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Why Is Word Recognition Impaired by Disorientation While the Identification of Single Letters Is Not?

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Past research has shown that speed of identifying single letters or digits is largely indifferent to orientation, whereas the recognition of single words or connected text is markedly disrupted by disorientation. In a series of four experiments, we attempted to reconcile these findings. The results suggest that disorientation does not impair the identification of the characters but disrupts the perception of their spatial arrangement. When spatial order information is critical for distinguishing between different stimuli, disorientation is disruptive because some rectification process is required to restore order information. Utilizing the similarity between the letter *B* and the number *13*, we found strong effects of orientation when a stimulus was interpreted as the two-digit number *13* but not when interpreted as the single letter *B*. This, however, occurred only when the set of numbers to be classified included permutations of the same digits (Experiments 1 and 2). Odd–even decisions on single-digit and two-digit numbers (Experiment 3) yielded strong effects of stimulus orientation for order-dependent numbers (e.g., *32*), weaker effects for order-independent numbers (e.g., *24*), and none for repeated-digit (e.g., *22*) or single-digit numbers. Classification time for two-letter Hebrew words evidenced strong effects of orientation for words that differed only in letter order but much weaker effects for words that had no letters in common, even when these were embedded within some words that did (Experiment 4).

In the present study we address an apparent inconsistency in the experimental literature on the recognition of disoriented alphanumeric characters. On the one hand, the identification and classification of single characters appears to be largely indifferent to orientation. On the other hand, the recognition of words or sentences is greatly impaired by disorientation.

As for single characters, several researchers examined the identification of alphanumeric characters at different orientations. Corballis, Zbrodoff, Shetzer, and Butler (1978) found that angular orientation had little effect on the latency of identifying alphanumeric characters. A slight effect on the latency to name the characters was found, but it dissipated with practice. Corballis and Nagourney (1978), who asked subjects to classify characters as letters or digits, also found response time to be largely unaffected by angular orientation. In another study, Cooper and Levin (see Cooper & Shepard, 1978) required subjects to name letters appearing at different orientations and found that identification was equally rapid and accurate at all orientations. These findings are in contrast with those obtained for the reflection decision task, in which strong and systematic effects of angular deviation from the upright are typically found (see Cooper & Shepard, 1973). The indifference of identification time to angular orientation has been interpreted as suggesting that simple identification does not require a rectifying mental rotation of measurable duration. Further support for this conclusion comes from the finding that advance information concerning the identity of a rotated alphanumeric character speeded up reflection decisions by about 100 ms, but did not change the function relating response time to orientation. It thus appears that about 100 ms are required to identify the alphanumeric character regardless of its orientation (Cooper & Shepard, 1973).

In a more recent study, White (1980) compared subjects' performance in making one of three decisions regarding single alphanumeric characters, depending on a cue that preceded the character. Reflection decisions evidenced large effects of stimulus orientation, but again no such effects were found for naming the character or for classifying it as a letter or a number. The failure of such studies to demonstrate systematic effects of orientation on identification might have been due to their using a small ensemble of stimuli, which enabled the subjects to learn a set of distinctive orientation-free features. However, in Eley's study (1982) subjects were trained to recognize 20 novel letterlike symbols, and then were tested in recognizing the symbols at different orientations. No orientation effects were obtained regardless of the amount of practice. Nor were systematic effects of disorientation found for stimuli consisting of visually complex Japanese characters (Eley, 1983).

There are some instances in which angular orientation does affect identification performance on single characters. First, when subjects were required to discriminate between letters that were mirror-images of each other (e.g., *b* and *d* or *p* and q), response time increased systematically with degree of disorientation, similar to what is normally found for the

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reflection decision task (Corballis & McLaren, 1982). Second, when Jolicoeur and Landau (1984) required subjects to identify single characters that were presented briefly and then masked, they found systematic and pronounced effects of orientation on proportion of errors. They argued that because letter identification is extremely rapid, reaction time is not sensitive enough to capture the effects of disorientation. Apart from these reports, however, the time required to recognize alphanumeric characters has been found to yield only minor effects of disorientation; this suggests that disoriented alphanumeric characters are directly identified without rotation to the upright (e.g., Cooper & Shepard, 1978; Corballis & Nagourney, 1978; Simion, Bagnara, Roncato, & Umiltá, 1982; White, 1980).

The conclusion that the identification of alphanumeric characters is largely indifferent to disorientation stands in sharp contrast to the common observation that upside-down text is substantially more difficult to read than normal text. Several studies have indicated that word recognition and reading are greatly disrupted by disorientation (e.g., Dearborn, 1899; Navon, 1978). Kolers and his associates (e.g., Kolers & Perkins, 1969a, 1969b), for example, had subjects read texts at various transformations and examined the effect that training might have on this task. Although there was an improvement with practice in reading each transformation, even after extensive practice the transformed text was clearly much more difficult to read than the normal text. Thus, Kolers (1968) measured the time it took to read 310-word passages of text. At the beginning of the experiment, upside-down text took nearly three times longer to read than normal text. Although there was a slight improvement in the speed of reading upside-down text over the experimental days, it still took 2.5 times longer at the end of the experiment.

In one study, we (Koriat & Norman, 1984) systematically investigated the effect of visual orientation on word recognition. Subjects performed lexical decisions on five-letter Hebrew strings that appeared at different orientations. Response time was found to increase considerably with angular deviation from the upright. In Experiment 2, for example, this increase was from 847 ms for the 0° orientation to 2,055 ms for the 180° orientation. These results suggest that, unlike the identification of a single alphanumeric character, the recognition of a word is strongly impaired by disorientation. This presents a dilemma. Why is an upside-down letter identified as quickly as an upright letter, whereas an upside-down word takes so much longer to recognize than an upright word?

A subsequent study (Koriat & Norman, 1985) provided some clues to the solution of this dilemma. We investigated the effect of orientation for strings of different lengths, from two to five letters. Response time again revealed very strong effects of orientation, but the extent of these effects increased monotonically with the number of letters in the string. In Experiment 1, for example, the extent of the orientation effect, from 0° to 180°, amounted to 339 ms for two-letter strings and 1,100 ms for five-letter strings.

The increase in the extent of the orientation effect with increasing string length is difficult to explain in view of the observation that for normally oriented words, lexical decision latency is generally indifferent to word length (e.g., Frederiksen & Kroll, 1976; Koriat, 1984). Thus, angular disorientation seems both to impair word recognition and to make recognition time more heavily dependent on the number of constituent letters. It should also be noted that in our studies (Koriat & Norman, 1984, 1985), as well as in earlier studies (e.g., Dearborn, 1899), the shape of the rotation function differs considerably from that found for reflection decisions on single letters. Notably, the function does not peak at 180° but has a flat top, in that for orientations between 120° and 240° response time does not increase with disorientation. This may suggest that the rotation functions obtained for words do not stem from the type of mental rotation operation assumed to underlie the typical rotation function obtained for reflection decisions on single letters.

The stronger effects of orientation on word recognition than on letter identification may derive from some aspect of the reading process that underlies the recognition of words. This implies an interesting possibility: Perhaps the latency of identifying the letter *a* is indifferent to disorientation, but the time to decide that *a* is a word increases systematically with angular deviation from the upright. Because no single-letter words exist in Hebrew, we could not test this possibility in our study. However, there is an observation which suggests that the orientation effects found for the lexical decision task, but not for the letter identification task, do not derive from an inherent difference between the two tasks but probably from the number of visual "elements" that have to be processed.

This observation is based on a reanalysis of the data from two previously reported experiments (Koriat & Norman, 1985, Experiments 1 and 3). Both entailed lexical decisions on two- to five-letter strings that appeared in 6 (Experiment 1) or 12 (Experiment 3) different orientations. In this reanalysis we calculated the size of the orientation effect (i.e., the increase in reaction time [RT] from 0° to 180° orientation) for each string length. These values are plotted in Figure 1 as a function of number of letters in the string. Two features are immediately apparent. First, the extent of the orientation effect increases in a remarkably linear manner as a function of string length in both experiments. Second, and more important, when the curves are extrapolated to "one-letter strings," they seem to intercept the ordinate at a value quite close to a null orientation effect.

Further evidence substantiating the idea that orientation has little effect on single-letter lexical decisions was obtained in a pilot study. Twenty-four subjects performed lexical decisions on two-letter Hebrew strings when the first letter was presented orally and the second letter was displayed visually at varying orientations. Sixty words and 60 nonwords were used, all containing only consonantal letters (in Hebrew the word *har*, for example, is spelled *hr*; see Koriat, 1984). The experimenter's reading of the first letter aloud activated a voice-operated relay, and 500 ms later the second letter appeared on a screen at one of six orientations: 0°, 60°, 120°, 180°, 240°, and 300°. Analyses of response time and percent errors yielded no significant effects of, or interactions with, second-letter orientation, except for a somewhat faster response time for the upright orientation (1,030 ms) than for all nonupright orientations combined (1,085 ms), $F(1, 23) =$

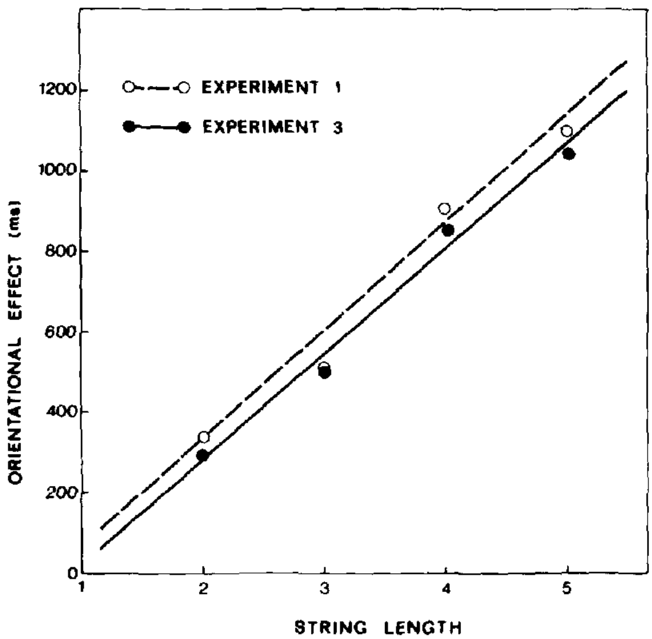

Figure 1. The extent of orientation effects on lexical decision time as a function of string length for Experiments 1 and 3 of Koriat and Norman (1985).

6.02, $p < .05$. A similar pattern of results was found by Eley (1983) for the recognition of Japanese characters. Subjects apparently prepared themselves for the presentation of an upright letter. But when the letters were not upright, no sign was found for any systematic effect of the extent of the angular deviation from the upright. In sum, it does not appear that orientation effects occur in a lexical task when only a single letter is presented visually.

Experiment 1

Given that no systematic orientation effects are found for single letters, why, then, are such effects obtained for alphanumeric strings containing two or more elements? As a first step in addressing this issue, we examined the question of whether the definition of *element* that underlies the differential effects of orientation on single- and multielement stimuli is visually or lexically based. On the one hand, words differ visually from single letters in that they consist of a pattern of distinct, spatially discrete units, and it is perhaps this characteristic that is responsible for the debilitating effect of disorientation. If this is the case, we might expect orientation effects even for single characters, when these are represented by several visually distinct elements (e.g., the Hebrew letter *Heh*; see Koriat & Norman, 1984, Figure 1). On the other hand, words, unlike letters, consist of subunits that have independent lexical representation. If this is the critical feature, then we should expect orientation effects for the same stimulus when it is coded as a multielement stimulus but not when it is coded as a single unit. This idea was explored in Experiments 1 and 2. In these experiments we took advantage of the similarity between the letter *B* and the number *13*. This similarity is often exploited to demonstrate the effects of context or expectation on perception, where the same stimulus may be interpreted either as the letter *B* or as the number *13*, depending on the context (see, for example, Coren, Porac, & Ward, 1984, p. 362), as represented in Figure 2. From the point of view of the present research, the advantage of this ambiguity is that it allows us to use exactly the same stimulus either as a single alphabetic character or as a "string" of two digits. The question is whether the same stimulus is subject to orientation effects when interpreted as a string of two characters (*13*) but not when interpreted as a single character (*B*).

In Experiments 1 and 2, subjects were required to classify either four letters (the letter condition) or four two-digit numbers (the number condition) that appeared at six different orientations. The two conditions had one stimulus in common, which could be interpreted either as *B* or as *13*, depending on the condition.

Method

Subjects. Twenty University of Haifa students participated in the study—18 for course credit and 2 for pay.

Apparatus and stimuli. The experiment was run on an Apollo Domain DN300 computerized graphics display unit. The stimuli in the letter condition were *B*, *P*, *Q*, and *W*; in the number condition they were *13*, *26*, *45*, and *70*. Exactly the same stimulus was used for *B* and *13* (See Figure 3). Each stimulus subtended about 2.0 cm vertically and 1.3–1.8 cm horizontally, and appeared at six different orientations: 0°, 60°, 120°, 180°, 240°, and 300°, rotated clockwise. The stimuli appeared white on a dark background.

Procedure. The subjects sat at a viewing distance of 50 cm from the screen. They were instructed that they would see one of four letters/numbers on the screen in different orientations and that they were to identify them by pressing one of four keys by using the index and middle fingers of the two hands. The assignment of keys to stimuli was counterbalanced across subjects in each of the conditions. Ten subjects participated in the letter condition and 10 in the number condition.

A practice block was followed by eight experimental blocks of 240 trials each, consisting of 10 replications of each of the four stimuli in each of the six orientations, in random order. On each trial the stimulus remained on until the subject responded; it was replaced by the next stimulus after 500 ms. When the subject made an error, the computer sounded a high-pitched tone.

Results

Response times outside the 200–3,000-ms range were eliminated (1.4%). Subject median response times and percent errors were calculated, and their means are presented in Figure

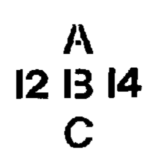

Figure 2. An illustration of the effect of context on the interpretation of an ambiguous stimulus.

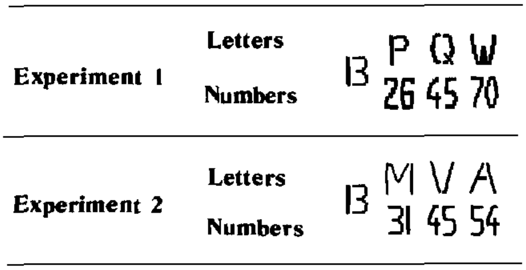

Figure 3. The stimuli used in Experiments 1 and 2.

4 as a function of angular orientation for the critical (*B*/*13*) and the noncritical stimuli for the two conditions.

There was no strong effect of orientation, although some weak systematic effects are evident. A Condition × Orientation analysis of variance (ANOVA) yielded $F(1, 18) = 6.82$, $p < .05$, for condition; $F(5, 90) = 5.58$, $p < .001$, for orientation; and $F(5, 90) = 4.88$, $p < .001$, for the interaction. Separate ANOVAS indicated that the effects of orientation were significant for the number condition, $F(5, 45) = 9.36$, $p < .0001$, but not for the letter condition ($F < 1$). This interactive pattern, however, was not significant when only the critical, common stimuli were included in the analysis, $F(5, 90) = 1.07$. The overall effect of orientation was rather small, amounting to only 20 ms from 0° to 180°.

Discussion

The results of Experiment 1 were rather surprising. The critical stimulus was not affected by orientation whether it was interpreted as a single letter or as a two-digit number. This might be taken to suggest that the debilitating effects of disorientation on the recognition of multielement strings do not depend on whether the elements have an independent lexical status. However, the overall effect of disorientation on the recognition of two-digit numbers was very slight and not much stronger than that found for single letters. This unexpected result suggests the possibility that it is not the number of elements per se that determines the occurrence of orientation effects.

Experiment 2

The effect of orientation for the two-digit numbers in Experiment 2 amounted to only 20 ms in comparison with over 300 ms for lexical decisions on two-letter strings (Figure 1). One possible explanation for this large difference is that it derives from the nature of the nontarget numbers employed. In our previous article (Koriat & Norman, 1985), we proposed two explanations for orientation effects in word recognition. According to one explanation, word recognition is based on whole-word units, and disorientation disrupts the total configuration of the word. The observation that orientation effects are length dependent may then be explained by assuming that with increased disorientation, more of the transgraphemic features are lost, and recognition must rely on increasingly smaller units. A second account is more consistent with letter-based theories of word recognition (e.g., McClelland & Rumelhart, 1981), which assume a position-specific, parallel activation of the appropriate codes for all the letters in a word. According to this account, the rotation of a word disrupts the letter-position mapping, and it is this mapping that is restored by "mental rotation."

This latter account was examined in Experiment 2. If orientation effects are dependent on the criticality of order information—that is, of the character-position mapping—perhaps they obtain only when different permutations of the same elements call for different responses. This possibility was examined in Experiment 2 by using two-digit numbers that differed only in the order of the two digits. Thus, the number condition included the numbers *13*, *31*, *45*, and *54*. The letter stimuli included letters that shared some of their segments (see Figure 3). Thus, the letters *B* and *M* had the same segment on the left side for *B* and on the right side for *M*. A similar relationship held between *V* and *A*.

Method

Subjects. Twenty-four University of Haifa students participated in the study—21 were paid, and 3 participated for course credit.

Apparatus and procedure. The apparatus and procedure were the same as in Experiment 1.

Stimulus materials. The experimental stimuli were *13*, *31*, *45*, and *54* for the number condition, and *A*, *B*, *M*, and *V* for the letter condition.

Results

Response times outside the 200–3,000-ms range were eliminated (1.2%). Figure 5 presents the means of the subject

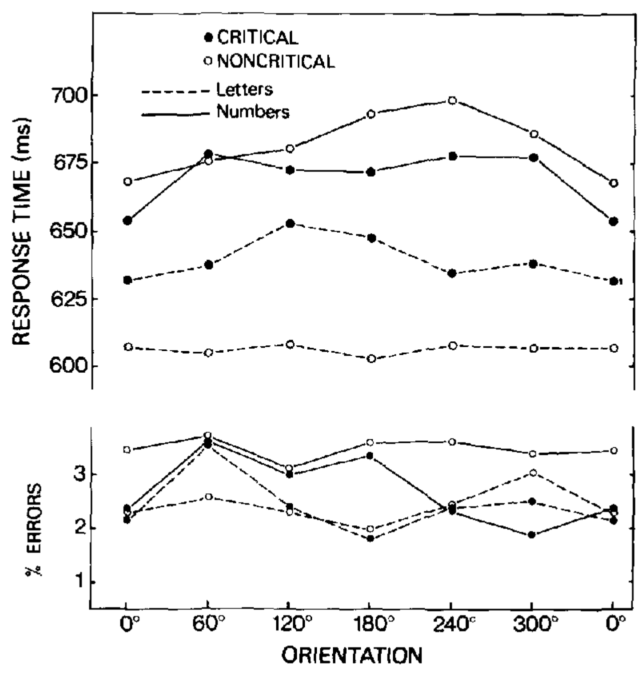

Figure 4. Mean response time and percent errors as a function of orientation for critical and noncritical stimuli in the letter and number conditions (Experiment 1).

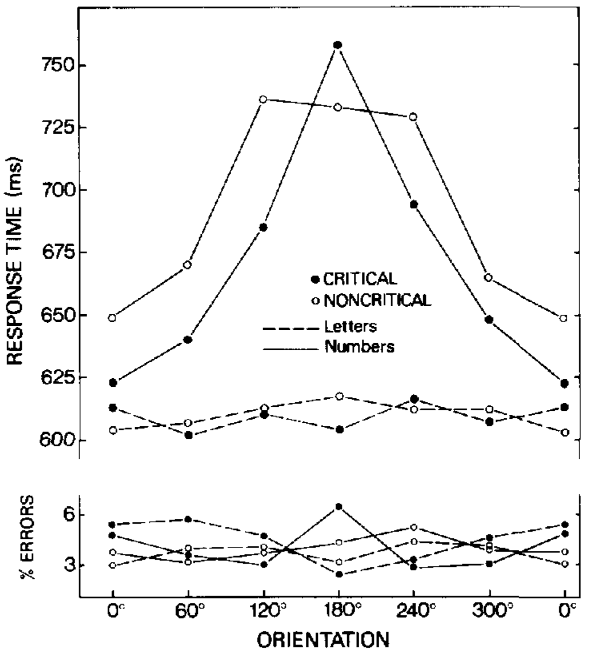

Figure 5. Mean response time and percent errors as a function of orientation for critical and noncritical stimuli in the letter and number conditions (Experiment 2).

median response times and of percent errors. The effects are very different from those of the previous experiment: Large and systematic effects of orientation are now found for response time in the number condition. The letter condition, in contrast, exhibits few orientation effects.

Response times for the critical stimuli yielded $F(5, 110) = 8.01$, $p < .0001$, for orientation; $F(1, 22) = 3.40$, $p < .10$, for condition; and $F(5, 110) = 8.40$, $p < .0001$, for the interaction. Separate one-way ANOVAS yielded a significant orientation effect for the number condition, $F(5, 55) = 8.56$, $p < .0001$, but not for the letter condition, $F(5, 55) = 1.82$, *ns*. Thus, response times to the same visual stimulus evidenced strong effects of orientation when it was interpreted as *13* but not when it was interpreted as *B*.

Similar results were obtained for the noncritical stimuli. A two-way ANOVA indicated $F(5, 110) = 18.15$, $p < .0001$, for orientation; $F(1, 22) = 8.39$, $p < .01$, for condition; and $F(5, 110) = 12.79$, $p < .0001$, for the interaction. A separate one-way ANOVA for the number condition yielded a highly significant effect of orientation, $F(1, 55) = 16.39$, $p < .0001$. The respective ANOVA for the letter condition also yielded a significant effect, $F(5, 55) = 2.84$, $p < .05$, but the size of the orientation effect was considerably smaller, amounting only to 13 ms overall.

The latency-orientation functions obtained in the number condition seem to differ for the critical and noncritical stimuli. For the critical stimulus *13*, the function is very similar to that typically obtained in studies of mental rotation (e.g., Shepard & Cooper, 1982). In contrast, the function obtained for noncritical stimuli evidences little effect of orientation for orientations between 120° and 240°, similar to what we reported for the lexical decision task (Koriat & Norman, 1984, 1985). It should be noted that this flat-top pattern occurred for each of the three stimuli *31*, *45*, and *54*.

As for the error data, the results indicate a slight increase in percent errors with angular deviation from the upright in the number, but not in the letter, condition. A two-way ANOVA yielded $F(5, 110) = 4.97$, $p < .0005$, for the interaction between condition and angular deviation from the upright.

Discussion

The results of Experiment 2 are markedly different from those of Experiment 1. First, strong and systematic effects of orientation were obtained in the number condition. Second, the critical stimulus yielded large orientation effects when it was interpreted as *13*, but no effects when it was interpreted as *B*.

The contrast between the results of Experiments 1 and 2 for the number condition clearly highlights the important role of element order. Identification latency for the number *13* was indifferent to orientation in Experiment 1 but yielded strong effects of orientation in Experiment 2, amounting to 135 ms overall. This effect was apparently due to the inclusion of the number *31* in the stimulus ensemble and perhaps to the confusability of *45* and *54* (but see Experiment 4). These results support the view that orientation effects are intimately linked to order information. When order information is critical for distinguishing between different stimuli, some rectification process is required before identification. This rectification appears to be necessary for restoring order information. This account may also explain the fact that the extent of the orientation effect varies systematically with the number of elements in the string (Figure 1). Because no order information exists in single-element stimuli, we find little or no orientation effects for these stimuli. The greater the number of elements, the larger the effect.

Experiment 3

In Experiment 3 we further examined the idea that orientation effects are linked to order information. In this experiment subjects made odd–even judgments on one- and two-digit numbers composed of the digits *1*, *2*, *3*, and *4*. In principle, such judgments depend on order information because they are determined solely by the rightmost digit. The numbers appeared at one of six orientations. For the four single-digit numbers, no order information is involved, and minimal orientation effects should be expected, consistent with previous results. The two-digit numbers form two groups: those for which the decision is indifferent to the order of the digits (e.g., *24*, *31*) and those in which the response depends on the order of the two digits (e.g., *32*, *14*). The latter, order-dependent stimuli should evidence strong effects of orientation, similar to what was found in the number condition of Experiment 2. In contrast, the order-independent two-digit numbers should evidence minimal orientation effects. Among these, the comparison of repeated-digit (e.g., *22*, *11*) with different-digit numbers (e.g., *42*, *31*) may be of help in clarifying possible differences between the responses to single-digit and two-digit numbers.

Method

Subjects. Twelve University of Haifa students participated in the study—9 for payment and 3 for course credit.

Apparatus. The experiment was controlled by a PDP-11/34 minicomputer, and the stimuli were presented on a VT-11 Graphic Display Unit.

Stimuli. The stimuli consisted of 20 numbers, the 4 one-digit numbers *1*, *2*, *3*, and *4*, and 16 two-digit numbers that represented all permutations of these four digits. Each digit was 1.0 cm in height and not more than 1.0 cm wide. A 0.10-cm gap separated the digits in the two-digit numbers. The numbers were presented at six different orientations, as in the previous experiments.

Procedure. The subjects sat at a viewing distance of 80 cm from the screen. The experiment included a 40-trial practice block, followed by six experimental blocks of 130 trials each. The first 10 trials of each experimental block served as warm-up, and in the following 120 trials each of the 20 numbers appeared once in each of the six orientations. Stimulus order was randomly determined for each subject and for each block. Subjects were told that they had to classify numers as even or odd by pressing one key with their right index finger for "even," and another key with their left index finger for "odd." On each trial the stimulus remained on until the subject responded; it was replaced by the next stimulus after 500 ms.

Results

Response times outside the 200–3,000-ms range were eliminated (0.30%). Figure 6 presents the means of subjects' median response times and percent errors as a function of orientation. The results are plotted separately for four classes of numbers: Single-digit numbers (*1*, *2*, *3*, *4*), two-digit numbers in which the same digit is repeated (*11*, *22*, *33*, *44*), order-independent two-digit numbers (*13*, *24*, *31*, *42*), and order-dependent two-digit numbers (*12*, *14*, *21*, *23*, *32*, *34*, *41*, *43*).

Looking first at the results for single-digit numbers, we see that responses to these numbers are indifferent to orientation for both latency, $F(5, 55) = 1.24$, *ns*, and percent errors ($F < 1$). This is of particular interest because these numbers appeared in the context of other numbers that seem to evidence systematic effects of orientation. Repeated two-digit numbers also evidenced little effects of orientation for response time, $F(5, 55) = 1.26$, *ns*, and percent errors ($F < 1$).

The most interesting comparison is that between the order-independent (nonrepeated) and the order-dependent numbers. The effects of orientation are clearly stronger for the latter than for the former type (Figure 6). A two-way ANOVA on response time for these two types yielded significant effects for type, $F(1, 11) = 68.59$, $p < .0001$; for orientation, $F(5, 55) = 13.95$, $p < .0001$; and for the interaction, $F(5, 55) = 8.09$, $p < .0001$. The respective effects for percent errors were $F(1, 11) = 10.01$, $p < .01$, for type; $F(5, 55) = 2.27$, $p < .10$, for orientation; and $F < 1$ for the interaction. Separate ANOVAS for each of these two types indicated that the orientation effects on response time were significant for both the order-independent (nonrepeated) numbers, $F(5, 55) = 6.06$, $p < .001$, as well as the order-dependent numbers, $F(5, 55) = 18.51$, $p < .0001$. The respective ANOVAS on percent errors yielded $F < 1$ for the order-independent numbers, and $F(5, 55) = 2.69$, $p < .05$, for the order-dependent numbers.

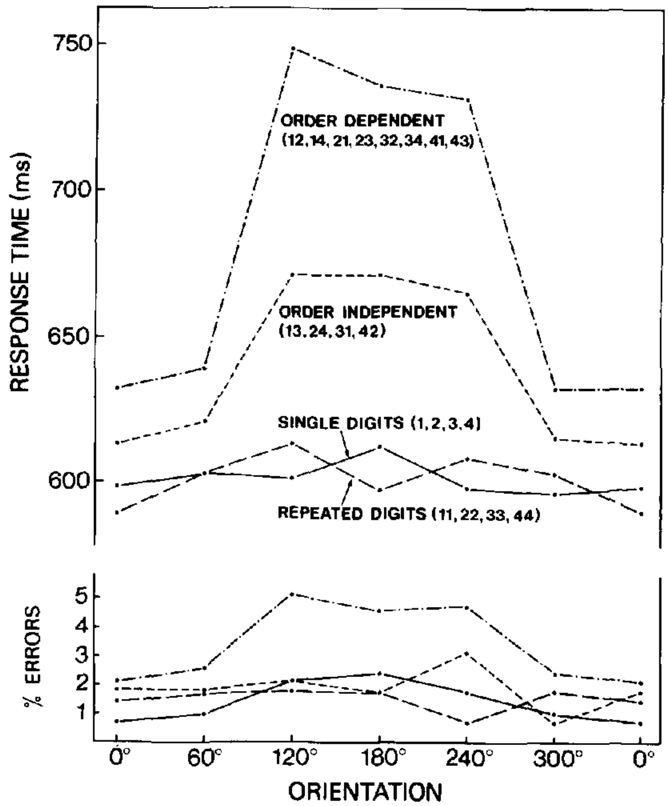

Figure 6. Mean odd–even decision times and percent errors as a function of orientation for one-digit numbers, and for repeated, order-independent, and order-dependent two-digit numbers (Experiment 3).

Discussion

The results of Experiment 3 indicate that response time is indifferent to orientation for both single-digit numbers and numbers comprising two repeated digits. This suggests that number of digits is not in itself the critical factor in determining the occurrence of orientation effects.

The comparison of greater interest concerns the contrast between order-independent and order-dependent two-digit numbers. The order-dependent numbers yielded considerably stronger orientation effects. In other words, when the odd–even decision could be performed regardless of the order of the two digits, much weaker orientation effects were found than when the decision depended on the specific order of the two digits.

The fact that order-independent two-digit numbers yielded a significant orientation effect was somewhat surprising. Two explanations may be offered for this finding. First, these numbers were embedded within a stimulus ensemble that included order-dependent numbers, and it is likely that subjects were not always successful in applying different operations to the two types of numbers. Perhaps, if the different types of numbers were presented in separate blocks, the order-independent numbers would yield a flat orientation function. But this is not a feasible project, because subjects can then learn to respond on the basis of just one digit for the order-independent numbers.

Second, it is possible that some subjects did not utilize the fact that for some of the nonrepeated two-digit numbers the response was independent of the digits' order. Plotting the results separately for each subject indicated that, in fact, for 6 subjects the function for order-independent numbers was practically flat, like those for single-digit and repeated two-digit numbers. The results for the other 6 subjects, in contrast, indicated strong orientation effects for the order-independent numbers, only slightly weaker than those found for the order-dependent numbers. It should be noted that an informal postexperimental questioning of the subjects indicated, to our surprise, that most subjects, even those in the latter group, were unaware of having adopted different strategies for the order-dependent and the order-independent numbers.

Another interesting aspect of the data concerns the shape of the orientation functions. For both the order-dependent and order-independent numbers, this shape is very similar to that obtained for lexical decisions on letter strings, with a relative indifference to orientations between 120° and 240° (see e.g., Koriat & Norman, 1984, Figure 2). The possibility exists that the flat-top shape is a general phenomenon that occurs when disoriented stimuli impair recognition because they impede order information.

Experiment 4

The original motivation of the present study was to explain the different orientation effects found for single letters and for letter strings. Because Experiments 1–3 used either single letters or digit strings, it is important to show that the results pertaining to order information generalize to letter strings as well.

In Experiment 4 subjects were presented with four two-letter Hebrew words at different orientations and were asked to identify them by pressing one of four keys for each word. In the control condition, none of the words had any letter in common. In the experimental condition, in contrast, the words were chosen so that for each subject two words differed only in the order of the letters (confusable words), whereas the other two did not have any letters in common with any of the other words (nonconfusable). The first aim of this experiment was to examine the hypothesis that the effects of word orientation would be stronger for the experimental condition, where some of the words must be distinguished on the basis of order information, than for the control condition, where order information is not critical. The second aim pertained to the contrast between the confusable and nonconfusable words in the experimental condition. If subjects could adopt different recognition procedures for the two types of words, then the nonconfusable words should evidence smaller orientation effects than the confusable words, perhaps of the same size as the control condition. On the other hand, if word recognition is context-sensitive, angular disorientation should be more disruptive for the nonconfusable words in the experimental than in the control condition.

Method

Subjects. Twenty-four University of Haifa students participated in the study—5 for course credit and the others for payment. Hebrew was their primary language. Twelve subjects were assigned to the experimental condition, and 12 to the control condition.

Stimulus materials. The stimuli were four control and four experimental two-letter Hebrew words. The control words had no letters in common. Each had a matching experimental word that contained the same letters in the reverse order (like *on* and *no* in English; Hebrew offers many more such pairs than English). All eight words consisted of two pronounceable consonants and were presented unpointed (see Koriat, 1984). The size of each word was approximately 2 cm vertically and 2.2–2.5 cm horizontally. Each word appeared in the same six orientations used in the previous experiments, rotated about their center.

Apparatus and procedure. The apparatus was the same as that employed in Experiment 1. Subjects were instructed that they would see four Hebrew words in different orientations and that they were to press one of four keys for each word. On each trial the word appeared in the center of the screen until the subject responded; it was replaced by the next word after 500 ms. The experiment included one practice block followed by eight experimental blocks of 240 trials each. In each block each word appeared 10 times in each orientation. The order of the stimuli was random. Subjects responded with the index and middle fingers of the two hands.

Subjects in the control condition were presented with the set of four control words, with the assignment of words to response keys counterbalanced across subjects. For the experimental condition, four sets of words were generated by using the four control words and replacing one of the words by an experimental word that matched one of the remaining words in terms of its constituent letters. Each set of words was used with 3 subjects. Thus, in the experimental condition there were two confusable and two nonconfusable words for each subject, and across all subjects each of the control words appeared equally often in all conditions. The assignment of words to response keys was randomized.

Results

Response times outside the range of 200–5,000 ms were eliminated from the analyses (0.7%).

We shall first compare the results for the two conditions. A two-way ANOVA—Condition (between subjects) × Orientation (within subjects)—on subject median response times yielded $F < 1$ for condition; $F(5, 110) = 24.27$, $p < .0001$, for orientation; and $F(5, 110) = 6.64$, $p < .0001$, for the interaction. Mean response times for orientations of 0° to 300° were 672, 681, 696, 692, 700, and 685 ms, respectively, for the control condition; and 672, 682, 736, 725, 717, and 679 ms, respectively, for the experimental condition. Thus, orientation effects are clearly stronger for the experimental than for the control condition, with the difference between the two conditions confined to the orientations 120°, 180°, and 240°. It should be noted, however, that the effects of orientation were significant for both the experimental, $F(5, 55) = 18.81$, $p <$

.0001, and the control conditions, $F(5, 55) = 6.74$, $p < .0001$. Similar analyses carried out on percent errors yielded no significant effects. Percent errors averaged 3.34%.

We shall turn next to the difference between confusable and nonconfusable words. Figure 7 presents the means of the subject median response times for the two types of words in the experimental condition. This figure also includes, for comparison purposes, the means for the control condition. It may be seen that confusable words yielded higher mean response times, $F(1, 11) = 26.45$, $p < .0005$, and stronger effects of orientation, $F(5, 55) = 5.14$, $p < .001$. Thus, it appears that subjects in the experimental condition were able to process the two types of words differently. It is interesting to note that a large difference was found even for the 0° orientation, $F(1, 11) = 13.78$, $p < .005$. Analyses of percent errors also indicated a somewhat stronger orientation effect for confusable than for nonconfusable words, $F(5, 55) = 2.29$, $p < .06$.

We shall turn next to the comparison between the results for the nonconfusable words in the experimental condition and those of the control condition. Mean response time was not different for the two conditions ($F < 1$). The effect of orientation was somewhat stronger for the confusable words in the experimental condition than for the control condition, but the difference was not significant, $F(5, 110) = 1.25$. A similar ANOVA on percent errors yielded no significant effects. Thus, it appears that the inclusion of confusable words in the experimental condition did not greatly affect the response to the nonconfusable words.

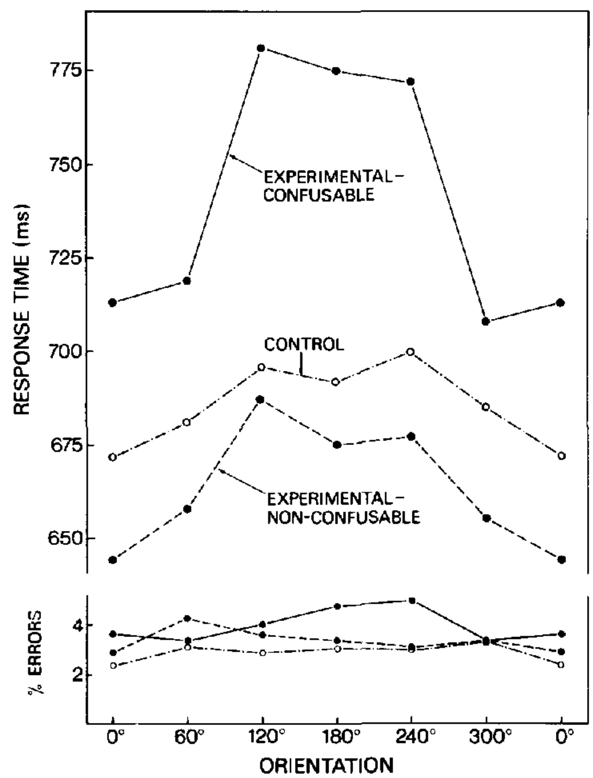

Figure 7. Mean response time and percent errors as a function of orientation for the control condition and for the confusable and nonconfusable words in the experimental condition (Experiment 4).

Discussion

The results of Experiment 4 are consistent with the idea that the disruptive effect of disorientation on word recognition stems from the criticality of the letter-position mapping. When words could be correctly classified on the basis of their constituent letters, irrespective of their order, weaker orientation effects were found than when correct classification depended on letter permutation.

Inconsistent with predictions, however, was the observation that even when order information was not critical to word classification, the effect of orientation, although slight, was still significant. The same trend was found in Experiment 1, where two-digit numbers evidenced a small effect of orientation, despite the fact that single letters did not.

The differences found between confusable and nonconfusable words indicate that subjects can evolve different modes of pattern recognition for different stimuli within the same ensemble, depending on the criticality of order information for their classification. Probably, confusable words require some rectification process that restores their letter-position mapping prior to recognition. The decision whether to undertake such a rectification operation seems to be based on a preliminary stage in which the constituent letters are identified. This implies that letter identities allow the identification of some of the stimuli in the ensemble (nonconfusable), as well as the classification of others (confusable) as requiring rectification.

Further support for this notion comes from the examination of the distribution of errors in the experimental group. This strongly suggests that subjects handle the task by distinguishing between the class of confusable words and the class of nonconfusable words. Thus, when an error was committed with a confusable word stimulus, the response was 2.7 times more likely to be the second confusable word than one of the two nonconfusable words. This could suggest that the two confusable words were more likely to be interchanged with each other, but the same error pattern was found with nonconfusable word stimuli as well. When the stimulus was a nonconfusable word, the likelihood of responding with the second nonconfusable word was 2.3 times greater than that of responding with one of the two confusable words. It should be recalled that the nonconfusable stimulus and response words had no letters in common. It thus seems that the stimulus words were hierarchically processed so that they were first sorted into confusable and nonconfusable stimuli, and within each class sorted into the respective word codes. This may explain the finding that response time was higher for the confusable than for the nonconfusable words even for the 0° orientation. Perhaps the initial classification of the word as confusable led to the adoption of a more cautious strategy.

It is interesting to note that all three RT functions depicted in Figure 7 exhibit the characteristic flat-top function observed for the lexical decision task (Koriat & Norman, 1985).

General Discussion

In the present study we attempted to reconcile two findings in the literature: first, that the identification of single alphanumeric characters is largely indifferent to orientation, and second, that the recognition of letter strings is greatly impaired by disorientation.

Two observations suggested that this difference is not due to an inherent difference between the two tasks, but rather to the number of visual elements that have to be processed. First, the effect of disorientation on lexical decision time was found to increase as a linear function of string length for strings of two to five letters, and when this function was extrapolated to single-letter stimuli, it suggested that the effect of orientation on the recognition of these stimuli should be very close to zero. Second, when lexical decisions were performed on two-letter strings when only the second letter was presented visually, response time did not increase systematically as the orientation of this letter departed from the upright.

If orientation effects depend on the number of alphanumeric characters in the string, perhaps they could be found for exactly the same stimulus when it is interpreted as *13* but not when it is interpreted as *B*. In Experiments 1 and 2 we examined this possibility, and their results allowed us to delineate the conditions where this occurred. Thus, when the four two-digit numbers employed did not have any digit in common, the results indicated only very slight orientation effects on classification latencies (Experiment 1), although these effects tended to be somewhat stronger than those obtained for single letters. In contrast, when the numbers were permutations of the same digits (Experiment 2), the results indicated strong monotonic effects of angular deviation from the upright, and these effects were very different from those found for single letters. Furthermore, the critical stimulus now yielded systematic effects of orientation when interpreted as *13*, but not when interpreted as *B*.

These results strengthened the idea that it is not the number of elements per se that determines the occurrence of orientation effects, but the criticality of their spatial arrangement (i.e., element-position mapping) for classification. When a two-element stimulus can be identified or classified without regard to the order of the elements, orientation should have little effect, as was the case in Experiment 1. Apparently, disorientation disrupts the element-position mapping, and when this mapping is critical for classification (as is the case in the number condition of Experiment 2), some rectification process is needed to recover this mapping.

The results of Experiment 3 further substantiated this conclusion. When an odd-even decision could be based solely on the identity of any of the constituent digits, regardless of their order, the effects of orientation were weaker than when the response depended critically on the order of the digits.

Experiment 4, using word stimuli, further substantiated the conclusion that orientation effects are particularly strong when words cannot be classified solely on the basis of the identity of their constituent letters. This experiment also indicated that subjects can apply different recognition procedures to different words in the same ensemble, depending on whether order information is or is not critical for their classification. This result suggests an initial stage in which some of the strings (order independent) can be classified on the basis of the identity of their constituent letters or other features, whereas other strings (order dependent) are assessed as requiring rectification prior to their identification.

The proposition that orientation effects are found when the element arrangement is critical explains why these effects are obtained for the reading of words and sentences, but not for the identification of alphanumeric characters. Reading performance is impaired by disorientation because of the logic of alphabetic orthographies, in which all words of the language are represented by different permutations of a finite set of elements—the alphabet. Therefore, letter permutation is critical for word identification. This is not the case for ideographic scripts, and for these the recognition of an ideogram (which corresponds to a word) is apparently indifferent to orientation (See Eley, 1983).

The results on the whole are inconsistent with the idea that disorientation impairs the recognition of letter strings "because feature analyses proceed more efficiently when the features are in their usual orientation" (Cooper & Shepard, 1978, p. 131). Rather, according to the present formulation, the effects of orientation on letter strings are due mainly to the extraction of letter-position mapping rather than to processes of feature extraction or letter identification.

The foregoing discussion raises several important issues. First, what is the effective element in identification? For example, in terms of a multilevel view of word identification (see McClelland & Rumelhart, 1981; Santa, Santa, & Smith, 1977), word units represent a higher level in the hierarchy than do letter units, and in this sense, the letters are the constituent elements of a word. However, letters are also composed of an alphabet of visual features (see e.g., Geyer & DeWald, 1973; Gibson, 1969). Indeed, as Treisman and Gelade (1980) have shown, under certain circumstances, the identification of letters may yield illusory conjunctions that combine features from different letters (e.g., *P* and *Q* resulting in the perception *R*). The question then is why are orientation effects not obtained for the identification of single letters?

Our speculative answer is that most words differ only in the order of the letters, whereas not many letters of the alphabet differ only in the order of different visual features. In fact, strong orientation effects were found for distinguishing between the letters *p* and *q* or *b* and *d*, which differ in the position mapping of the same features (Corballis & McLaren, 1982). Thus, perhaps the difference between words and letters is only one of degree, with the extent of orientation effects varying with the likelihood that a different permutation of the same constituent elements (features in the case of letters, and letters in the case of words) will require a different response.

A second issue pertains to the nature of the rectification process by which order information is presumably recovered. A logical candidate would be the mental rotation process posited by Shepard and Cooper (1982). If a disoriented word is mentally rotated in a similar manner, then this rotation would obviously recover the normal letter-position mapping. However, our previous study with the recognition of rotated words (Koriat & Norman, 1985) yielded evidence suggesting that letter strings are not mentally transformed as whole patterns, except, perhaps, in a limited range of orientations around the upright. Thus, the effects of disorientation were found to increase systematically with the number of letters in the string. This suggests that the string is first decomposed into its constituent letters, and then the letters are mentally rotated in turn. This letter-by-letter account, however, is also untenable for two reasons. First, as was stressed throughout this article, the identification of single alphanumeric characters does not seem to require a preceding stage of rotation to the upright. Second, as we have previously shown, when letter strings are rotated while their constituent letters remain upright, response time is, in fact, slower than when the entire string is rotated (Koriat & Norman, 1985; Experiment 4).

On the basis of these considerations, we are inclined to believe that the orientation effects observed for reading tasks are due to a different process than that discussed by Shepard and Cooper in connection with the reflection decision task. Evidence in support of this contention comes from the very different shape of the "rotation" curves obtained for the two tasks. The rotation function for word recognition evidences a relative indifference to deviations from the upright of up to 60° and for near upside-down orientations (120°–240°). Furthermore, response time for 180° appears to be faster than for 120° or 240° (the "upside-down effect"; see Koriat & Norman, 1984, 1985). This may be due to the fact that order information is more easily extracted when a letter string is exactly upside down than when it is nearly upside down. In sum, further research is needed to specify the nature of the transformation that underlies the orientation effects observed for the order-dependent classification of alphanumeric strings and to clarify its relationship to the Shepard–Cooper process of mental rotation.

A final issue is whether the present study can also shed some light on other instances in which the time to identify a stimulus is found to be affected by disorientation. Apart from letter strings, disorientation disrupts the perception of faces (e.g., Yin, 1969) and drawings of common objects (Jolicoeur, 1985). We may speculate that because faces represent a configuration of distinct elements, perhaps it is the spatial configuration of the elements that is disrupted by disorientation, not the identity of the individual elements. The same may be true with regard to drawings of common objects.

Also, Jolicoeur and Landau (1984) obtained marked and systematic orientation effects on the accuracy of identifying briefly presented single characters that were masked. Thus, perhaps this is so because brief masked presentations also make it particularly difficult to recover the spatial arrangement of letter segments.[1]

The present work fits nicely into the recent approaches to object recognition which assume that objects are recognized by parts, modules, or components (e.g., Biederman, 1985; Hoffman & Richards, 1984). Acccording to Biederman, for example, objects are recognized by segmenting an image into a relatively small set of components in much the same way that speech perception is mediated by the identification of the individual elements, the phonemes. The representational power of both the speech recognition and the object recognition systems derives, then, from the allowance for free combinations of the primitives. In speech the relations are limited to a sequential left-to-right ordering, whereas in object recognition the possible relations are richer. Biederman assumes that in object recognition the detection of the individual components is generally invariant over different viewing positions and that the matching of the components with their memory representations occurs in parallel. Thus, as long as the spatial arrangement can be recovered from the input, objects can be quickly recognized despite variations in orientation.

According to this formulation, the effect of orientation on object perception should depend on the extent to which the object can be identified on the basis of a single element or else on the basis of a number of elements, irrespective of their spatial arrangement. When identification depends critically on the spatial arrangement of several elements, strong orientation effects may be expected.

[1] We are indebted to Pierre Jolicoeur for this suggestion.

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Squire Appointed Editor of *Behavioral Neuroscience*, 1990–1995

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