CANADIAN JOURNAL OF PSYCHOLOGY, 1987, 41(3), 303–316

The Time to Identify Disoriented Letters: Effects of Practice and Font*

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ABSTRACT Subjects named letters shown in four orientations (0°, 60°, 120°, & 180°) as quickly as possible. Identification performance was examined on the first two and the second two presentations of each letter in order to study the effects of orientation on identification before subjects became familiar with the visual characteristics of the stimuli. Two letter fonts were employed; one was familiar and one was less familiar. Performance was examined across trial blocks in the experiment to estimate the effects of practice on subjects' ability to identify the disoriented letters. Naming time increased roughly linearly as the letters were rotated further from the upright from 0° to 120°, but not from 120° to 180°. The orientation effect on the time to identify letters was more pronounced for the less familiar font than for the more familiar font. Furthermore, the magnitude of the orientation effect was larger in the first half of the experiment than in the second half. The results suggest that smaller orientation effects on letter identification time compared with the time to identify other types of visual patterns may be due, in part, to the visual familiarity of typical alphanumeric characters.

RÉSUMÉ Des sujets nommaient des lettres présentées selon quatre orientations (0°, 60°, 120°, et 180°) aussi vite que possible. La performance d'identification était examinée pour les deux premières et les deux dernières de façon à étudier les effets de l'orientation sur l'identification avant que les sujets deviennent familiers avec les caractéristiques visuelles des stimuli. Deux caractères de lettrage ont été employés; l'un familier, l'autre moins. La performance était examinée à travers les blocs d'essais dans l'expérience pour estimer les effets de pratique sur l'habileté des sujets à identifier les lettres mal orientées. Le temps pris pour nommer augmentait presque de façon linéaire au fur et à mesure que les lettres étaient tournées de la position verticale de 0° à 120°, mais pas de 120° à 180°. L'effet d'orientation sur le temps d'identification des lettres était plus prononcé pour les caractères moins familiers que pour les plus familiers. De plus, la grandeur de l'effet d'orientation était plus importante dans la première partie de l'expérience que dans la deuxième. Les résultats suggèrent que les effets d'orientation les plus petits sur le temps d'identification des lettres comparés au temps pris pour identifier d'autres types de patrons visuels peuvent être dus, en partie, à la familiarité visuelle des caractères alphanumériques typiques.

A fundamental problem in visual perception is that of recovering the real-world properties of objects and patterns in the environment from images of these stimuli on the retina. A special case of this general problem is encountered when a perceiver identifies a two-dimensional pattern that has undergone a transforma-

*We thank Larry Jacoby and two anonymous reviewers for insightful comments on a previous version of the manuscript. The research was supported by NSERC grant A2579 awarded to Pierre Jolicoeur. Address reprint requests to Pierre Jolicoeur, Department of Psychology, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1.

tion such as translation in the visual field, expansion or contraction in size, or rotation in the image plane. People are remarkably good at identifying known patterns despite the marked changes in the retinal image associated with these transformations. This remarkably efficient and effortless identification of transformed patterns, however, may conceal underlying computational difficulties associated with the recognition of transformed images (e.g., see Cavanagh, 1984; Hinton, 1981; Marr, 1982; Pinker, 1984; Ullman, 1984). The detailed study of the identification of disoriented patterns is likely to provide valuable information about how patterns are represented in memory and how they are processed during the identification process. This may be the reason for the sustained interest in this problem in psychology (Braine, 1965; Corballis & Nagourney, 1978; Corballis, Zbrodoff, Shetzer, & Butler, 1978; Dearborn, 1899; Eley, 1982; Gibson & Robinson, 1935; Jolicoeur, 1985; Jolicoeur & Landau, 1984; Kolers & Perkins, 1969a, b; Maki, 1986; Rock, 1956, 1973; Rock, Di Vita, & Barbeito, 1981; Rock & Heimer, 1957; White, 1980; Wiser, 1980). In this paper we focus on the identification of letters that have undergone rotations in the image plane.

A number of studies in the literature have purported to show that the visual system identifies simple patterns equally fast at all orientations (e.g., Eley, 1982; White, 1980). If this empirical conclusion were true, then a possible implication of these results might be that the visual system identifies simple patterns by means of a decomposition of patterns into a set of orientation-invariant elementary features. Although models based on the extraction of orientation-invariant features may not prove powerful enough to account for the full range of human pattern recognition abilities (see Pinker, 1984, for some incisive arguments), it is plausible that such models could provide an adequate account of letter recognition. Letters form a small, well defined set of patterns, and it is conceivable that such patterns could be represented efficiently in the visual system using a small set of elementary features. In fact, many models of pattern perception implicitly or explicitly assume that patterns are analyzed into discrete features (e.g., Eley, 1982; Estes, 1972; Gibson, 1969; Johnston, 1981; McClelland & Rumelhart, 1981; Reed, 1978; Rumelhart, 1970; Selfridge & Neisser, 1960; Triesman & Gelade, 1980; White, 1980). The problem of identifying transformed patterns is usually ignored in these models or it is assumed that the features are invariant over various sorts of transformations. Thus, it is assumed that recognition is equally fast at all orientations (e.g., Eley, 1982; White, 1980; but see Hinton, 1981, for a scheme in which orientation-dependent features are mapped into orientation-independent object representations).

In contrast with the above view, there is an increasing amount of evidence that the identification of visual patterns is strongly affected by disorientation. For example, the time to name objects depicted in disoriented line drawings is increasingly longer as the drawings are rotated further from the upright (Braine, 1965; Jolicoeur, 1985; Jolicoeur & Milliken, 1986; Maki, 1986; Shwartz, 1981). Furthermore, the identification of disoriented alphanumeric characters is increasingly error prone as the characters are rotated further from the upright (Jolicoeur & Landau, 1984; Kolers & Perkins, 1969a). These results suggest that feature models in which image transformations are not addressed explicitly may be incomplete.

Many readers will be somewhat confused by now, and for good reason. On the one hand, there are about half a dozen studies in which the time to identify rotated alphanumeric characters (or simple letter-like symbols) has been found either not to vary with orientation or to do so inconsistently (Corballis & Nagourney, 1978; Corballis et al., 1978; Eley, 1982; Simion, Roncato, Bagnara, & Umilta, 1982; White, 1980; Young, Palef, & Logan, 1980; see also Shepard & Cooper, 1982, p. 120). On the other hand, other studies have reported marked and systematic orientation effects for the same sort of stimuli (Jolicoeur & Landau, 1984; Kolers & Perkins, 1969a, b). In addition, substantial orientation effects have been found in the identification of line drawings (Braine, 1965; Jolicoeur, 1985; Maki, 1986; Shwartz, 1981).

In this paper, we reexamine this problem and we propose that some of the inconsistencies in the literature on the identification of disoriented alphanumeric characters may have been produced by the use of different amounts of practice before the collection of experimental data, which may have led to different degrees of stimulus familiarity across different experiments. Recent experiments reported by Jolicoeur (1985) are relevant for our argument. Jolicoeur asked subjects to name line drawings of common objects that were presented in various orientations (the drawings can be seen in Snodgrass & Vanderwart, 1980). In general, naming time was longer for objects rotated further from the upright. More important for the present discussion, however, is the fact that the orientation effect was larger at the beginning of the experiment and decreased as subjects named the same objects over the course of the experiment. The decreased orientation effect with practice was found in three separate experiments. Maki (1986) has also found reduced orientation effects with repeated presentations (see also Braine, 1965). Furthermore, Jolicoeur found that the reduction in the magnitude of the orientation effects did not transfer to objects that had not been seen in the experiment. These results suggest that the reduced orientation effect following previous identifications is not a general ability to identify disoriented patterns. If a general ability was acquired, then the effect would generalize to new objects, but it does not (the boundary conditions of the lack of transfer to new objects remain to be investigated; for example, although there may be little or no transfer to entirely new objects, there may be some transfer to new views of a practiced stimulus, see Bartram, 1974). Again, these results are robust and have all been replicated in additional experiments (Jolicoeur & Milliken, 1986).

The considerations outlined above led us to the following hypotheses about the identification of disoriented letters. First, letters are very familiar forms, and if familiarity with the visual characteristics of a particular class of pattern tends to be associated with small orientation effects, then we would expect relatively small effects of orientation on the identification of letters. In addition, if effects of orientation on identification performance are found in the first blocks of the

Figure 1. The first row shows example letters in the Profil font (unfamiliar). The second row shows the same letters in the Gill Extra Bold font (familiar).

experiment, then these effects should decrease with additional practice (Jolicoeur, 1985; Maki, 1986).

The experiment also tested another aspect of the hypotheses presented above. If letters are associated with small effects of orientation by virtue of the fact that they are visually familiar patterns, then we would expect that somewhat less familiar visual patterns would be associated with more substantial effects of orientation. This notion was tested by including letters shown in two different fonts. One font was a typical and very frequent style of character, whereas the other font was a less familiar style of character. Example letters in each font can be seen in Figure 1.

The main predictions for the experiment are straightforward: First, the time to identify letters should increase with increasing disorientation. Second, the orientation effect should decrease with practice. Finally, the magnitude of the orientation effect should be larger for the less familiar letters than for the familiar ones.

Method

Subjects: The subjects were 32 undergraduates at the University of Waterloo who participated in the experiment for pay. All subjects had normal or corrected-to-normal vision.

Stimuli: The stimuli were created using 24 point upper-case Letraset letters taken from two fonts: Gill Extra Bold and Profil (see Fig. 1). The following letters were used as the experimental set: A, F, G, L, P, R, T, Y. The letters D, E, H, K, M, S, V, and X were used in practice trials and warm-up trials. Each letter was transferred from the Letraset sheet directly onto a mylar film, which was then cut out and held in a 35 mm slide frame. Each letter was mounted at 0°, 60°, 120°, and 180° of clockwise rotation in the image plane. The letters subtended a maximum of about 4.6° of visual angle.

Procedure: On each trial a single letter was presented on a rear-projection screen with a Kodak carousel slide projector equipped with an electromechanical shutter. The task was to name the letter as quickly as possible, while making as few errors as possible. A millisecond clock was started simultaneously with the opening of the shutter and was stopped by the onset of the subject's verbal response, as indicated by a voice-activated relay. The letter remained in view until the subject's response. After each trial, the experimenter entered whether the response was correct or incorrect into a microcomputer that controlled the presentation of the stimuli and recorded response times and response accuracy. Trials spoiled by accidental or spurious triggerings of the voice-activated relay were treated as errors.

The letters for each font were arranged into blocks of eight trials with each letter appearing once in each block. All the letters in a given block were from the same font. Two letters in each

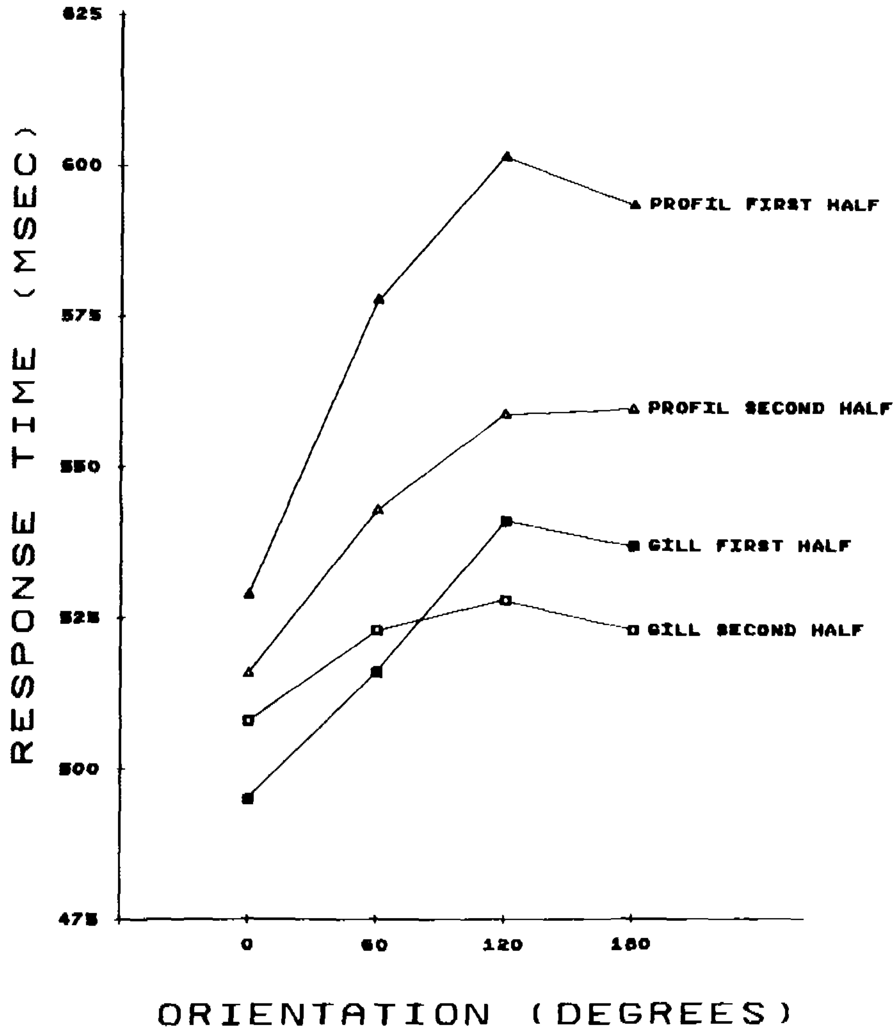

Figure 2. Mean naming time for Gill (familiar font) and Profil (unfamiliar font) letters at each orientation in each half of the experiment.

block were shown at each of the four orientations. The letters within each block were ordered at random with the constraint that each half block (four trials) include each orientation once. There were four blocks for each font. Two trials were added to the beginning of each block to serve as warm-up trials; the data from these trials were not recorded. Half of the subjects were tested with four blocks of trials showing familiar letters (Gill Extra Bold) followed by four blocks of unfamiliar letters (Profil). The other half of the subjects saw the fonts in the other order. The order of blocks for each font was varied from subject to subject using a Latin square design. Finally, before the four blocks of trials in a given font, the subject named letters (not included in the experimental trials) in 10 practice trials in the same font as the upcoming experimental trials. There was a brief pause between each block of trials during which the experimenter set the slide tray to the first slide of the next block.

Results

Naming Times: The mean naming time for correct responses for trials in each orientation, each font, and in each half of the experiment (first two blocks vs. last two blocks) was computed for each subject. Observations greater than 1500 msec were treated as outliers and rejected from the analysis, which resulted in the loss of three observations (0.15% of the data). The means were submitted to a repeated measures analysis of variance in which half, font, and orientation were the factors. The means of these means for the two fonts, the two halves of the experiment, and the four orientations are shown in Figure 2.

Overall Orientation Effect. Letters that were rotated further from the upright, in general, were named more slowly than less rotated letters, $F(3, 94) = 70.10$, $p < .0001$. This increase in identification time across orientation was also reflected in a significant linear trend in orientation, $F(1, 15) = 124.50, p < .0001$. These results demonstrate a clear-cut effect of orientation on the time to identify disoriented letters. Furthermore, as expected from the results of Jolicoeur and Landau (1984) in which errors of identification increased linearly from upright characters to upside-down ones, the increase in naming time with increasing disorientation had a strong linear component. As evident in Figure 2, however, the increase in identification time was linear only from 0° to 120°, and there was a dip in the function at 180°. Although the reasons for the dip at 180° are not fully understood, the result itself is not unusual (e.g., Corballis et al., 1978; Jolicoeur, 1985). Because of the dip at 180°, the increase in identification time with greater rotations of the pattern also had a significant nonlinear component, which is reflected in the quadratic trend in orientation, $F(1, 31) = 36.17, p < .0001$.

Practice and the Orientation Effect. As can be seen in Figure 2, the magnitude of the orientation effect was larger in the first half of the experiment than in the second half, $F(3, 93) = 3.37, p < .025$. The decrease in the orientation effect was also reflected by a significant decrease in the average slope of the regression lines across subjects from the first to the second half, $F(1, 31) = 10.04$, $p < .004$. The decreased orientation effect on the identification of rotated letters with practice converges nicely with the results of Jolicoeur (1985) in which orientation effects on the time to identify rotated line drawings also decreased with practice.

Differences in the Orientation Effect Across Fonts. Also evident in Figure 2 is the fact that the increase in identification time from upright to upside-down letters was larger for Profil letters than for Gill letters. The overall interaction between font and orientation was significant both in the omnibus analysis of variance, $F(3, 93) = 5.54, p < .002$, and in the analysis of linear trends in orientation, $F(1, 31) = 19.64, p < .0001$. These results support the hypothesis put forth in the Introduction that the identification time for letters presented in a less familiar font (Profil, see Fig. 1) would be affected by rotation more than letters shown in a more familiar font (Gill Extra Bold).

Other Effects Involving Fonts and Practice. Naming times were longer for the Profil letters than for the Gill letters (Profil, 560 msec; Gill, 521 msec), $F(1, 31) = 61.62, p < .0001$. As would be expected, naming time was longer in the first

TABLE 1
Mean Naming Time for Letters

Font	Named	Orientation				
		0°	60°	120°	180°	*M*
Gill	First	518	535	556	552	541
	Second	485	504	511	508	502
Profil	First	519	561	580	576	559
	Second	526	561	581	578	562

half of the experiment than in the second half, $F(1, 31) = 21.51$, $p < .0001$. Finally, naming latency decreased more with practice for Profil letters than for Gill letters (Profil first half, 576 msec, second half, 545 msec; Gill first half, 522 msec, second half, 520 msec), $F(1, 31) = 16.62$, $p < .0003$. The only non-significant effect was the three-way interaction between font, half, and orientation, $F < 1$, in the overall analysis and in the interaction with the linear component of orientation.

Separate Analysis of Results for the Gill Font. Given that several studies suggest that the time to identify letters in a familiar font is not related systematically to the orientation of the letters, we analyzed the results for Gill letters separately. In this analysis the factors were orientation and half. As suggested by a visual inspection of Figure 2, there was a significant effect of orientation, $F(3, 93) = 21.78$, $p < .0001$, and the orientation effect had a significant linear component, $F(1, 31) = 51.61$, $p < .0001$. Finally, the decrease in the magnitude of the orientation effect across halves of the experiment was significant in the overall analysis, $F(3, 93) = 2.86$, $p < .042$, and in the analysis of linear trends, $F(1, 31) = 10.87$, $p < .003$.

Analysis for Transfer of Practice Across Fonts. Recall that each subject named letters in eight blocks of trials, four blocks involving the Gill font and four blocks involving the Profil font. Furthermore, half of the subjects named Gill letters first and then Profil letters, whereas the other half saw the fonts in the other order. Because the letters were the same across fonts, the experimental design allows us to test whether the reduced orientation effect observed for trials involving one font transferred to the other font. We performed two additional analyses to test for between-font transfer, one for each font. In each analysis the factors were group (whether the subject named letters in the font targeted by the analysis first, or after naming letters in the other font), half, and orientation. The logic of the analyses is as follows: If experience acquired in naming letters in the other font transfers across fonts, then the magnitude of the orientation effect on identification time should be smaller for subjects in the group that named letters in a particular font after having named letters in the other font than for subjects who named these letters without prior practice.

The mean naming times across fonts, groups (whether that font was seen first or second), and orientations are listed in Table 1. Overall, the results provide little or no evidence of transfer across fonts. Consider first the results for Gill letters.

The effect of orientation on naming times did not differ across the two groups, according to the test of the overall interaction between group and orientation, $F(3, 90) = 1.14$. However, the test of the difference in linear trends did approach significance, $F(1, 30) = 3.04, p < .092$. Compared with the significant effects of practice within trials for a particular font, however, these results suggest that there was minimal transfer of practice from naming disoriented Profil letters to naming disoriented Gill letters.

Now consider the results for Profil letters. In this case, there was no hint of transfer from naming Gill letters to naming Profil letters: The pattern of means across orientations was virtually identical for the two groups of subjects (those who named Profil letters first vs. those who named Profil letters after having named Gill letters), $F < 1$, both for the overall group by orientation interaction and for the group by orientation linear interaction.

A Possible Artifact. Because of the small number of letters in the experiment, and because of the structure of each block of trials (eight trials in which each letter occurred once), it is possible that subjects could have come to predict the identity of up-coming letters near the end of a block by keeping track of which letters had been named up to that point. Furthermore, we would expect that if subjects used this strategy, they would do so only after a number of blocks of trials during which they would learn the structure of trial blocks and the set of letters used in the experiment. It seems possible that the reduction in the magnitude of the orientation effect with practice could have been due to the adoption of the cognitive strategy suggested above, rather than to fundamental mechanisms of pattern recognition in the visual system, as we wish to argue.[1] We will refer to the possibility that subjects adopted a guessing strategy and that this strategy was responsible for the reduced orientation effect with practice as the *guessing hypothesis*.

We performed an additional analysis to discover whether the reduction in the magnitude of the orientation effect was due to a sophisticated guessing strategy or to some form of visual learning. In this analysis we considered only the results from the first four trials in each block. The strategy assumed by the guessing hypothesis could manifest itself only in the later trials of any particular block of trials, given that this strategy depends on predicting up-coming letters based on which letters have already been seen in that block. If the guessing hypothesis is the correct explanation of the reduced orientation effects after practice, then there should be little or no reduction in the magnitude of the orientation effect in the results from the first few trials in each block. In fact, the practice effect reported above was also found in the present analysis, which considered only the first four trials in each block: The orientation by half (first two blocks vs. second two blocks) interaction was clearly significant, $F(3, 93) = 3.78, p < .015$, in the overall analysis and in the analysis of linear trends, $F(1, 31) = 9.02, p < .006$.

Another set of analyses in which the results from the first four trials in each block were contrasted with the results from the last four trials also failed to sup-

[1]We thank Larry Jacoby for pointing out this potential problem.

TABLE 2
Mean Percent Error Rate

Font	Half	Orientation 0°	60°	120°	180°	M
Gill	First	0.8	1.6	3.1	0.0	1.4
	Second	1.6	1.6	0.8	1.6	1.4
Profil	First	2.3	0.8	4.7	4.7	3.1
	Second	3.1	1.6	3.9	1.6	2.5
M		1.9	1.4	3.1	2.0	

port the guessing hypothesis. Additional evidence against the guessing hypothesis can be found in the absence of transfer from one font to the other. This lack of transfer suggests that the reduced orientation effect resulted from learning specific visual attributes associated with the particular fonts rather than from a general guessing strategy based on the structure of the trial blocks.

Finally, although the guessing hypothesis could have provided a plausible explanation of the results in the present experiment, in which each block had only eight letters, it is implausible as a general account of the reduced orientation effect phenomenon. In several other experiments the number of items in each block was much larger (ranging from 36 to 72 in Jolicoeur, 1985). It seems unlikely that subjects would be able to predict the identity of the remaining items in a block except for a very small proportion of trials near the end of the block. Finally, in other experiments, we observed the reduced orientation effect on practiced items when the practiced items were intermixed with nonpracticed items in a random sequence. The guessing strategy would be virtually useless under these conditions, yet the reduced orientation effect was observed nonetheless (Jolicoeur & Milliken, 1986).

Overall, we are confident that the reduction in the magnitude of the orientation effect across halves of the present experiment was not due to a guessing strategy, as assumed by the guessing hypothesis. Rather, the phenomenon appears to result from learning, and later use of, visual attributes of the stimuli.

Errors: The average number of errors (and spurious triggerings of the voice-activated relay) was computed for each subject, each half, each orientation, and each font. The mean error rates are listed in Table 2. The means were submitted to the same type of analysis used for the naming times. There was only one marginally significant effect, reflecting the larger error rate on Profil letters than on Gill letters (Profil, 2.8%; Gill, 1.4%), $F(1, 31) = 3.62, p < .07$. As evident in Table 2, the orientation effect on errors was nonsystematic, which is also indicated by the nonsignificant linear trend over orientation, $F < 1$. All other effects were nonsignificant. The results in Table 2 do not suggest a speed-accuracy trade-off interpretation of the identification time results.

Discussion

The results were as predicted in the Introduction. First, there was a clear-cut increase in identification time for both the Gill and Profil letters as the letters were rotated further from the upright. Second, the magnitude of this effect decreased with repeated exposure to the letters used in the experiment. These results converge nicely with earlier work showing the same decreased orientation effect on identification time when subjects name line drawings of natural objects (e.g., Jolicoeur, 1985).

As in several previous reports, the identification performance for upside-down letters (see results for 180° in Fig. 2) was better than would be expected from a linear extrapolation of the increase in naming time from 0° to 120°. We have no ready explanation for this phenomenon. However, such results have been obtained in a number of earlier studies (e.g., Braine, 1965; Corballis et al., 1978; Jolicoeur, 1985; Koriat & Norman, 1985; Rock, 1973), and the phenomenon may provide interesting clues about the perception of disoriented forms.

The overall pattern of results strongly supports the following claims about the time to identify letters rotated in the image plane. First, the time needed to identify letters can be affected in a systematic way by the orientation of the letters. In the present study, identification time increased linearly as letters are rotated further from the upright from 0° to 120°, but the orientation function had a dip at 180°. Second, the effect of orientation is stronger on the initial viewing of the patterns than after a number of presentations, which suggests that familiarity with the visual characteristics of the stimuli is instrumental in reducing the initial effects of orientation on identification time. The claim that subjects quickly learn specific visual characteristics of disoriented stimuli is supported further by the fact that the reduced orientation effect resulting from practice with one letter font did not appear to transfer to the other font.

A third claim is weakly supported by the results: The effect of orientation is stronger for less familiar letter fonts than for more familiar fonts. The present study offers only weak support for the hypothesis that familiarity with different fonts is associated with different magnitudes of orientation effects because there are other possible explanations of the differential results across the two fonts used in the present study, including complexity and implied three-dimensionality. The possibility that more complex patterns may be more difficult to normalize (or more neutrally, that complexity and orientation interact statistically) is interesting, however, given the difficulty in obtaining orientation effects of different magnitudes for stimuli differing in complexity in studies of mental rotation (e.g., Cooper & Podgorny, 1976; but see Kosslyn, 1980, and Yuille & Steiger, 1982). In any case, these considerations do not militate against our claim that familiarity leads to decreased orientation effects given that the size of the orientation effect was smaller in the second half of the experiment than in the first half for both Gill and Profil letters. Furthermore, the present results demonstrated clear-cut effects of letter font on the size of the orientation effect, which may be worthy of study in future work. If nothing else, the results add further embarrassment to the view that pattern recognition in humans relies solely on the extraction of orientation-invariant features.

Taken together, these results suggest a resolution to some inconsistencies in the literature concerning the identification of disoriented alphanumeric characters or letter-like symbols. On the one hand, it is clear that one can observe systematic orientation effects on the time to identify disoriented characters. These results confirm the findings of earlier studies reporting such effects (e.g., Jolicoeur & Landau, 1984; Kolers & Perkins, 1969a, b). On the other hand, with repeated testing on the same set of characters in the same font, the magnitude of the orientation effect is reduced. Although orientation effects were still significant in the second half of our experiment, the experiment was rather short and involved relatively few trials. It is likely that continued testing would have resulted in further decreases in the effect of orientation, which would produce results like those reported by studies in which orientation effects were negligeable (e.g., Corballis & Nagourney, 1978; Corballis et al., 1978; Eley, 1982; Simion et al., 1982; White, 1980; Young et al., 1980; see also Shepard & Cooper, 1982, p. 120).

As an example, consider how our results may help explain some apparently inconsistent or variable aspects of the results reported by Corballis et al. (1978) in which subjects identified normal and mirror-reversed views of letters and digits shown in various orientations. In their first experiment, Corballis et al. reported significant orientation effects only for the identification of mirror-reversed characters and that these effects were significant only in the first of two blocks of trials. A similar pattern of results was found in their third experiment. These results are consistent with ours on the assumption that mirror-reversed characters are less familiar visual patterns than are normal characters. This assumption is supported by the fact that mirror-reversed characters were identified more slowly than normal characters by about 40 msec. Given our results, in which less familiar letters were associated with larger orientation effects than more familiar letters, we would also expect larger orientation effects with mirror-reversed characters. The disappearance of the orientation effect in the second half of the experiment is consistent with our notion that more familiar patterns are more immune to orientation effects and with the reduction in the magnitude of orientation effects obtained with practice in the present study. Again, it is likely that the nonsignificant orientation effects for normal characters reported by Corballis et al. were due to the fact that subjects had received practice trials that included several exposures to each of the six characters prior to their use in the experiment proper (six exposures to each stimulus in normal version and six exposures in mirror-reversed version). A similar account can explain why orientation effects were found in Experiment 3 of Corballis et al., but not in Experiment 2.

In general, our results highlight the flexibility and adaptability of the human pattern recognition system. When subjects identify familiar patterns in a familiar context, orientation effects are much smaller than is otherwise the case. It is possible that the reduction in the effects of orientation are due, in part or in whole, to the extraction and use of orientation-invariant attributes of the patterns. In this view, as subjects see the entire stimulus set in the early phases of an experiment, they learn which orientation-invariant attributes can discriminate between various alternatives in the stimulus set. As the experiment progresses, they may base their identification responses increasingly on the extraction of these attributes. This strategy would account for the gradual decrease in the magnitude of the orientation effect with practice. Before they have seen all the stimuli, however, they would not know which attributes would likely be reliable discriminators. Thus, initial identifications would not rely on the extraction of orientation-invariant attributes, which is consistent with the substantial initial effects of orientation. This account is also consistent with the lack of transfer to new patterns observed in studies of object identification (Jolicoeur, 1985; Jolicoeur & Milliken, 1986) and for the lack of transfer across fonts in the present experiment.

Although the strategy outlined above is plausible, other alternatives are possible. A straightforward possibility is that subjects store multiple representations of each pattern, especially when the same pattern is presented in multiple orientations across a number of trials. In subsequent trials, the identification of a pattern seen previously, even if shown in a novel orientation, could benefit from the presence of multiple representations. On the assumption that inputs are normalized in an analogue fashion along the dimension of orientation (Dixon & Just, 1978), the input would not, in general, need to be normalized to the upright. Any of the previously stored views would do, and it would become increasingly likely, over the course of an experiment, that the orientation of one of the previous views would be closer to the orientation of the input pattern than the upright (see Cavanagh, 1984, for a contemporary approach to pattern recognition using analogue representations based on spatial-frequency analysis). According to the view that multiple representations are stored, one would also expect a gradual decrease in the effect of orientation over the course of an experiment and that this decrease would be specific to a particular set of patterns; namely, those patterns for which the subject has had an opportunity to store multiple representations. In general, the notion that the visual system quickly adapts to novel situations by storing multiple specific instances is consistent with some recent proposals in the literature on memory and categorization (Brooks, 1978, in press; Jacoby, 1983a, b).

Conclusions: Although our results cannot distinguish between the above two explanations (and between other possible explanations) of the reduction in the effect of orientation with practice, they suggest that classical approaches to pattern recognition that are based solely on the extraction of orientation-invariant features are incomplete (e.g., Milner, 1974; Sutherland, 1968; see Pinker, 1984, for other criticisms of such models). The present results and those of Jolicoeur (1985) are suggestive of more complex pattern recognition systems. One possibility involves multiple, possibly analogue, representations of visual patterns along with the likely involvement of some form of normalization. Another possibility is that of a dual system in which both analogue and analytic forms of representation are involved, with the analogue system mediating the recognition of novel patterns and the analytic system mediating the recognition of familiar patterns (see Cavanagh, 1984, for another proposal involving a mixture of analogue and analytic mechanisms).

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Received 30 September 1986
Accepted 7 January 1987