from these individual letters.

- *Drawing Method as a Source of Ambiguity*

Why might some pairs of hand-drawn[2] characters be more or less distinguishable? We propose that the discriminability of graphically similar characters depends on the method in which they are drawn. Specifically, we hypothesize that hand-drawn versions of two graphically similar characters will become more differentiated if they are drawn in dissimilar ways (e.g., using a different stroke order or direction).[3]

Such a finding would be consistent with Macleod and Procter's (1979) suggestion that the "*process* used to create cursive script has subtle yet profound effects on the appearance of the product" (p. 29, italics added). Lindsey and Beck (1984) also cite confusion with directionality as a major source of handwriting difficulties. Given Macleod and Procter's observation that incorrect stroke order and direction lead to a progressive deteriorization from the standard form, it is plausible to hypothesize that differences in the dynamics of character formation could lead to differences in the discriminability of certain character pairs.

*Mirror reversals.* Other evidence suggests that there is a similar connection between the writing process and the discriminability of written products for the printed alphabet. Goodnow and Levine (1973) have hypothesized that certain printing errors are linked to the rules children use when copying simple characters. Specifically, they attribute the asymmetry in the number of reversals for b- and d-shaped figures to subjects' adherence to rules specifying that figures should begin with a vertical line and then progress from left to right. Thus, the method in which the characters were drawn is thought to be responsible for errors in which one member of a character pair was drawn as the other member of the pair. However, since adherence to drawing rules was examined only for a different set of four characters and not for the b- and d-shaped figures themselves, it is not possible to be certain that such errors were due to the way in which the individual characters were drawn.

However, there appears to be some disagreement as to whether children's drawing rules extend to printing. Lewis and Lewis (1965) have reported a mirror reversal asymmetry for printing and Cohn and Stricker (1979) have reported a similar effect for reading. In addition, Nihei (1983) has found that Japanese preschoolers' mirror reversals of nonletters have a left to right bias. Although the author does not examine mirror reversals for Japanese letters (*Hiragana*), he does demonstrate that the covert principles for the organization of strokes follows the same developmental pattern for drawing and handwriting. However, Nihei's study used only right-handed subjects.



In contrast, Simner (1984) reported that both left- and right-handed kindergarten children reverse b-type letters more than d-type letters. This result contradicts Lehman and Goodnow's (1975) assertion that the two groups should use opposing motor rules when drawing letters. Furthermore, Simner shows that the left-to-right mirror reversals made by left-handed subjects when printing are not the result of a general left-to-right preference for horizontal strokes. Thus, his results cannot be explained by assuming that left- and right-handed subjects have different rules for drawing but a common left-to-right rule for printing. Following the arguments of Frith (1971), Simner suggests that the mirror reversal asymmetries may be the result of familiarity effects arising from the greater frequency of b-type letters in the alphabet. Children may be more likely to write or read b- and d-type characters as b-type characters for unconscious reasons (because children are simply more familiar with the characteristics of b-type letters) or conscious reasons (in order to capitalize on chance).

In summary, evidence for the notion that mirror reversals are the result of the application of a particular set of drawing rules is mixed at best. Still, a method- or rule-based explanation of b/d reversals appears to have been one of the main forces behind the creation of the D'Nealian alphabet (Thurber, 1983, 1984). In D'Nealian manuscript, b's and d's are formed more differently than in traditional ball-and-stick systems. Research presented by Thurber (1984) indicates that the D'Nealian approach is successful in reducing the number of mirror reversals.

*More subtle distortions.* Of course, the difficulties involved in deciphering handwritten messages usually do not arise from such gross errors as the reversal of individual characters. For example, the ambiguous characters of figure 1 and the confusion matrices in Suen's (1983) article reflect errors that are less severe than outright reversal. Ullmann (1974) refers to most of these more subtle distortions as *continuous* because the distorted characters are "related to the ideal characters by stylistic variations and random combinations of dilation, translation, and rotation" (p. 294). Mirror reversals, as well as a few of the more subtle errors (e.g., failure to dot an i), can be thought of as *discontinuous* distortions.

Freyd (1983) has taken the notion of continuous distortions one step further by suggesting that distortions are not solely the products of random processes. She suggests that the likely form of a distorted character is rooted in the method (e.g., stroke direction) used to draw the character. For example, strokes may be lengthened or connecting strokes added in a way that is consistent with the drawing method. Thus, different drawing methods may be expected to produce different distortions. Such distortions may be generated purposefully by the experimenter (as in Freyd, 1983) or unintentionally by naive subjects (as in Babcock and Freyd, 1988). Interestingly, a computer model for the generation of continuous trajectories from discrete stroke instructions has been developed by Morasso, Ivaldi and Guggiero (1983). Continuous trajectories can lead to connecting strokes within characters (as in Freyd's studies) or between characters (as in cursive writing).

While any distorted character is likely to be more difficult to recognize than an undistorted one, a truly ambiguous character results only when the distortion of the character corresponds to a possible distortion of another character. The more likely the distorted versions of the two characters, the more likely either character will be drawn in an ambiguous fashion.

- *Knowledge of the Drawing Method as a Key to Deciphering Ambiguous Characters*

There is an interesting corollary to the notion that ambiguous characters may result from the method used to create those characters. Specifically, we suggest that ambiguous characters will be easier to decipher if the reader has knowledge of the method that was used to create the characters in the first place. In practical terms, this means that persons who have learned the same method for creating a set of characters will have less trouble communicating than persons who have learned to create the same characters in different ways. We refer to this corollary as the "common method hypothesis."

We should note that the plausibility of this hypothesis does not depend on whether characters are perceived in a static manner, by comparing the features of the characters to those of undistorted prototypes, or in a more dynamic manner, by mentally retracing the strokes of the writer's instrument. Static feature-analytic theories, such as those reviewed by Gibson and Levine (1975), would predict better performance for readers who share the writer's production system because the distortions made by the writer are similar to distortions that the readers make when they write. This is true even if the distortions are the direct result of the drawing method used to create the characters. If the characters look familiar, they will be easier to recognize. Alternatively, a theory which emphasizes dynamic cues would consider many of the configural properties of the distorted characters to be dynamic in origin. Therefore, the presence of such cues would serve to convey information about the method in which the characters were drawn. This methodological information could later be tapped by readers, regardless of their familiarity with the drawing method. However, such information would clearly be most useful if the characters were drawn in the reader's own method, since only familiar cues would be present.

*The dynamics of character perception.* Although it would be folly to suggest that the static features of characters are not a very important part of the character recognition process and, indeed, the reading process as a whole, recent research indicates that dynamic processes may also be at work. For example, Kosslyn, Cave, Provost and von Gierke (1988) have shown that mental images of letters and letter-like forms are created in a dynamic fashion. Furthermore, the way that novel letter-like forms are imaged depends upon the order in which the strokes are initially learned. In their study, the time it took subjects to decide whether a probe fell on images of letter-like forms increased steadily for segments farther along in the sequence. This result is consistent with Zimmer's (1982) finding that subjects' images of certain script letters are more accurate when the subjects are asked to image them in a dynamic fashion (visually, kinesthetically or both) than when they are asked to image the letters in a static form. It is also worth mentioning that some optical character recognition programs have used contour- and stream-following models which attempt to identify characters by sequentially retracing the original writing process (see Ullmann, 1974, for references). Presumably, these models are able to use dynamic information resident in the static character trace.

However, not all of the evidence supports a dynamic model of character perception. In a study by Calis, Teulings and Keuss (1983), subjects viewed two component letters (e.g., c and i), which together composed a third letter (e.g., a), and identified the most salient letter or letters of the three. The letters were presented in typing and writing modes in forward (left-to-right) and reverse (right-to-left) directions. Although the results of their three experiments are rather difficult to summarize, the authors claim that there were "no effects due to typing versus writing that would suggest the existence of a handwriting-like activity in the recognition phase of letter perception" (p. 313).

On the other hand, if characters are mentally represented in terms of dynamic processes rather than as sets of static features, it is not surprising that dynamic presentations of letters and letter-like characters facilitate more accurate copying. For example, copying performance is increased when letters are presented using animation (Wright and Wright, 1980) or live modelling (LaNunziata, Cooper, Hill and Trap-Potter, 1985). Similarly, copying performance is improved for nonletters when videotape is accompanied by the teacher's hand motion (Søvik, 1976) and when projected images are presented close to the subject in a dynamic fashion (Søvik, 1979). It is important to note that performance is not improved by some static techniques (e.g., the use of overlays by students to correct their own handwriting illegibilities; Burkhalter and Wright, 1984), even though the procedures are plausible on the surface and involving for the students. These results suggest that more dynamic methods could be profitably employed to teach proper letter formation in elementary schools.

*Tests of the common method hypothesis.* There have been several studies which bear on the common method hypothesis. For instance, Freyd (1983) has shown that certain types of distortions make characters more difficult to identify than do others. In her experiment, subjects viewed novel characters as they were drawn on a computer graphics screen in one of two methods (e.g., stroke directions). Later, subjects were asked to identify distorted and undistorted versions of the characters they had learned. Results indicated that subjects performed better on undistorted characters and on characters which were distorted in a way that was consistent with their learning method. In addition, one category of consistently distorted characters, "sloppy lines," actually facilitated character recognition, suggesting that some distortions might contain useful information. Presumably, subjects' tacit knowledge of the method in which the characters were drawn during the learning task aided their recognition of the distorted forms when the distortions could reasonably



result from the original drawing method. These results suggest that readers will perform better when they share the writer's production system. However, it should be noted that the distorted characters used in the recognition task were created by the experimenter and not by subjects trained in a particular drawing method.

More recently, Babcock and Freyd (1988) have demonstrated that some information about the method in which characters are drawn is available to others who later view the static character traces. Their study included an implicit detection task, in which subjects who learned static characters that had been drawn in a particular method (e.g., stroke direction) were more likely to draw the characters in a similar fashion, and an explicit detection task, in which subjects demonstrated an ability to recreate the stroke pattern in which the static characters had been drawn. Although these results indicate that information regarding the drawing method had been incorporated into the static character traces, the exact nature of the information was not investigated in a systematic fashion. Moreover, the experimenters did not look for an effect of these method-based differences on the recognizability of the characters, so there was no test of the common method hypothesis. However, the very presence of discernable method-based differences in a set of hand-drawn characters suggests that such a test is possible.

A more direct test of the common method hypothesis is found in Suen's (1983) article. One group of left- and right-handed subjects generated a large number of characters by writing a sentence in each of three styles: printing, manuscript and cursive. After the sentences had been dissected into individual letters, a second group of left- and right-handed subjects were required to identify each of the letters. If one considers the letters produced by left- and right-handed subjects to be written using different methods, then the common method hypothesis would predict that left-handed readers would be better at recognizing letters written by left-handed writers and that right-handed readers would be better at recognizing characters written by right-handed writers. The implied interaction between the handedness of the writer and the handedness of the reader was not found.

However, there are at least two reasons that this test of the common method hypothesis was not a strong one. First, it is not clear that the left- and right-handed writers used entirely different methods for forming the letters in the first place. Another experiment in the same paper investigated the actual methods (e.g., stroke orders and directions) used by the same group of subjects when writing characters in boxes. The quickest method for writing a particular letter was the same for left- and right-handed subjects in twenty-one of twenty-six cases (the most common method used by the two groups to form each character is not reported). Second, data regarding the writing methods used by readers was not collected. Thus, it is possible that the group of left- and right-handed readers used different writing methods than their same-handed writer counterparts. In fact, it is entirely possible that there was as much variability within handedness groups across writing and reading conditions as between handedness groups within writing and reading conditions. A stronger test of the common method hypothesis would use writers and readers whose writing methods are known and a set of characters known to be produced in different ways by the two method groups.

In summary, the data regarding the common method hypothesis are equivocal at best. On the positive side, Freyd's (1983) experiment suggests that readers are better at recognizing distortions that are consistent with their "writing" method, but the distortions were generated by the experimenter and the subjects never actually wrote any characters themselves. Babcock and Freyd's (1988) study indicates that readers are sensitive to method-based information present in the static traces of characters. In principle, such information could form the basis for a common method effect if such characters were used in a recognition task similar to that in Freyd's (1983) study and if subjects in the recognition task were practiced in one of the two drawing methods. On the negative side, Suen (1983) reports that there is no interaction between the handedness of writers and readers in a character recognition task. However, the investigator was primarily interested in other questions, so the test of the hypothesis was rather weak.

## The Current Research

### *Unanswered Questions*

In this paper we focus on three related questions. First, does the ambiguity of hand-drawn characters vary with the methods in which the characters are drawn? Freyd's (1983) finding that some types of distortion facilitate character recognition suggests the possibility that some character pairs might be distorted in ways which make the members of the pairs more distinguishable, whereas the finding that other types of distortion make character recognition more difficult suggests that characters pairs might also be distorted in ways that make members of the pairs less distinguishable. In other words, if character distortions are somewhat predictable on the basis of drawing method, it should be possible to demonstate that the use of a common drawing method for two graphically similar characters leads to ambiguity, whereas the use of different drawing methods for the two characters leads to character differentiation. We hypothesize that any marked differences between character pairs drawn using similar and dissimilar methods should be evident in the appearance of the hand-drawn characters themselves. We should be able to measure these differences using a quantitative geometric scale.

Perhaps more importantly, does the use of different drawing methods for members of character pairs lead to distorted versions of the characters that are more distinguishable to humans than the distorted versions of the characters that result from the use of similar drawing methods? In other words, are the effects of drawing method large enough to enable humans to distinguish characters that result from different methods, and are the characters that result from similar methods truly ambiguous to humans? This is really the same question as the first, but the measure of character differentiation is human performance in a recognition task rather than a geometric assessment of the characters. We prefer to keep the questions separate because human performance may be better or worse than geometric measures of character differentiation lead one to predict.

Finally, there is our question about the importance of a shared character production system. Is a subject's ability to correctly identify hand-drawn characters dependent upon the consistency between the method he or she uses when learning the characters and the method used by other subjects when producing the stimuli to be identified? The common method hypothesis suggests that recognition should be better when the writer and reader share a common method for writing the characters. Freyd's (1983) finding needs to be replicated using more naturalistic hand-drawn distortions instead of computerized forms. The results of Babcock and Freyd (1988) suggest that hand-drawn characters might contain enough information to be used as test stimuli in a recognition task similar to that in Freyd's original study.

We should point out that distinguishing between dynamic and static theories of character perception is not one of the goals of this work. Thus, the results of our experiments are consistent with either theoretical stance.

- *An Experimental Approach*

We believe that many of the difficulties associated with much of the research cited above can be overcome if a more experimental approach is used. For instance, we believe that one of the major problems with the mirror reversal research is that the studies are correlational in nature. Except for the D'Nealian research, the drawing "rules" are inferred from the behavior of the subjects and used to predict the kinds of errors that should occur if those rules are overused. In the case of D'Nealian manuscript, there are many variables that could be responsible for the decrease in mirror reversals. It remains to be demonstrated that the use of particular drawing rules actually *causes* any errors at all. It doesn't matter whether the errors are mirror reversals or more subtle distortions like those in figure 1. Drawing rules needs to be experimentally manipulated before one can come to any concrete conclusions about the causal relation between rules and errors.

Thus, we believe that subjects should be randomly assigned to drawing rules. Because our college-level subjects already have extensive experience with the methods for writing letters and numbers and in recognizing the distortions that may result from different writing methods, the creation of novel drawing rules necessitates the use of novel characters as well. The use of nonletters is not without its benefits, however. Frith (1971) and Simner (1984) have suggested that the English alphabet is biased toward certain types of characters, leading to alternative explanations of effects once thought to be rule-based. The use of nonletters allows us to eliminate such alternative explanations in the experiments that follow. Frith (1974) also reports that adults have acquired "schemata" for letters that affect both production and recognition processes. These familiarity effects can also be avoided if nonletters are used. Also, it has been suggested elsewhere (e.g., van Galen, 1984) that more research is needed with artificially constructed graphemes.

Finally, we choose to study individual characters rather than groups of characters because it simplifies the experimental process. Thus, the results of our experiments are more applicable to the study of letter formation and recognition than to higher processes involved in writing and reading. We are, of course, aware that letter formation and recognition are dependent on the surrounding context (Gibson and Levine, 1975; Rumelhart, 1977; Wing, 1979; Wing, Nimmo-Smith and Eldridge, 1983). However, a large body of research has shown that the formation of individual letters is the single most important determinant of handwriting legibility (Graham, 1986a, 1986b; Graham, Boyer-Shick and Tippets, 1989; Graham and Miller, 1980; Quant, 1946; Rondinella, 1963). It therefore seems reasonable to ask our questions at the individual character level.

**Experiment 1**

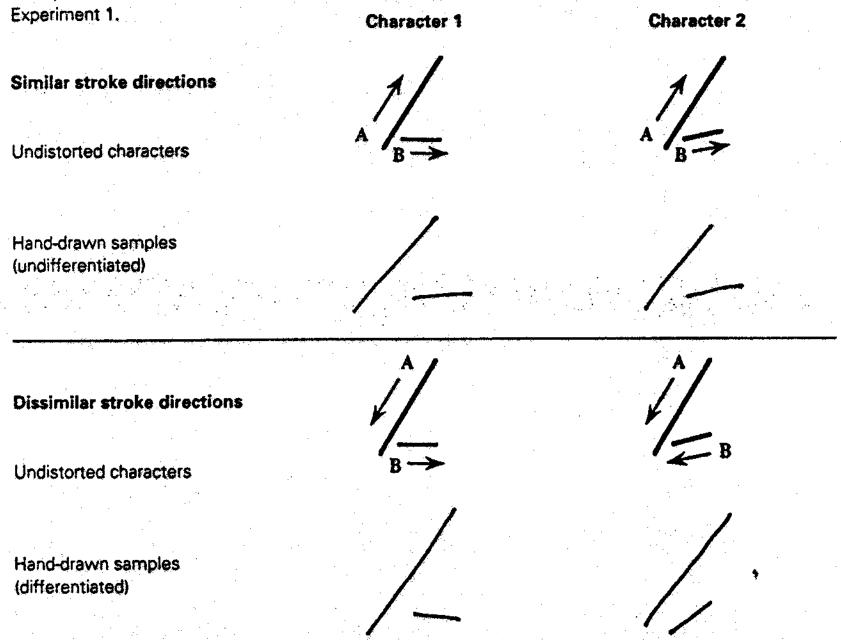
The primary purpose of the first experiment was to determine if the methods used to draw graphically similar characters affect the extent to which such characters become differentiated. A secondary goal of this study was to generate a large pool of naturalistic stimuli to be used in subsequent experiments.

In principle, a drawing method for a particular character or set of characters might have several important aspects, such as stroke order, stroke direction, or the inclusion or exclusion of connecting lines between successive strokes. However, in the interest of simplicity, we varied only stroke direction in the present study. Since it is plausible to expect that the inclusion of additional differences in drawing method might contribute to a higher level of discriminability in the hand-drawn products, the approach taken here is conservative.

We created pairs of graphically similar characters which we thought would remain undifferentiated if drawn using similar stroke directions but would become differentiated if drawn using dissimilar stroke directions. Figure 2 illustrates the manner in which different stroke directions might affect the discriminability of one pair of graphically similar characters. The letters A and B indicate stroke order (A first, then B) and the arrows indicate stroke direction.

When the two characters are drawn using similar stroke directions, as in the top portion of the figure, there is little reason to expect any method-based differences in the appearance of the hand-drawn versions of these two characters, even if they are practiced repeatedly. This is because the drawing methods for the two characters are as similar as possible given the slight difference in the angle of the short stroke, B. We expected this pair to remain

**FIGURE 2.** The possible effects of stroke direction on the discriminability of a pair of characters. When drawn using similar stroke directions, the characters are expected to remain relatively undifferentiated. When drawn using dissimilar stroke directions the characters are expected to become differentiated. The hand-drawn examples were selected from those produced by subjects in Experiment 1.




relatively undifferentiated if drawn using similar stroke directions. When the two characters are drawn using dissimilar stroke directions, as in the bottom portion of the figure, we anticipated method-based differences in the appearance of the hand-drawn characters. We expected that the difference in direction of the short stroke, B, if practiced repeatedly, would enhance the subtle angle difference present in the original characters. Specifically, we expected that the acute angle between the two strokes A and B would change for one or both of the characters in a way that would make the characters more distinguishable. Since these angles differ for the undistorted characters (the acute angle of character 1 is larger than the acute angle of character 2 by 14 degrees), an enhancement of this difference could lead to a larger angle in hand-drawn versions of character 1, a smaller angle in hand-drawn versions of character 2, or both. In any case, such distortions would result in the acute angle of character 1 being larger than the acute angle of character 2 by an amount that is greater than 14 degrees. Thus, we expected this



character pair to become differentiated if drawn using dissimilar stroke directions.

- *Method*

*Subjects.* Ten right-handed subjects from the University of Oregon community were paid for their participation in this study. Left-handed subjects were excluded in an effort to simplify the experimental design. This simplification becomes increasingly important in later experiments.

*Character construction.* Eight two-stroke characters were created and paired with the numbers one through eight (see *figure 3*). However, subjects in this experiment were not aware that the characters were numbered. Each of the characters has at least one diagonal with a positive slope. This is a key feature which allows for a stroke to be drawn in two different directions without feeling awkward.

Two drawing rules were created for each character: a "top-to-bottom" rule and a "left-to-right" rule. Complete statements of these two rules are given in table 1. When either drawing rule is applied to the entire eight-character set, the result is that two character pairs are drawn using similar stroke directions and two character pairs are drawn using dissimilar stroke directions (see *figure 3*). Thus, it was possible to investigate stroke directions (similar or dissimilar) as a within-subjects variable while requiring

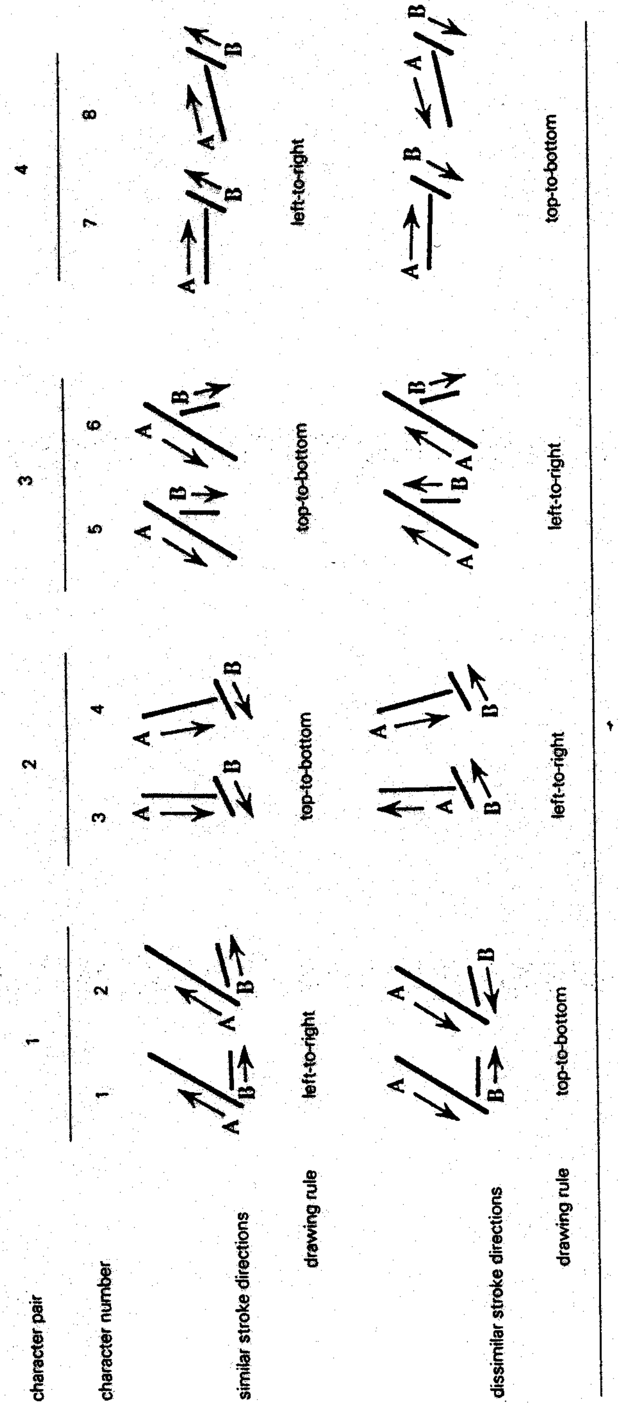
**TABLE 1.** Complete statements of the two drawing rules.

| Drawing rule | Statement of rule |
|---|---|
| Top-to-bottom | Draw the long stroke before the short stroke.<br>Draw all strokes from top-to-bottom unless they are *exactly* horizontal.<br>Draw exactly horizontal strokes from left-to-right. |
| Left-to-right | Draw the long stroke before the short stroke.<br>Draw all strokes from left-to-right unless they are *exactly* vertical.<br>Draw exactly vertical strokes from bottom-to-top. |

that individual subjects learn only one of the two drawing rules.

*Practice and test booklets.* Two booklets for each drawing rule were created: a practice booklet, illustrating the novel characters and the proper methods for drawing them, and a test booklet. The characters measured approximately 1 x 1 inch and were composed of lines approximately 1/16th inch wide. Space was provided in the booklets so that

**F I G U R E 3.** For each of the eight characters in the two drawing rules, stroke order is indicated with the letters A and B (A first, then B) and stroke direction is indicated with arrows. Members of character pairs drawn using dissimilar stroke directions differ in the direction of one of the two strokes, whereas members of character pairs drawn using similar stroke directions do not differ in the direction of either stroke.




subjects could copy the characters in close proximity to the exemplar characters. The nineteen-page practice booklet consisted of three sections separated by blank pages. The first section contained eight pages, one for each character, presented in numerical order. One character was presented at the top center of each page, along with the letters A and B to indicate stroke order, and two arrows to indicate stroke direction. The rest of the page was blank. The second section was two pages long and consisted of twenty-four characters presented in a random order. Characters were arranged twelve to a page in three lines of four characters each. Letters and arrows were not shown in this section. The third section was seven pages long and consisted of eighty characters (ten copies of each character) presented in a random order. Presentation of the characters was the same as in the previous section, except that there were only two rows of characters on the last page. The test booklet was identical to the third section of the practice booklet.

*Experimental procedure.* The experiment lasted approximately one hour, including instructions and debriefing. Subjects were tested individually. Five subjects were assigned to each of the two drawing rules (top-to-bottom or left-to-right) and completed a practice booklet and a test booklet using that rule. Subjects used a black roll-tip pen to copy the characters.

After subjects had finished reading the instructions for the entire experiment, they were briefly told one of the two drawing rules and presented with the appropriate practice booklet. In the first section of the booklet, subjects practiced the first character in the correct method for one minute before being told to go on to the next page. This process continued until all eight characters had been practiced.

For the second section of the booklet, subjects were told to copy each row of characters in the space provided beneath that row. Each character was to be copied once using the correct stroke order and direction. This section was included to make sure that the subjects were reasonably familiar with the drawing method before proceeding to the speeded copying in the third section. If the subject made an error when drawing a character, the experimenter immediately pointed out the error and asked the subject to draw the character again in the correct manner. No criteria were set for the appearance of completed characters; only errors of method were corrected.[4]

The procedures used in the third section of the booklet were the same as those used in the second section, except that, in addition to correcting the subject, the experimenter recorded the total number of errors made and the total time spent on the eighty-character copying task. Subjects were told that this was a speeded copying task in which they would be penalized ten seconds for each error made. It was made clear that time and method were of the utmost importance. (A speeded copying task was used because we wanted to maximize the natural distortions that subjects would make in copying the characters.) The procedures used in the test booklet were identical to those used in the third section of the practice booklet. Only data from the test booklet were used in the following analyses.

*Angle measurement.* The angle of each stroke (relative to the page) was later measured for each of the hand-drawn characters in the test booklets using a protractor and T-square. If a subject had made an error, only strokes from the second, correctly drawn character were measured. Individual subject means for each stroke of each of the eight characters were then computed. Individual subject means for the acute angle between the two strokes of each character were then computed by subtracting the mean angle of one stroke from the mean angle of the other stroke. Finally, composite means for each of the eight characters drawn using similar and dissimilar stroke directions were computed from the individual subject means.[5]

- *Results and Discussion*

Composite means for the acute angles of the eight characters drawn using similar and dissimilar stroke directions are presented in table 2. The difference between these angles is also given for each pair of characters (larger differences indicate that the members of the pair are more differentiated). Within each character pair, the character which has the larger acute angle in the undistorted version (see *figure 3*) also has the larger angle in the distorted hand-drawn versions of the characters, regardless of whether the characters were drawn using similar or dissimilar stroke directions.

However, it was the *size* of these differences that we predicted would vary with the stroke directions used. As predicted, the angle differences between members of character pairs are greater when the characters are drawn using dissimilar stroke directions than when they are drawn using similar stroke directions. Thus, for character pairs 1 and 4, the angle differences between the members of the pairs are greater when the characters are drawn using the top-to-bottom rule. For character pairs 2 and 3, the angle differences are greater when the characters are drawn using the left-to-right rule.



**TABLE 2.** Differences between mean acute angles for character pairs drawn using similar and dissimilar stroke directions.

| Character | | Similar stroke directions | | Dissimilar stroke directions | |
|---|---|---|---|---|---|
| Pair | Number | Acute angle (degrees) | Differences (degrees) | Acute angle (degrees) | Differences (degrees) |
| 1 | 1 | 45.6 | 15.4 | 59.3 | 32.3 |
| | 2 | 30.2 | | 27.0 | |
| | | left-to-right | | top-to-bottom | |
| 2 | 3 | 49.8 | 11.4 | 50.5 | 34.3 |
| | 4 | 61.2 | | 84.4 | |
| | | top-to-bottom | | left-to-right | |
| 3 | 5 | 33.3 | 21.3 | 30.2 | 39.9 |
| | 6 | 54.6 | | 70.1 | |
| | | top-to-bottom | | left-to-right | |
| 4 | 7 | 46.3 | 17.2 | 59.3 | 27.6 |
| | 8 | 29.1 | | 31.7 | |
| | | left-to-right | | top-to-bottom | |

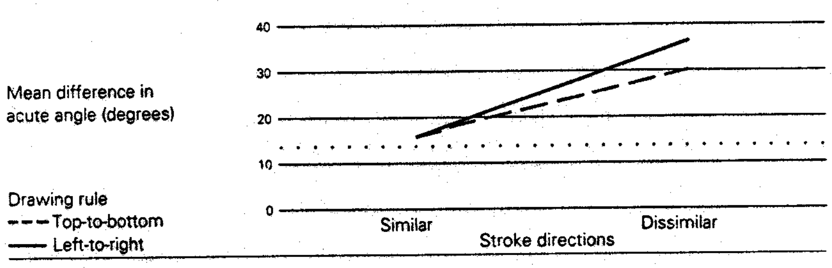
Note: Larger differences indicate that the members of the pairs are more distinguishable. Regardless of the drawing rule used, angle differences are greater when the character pairs are drawn using dissimilar stroke directions.

Angle differences between the members of character pairs were subjected to a two-way analysis of variance (ANOVA) using drawing rule (top-to-bottom or left-to-right) as a between-subjects factor and stroke directions (similar or dissimilar) as a within-subjects factor. As expected, the results indicated that drawing rule was not significant [$F(1,8) = 1.16$, $p = 0.314$]. However, the angle difference between members of character pairs drawn using dissimilar stroke directions ($M = 33.6$ degrees) was significantly greater than the angle difference between members of character pairs drawn using similar stroke directions [$M = 16.3$ degrees; $F(1,8) = 74.70$, $p<0.001$]. The effect of stroke directions was larger for character pairs drawn using the left-to-right rule than for character pairs drawn using the top-to-bottom rule, but this interaction was not significant [$F(1,8) = 3.22$, $p = 0.111$]. The main effect of stroke directions was significant for the top-to-bottom drawing rule [$F(1,4) = 22.82$, $p<0.01$]] and for the left-to-right drawing rule [$F(1,4) = 56.03$, $p<0.01$].[6] These results are depicted in figure 4.

Since the difference between the acute angles of two members of the same character pair is the same for all pairs of undistorted characters (14 degrees), it was meaningful to compare angle differences for character pairs drawn using similar and dissimilar stroke directions to this value. Single distribution t tests revealed that the angle differences for pairs drawn using dissimilar stroke directions were signficantly greater than 14 degrees [$t(9) = 9.06$, $p<0.001$]. The angle differences for pairs drawn using similar stroke directions were also greater than 14 degrees, but the difference was not significant [$t(9) = 1.24$, $p = 0.247$]. The results are similar when the two drawing rules are considered individually. For the character pairs drawn using the top-to-bottom rule, the angle differences for pairs drawn using dissimilar stroke directions were significantly greater than 14 degrees [$t(4) = 4.90$, $p<0.01$], whereas the angle differences for pairs drawn using similar stroke directions were not [$t(4) = 0.617$, $p = 0.571$]. Analogous results were obtained for character pairs drawn using the left-to-right rule [$t(4) = 11.81$, $p<0.001$ and $t(4) = 2.08$, $p = 0.106$ for pairs drawn using dissimilar and similar stroke directions, respectively; see note 6].

In summary, these results indicate that only those character pairs which were drawn using dissimilar stroke directions actually became more differentiated, at least as evidenced by differences in angle measurements. Thus, drawing any of the character pairs using dissimilar stroke directions differentiates the members of the pair in the process, whereas drawing the same character pairs using similar stroke directions leaves the pairs relatively undifferentiated. It is important to remember that the labels differentiated and undifferentiated refer only to the distorted hand-drawn versions of the character pairs and not to the original undistorted pairs or to the drawing methods that might have facilitated or hindered differentiation.

**FIGURE 4.** Mean differences in the acute angle for character pairs drawn using similar and dissimilar stroke directions in each drawing rule. The line at 14 degrees represents the acute angle difference for all pairs of original, undistorted characters.




**Experiment 2**

This experiment was designed to investigate whether the perceptions of subjects would mirror the results of Experiment 1. That is, would subjects actually be better able to distinguish between members of character pairs drawn using dissimilar stroke directions in the previous study? To answer this question, we developed a forced-choice tachistoscope task emphasizing within-pair choices. We hypothesized that subjects would be better able to recognize members of pairs drawn using dissimilar stroke directions than members of pairs drawn using similar stroke directions. Secondly, using the Experiment 1 characters as stimuli in a recognition task provides an opportunity to test the common method hypothesis. We thought that subjects might be more accurate when identifying characters which were drawn using their own drawing rule than when identifying characters which were drawn using the other drawing rule.

Given the results of Experiment 1, it may seem that our first prediction is a foregone conclusion. However, the fact that angle differences are greater when pairs of characters are drawn using dissimilar stroke directions than when the same pairs are drawn using similar stroke directions does not imply that subjects will be able to perceive these differences. For instance, subjects might recognize individual characters without reference to knowledge about other characters in the set. Even if subjects do perceive the angle differences measured in Experiment 1, there is no reason to believe that this is the only criterion subjects would use in identifying characters. Other character features (such as stroke length, hooked strokes, or the angle of one stroke relative to the page) might diminish the saliency of the angle between the two strokes. Since we measured only stroke angles in Experiment 1, it is impossible to predict the pattern of discriminability that might arise from subjects' focusing on other character features in the recognition task. This is not to say that a prediction based on the similarity of stroke directions is unwarranted, but rather that any such prediction needs to be tested experimentally.

- *Method*

*Subjects.* Twenty-one right-handed subjects from the University of Oregon community took part in this study: thirteen received course credit in introductory psychology and eight were paid for their participation. Of those receiving course credit, two were excluded because they failed to meet the pre-set accuracy criterion described below and three chose not to complete the experiment because it was "too difficult."

*Practice and criterion booklets.* One twenty-page practice booklet was created for each drawing rule. The first section was four pages long and consisted of two repetitions of the character set. The characters and their corresponding numerals were presented in order, four per page. Letters and arrows were shown to indicate stroke order and direction. Space was provided to the right so that subjects could copy the characters and numerals. In the second section, characters were presented with their corresponding numerals, but without letters and arrows. Four repetitions of the character set were shown in a mixed order in which no character ever appeared twice on the same page. The third section showed characters without letters, arrows or numerals. Four repetitions of the set were shown in a different mixed order. A two-page criterion booklet was also created for use in screening subjects. One repetition of the character set was shown in a random order with no letters, arrows or numerals.

*Stimulus and choice cards.* Two sets of eighty stimulus cards were created from the characters generated by subjects in Experiment 1: one set composed of characters drawn using the top-to-bottom rule and one set composed of characters drawn using the left-to-right rule. Two examples of each character were selected from the center portion of each of the test booklets in Experiment 1. The characters came from exactly the same locations in each of the ten test booklets. No characters were excluded because they did not look right. If a subject had made an error, only the second, correctly drawn character was used. The individual characters were enlarged by approximately sixty-one percent to a size of about 1 x 1 inch and mounted in the bottom center of 4 x 6-inch tachistoscopic cards. Twenty percent of the characters in the test booklets of Experiment 1 were used to make stimulus cards. A statistical analysis of the selected characters revealed all of the trends previously found for the entire character set (*see figure 5*).[7]

In addition to the two sets of stimulus cards, a set of fifty-six choice cards was also created. One sixty-point Helvetica numeral appeared in each of the top corners of each choice card. These cards represented all possible presentations of non-redundant digit pairs using the numerals one through eight.



One-inch squares were cut from the top corners of the stimulus cards so that one stimulus card and one choice card could be presented simultaneously, the stimulus card in front of the choice card, using only one tachistoscope field. This procedure allowed the experimenter to select individual examples of characters independently from the choice cards.

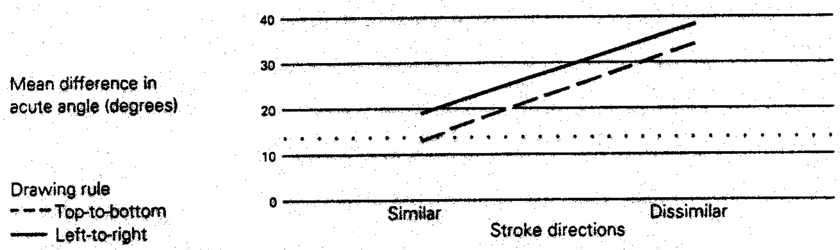
*Experimental procedure.* The entire experimental procedure lasted about one hour. Subjects were tested individually. Of the sixteen subjects retained in the experiment, eight completed booklets using the top-to-bottom drawing rule and eight completed booklets using the left-to-right drawing rule.

For the practice booklet, subjects were instructed to copy each character once in the correct manner and to write the corresponding numeral beside the character they had drawn. This task remained the same throughout the three-section booklet. The experimenter corrected drawing errors as in the previous experiment. If the subject wrote an incorrect numeral beside the character, the experimenter pointed out the error and told the subject the correct number. Depending on the type of error, the subject either re-drew the character in the correct manner or wrote the correct numeral.

After the practice booklet had been completed, the subject participated in a forced-choice task on the tachistoscope. There was one twenty-trial practice block followed by two eighty-trial experimental blocks. Each experimental block used characters from one of the two drawing rules. The order of the experimental blocks was counter-balanced across subjects. The practice block used the same stimulus cards as the first experimental block. Subjects were not told when the practice block was over and the first experimental block began.

In each trial, one stimulus card (showing a hand-drawn character) and one choice card (showing two numerals) were presented on the tachistoscope.[8] The subject's task was to decide which of the two numerals corresponded to the hand-drawn character, and to respond by pressing one of two hand-held buttons (the left button if the correct numeral appeared on the left, and the right button if the correct numeral appears on the right). As soon as the subject responded, the cards disappeared and the computer recorded the subject's answer and response time. If the subject did not respond within three seconds, the

**FIGURE 5.** Mean differences in the acute angle for character pairs drawn using similar and dissimilar stroke directions in each drawing rule. Only data from characters used as stimuli in the recognition task of Experiment 2 are included. The line at 14 degrees represents the acute angle difference for all pairs of original, undistorted characters.




computer beeped, the cards disappeared and no responses were recorded. Other than this limit on response time, no feedback was given during this portion of the experiment.

In each experimental block, the trials were chosen randomly and without replacement from an eighty-trial file that had been skewed in favor of within-pair choices. Of the ten stimulus cards created for each character, four were shown with choice cards depicting within-pair choices and six were shown with choice cards depicting the six possible between-pair choices. The side on which the correct answer appeared was balanced across each of these two trial types. The procedure for the practice block was the same except that only twenty trials were selected from the file. Because the stimulus cards used in the practice block were reused in the first experimental block, it is fairly likely that at least one of these stimulus cards was presented with the same choice card in both blocks (a 77.3 percent chance). However, such occurences were not expected to affect the results of the experiment.

After the tachistoscope task, subjects completed the two-page criterion booklet. Subjects were asked to write the correct numeral by each character in the booklet in any order they wished. They were not required to copy any of the characters. If the subject did not correctly identify all of the undistorted characters, his or her data from the forced-choice task were excluded from the analyses below.

### *Results and Discussion*

Since we were primarily interested in determining which character pairs were more distinguishable, only within-pair choices were included in the analyses. The fraction of within-pair responses that were correct and the mean response time for these correct responses were computed for each character pair in each experimental block. Trials in which subjects' response times were less than 250 ms or greater than three seconds were not included in these computations. Less than one percent of the data were excluded on this basis.

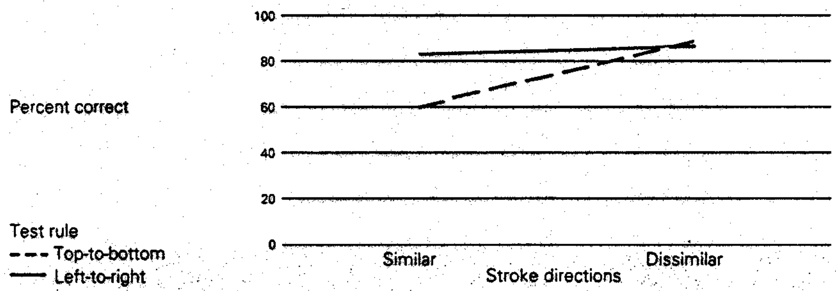
Two separate analyses of variance (ANOVAS) were performed: one for the fraction of responses which were correct and one for the mean response time for correct responses. In both ANOVAS, learning rule (top-to-bottom or left-to-right) was a between-subjects factor and test rule (top-to-bottom or left-to-right) and stroke directions (similar or dissimilar) were within-subjects factors. Learning rule refers to the drawing rule that the subject used in his or her practice booklet, whereas test rule refers to the drawing rule used to create the characters that were shown on the tachistoscope. Initially, block order was also considered as a between-subjects factor. However, since there were no significant main effects or interactions involving this factor, the data were collapsed across block order for these analyses.

There were no signficant main effects or interactions when response time was used as the dependent measure. However, several interesting trends were evident in the accuracy data. As predicted, subjects were significantly more accurate when considering members of character pairs drawn using dissimilar stroke directions ($M = 86.5$ percent correct) than when considering members of character pairs drawn using similar stroke directions [$M = 71.5$ percent correct; $F(1,14) = 44.43$, $p<0.001$]. There was also a significant main effect of test rule [$F(1,14) = 13.59$, $p<0.01$]. Subjects were more accurate on characters drawn using the left-to-right rule ($M = 83.8$ percent correct) than on characters drawn using the top-to-bottom rule ($M = 74.3$ percent correct).

The interaction between these factors was also significant [$F(1,14) = 53.84$, $p<0.001$]. The accuracy difference between members of character pairs drawn using similar and dissimilar stroke directions was much greater when the pairs were drawn using the top-to-bottom rule (28.2 percent) than when the pairs were drawn using the left-to-right rule (1.9 percent). These results are shown in figure 6.

As expected, there was no main effect of learning rule ($F<1$). However, the expected interaction between learning rule and test rule was also absent ($F<1$). Thus, the results of this experiment do not support the hypothesis that recogni-

**FIGURE 6.** Accuracy levels of Experiment 2 subjects viewing members of character pairs drawn using similar and dissimilar stroke directions in each test rule. Data are shown for each of the two test rules, but have been collapsed across learning rule and block order.




tion is improved when readers and writers share a common production system. However, it may be that in this instance the predicted interaction was masked by the unexpectedly large main effect of test rule. Alternatively, subjects may not have been given enough practice at drawing the characters to fully master the drawing rules. This is quite possible, since the practice booklet used in this experiment contained only ten repetitions of the character set, compared to well over thirty repetitions (more or less, depending on the number of characters drawn in the first section of the practice booklet) in the booklets of Experiment 1. If the subjects failed to learn a particular drawing rule adequately during the practice booklet, there would be no reason to expect that they would perform better on characters which had been drawn using the same rule.

The main effect of test rule and the interaction between the test rule and stroke directions factors both appear to be primarily the result of subjects' unexpectedly high level of accuracy on trials depicting members of character pairs drawn using similar stroke directions and the left-to-right drawing rule (i.e., the trials represented by the upper left-hand point in *figure 6*). Why were subjects so accuracte when viewing these characters?

One possible explanation is evident from figure 5. The members of these character pairs have acute angles that differ by 19.2 degrees whereas the members of character pairs drawn using similar stroke directions and the top-to-bottom drawing rule have acute angles that differ by only 12.1 degrees. Neither of these means is significantly different from the 14-degree value for undistorted characters, especially if the Scheffé correction for post hoc comparisons is employed [$t(4) = 2.06$, $p = 0.108$ and $t(4) = -0.42$, $p = 0.694$, respectively; see note 6]. However, this difference only gives us a measure of the amount of additional differentiation, if any, that resulted from the drawing rule. Such a comparison is much less useful here than in Experiment 1. Perhaps the minimum angle difference that is sufficient for subjects to adequately distinguish hand-drawn versions of similar characters in this character set lies somewhere between 12 and 19 degrees.

Alternatively, subjects may have used some other factor to distinguish between members of similar character pairs in the recognition task. For example, subjects may have been sensitive to the angle of one stroke relative to the page rather than to the angle between the two strokes of each character. To test this hypothesis, a second analysis of the subset of Experiment 1 characters used in Experiment 2 was conducted using the angle of one stroke (relative to the page) as the dependent measure. For each character pair, only the stroke which distinguished between members in the dissimilar stroke directions condition was considered. In character pair 1, for example, only the angle of stroke B was considered. We reasoned that subjects might use only the angle of stroke B (and not the angle between strokes A and B) to distinguish the members of pair 1. Likewise, stroke B was considered for pair 3, and stroke A was considered for pairs 2 and 4 (see bottom row of figure 3 for distinguishing strokes).

Using this measure, members of character pairs drawn using the left-to-right rule (test rule in Experiment 2) and similar stroke directions were found to be signficantly more differentiated than their undistorted counterparts [$t(4) = 13.68$, $p<0.001$; see note 6]. All other results were the same as in the original analysis of the characters used in Experiment 2. In other words, some pairs of characters found to be undifferentiated using the "acute angle between strokes" measure were found to be differentiated using the "angle of distinguishing stroke" measure. Thus, it is entirely possible that the subjects' use of criteria other than the difference in acute angle may have resulted in improved performance on the characters in question. Subjects may have used other criteria throughout the recognition task, either in conjunction with, or instead of, the difference in acute angle, or they may have resorted to other criteria only when the difference in acute angle failed to adequately distinguish between similar characters. The angle of the distinguishing stroke is one such alternative criterion that may have improved subjects' performance on members of character pairs drawn using similar stroke directions and the left-to-right drawing rule.

In summary, the results of this experiment lend support to the hypothesis that subjects are better at distinguishing members of pairs labelled differentiated in Experiment 1. However, this was only true for character pairs drawn using the top-to-bottom rule. Apparently, members of all character pairs drawn using the left-to-right rule were differentiated to a sufficient extent to make the forced-choice task relatively easy for subjects in this study, regardless of whether the characters were drawn using similar or dissimilar stroke directions.

The anticipated interaction between learning rule and test rule was not observed. Thus, there is no evidence for a common method effect in these data. However, it once again seems likely that the high degree of differentiation in character pairs drawn using the left-to-right rule made choices between members of those character pairs easier for all subjects regardless of their learning rule. On the other hand, the practice booklet may have been too short for subjects to adequately learn a drawing rule before progressing to the tachistoscope task. The next experiment was designed to investigate the possibility of a common method effect while avoiding these problems.

**Experiment 3**

The purpose of this experiment was to retest the hypothesis that subjects would be more accurate when identifying characters which were drawn using a familiar rule than when identifying characters which were drawn using an unfamiliar rule. In order to avoid possible ceiling effects resulting from subjects' high level of performance on characters drawn using the left-to-right rule, we decided to use only those stimulus cards which depicted characters drawn using the top-to-bottom rule. Subjects learned half of the character set using the top-to-bottom rule and half of the character set using the left-to-right rule. Because test rule was not varied in this experiment, the hypothesized relationship between learning rule and test rule (the common method effect) would be seen as a main effect of learning rule. To insure that subjects adequately learned the correct drawing rule for each character pair, a longer practice booklet, similar in form to the booklets used in Experiment 1, was used in this experiment. We were also interested in determining the time-course of such learning rule effect, if it existed. For instance, subjects might learn to identify characters drawn using one rule more quickly than those drawn using another. Alternatively, there might be no change in the magnitude of a learning rule effect over time. Since we had no reason to suspect that either of these possibilities was more likely than the other, we made no predictions regarding the time-course of the anticipated learning rule effect.

- *Method*

*Subjects.* Fifty-nine right-handed University of Oregon undergraduates received course credit in introductory psychology for participating in this study. Data from twenty-seven of these subjects were excluded from the analysis because the subjects failed to meet the pre-set accuracy criterion, described below.

*Accuracy criterion.* Our pre-set accuracy criterion, designed to be independent of the experimental factors of interest, was that a 75 percent overall accuracy rate be achieved by the end of the recognition task. This accuracy level represents the half-way point between chance and perfection. Although we suspected that the brevity of the recognition task (one eighty-trial block with no practice) might present some difficulty for subjects, we did not anticipate that it would be necessary to test fifty-nine subjects in order to get the planned thirty-two subjects (eight subjects in each of four conditions). In fact, we thought that greater familiarity with the characters (resulting from longer practice booklets) would offset the brevity of the tachistoscope task. A post hoc inspection of the data collected on the twenty-seven excluded subjects suggests that the high percentage of excluded subjects did not affect the experimental results.

*Learning rules.* We required that each subject learn one character pair using similar stroke directions and one character pair using dissimilar stroke directions in each of the two drawing rules. Eight subjects completed the experiment in each of four learning rule/stroke direction combinations.

*Practice booklets.* Subjects practiced drawing the characters in booklets very similar to practice and test booklets used in Experiment 1. However, characters in the first section of the booklet were not presented in numerical order as in that experiment. Instead, characters were presented in a mixed order in which members of the same pair were grouped together. The exact presentation order used for the eight characters in this experiment was 6, 5, 7, 8, 4, 3, 1, 2.

The test booklet of Experiment 1 was included as a fourth section of the practice booklet in this experiment to insure that subjects had as much practice at drawing the characters as did the subjects who generated the characters used for the stimulus cards. There was no test booklet in this experiment.

*Stimulus and choice cards.* Only those stimulus cards from Experiment 2 which depicted characters drawn using the top-to-bottom rule were used. All of the choice cards from that experiment were used. In addition, one set of eight cards depicting the undistorted characters was made. These characters were identical to those in the booklets. Each of the undistorted characters was mounted in the bottom center of a 4 x 6-inch tachistoscope card. The top corners were not cut out of these cards as they were not intended to be shown simultaneously with choice cards.

*Experimental procedure.* As before, the individually-tested subjects completed the experiment in about one hour. Because the experimenter was required to monitor the subjects' drawing methods and quickly correct subjects if they made any mistakes, it was not possible to run subjects from the four learning rule/stroke direction conditions in a random order. Instead, the experimenter continued running subjects in one condition until eight subjects had met the pre-set accuracy criterion. Only then did he move on to the next condition.

Subjects completed the practice booklet according to the procedure in Experiment 1. However, since the subjects learned half of the characters using the top-to-bottom rule and half using the left-to-right rule, it was not possible to tell them a simple drawing rule which applied to all of the characters. This made completion of the practice booklet somewhat more difficult. The experimenter corrected subjects' errors in the last three sections and timed the subjects in the last two sections of the booklet, just as in Experiment 1.

After the subjects completed the practice booklet, they participated in a forced-choice task on the tachistoscope.[9] The task was very similar to that described in Experiment 2. There were several important differences, however. The subjects' task was to learn to pair the numerals one through eight with the characters they had already practiced. To facilitate this learning task, subjects were given auditory feedback by the computer. If the response was correct, a short, high-pitched tone (250 ms, 1800 Hz) was played. If the response was incorrect, a longer, lower tone was played (1000 ms, 600 Hz). In either case, the stimulus and choice cards disappeared as soon as the subject responded. If no response was made within three seconds, the cards disappeared and a pulsing tone was played (five 50-ms, 1200-Hz tones separated by 50 ms of silence, for a total duration of 950 ms). These tones were demonstrated to the subjects before the task began.

Also, to reduce the amount of guessing during the initial trials, cards depicting the undistorted characters were shown in order, one through eight. Each card appeared in the viewing field for three seconds. During this time, the experimenter told the subject the number that corresponded to the character being shown. The test trials began immediately thereafter.

Individual trials were indentical to those in the previous experiment. However, the eighty experimental trials were divided into five blocks of sixteen trials each so that the time-course of subjects' learning might be investigated. Subjects were not aware that the trials had been divided in this way. Since we were interested in monitoring subjects' progress beginning with the very first trial, there were no practice trials in this experiment. Within each of the five blocks of experimental trials, there were eight within-pair choices and eight between-pair choices. Each character appeared once in each of these trial types. The side on which the correct numeral appeared was chosen randomly for each trial.

The fraction of responses that were correct and the mean response time for correct responses were computed for within-pair choices for each of the four character pairs in all five blocks of the experiment. In addition, the fraction of responses that were correct was computed over all trials (including within-pair and between-pair choices) in each of the five blocks. As before, trials in which subjects' response times were less than 250 ms or greater than three seconds were not included in these computations. Less than three percent of the data were excluded on this basis.

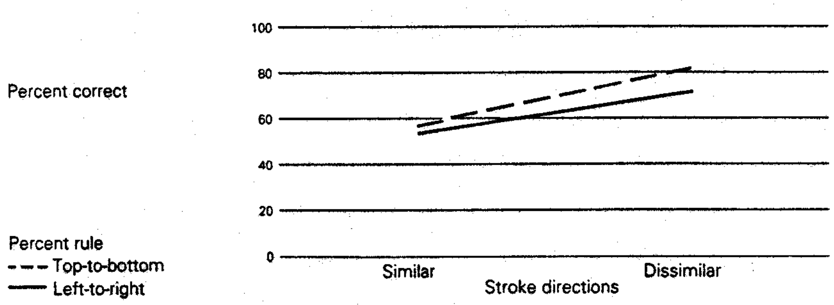
The fractions of responses that were correct (computed over all trials) for the last two blocks were averaged for each subject and the resulting fraction was used as a criterion for inclusion in this study. Data from subjects who did not average 75 percent correct responses over all trials in the last two blocks were excluded from the analysis below.

*Results and Discussion*

As before, only within-pair choices were considered in the data analysis. Because of the large number of cells in which individual subjects made no correct responses, we were unable to consider the mean response time for correct responses as a dependent measure. Hence, data were analyzed using only the fraction of responses that were correct. A three-way ANOVA was conducted using learning rule (top-to-bottom or left-to-right), stroke directions (similar or dissimilar) and block number (1, 2, 3, 4 or 5) as within-subjects factors.

In contrast to Experiment 2, the results of this experiment indicate a significant common method effect, which shows up here as an effect of learning rule [$F(1,31) = 5.76$, $p<0.05$]. Subjects were more accurate when viewing members of characters pairs they had learned using the top-to-bottom rule (M = 69.7 percent correct) than when viewing members of character pairs they had learned using the left-to-right rule (M = 63.8 percent correct). In other words, subjects were significantly more accurate when viewing characters which had been drawn using the rule they had learned during the practice session. This effect of learning rule was in the predicted direction for all four character pairs. The effect of stroke direction was also significant [$F(1,31) = 51.94$, $p<0.001$]. Subjects were more accurate when viewing members of pairs drawn using dissimilar stroke directions (M = 77.2 percent correct) than when viewing members of pairs drawn using similar stroke directions (M = 56.2 percent correct). These results are depicted in figure 7.

**FIGURE 7.** Accuracy levels of Experiment 3 subjects viewing members of character pairs drawn using similar and dissimilar stroke directions in the top-to-bottom rule. Data are shown for each of the two learning rules, but have been collapsed across block order.






Block order also yielded a significant effect [$F(4,124) = 6.52$, $p<0.001$]. Subjects became more accurate as the experiment progressed. There were no interactions between any of the three factors.

The results of this experiment indicate that the method in which subjects practice drawing characters significantly affects their ability to pair those characters with their corresponding numerals. This common method effect holds for all four character pairs in the study. However, there was no indication that the method in which subjects practiced drawing the characters had any bearing on the time course in which the corresponding numbers were learned. It should also be noted that subjects in this experiment learned the characters and their names (in this case, their corresponding numerals) in an unusual way. Normally, people would be expected to practice the character name simultaneously with the drawing method, as in Experiment 2. We deviated from this procedure in Experiment 3 so that we could monitor the time-course of the learning process for the corresponding numbers. Thus, we have demonstrated only that learning to draw characters in a particular method affects subjects' ability to learn the corresponding numerals in a later task. It remains to be demonstrated that a similar common method effect occurs when the characters and their corresponding numbers are learned simultaneously.

**General Discussion**

The answers to the first two of the three questions raised at the beginning of this paper now seem fairly clear. First, drawing method can affect the appearance of individual characters and the differentiation of character pairs in a predictable manner. Second, these differences can be shown to affect the performance of human subjects in a character recognition task. Thus, the results of the first two experiments provide further confirmation of Babcock and Freyd's (1988) finding that the method in which characters are drawn affects the final static traces of the characters. However, these results extend their findings in two important ways. First, the method in which the characters were drawn was shown to affect their appearance in a way which was quantifiable by a simple geometric measure, whereas Babcock and Freyd's study relied only on subjects' perceptions to demonstrate differences in the static character traces. Second, these results show, for the first time, that drawing method can affect the discriminability of character *pairs*. Differences in character pair discriminability were found when the character pairs were measured geometrically and when subjects identified members of the character pairs in a forced-choice tachistoscope task.

On the other hand, the answer to our third question is much less clear because Experiments 2 and 3 provide conflicting information about the presence of a common method effect. Although Experiment 2 provides no evidence for such an effect, there are several alternative explanations for the negative finding. In Experiment 3, the finding that subjects are better able to correctly pair characters with their corresponding numbers when viewing characters which were drawn in their own method is consistent with the results of Freyd's (1983) study and the notion that recognition performance is increased when readers and writers share a common production system. However, this result must be interpreted cautiously because subjects learned the characters in an unusual way. Still, these results represent the first evidence of recognition differences which are directly related to the dynamics of the learning method for *hand-drawn* characters.

The common method effect of Experiment 3 does not distinguish between static and dynamic theories of character perception, however, because subjects saw not only the undistorted characters in the learning process (as in Freyd's 1983 experiment), but also many examples of their own distortions. Therefore, the observed common method effect is consistent with theories of either type. Static feature-analytic theories would predict enhanced performance for members of differentiated pairs on the basis of real configural differences like those shown to exist in the first experiment, even though such differences were clearly the result of the different methods used to create the characters. Likewise, subjects would be better at recognizing characters drawn in their own method, since such characters would look more like the ones that the subjects generated themselves.

In contrast, a dynamic theory of character perception would consider any configural differences in characters generated in Experiment 1 to be dynamic in origin. Therefore, the presence of such cues would serve to convey information about the method in which the characters were drawn (as in Babcock and Freyd, 1988). This methodological information could be later tapped by subjects in the character recognition task. Clearly, such information would be most useful in recognizing characters which were drawn in the subject's own learning method (since only familiar dynamic cues would be present) and in recognizing members of character pairs drawn using dissimilar stroke directions (since members of these pairs would contain different, and therefore distinguishing dynamic cues). Thus, these experiments do not provide any information which favors either static or dynamic theories of characters perception per se. However, the results presented do echo previous suggestions that the dynamics of the learning process are indeed important.

Although in the strictest sense the results of these experiments are generalizable only to novel character pairs which are highly confusable, we feel that these conditions will be met by certain character pairs in the English alphabet. Specifically, we feel that the results are applicable to confusable character combinations like those presented earlier because those characters may be considered novel to a child who is just learning the alphabet. It is not known how long the reported effects may persist in the face of continued experience with the character set.

Even so, the finding that the drawing method in the learning process affects both the appearance of the characters and the writer's perceptions of characters drawn by other individuals may have implications for the teaching of handwriting. The results of Experiments 1 and 2 suggest that confusion between similar characters will be reduced if different stroke orders or directions are used for those characters. Thus, the confusion between the script versions of b and f or d and cl might be reduced by altering the method of production for one of the members in each confusable pair.

However, Freyd's (1983) results and the results of Experiment 3 suggest that creating new drawing methods for characters might make those characters more difficult to recognize for individuals who have already learned to form them in the currently accepted way. It might not prove beneficial to create new drawing methods to disambiguate similar characters since such a change might lead to confusions for the individual characters themselves.

Nonetheless, if there were ever a broad-based movement to standardize the methods of character production, say, for English script or Arabic numerals, it is possible that such confusions would be short-lived. The interim difficulties might be outweighed by the long-term benefits of a more unified vehicle for communication, just as the benefits of adopting the metric system in the United States would probably outweigh the costs of the changeover. In any case, it seems clear that there should be more emphasis on teaching students a common writing method and less emphasis on students' ability to conform to the standard model for each character.

## ENDNOTES

1 Character pair refers to two characters that may be confused with each other (i.e., the c/e character pair) and not to two linked characters (i.e., cl) that may be confused with another character (d, in this case).

2 We use the term hand-drawn rather than handwritten because we are interested in nonletters as well as letters. Nonletters are used in the experiments reported in this paper.

3 The terms differentiate, distinguish and discriminate have very similar meanings, as do their derivatives. Throughout this paper, we use the term differentiated to refer to pairs of characters that, as the result of the writing process, have become more different from each other than were the original, undistorted exemplars. We describe the characters as distinguishable if such differentiation is noticeable to later observers. If the differentiation is noticeable, then the characters (or character pairs) are said to have the property of discriminability.

4 Two types of errors were considered drawing method errors: errors of stroke order and errors of stroke direction. If a stroke drawn in roughly the same direction as the long stroke, A, was followed by a stroke drawn in roughly the same direction as the short stroke, B, the character was considered to be drawn using the correct method. Stroke direction was determined by comparison of the beginning and ending points of the stroke and was based on experimenter judgment. In principle, this could have presented a problem in the case of lines that were drawn nearly perpendicular to the correct stroke direction. However, since no hand-drawn strokes differed from the correct angle by more than about 45 degrees, such judgments were not difficult and do not represent a source of bias in the final set of hand-drawn characters. Incorrect stroke length or placement were not errors of method since they did not violate the drawing rule. Such errors were not corrected by the experimenter. All of the characters accepted by the experimenter could be described as "reasonable distortions" of the characters being copied. Other authors (e.g., Suen, 1983) have also used experimenter judgment as a basis for real-time error correction.

5 The angle between the two strokes was determined by subtraction rather than direct measurement because the strokes usually did not intersect. Direct measurement would have required extending the strokes to their point of intersection, potentially introducing greater measurement error. Subtraction always resulted in a measure for the angle that corresponded to the acute angle between the strokes of the undistorted character, even though this angle may have been greater than 90 degrees for some individual hand-drawn characters. Subtracting the mean angle of one stroke from the mean angle of the other stroke yields the same result as subtracting first and then computing the mean.

6 For all significant post hoc comparisons, F values for simple effects and F values that correspond to stated t values ($F = t^2$) exceed the Scheffé adjusted critical value for F [for example, the adjusted critical value equals $3 \times F_{critical}(3,16) = 9.72$ in the first case].

7 A table analogous to table 2 is available from the first author.

8 Stimulus and choice cards were presented using a Gerbrands G1135 four-field tachistoscope equipped with a Gerbrands 404A lamp driver. The tachistoscope was controlled through a Gerbrands G1157 computer interface that had been adapted for use with an IBM PC/XT.

9 The tachistoscope and computer were the same as used in Experiment 2.



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***Michael DeKay** is a graduate student in social psychology at the University of Colorado in Boulder. After acquiring degrees in chemistry from the California Institute of Technology and Cornell University, he worked as a research assistant in cognitive psychology at Cornell and the University of Oregon. He is interested in social aspects of environmental issues, public policy applications and intergenerational equity.*

***Jennifer Freyd** is associate professor of psychology at the University Oregon. Her Ph.D. (1983) is from Stanford. She received a Presidential Young Investigator Award from NSF (1985) and a fellowship from the Guggenheim Foundation (1989-90). She currently holds a research Scientists Development Award from NIMH. Freyd is interested in cognitive processes underlying human action and experience.*