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Recognition of Rotated Letters: Extracting Invariance Across Successive and Simultaneous Stimuli

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Response time (RT) for identifying single letters is usually indifferent to disorientation, but in Experiment 1 RT increased with the angular deviation from that of the preceding letter (ADP). This occurs only when the same letter is repeated, which suggests a process of *backward alignment.* RT again increased with ADP when the same letter was repeated in the same format (normal or mirror-reflected; Experiment 2). These findings were replicated for a same–different task by using 2 simultaneously presented letters (Experiment 3). Experiments 4 and 5 focused on stimuli that are related by a rotation in depth and suggested that transformation in the depth plane may facilitate judgments of sameness and that backward alignment can occur for different views of the same three-dimensional shape. The results suggest the operation of a pattern-recognition mechanism that relies on the extraction of invariance over temporally or spatially contiguous events.

When subjects decide whether disoriented alphanumeric characters are normal or reflected (mirror image), response time increases monotonically with orientational disparity from the upright. This phenomenon has been interpreted as indicative of a mental rotation process in which the disoriented character is imagined to rotate to the upright and then matched to the internal representation of the normal canonical character (see Shepard & Cooper, 1982). When subjects identify disoriented characters, however, response time appears to be largely indifferent to orientation (Corballis & Nagourney, 1978; Corballis, Zbrodoff, Shetzer, & Butler, 1978; Eley, 1982, 1983; Koriat & Norman, 1989b; Simion, Bagnara, Roncato, & Umilta, 1982; White, 1980). These results were taken to suggest that the identification of simple alphanumeric characters does not require mental rotation to the upright.

In contrast to the typical absence of orientation effects for the letter-classification task, such effects have generally been obtained for same–different judgments of rotated letters. In the latter task response times generally increase with the orientational disparity between the two letters (Bundesen, Larsen, & Farrell, 1981). This effect was also observed by Bagnara, Simion, and Umilta (1984) and by Simion et al. (1982), but only for same responses.

In the present study the effects of orientation on the identification of alphanumeric characters was investigated in the context of the recent distinction between two types of mental transformations (Koriat & Norman, 1988). This distinction was based on the examination of sequential effects in the reflection decision task of Cooper and Shepard (1973). Response time in this task was found to increase with the angular deviation from the upright (ADU), which is consistent with previous findings. When the stimulus on one trial was the same letter and in the same format (normal/reflected) as in the previous trial, however, response time also increased markedly with the angular deviation from the preceding orientation (ADP). These results led Koriat and Norman to distinguish between two types of mental rotation processes. In the first, the *uprighting process,* the stimulus is imagined to rotate to the upright and then matched against the long-term canonical representation of the character. It is this process that has been labeled "mental rotation" by Shepard and his co-workers (see Shepard & Cooper, 1982). In the second, the *backward alignment process,* the stimulus is apparently aligned with the short-term visual trace of the preceding character. (The term *backward* is used here in the temporal sense.) This occurs only for sequences involving a repetition of the same orientation-invariant shapes. For such sequences, the established correspondence between successive stimuli allows repetition of the same response. In addition, for same-shape sequences the size of the ADP effects increases systematically with increasing ADUs, which suggests that for such sequences competition arises between the two processes, uprighting and backward alignment, and the response generally depends on the process requiring the shortest transformational path.

The present study investigated the possibility that although the identification of letters does not reveal an uprighting process, it is subject to backward alignment. This is based on the idea that if the backward alignment process serves to establish visual correspondence between successive stimuli (Koriat & Norman, 1988, 1989a), it may be expected to yield similar effects to those found for same responses in the *same–different* comparison task. Thus, we expect that although the latency of letter identification may not vary with ADU, it still ought to increase with increasing ADP for sequences consisting of a repetition of the same letter.

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Experiment 1

In Experiment 1 subjects classified four letters presented at six orientations by pressing one of four keys. The order of presentation was programmed to produce all possible combinations of preceding and current orientations to allow examination of the effects of both ADU and ADP.

Method

Subjects. Twelve University of Haifa students participated in the study. They were paid for their participation.

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

Stimuli. The stimuli consisted of four Hebrew letters (see inset, Figure 1). The height of the letters was 1.8 cm (1.3° visual angle). They appeared at one of six orientations (0°, 60°, 120°, 180°, 240°, and 300°) rotated in a clockwise direction (as in Cooper & Shepard, 1973).

Procedure. The subjects sat with their heads on a chin-and-head rest that prevented head rotations. Viewing distance was 80 cm. They were instructed that four Hebrew letters would appear one at a time on the screen and that they would have to press one of four keys with the middle and index fingers of the two hands. The letters were assigned to the keys according to their alphabetical order.

The session began with one practice block of 140 trials in which the letters appeared upright. A second practice block followed in which the letters appeared at different orientations; subjects were told to respond in the same manner as before, ignoring stimulus orientation. These practice blocks were followed by eight experimental blocks of 150 trials each. Each such block consisted of five warm-up trials followed by 145 trials, which allowed for 144 "sequences," with the first stimulus serving only as a prime. The 144 sequences were preprogrammed to form all combinations of two variables, the orientation of the preceding stimulus (6) and the orientation of the current stimulus (6). The four letters were randomly assigned to each of the trials. Subjects took a short break after the fourth block and were allowed to proceed from one block to the next at their own pace. The stimulus appeared at the center of the screen and remained in view until subjects responded. It was replaced by the next stimulus after a 500-ms interval.

Results

Response latencies outside the range of 250–3,500 ms were eliminated from the following analyses (0.41%). All of the response time analyses reported in this article were based on subjects' median latencies for correct responses.

A one-way analysis of variance (ANOVA) of the effects of angular deviation from the upright (ADU) yielded $F(3, 33) = 1.57$, *ns*, for response time, and $F(3, 33) = 1.38$, *ns*, for percentage errors. Mean response times for ADUs of 0°, 60°, 120°, and 180° were 638, 639, 651, and 645 ms, respectively. The respective means for percentage errors were 2.65%, 2.96%, 2.98%, and 2.53%. These results are consistent with previous findings which indicated that the identification of rotated alphanumeric characters is largely unaffected by degree of disorientation.

A Sequence Type (same vs. different letter) × ADP ANOVA yielded $F(1, 11) = 58.08$, $p < .0001$, for sequence type, $F(3, 33) = 17.77$, $p < .0001$, for ADP, and $F(3, 33) = 18.28$, $p < .0001$, for the interaction. Only for same-letter sequences did response time increase with increasing ADP. Thus, mean response times for ADPs 0°, 60°, 120°, and 180° were 680, 668, 675, and 668 ms, respectively, for different-letter sequences, and 520, 553, 568, and 571 ms, respectively, for same-letter sequences. A one-way ANOVA on same-letter sequences alone yielded $F(3, 33) = 25.31$, $MS_e = 256$, $p < .0001$, for ADP. This latter effect was also significant when the results for ADP = 0° were excluded, $F(2, 22) = 4.33$, $MS_e = 268$, $p < .05$. A two-way ANOVA on percentage errors indicated lower error rate for same-letter sequences (1.2%) than for different-letter sequences (3.6%), $F(1, 11) = 10.01$, $p < .01$, but no effects for either ADP or the interaction.

Figure 1 presents mean response time as a function of ADP, with ADU as a parameter. Unlike the reflection decision task, in which the effects of ADP increased with increasing ADUs for same-letter sequences (see Koriat & Norman, 1988), the results for the letter-identification task failed to yield such an interactive pattern ($F < 1$).

Discussion

No effects of angular deviation from the upright were found in Experiment 1, which is consistent with previous findings.

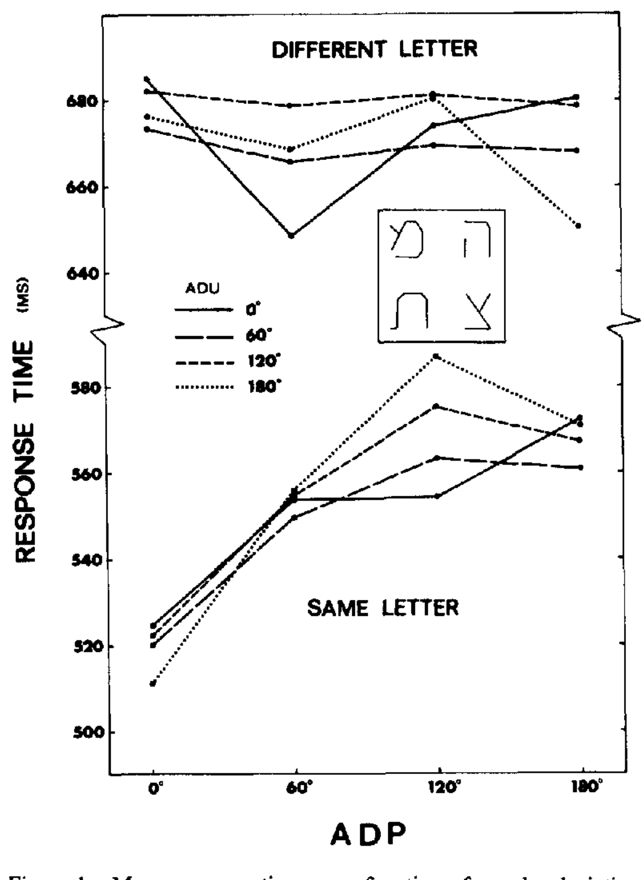

Figure 1. Mean response times as a function of angular deviation from preceding orientation (ADP) for same-letter and different-letter sequences, with angular deviation from the upright (ADU) as a parameter in Experiment 1. (Inset shows the stimuli used in their upright orientation and normal format.)

These results suggest that an uprighting mental rotation is normally not required for the recognition of familiar characters.

The results pertaining to relative orientation (ADP), however, indicate that some type of mental transformation does take place when the same letter is repeated. Thus, only same-letter sequences evidenced systematic and significant effects of ADP. These effects are consistent with the backward alignment process that was hypothesized to occur when the target is a rotational transform of the preceding stimulus (Koriat & Norman, 1988, 1989a). Apparently, when the same letter is repeated the current target is aligned with the preceding stimulus, which allows a repetition of the response. Although backward alignment takes time, the entire process may be faster than that of making an independent response by comparing the stimulus letter to its internal representation.

Experiment 2

The aim of Experiment 2 was to delimit the variables that contribute to the ADP effects found for same-letter sequences in Experiment 1. These effects may derive from the repetition of one or more of the following components: motor (repetition of the same response), name code (repetition of the same letter), and visual code (repetition of the same orientation-invariant visual stimulus). Similarly, the finding that ADP effects are obtained for same-letter sequences but not for different-letter sequences may also be due to one or more of these components.

In the backward alignment model, the ADP effects are specifically attributed to the visual component, that is, to a process in which the current stimulus is aligned with the visual trace of the preceding stimulus. Thus, although motor repetition and name-code repetition may reduce response time, the increase in response time with increasing ADP ought to be expected to obtain only when the same orientation-invariant visual stimulus is repeated.

To examine this possibility we ran a replication of Experiment 1, with one important difference: The letters appeared in either a normal or a mirror-reflected format, and subjects were required to classify them regardless of format and orientation. This design allows a distinction between two types of same-letter sequences: those in which the letter is repeated in the same format and those in which it is repeated in a different format. Whereas both types of sequences entail response repetition as well as name-code repetition, only the former sequences also involve a repetition of the same orientation-invariant visual shape. It is expected that both types of same-letter sequences should yield shorter response times than different-letter sequences, but only for same-letter–same-format sequences should response time increase with increasing ADP.

Method

Apparatus and procedure. The apparatus and procedure were the same as those of Experiment 1, with the following exceptions. First, each of the Hebrew letters appeared in either of two formats, normal and reflected. The 144 sequences of each block were programmed to yield all combinations of preceding orientation (6), current orientation (6), preceding format (2), and current format (2). Choice of letters to combinations was random except that each letter occurred once in each combination across the four blocks of each part of the experiment. Second, the assignment of the four letters to the four keys was counterbalanced across subjects. Third, the response–stimulus interval was reduced to 200 ms. Finally, the size of each letter was about 1.0 × 1.0 cm (0.7° × 0.7° visual angle). Subjects were instructed to discriminate between the letters regardless of orientation and format.

Subjects. Twelve University of Haifa students participated in the study for course credit. None had participated in the previous experiment.

Results

Response latencies outside the range 250–3,500 ms were eliminated from the analyses (0.37%). Mean response time for ADUs 0°, 60°, 120°, and 180° were 598, 610, 607, and 605 ms, respectively: $F(3, 33) = 1.95$, *ns*. The respective means for percentage errors were 4.88%, 4.53%, 4.16%, and 4.22%; $F(3, 33) = 1.04$, *ns*. As in Experiment 1, it appears that the identification of rotated characters does not require an uprighting process.

For the analysis of sequential effects, we divided the sequences into four types according to whether the letter and/or the format were repeated across successive stimuli. Figure 2 presents mean response time as a function of ADP for each of these sequence types. A two-way ANOVA on the data of this figure yielded $F(3, 33) = 30.55$, $p < .0001$, for sequence type, $F < 1$ for ADP, and $F(9, 99) = 4.05$, $p < .0005$, for the interaction.

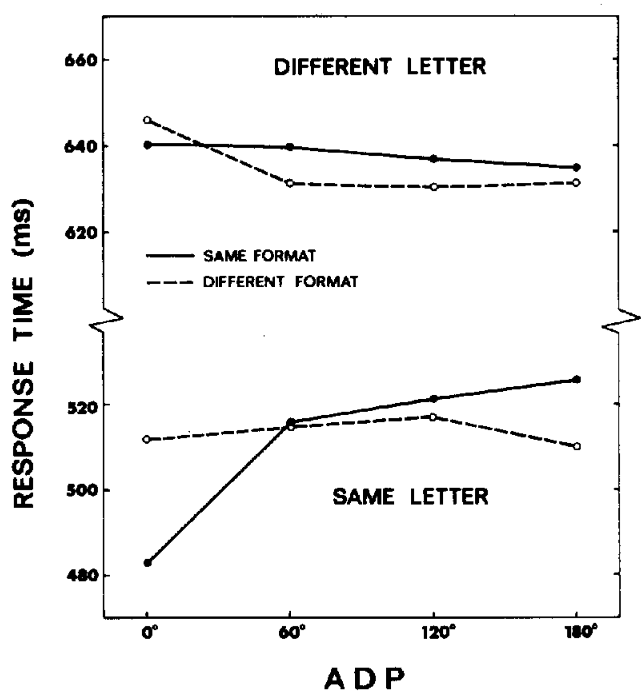

Figure 2. Mean response times as a function of angular deviation from preceding orientation (ADP) for four different types of stimulus sequences (Experiment 2).

It may be seen in Figure 2 that response times are faster by about 120 ms for same-letter sequences than for different-letter sequences. Different-letter sequences show very weak effects of ADP, as do same-letter sequences involving a change in format. Only for same-letter–same-format sequences do response times increase systematically with increasing ADPs. Indeed, separate one-way ANOVAs evaluating the effects of ADP for each of the four sequence types yielded $F(3, 33) = 8.12$, $MS_e = 554$, $p < .0005$, for same-letter–same-format sequences, and no significant effects for any of the other sequence types.

A similar ANOVA on percentage errors did not yield any significant effects, but the means from this analysis mimicked the pattern observed for response time, thus negating the possibility that this latter pattern is due to a speed–accuracy trade-off: Mean percentage errors for ADPs of 0°, 60°, 120°, and 180° were 1.9%, 2.9%, 2.6%, and 3.5%, respectively, for same-letter–same-format sequences, and 1.8%, 1.7%, 1.7%, and 1.7%, respectively, for same-letter–different-format sequences.

As in Experiment 1, the effects of ADP for same-letter–same-format sequences did not increase with increasing ADUs.

Discussion

The results of Experiment 2 further substantiated the conclusion that although the identification of disoriented letters may not require a preceding stage of mental rotation to the upright, it is facilitated by alignment with the preceding stimulus. The results specifically indicated that the effects of ADP are confined to sequences in which the two successive stimuli are rotational transforms. Thus, these effects are not due to either a repetition of the same response or a repetition of the same nominal code but to a repetition of the same orientation-invariant visual stimulus. This is consistent with the interpretation that ADP effects result from a process that extracts invariance across successive stimuli.

Experiment 3

Whereas the two previous experiments used a speeded classification task, Experiment 3 used a same–different comparison task. Subjects were required to decide whether two letters were the same or not regardless of orientation and format. Previous studies that used this procedure (e.g., Bagnara et al., 1984; Bundesen et al., 1981; Simion et al., 1982) observed a systematic effect of angular disparity between the two letters for same but not for different responses. In these studies, however, only the normal format was used and therefore it is not clear whether the occurrence of angular disparity effects depends on a repetition of the nominal code or on a repetition of a visual code. In Experiment 3 each letter in a pair may appear either normal or reflected. If the backward alignment process rests on the same type of operations as those underlying same responses in the same–different comparison task, then we ought to expect the same pattern of results as those of Experiment 2 (see Figure 2): The effect of angular disparity ought to obtain only for same-letter–same-format pairs but not for same-letter–different-format pairs. Such results support the notion that the effects of angular disparity in both the classification task and the same–different comparison task derive from a process in which two stimuli are visually aligned.

Method

Subjects. Twelve students participated in the experiment, 3 for course credit and 9 for pay. None had participated in the previous experiments.

Stimulus materials. The stimuli were composed of the same four Hebrew letters used in the previous experiments. They appeared in pairs so that the distance between the members of a pair was 2.8 cm (2.3° visual angle). The letters appeared black on gray and were about 1.1 cm (0.9°) high. Each letter appeared normal or mirror-reflected in one of six orientations as in the previous experiments.

Procedure. The experiment was controlled by a Microvax Station II computer. Subjects sat at a distance of about 70 cm from a graphic screen. They were instructed to decide whether the two stimuli represented the same nominal letter regardless of format and orientation and to press one key with their right index finger for same and another key with their left index finger for different. There were nine blocks of 150 trials each, with the first block serving as practice. The first 6 trials of each block served as a warm-up, and the following 144 trials represented all combinations of four variables: letter identity (same letters vs. different letters), format identity (whether the letters had the same format or different formats), orientation of the left letter (6), and orientation of the right letter (6). The letter pair remained on the screen until the subject responded and was replaced by the next pair after a 500-ms interval.

Results

Response times outside the range of 250–3,000 ms were eliminated (0.11%). Figure 3 presents mean response time as a function of the angular disparity between the two members of a pair. The results are plotted separately for four types of pairs, which represent all combinations of letter and format identity.

Focusing first on same-format pairs, our results replicate those of previous studies (that used letters in only one format, the normal format), which indicate systematic effects of angular deviations for same but not for different pairs (see Farell, 1985). A two-way Angular Disparity × Pair Type ANOVA for same-format pairs yielded significant effects for pair type, $F(1, 11) = 29.65$, $p < .0005$, for angular disparity, $F(3, 33) = 4.02$, $MS_e = 594$, $p < .05$, and for the interaction, $F(3, 33) = 8.88$, $p < .0005$.

The inclusion of format manipulation in the present study revealed the following, however: For same-letter pairs the effect of angular disparity on response time was stronger for same-format than for different-format pairs, $F(3, 33) = 5.82$, $MS_e = 229$, $p < .005$. This was not true for different-letter pairs ($F < 1$). Same-letter–same-format pairs evidenced a significant and systematic increase in response time with increasing angular disparity, $F(3, 33) = 15.39$, $MS_e = 448$, $p < .0001$. This effect was also significant when the ADP = 0° results were excluded, $F(2, 22) = 8.12$, $MS_e = 426$, $p < .005$. Same-letter–different-format pairs also yielded a significant effect of angular disparity, $F(3, 33) = 5.76$, $p < .005$,

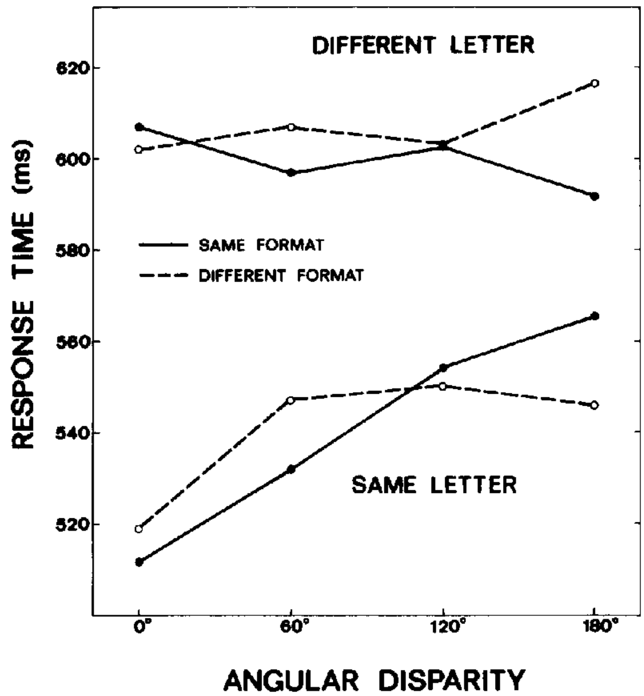

Figure 3. Mean response times as a function of angular disparity between two letters for four different types of stimulus pairs (Experiment 3).

but this effect was due solely to the response time for same orientation (ADP = 0°), which was faster than the response time for different-orientation pairs.

The response time pattern exhibited in Figure 3 for same-letter pairs is very similar to that obtained for the sequential effects in Experiment 2. As in Experiment 2, same-format pairs yielded somewhat faster response times than different-format pairs for 0° angular disparity, $F(1, 11) = 1.37$, *ns*, but slower response times for an angular disparity of 180°, $F(1, 11) = 16.06$, $p < .005$.

As for percentage errors, the effects of angular disparity were significant for same-letter pairs, $F(3, 33) = 12.14$, $p < .0001$, and did not differ for same-format and different-format pairs ($F < 1$). For both formats, percentage errors varied nonmonotonically with angular disparity: For same-format pairs, percentage errors averaged 1.6%, 3.9%, 6.7%, and 3.8% for 0°, 60°, 120°, and 180° angular disparities, respectively. The respective means for different-format pairs were 3.0%, 4.0%, 7.0%, and 3.6%. Different-letter pairs yielded a nearly flat function ($F < 1$), averaging 4.0%, 3.4%, 3.7%, and 3.1% for 0°, 60°, 120°, and 180° angular disparities, respectively.

Discussion

The results of Experiment 3 are similar to those of Experiment 2, with a task explicitly requiring the comparison of two simultaneously presented stimuli: Only for same responses to same-format pairs did response time increase monotonically with angular disparity. This supports the proposition that a comparison between successive stimuli occurs in the classification task and that the backward alignment process is based on a transformation similar to that underlying same judgments in the same–different comparison task (see Koriat & Norman, 1988, 1989a).

Previous research with the same–different task has yielded two general findings. First, same judgments are faster than different judgments, and second, same judgments show greater sensitivity to irrelevant dimensional disparities than different judgments (see Farell, 1985, for a review). The former finding was obtained in the present experiment for both same-format as well as different-format pairs, whereas the latter finding was obtained only for same-format pairs. The faster response times observed in Experiments 2 and 3 for same-letter–different-format pairs may also be due to a visual transformation, but one that is not confined to a rotation in the frontal plane. Indeed, previous studies indicated that same judgments are sensitive to irrelevant disparities other than orientation, for example, size disparity (e.g., Besner & Coltheart, 1976; Bundesen & Larsen, 1975; Santee & Egeth, 1980). Perhaps, in a letter-matching task, same responses ought to show systematic effects of all shape-preserving transformations, such as rotation, reflection, dilation or contraction, and translocation (see Palmer, 1983); this should also be true for sequential effects in the classification task. If this hypothesis is correct, then the fast same effect observed in Experiment 3 for different-format pairs may be due in part to the occurrence of a reflection transformation for these pairs. This idea was explored in Experiments 4 and 5.

Experiment 4

In the reflection task, only backward alignment in the picture plane can guarantee that the current character has the same format as the preceding character. In contrast, in the identification task the identity of two successive characters (regardless of reflection) may be established through mental rotation in the picture plane (for same-format sequences), in the orthogonal depth plane (for characters that have the same orientation but different formats), or in both planes together. Thus, unlike the reflection task, the identification task can benefit, in principle, from backward alignment in depth.

Experiments 4 and 5 examined the possibility that alignment through rotation in depth occurs in tasks that require subjects to compare or classify letters regardless of format and orientation. If such is the case, it may explain the relatively fast response times for same-letter–different-format pairs. It can also clarify the observation that for same-letter pairs with ADP = 180° response times were somewhat slower for same-format than for different-format sequences (Experiments 2 and 3). Perhaps for these pairs visual alignment is achieved more easily through rotation in depth (for different-format pairs) than through rotation in the frontal plane (for same-format pairs). Indeed, Cooper and Shepard (1973) suggested that mental rotation in depth may be occurring in the reflection decision task for upside-down characters (ADU = 180°).

Experiment 4 used a same–different task on pairs of letters. Each letter appeared in either one of the two orientations, 0°

and 180°, and in either a normal or a reflected format. The possibility of a reflection transformation was evaluated by manipulating the spatial arrangement of the two letters. To illustrate, consider all possible types of same pairs that can be generated using the Hebrew letter mem (see Figure 4). In the same-format–same-orientation (SFSO) pairs, the two members differ only in location and may be mapped onto each other by a simple mental translocation, that is, translation in space. In the same-format–different-orientation (SFDO) pairs the members are related by translocation plus a rotation in the picture plane. In the different-format pairs the identity of the two letters can be established by a reflection transformation, that is, a rotation in the depth plane. The two reflectional transform pairs in Figure 4 differ in the axis of the reflection transformation. For the different-format–same-orientation (DFSO) pairs this axis is more clearly suggested by the horizontal arrangement than by the vertical arrangement, whereas the reverse is true for the different-format–different-orientation (DFDO) pairs. This intuitively apparent effect of spatial arrangement may be understood in terms of the transformation presumably required to map one member of each pair onto the other. In the different-format pairs two types of transformation are required: a reflection transformation and a translocation in space. The prediction of Experiment 4 is that response time ought to be faster when the axis of reflection coincides with that of translocation than when it does not. When the two axes coincide, the mapping of one member onto the other may be achieved by an operation called *mental flipping*, perhaps similar to that underlying the mental paper-folding task studied by Shepard and Feng (1972). For the DFSO pairs this ought to occur with the horizontal arrangement, whereas for the DFDO pairs it ought to occur with the vertical arrangement. When the axis of reflection does not coincide with that of translocation, the rotation along the shortest path requires a more complex transformation.

Thus, if a transformation in depth occurs in the same-different task of Experiment 4, we expect it to result in a differential effect of spatial arrangement on the two types of reflection transform pairs. No such effects are expected for the identical or the rotational transform pairs.

Method

Subjects. Twelve University of Haifa students participated in the study for pay. None had participated in the previous experiments.

Apparatus. The experiment was carried out on an Apollo Domain 300 computerized graphics display unit.

Stimuli. The stimuli were constructed from two Hebrew letters (heh and mem). Each stimulus contained a pair of letters that appeared either side by side (horizontal arrangement) or one above the other (vertical arrangement). Each pair consisted of either the same two letters or two different letters. Each letter appeared in either of two formats, normal or reflected, and in either of two orientations, 0° or 180°. The stimuli appeared black on a white background. The height of each letter was 1.2 cm (1.4°), and the two letters of each pair were 0.3 cm apart (see examples in Figure 4).

Procedure. Viewing distance was 50 cm. Subjects were instructed to decide whether the two letters in a pair were the same or different regardless of orientation and format. Half of the subjects responded

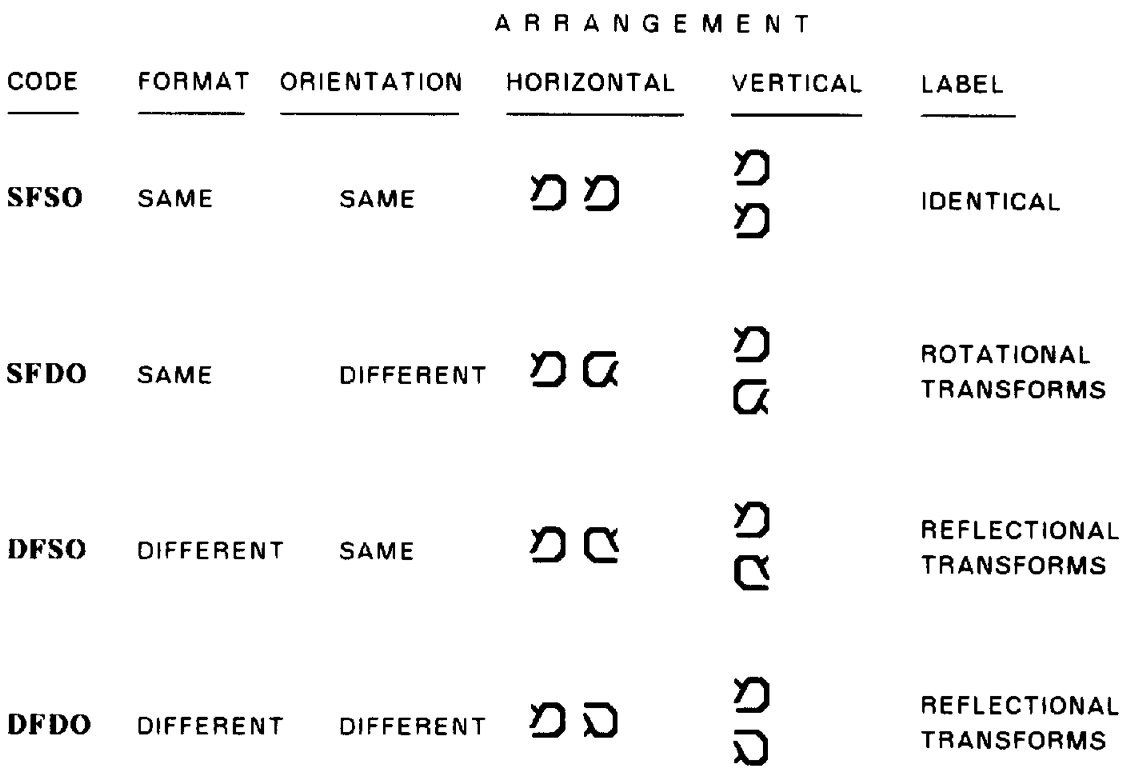

Figure 4. Example of the horizontal and vertical arrangements of the four types of same-letter pairs used in Experiment 4.

with their right index finger for same and with their left index finger for different, whereas the reverse assignment was used for the other subjects.

The session began with one practice block of 128 trials. It was followed by 12 experimental blocks of 134 trials each, with the first six trials used for warm-up. The 128 experimental sequences of each block formed all combinations of seven variables: first letter (2), second letter (2), format of the first letter (2), format of the second letter (2), orientation of the first letter (2), orientation of the second letter (2), and spatial arrangement (2). Stimuli appeared at the center of the screen until subjects responded, and there was a 500-ms response–stimulus interval between trials.

Results

Response times outside the range of 250–3,000 ms were eliminated (0.09%). In the analyses the stimuli were classified into four pair types: SFSO, SFDO, DFSO, and DFDO. These are illustrated for same types in Figure 4. Figure 5 presents mean response times for correct responses and percentage errors for the four types, for both same-letter pairs (left panel) and different-letter pairs (right panel).

We first examine the results for the same stimuli, focusing on the comparison between the DFSO and DFDO reflectional transform pairs. Consistent with predictions, we found that for the DFDO patterns the vertical arrangement yielded faster response times and a smaller percentage of errors than the horizontal arrangement, whereas the reverse was true for the DFSO pairs. A two-way ANOVA yielded a significant interaction for both response time, $F(1, 11) = 39.73$, $p < .0001$, and percentage errors, $F(1, 11) = 22.87$, $p < .001$. Thus, the response for reflectional transforms is faster and more accurate when the letters are arranged along the axis of reflection than when they are arranged along the orthogonal axis.

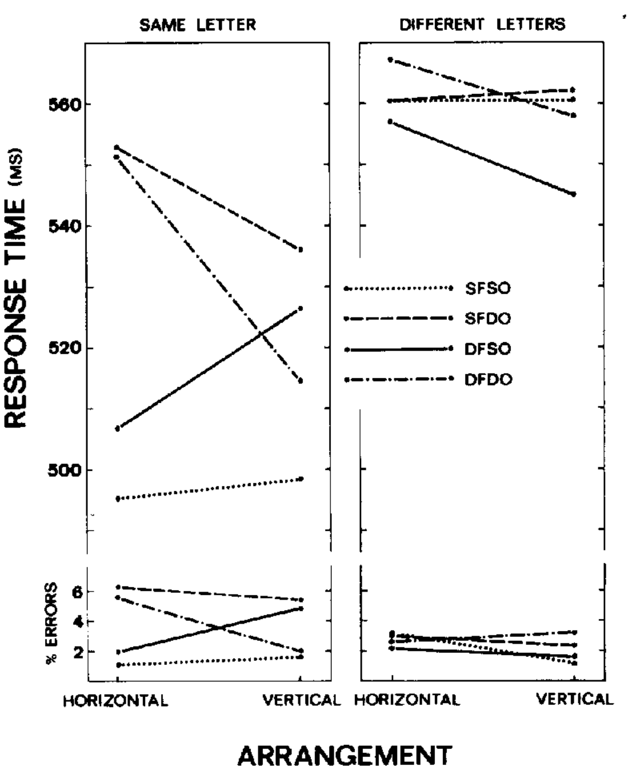

Figure 5. Mean response times and percentage errors for different types of same-letter pairs (left panel) and different-letter pairs (right panel) in Experiment 4.

Rotational transforms (SFDO) yielded slower same responses on the average (544 ms) than reflectional transforms (523 ms), $F(1, 11) = 19.92$, $p < .001$, and elicited more errors, $F(1, 11) = 8.92$, $p < .02$. These differences, however, were mainly due to the displays that allowed mental flipping. Rotational transforms evidenced somewhat faster response times for the vertical than for the horizontal arrangement, $F(1, 11) = 3.26$, $p < .10$, but this seems to be generally true for the reflectional transforms as well. Thus, a two-way ANOVA contrasting the effects of spatial arrangement for reflectional and rotational transforms yielded $F(1, 11) = 4.19$, $p < .10$, for spatial arrangement, $F(1, 11) = 23.03$, $p < .001$, for pair type, and $F(1, 11) = 1.20$, *ns*, for the interaction. Identical letters yielded the fastest response times and the lowest percentage of errors and showed little effects of spatial arrangement.

The results for different pairs failed to show the same type of interaction between pair type and spatial arrangement observed for the same reflectional transform pairs. An overall two-way Pair Type (4) × Arrangement (2) ANOVA for response time yielded only a significant effect for pair type, $F(3, 33) = 4.25$, $p < .02$, indicating somewhat faster responses for DFSO pairs than for the other pair types.

For same-orientation pairs similar mean response times were found for upright (527 ms) and upside-down (534 ms) pairs, which suggests that no uprighting mental rotation took place.

Discussion

The results of Experiment 3 suggested that sameness in the same–different task was established by rotation in the frontal plane. In Experiment 4 we examined the possibility that sameness may also be established through a transformation in depth for stimuli that differ only in reflection. Such a transformation ought to be more likely to facilitate performance when the two stimuli are spatially arranged along the axis of reflection than when they are arranged along the orthogonal axis. The results are consistent with this idea, suggesting that same responses may be based on a mental flipping operation in which the two reflectional transforms are mapped onto each other. In fact, when pairs related by reflection were arranged to induce mental flipping, response time was faster than for pairs related by rotational transformation. Similar results were not found for the different pairs, suggesting that these effects are derived from the transformational relations among the visual stimuli rather than among their intrinsic frames of reference (see Robertson, Palmer, & Gomez, 1987).

These results suggest that judgments of sameness may be based on different types of invariance depending on the task at hand. When the task called for reflection decisions, systematic ADP effects were found for same-letter–same-format sequences (i.e., pairs related by a rotation in the picture plane) but not for same-letter–different-format sequences (i.e., pairs that are related by a reflection transformation) (Koriat & Norman, 1988). In contrast, when the task required a comparison of the stimuli regardless of format and orientation (Experiment 4), the results suggest that a transformation does occur even for same-letter–different-format pairs. Apparently for this task the sameness of the stimuli may be established either by transformation in the picture plane or by transformation in depth.

In the foregoing discussion the effects of pair type and spatial arrangement obtained for the reflectional pairs were attributed to a transformation that is designed to map one member of the pair onto the other member. An alternative interpretation, however, is that the conditions that are favorable for a reflection transformation are by their nature those in which the display as a whole is symmetrical about the axis of reflection. Perhaps same responses are facilitated by the detection of global symmetry. Consistent with this claim, Fox (1975) found faster same response time for pairs of letters that formed an overall symmetrical display (e.g., VV) than for nonsymmetrical pairs (e.g., GG). Note, however, that in Fox's experiments interelement symmetry was confounded with intraelement symmetry, which was not the case in the present experiment. Furthermore, Fox concluded that bilateral vertical symmetry is more critical than horizontal symmetry, but this may be because he used only a horizontal arrangement. In the present study the same elements produced either a symmetrical display or a nonsymmetrical display depending on their spatial arrangement.

The mental flipping and the symmetry interpretations are not simple to distinguish, because visual symmetry can be defined in terms of a particular type of invariance (see Palmer, 1982, 1983). Thus, perhaps it is the extraction of such invariance across different segments of the visual field that gives rise to the perception of symmetry of the field as a whole. It might be argued that the perception of a figure as symmetric is based on a direct match between its symmetric parts without having to imagine mentally the two-dimensional figure "folded" about its axis of symmetry. Similarly, perhaps the reflection relation between the two letters in the symmetric pairs of Experiment 4 is directly extracted from the two-dimensional elements themselves without really actuating a mental rotation in the three-dimensional space. Experiment 5 explored this possibility.

Experiment 5

Experiment 5 attempted to extend the findings of Experiment 4 to a classification task by examining the possibility of backward alignment occurring in depth. The stimuli consisted of six perspective drawings portraying each of four three-dimensional Hebrew block letters at different orientations around the vertical axis (see Figure 6). Subjects classified each of these stimuli as one of the four letters. Apart from establishing the occurrence of backward alignment in depth, Experiment 5 sought to clarify the nature of the underlying transformation. Previous work on the mental transformation of three-dimensional objects (e.g., Metzler & Shepard, 1974; Shepard & Metzler, 1971) suggested that this transformation is performed on an internal representation more analogous to the three-dimensional objects portrayed than to their two-dimensional drawings. Thus, response time depended almost entirely on the angular disparity between the two objects in the three-dimensional space, with the degree of similarity in the surface features of the two-dimensional drawings exerting little effect.

In Experiment 5 we examined whether this is also the case for the backward alignment transformation. There are two ways in which backward alignment might operate. First, it may respond to changes in the objects, simulating the rigid rotation in the three-dimensional space that is required to bring the two objects into congruence with each other. In this case, response time for same-letter sequences ought to increase with increasing angular deviation between the respective three-dimensional objects. Second, it may focus on the characteristics of the two-dimensional perspectives, simulating the transformation that is required to map the two-dimensional perspectives onto each other. The results of Experiment 4 indicated relatively fast response times when the two letters could be mapped onto each other through mental flipping. Thus such a transformation may be applied to establish congruence between proximally symmetric perspectives such as the $-50°$ and $50°$ orientations of the same letter (see Figure 6). This transformation ought to result in a relatively fast response time for symmetrical perspectives regardless of the angular distance between the respective three-dimensional objects. If surface qualities of the two-dimensional objects also affect performance, then we might expect faster response times for the positive orientations (in which the drawing is most similar to what the letter looks like in normal print) than in the negative orientations (in which the letter is more similar to its mirror-image version).

Method

Subjects. Twelve University of Haifa students participated in the study for course credit. None had participated in the previous experiments.

Stimuli. The stimuli were six perspective views of each of four Hebrew letters (see Figure 6). These views corresponded to six equally spaced 20°-step rotations of the three-dimensional letter about its vertical axis in depth. The height of each letter was 2.5 cm (2.9° visual angle), and its maximal width was 2.0 cm. If the line of sight is defined as 0° orientation, then the orientations of the six views, in a clockwise rotation, were $-50°$, $-30°$, $-10°$, 10°, 30°, and 50°. Note that the 50° view was the most similar to the letter's normal appearance. The letters appeared at the center of the screen, with black fronts and gray sides on a sky-blue background.

Apparatus and procedure. The apparatus was the same as in Experiment 4. Viewing distance was 50 cm. Subjects were instructed to classify the letters by pressing one of four keys with the index and middle fingers of both hands. A three-dimensional wooden model of one of the letters was used to illustrate the nature of the stimuli. The assignment of keys to letters was counterbalanced across subjects.

The session began with one practice block of 145 trials. It was followed by 12 experimental blocks of 145 trials each, with the first stimulus in each block serving only as a prime for the first sequence. Each set of three successive blocks was programmed to produce 576 different sequences, representing all combinations of preceding letter (4), current letter (4), preceding orientation (6), and current orienta-

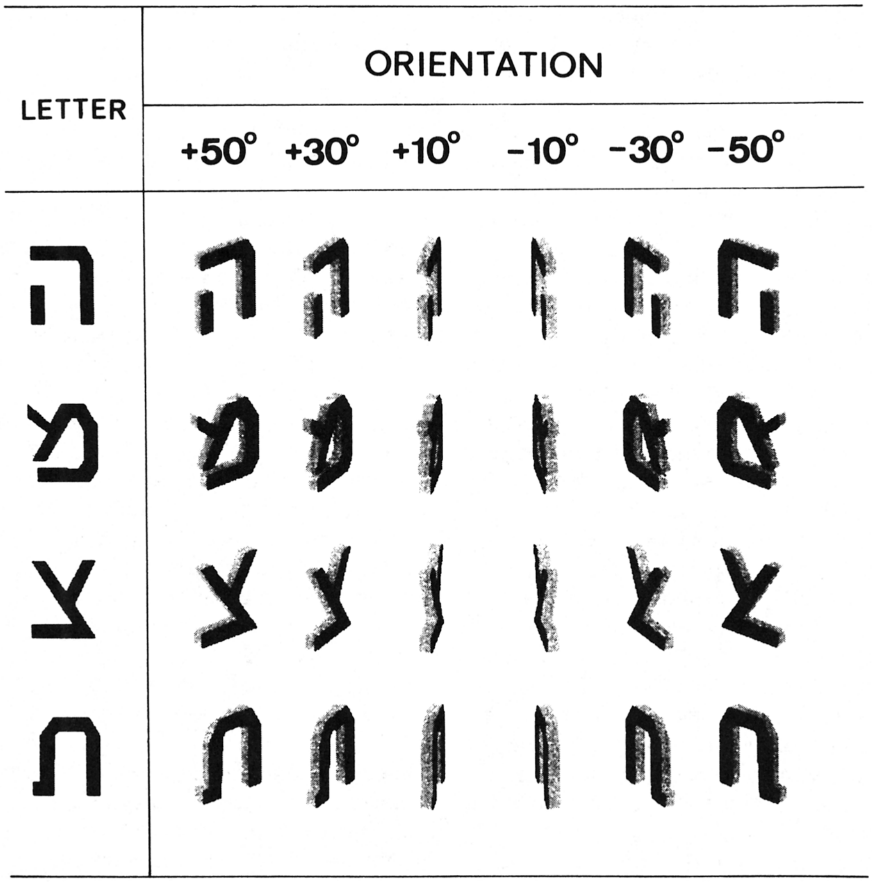

Figure 6. The stimuli used in Experiment 5.

tion (6). The stimulus appeared at the center of the screen until subjects responded and was replaced after 500 ms by the next stimulus.

Results

Response times outside the range of 250–3,500 ms were eliminated (0.5%). Table 1 presents mean response times for different-letter and same-letter sequences as a function of current and preceding orientations. We first examine the effects of current orientation. Mean response times for orientations 50° through −50° were 654, 661, 688, 696, 672, and 662 ms, respectively: $F(5, 55) = 15.15$, $p < .0001$. The respective means for percentage of errors were 3.9%, 4.6%, 5.1%, 4.7%, 4.2%, and 3.7%, respectively: $F(5, 55) = 2.61$, $p < .05$. Thus, performance was fastest and most accurate for the nearly frontal views of the letters and deteriorated as the letter became more closely aligned with the line of sight. When the orientations were grouped into those in which the letters were closer to their normal format (the positive angles) and those in which they were closer to the reflected format (the negative angles), the former were found to yield somewhat faster response times (667 ms) than the latter (677 ms): $F(1, 11) = 5.60$, $p < .05$.

We now turn to sequential effects. Figure 7 displays mean response time as a function of ADP, with current orientation as a parameter, combining the data for each pair of symmetrical orientations. The results are plotted separately for different-letter and same-letter sequences.

Different-letter sequences showed little change in response time with increasing ADP. In contrast, same-letter sequences yielded a rather different pattern, with response time generally increasing as a function of increased ADP but tending to decrease for large ADPs. The increase in response time between 0° and 60° ADPs was highly significant; $F(3, 33) = 39.75$, $MS_e = 248$, $p < .0001$; $F(3, 33) = 1.39$, *ns*, for percentage errors. Beyond ADP = 60° response time tended to decrease with further increases in ADP: A one-way ANOVA including ADPs of 60°, 80°, and 100° yielded $F(2, 22) = 4.10$, $MS_e = 356$, $p < .05$, for response time and $F(2, 22) = 1.77$, *ns*, for percentage errors.

The drop in response time with increasing ADP was most clearly observed for the ±50° orientation. Here the maximal ADP of 100° yielded relatively fast response times apparently derived from the symmetry relation between the two-dimensional perspective views. The results for the ±30° current orientation also showed a nonmonotonic function of ADP, but here response time was faster when the preceding orientation was 50° or −50° (ADP = 80°) than when it was the symmetric counterpart (ADP = 60°).

Table 1
Response Latencies (in Milliseconds) as a Function of Preceding and Current Orientations for Different-Letter and Same-Letter Sequences (Experiment 5)

Current orientation	Preceding orientation						
	50°	30°	10°	−10°	−30°	−50°	All
			Different letters				
50°	694	712	690	689	705	700	698
30°	719	713	694	702	698	701	704
10°	724	743	742	740	724	734	734
−10°	731	731	736	773	746	734	742
−30°	708	700	716	707	726	708	711
−50°	696	702	689	688	720	721	703
			Same letters				
50°	513	550	562	575	574	542	553
30°	523	521	537	565	552	551	542
10°	548	551	516	561	595	599	562
−10°	603	579	581	512	550	598	570
−30°	559	602	575	551	521	509	553
−50°	581	575	589	577	538	525	564

Discussion

The increase in response times with increasing ADPs suggests that backward alignment in depth may occur for perspective drawings of three-dimensional objects. This increase occurred only for same-letter sequences, which suggests that the ADP effects were not derived from an alignment of the intrinsic three-dimensional frames of the stimuli. The underlying transformation may be similar to the mental rotation of three-dimensional block figures studied by Shepard and Metzler (1971; Metzler & Shepard, 1974). This suggests that subjects can detect invariance over successive perspective views at the level of the three-dimensional object represented.

The relatively fast response times for ADPs larger than 60°, however, suggest that unlike the matching of three-dimensional block figures (Shepard & Metzler, 1971), backward alignment is also sensitive to similarities at the level of the two-dimensional pictures. This difference may be because letters can be easily classified on the basis of their surface features, rendering the similarity of their perspective views more salient than in the Shepard and Metzler task. Alternatively, it may reflect a more fundamental difference between the two processes, with mental rotation being effortful and imaginal and backward alignment being more automatic and perceptual (see Koriat & Norman, 1988). The former process may therefore rely on internal representations that are more akin to real-world objects in three-dimensional space. In contrast, the latter may take advantage of visual correspondences at the level of the two-dimensional perspective pictures when these are sufficient to guarantee response repetition.

What is the nature of the transformation that occurs between two symmetrical views of the same letter, for example, 50° and −50°? It is possible that the two views are treated as two-dimensional, "flat" patterns and yet are aligned through a rotation in depth (mental flipping). Such rotation may be faster than that operating on the three-dimensional objects because of the simplicity of the internal representation. Alternatively, visual correspondence may be directly extracted from the similarity in the surface features without actuating the necessary transformation (see *Discussion* section of Experiment 4). If this is the case, one may inquire whether the

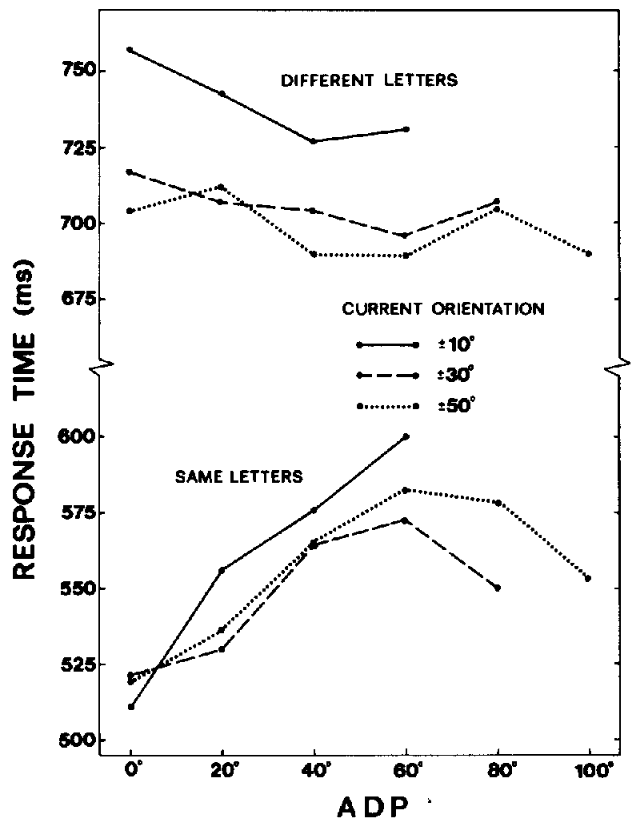

Figure 7. Mean response times and percentage errors as a function of angular deviation from preceding orientation (ADP), with current orientation as a parameter (Experiment 5).

ADP effects observed for the entire range of ADPs (Figure 7) may be accounted for in terms of a single process, one that establishes correspondence between successive stimuli on the basis of similarity at the level of the surface features. Clearly, two perspective views of the same object are more similar in some sense to each other when the angular difference between them is small, but so are two symmetric views (Fox, 1975). The problem with this proposition, however, is that it is difficult to imagine a mechanism that responds to some general dimension of similarity and that can still be adapted to establish the kind of visual correspondence that warrants response repetition in the task at hand. As we noted before, few effects of ADP have been observed for same-letter–different-format sequences in a reflection decision task (Koriat & Norman, 1988), yet such effects appeared to have been obtained in both Experiments 4 and 5 of the present study.

General Discussion

The present study investigated the recognition of alphanumeric characters. Previous research with the speeded classification task indicated that the time to identify single alphanumeric characters is indifferent to orientation. We took this to suggest that simple character identification is performed on the basis of orientation-invariant features and does not require a preliminary stage of mental rotation to the upright (e.g., see Corballis & Nagourney, 1978; Corballis et al., 1978; Eley, 1982, 1983; White, 1980). In contrast, systematic effects of orientational disparity have been observed for the same–different task, particularly for same responses (see Bagnara et al., 1984; Bundesen et al., 1981; Simion et al., 1982). These results suggested that same responses may be based on a transformational alignment of the two characters.

The effects of angular disparity for same judgments suggested to us that although the identification of a disoriented character does not require mental rotation to the upright, it might still be subject to a backward alignment transformation that brings two successive stimuli into correspondence with each other. This type of alignment has been found to occur in the Cooper and Shepard reflection decision task, but only when two stimuli in a sequence consisted of the same orientation-invariant shapes, thus allowing repetition of the same response (see Koriat & Norman, 1988). This result is similar to the finding from the same–different comparison task, in which the effect of angular disparity obtains only or mostly for same responses. Thus, our first aim was to examine the possibility that response time in the speeded classification task also increases with increasing angular deviation of the current stimulus from the preceding same-character stimulus. This indicates that processes concerned with relative judgments (comparison) occur in the context of the absolute judgment (speeded classification task).

Our second aim was to establish further the parallels between backward alignment in the speeded classification task and the processes underlying same judgments in the stimulus-comparison task by replicating the same pattern of findings across the two tasks. The third aim was to help specify the nature of the visual transformation underlying backward alignment and same responses. Specifically, unlike the reflection task, in which only rotation (in the frontal plane) but not reflection (in depth) can guarantee that two stimuli call for the same response, in the identification task either a rotation or a reflection transformation suffices. Therefore, we examined the possibility that the backward alignment process is sensitive to different types of transformation depending on the requirements of the task.

The results of the five experiments can be summarized as follows. In Experiment 1 a speeded classification indicated no effects of angular deviation from the upright, further supporting the view that letter classification does not require mental rotation to the upright (see White, 1980). Nevertheless, response time for same-letter sequences increased with increasing angular disparity between the two stimuli (ADP), which suggests a backward alignment that establishes the orientation-invariant identity of the two stimuli. This effect was not found for sequences that involved different letters.

Experiment 2 included stimuli of both formats (normal and reflected). The results confirmed that the systematic effects of ADP are only found when the two stimuli are rotational transforms, that is, when they involve a repetition of the same letter in the same format. This suggests that backward alignment depends on the orientation-invariant visual congruence between successive stimuli rather than on the congruence between their nominal codes. Very similar results were obtained in Experiment 3, which used same–different judgments on two simultaneously presented letters. This suggests that the effects of ADP observed in the speeded classification task depend on processes akin to those underlying same judgments in the stimulus-comparison task.

Experiment 4 examined whether backward alignment also occurs through rotation in depth among stimuli that are related by reflection. The results indicated that same judgments were strongly affected by the spatial arrangement of the letters, which suggests that different arrangements induce different types of transformations. Specifically, same response times for letters that differed in format were particularly fast when the letters were arranged to induce a mental flipping transformation that maps the two letters on each other through a reflection transformation.

Experiment 5 used different views of three-dimensional shapes that represented block letters. A speeded classification task suggested the occurrence of backward rotation in depth for same-letter sequences. This rotation appeared to operate on the three-dimensional shapes portrayed, but there was also some evidence for an alignment process that operates on the two-dimensional perspective views themselves.

These results have several implications. First, they help substantiate the link between backward alignment and the process underlying same judgments; second, they help clarify the nature of backward alignment; and third, they support the contention that the identification of disoriented stimuli may be achieved through qualitatively different mental operations. We discuss each of these points in turn.

Backward Alignment and Same–Different Judgments

The results of this and previous studies (Koriat & Norman, 1988, 1989a) imply that processes concerned with relative judgments occur in the context of a task requiring absolute judgments. These results suggest that both the reflection decision task (Koriat & Norman, 1988) as well as the stimulus-classification task (Koriat & Norman, 1989a, and the present study) entail a comparison process whereby each stimulus is automatically tested for the possibility that it represents a recurrence of the preceding stimulus. This congruence test consists of an attempt to align the two successive stimuli, hence the effects of angular disparity for sequences consisting of alignable stimuli. When the congruence test delivers a match signal, the preceding response may be repeated, preempting the default processes required for the generation of an independent classification response to the current stimulus.

This analysis implies a distinction between two types of processes. In the first the stimulus is matched with its corresponding internal representation in long-term memory, whereas in the second it is matched with the short-term visual trace of the preceding stimulus. The former process seems to require a preliminary stage of rotation to the upright in the case of the reflection decision task of Cooper and Shepard (1973) but not in the case of the classification task. Hence, the effects of ADP interact with those of ADU for the reflection task (Koriat & Norman, 1988) but not for the classification task (see Figure 1).

The bypassing of access to long-term codes perhaps represents the common denominator underlying backward alignment and same judgments. In both cases the response does not appear to require a complete identification of each of the matching stimuli (see Farell, 1985; Fox, 1975). This may explain why both backward alignment and same judgments are systematically affected by the visual properties of the stimulus, that is, by variations in irrelevant visual dimensions (see Dixon & Just, 1978). Such variations appear to be less critical when letter identification requires access to long-term memory, as suggested by the observation that alphanumeric stimuli are efficiently classified regardless of disorientation. Thus, the occurrence of orientational disparity effects in both the stimulus-comparison task and the speeded classification task may be taken as indicating that the response is not entirely mediated by access to long-term memory but also rests on the nonsemantic, visual characteristics of the stimulus.

This argument may help relate the concept of backward alignment to the concept of normalization advanced by Dixon and Just (1978). This concept was invoked to explain the finding that response time for same trials increases monotonically with the amount of disparity among the stimuli on an irrelevant dimension. This was seen to result from a process of "normalization" that transforms the irrelevant dimensions of the two stimuli until they are equal. Thus, according to Dixon and Just, disparity along an irrelevant dimension interferes with performance only when a comparison process takes place. This is because such comparison induces subjects to equate mentally the two stimuli on the irrelevant dimension.

Although the process of backward alignment has much in common with the process of normalization, it is different in important respects. Normalization was conceived (Dixon & Just, 1978) as a way of processing irrelevant information that cannot be ignored. In contrast, our conceptualization focuses on what remains invariant across the transformation. Thus, backward alignment is seen as a process that extracts invariance across successive stimuli in an attempt to establish their functional equivalence. Similarly, the effects of angular disparity in same–different judgments may be seen to result from a mechanism that establishes that two stimuli are transformational variants. For example, in the reflection task backward alignment can be seen as a mechanism for recovering shape identity that operates in addition to the normal mechanism whereby visual shapes are matched against their internal representations in long-term memory. This view is supported by the ADU × ADP interaction observed for same-shape sequences (Koriat & Norman, 1988, 1989a), which indicates that the extent of normalization effects varies with the relative ease of applying the normal default procedure of stimulus classification. The assumption that backward alignment represents an added option for stimulus classification naturally leads to emphasis on the benefit that accrues from the use of this process in relation to the default process. This contrasts with Dixon and Just's approach, which focuses on the interference from irrelevant dimensions.

Extraction of Invariance Across Stimuli

We interpreted the effects of orientational disparity as deriving from a particular type of recognition mechanism that extracts invariance across temporally and spatially contiguous events. The exact workings of this mechanism, however, are not clear, particularly in relation to the alternative default mechanism. Two issues remain open: the selection of the recognition mechanism and the choice of the type of invariance extracted.

The first issue concerns the observation that backward alignment operates only for sequences that permit a repetition of the same response. This raises the following dilemma: How can the selection of the recognition mechanism depend on the nature of the task required? In discussing the reflection decision task, Koriat and Norman (1988) proposed two mechanisms by which choice of transformation occurs. The first is that the congruence between successive stimuli is detected at a preattentive level, that is, at a level not accessible to the response mechanism, and backward alignment is used to establish this congruence. Thus, at an early stage the visual system assesses the angular distances in relation to both the upright and the preceding orientation, and the transformation requiring the shortest transformational path is then implemented. The second is simply that both rotation to the upright and rotation to the preceding orientation occur in parallel, and the response is determined by the first process to be completed.

The aforementioned dilemma naturally holds for the same–different comparison task as well, because in this task too the occurrence of orientation effects is contingent on the type of response (same or different). Again, one possibility is that the sameness of two stimuli is detected at a preattentive stage, perhaps on the basis of transitem structural properties (see Fox, 1975), and a transformation process is then implemented only for same stimuli. The alternative explanation is that the visual system automatically seeks to establish the sameness of the two stimuli to be compared by applying a transformation process that attempts to align them. When the system succeeds in establishing visual alignment, a same response is emitted; when it fails, it opts for a different response. This mechanism can explain both the increase in same response time with transformational disparity between the two stimuli and the fast same effect.

The second issue pertains to the selection of the criterion for congruence. The contrast between the reflection decision task (Koriat & Norman, 1988) and the classification task of the present study suggests that the type of transformation underlying backward alignment varies with the requirements of the task. The question is, How does the visual system determine what transformation is needed to recover the sort of invariance that would allow response repetition?

One possibility is that the criterion for congruence is determined at an early stage, so only those transformations that guarantee response repetition (or same response) are tested. A second possibility is that all shape-preserving transformations are tested, and only when invariance is detected does the system check whether that type of transformation guarantees response repetition. The present study does not allow an answer to this question. Thus, the finding from Experiment 4 that the spatial arrangement of the stimuli affects speed of responding is consistent with both of these accounts. Spatial arrangement may induce the testing of certain transformations rather than others, but it may also affect the speed of establishing the various transformations.

Possibility of Qualitatively Different Identification Processes

On a somewhat broader level, our results suggest that the interpretation of disoriented stimuli may be mediated by two qualitatively different types of operations. In the first, the stimulus is identified with its internal representation in long-term memory, possibly on the basis of orientation-invariant features (see Eley, 1982; Koriat & Norman, 1989b). In the second, it is identified with its previous occurrence through an orientation-dependent process. In this latter process the visual configuration of the stimulus as a whole is transformed into congruence with the short-term trace of the preceding stimulus.

A similar distinction is suggested by the results of Koriat and Norman (1989a). In that study, the time to classify multielement strings showed a systematic effect of disorientation, with the extent of this effect increasing systematically with the number of elements in the string (see Koriat & Norman, 1985). These results suggested that multielement strings are not rotated as global wholes. Nevertheless, as far as backward alignment is concerned, multielement strings were apparently rotated as configural wholes into alignment with a preceding stimulus in same-stimulus sequences. Thus different types of transformation appear to occur when the stimulus is matched against its preceding occurrence than when it is matched against its internal representation.

According to Koriat and Norman (1988), some of the characteristics of the backward alignment process derive from its automatic, stimulus-instigated nature. Unlike the uprighting process, which is controlled, effortful, and imaginal, backward alignment is a perceptual process activated ad hoc when the orientation-invariant identity of two successive stimuli are detected. This characterization suggests that the backward alignment process may differ not only from the usual type of classification process but also from the process underlying same judgments in the stimulus-comparison task. Although the two processes appear to have much in common, they differ in one important respect: Unlike same judgments, which are based on an explicit comparison process, the backward alignment process operates implicitly in the context of tasks that explicitly require absolute rather than relative judgments. This feature of backward alignment has led us to conclude that this process is largely automatic, reflecting the operation of a general, tacit mechanism that is designed to extract invariance across successive events and to allow detection of stimulus recurrence (see Shepard, 1984). Thus, it remains to be seen whether the processes underlying backward alignment and same judgments might not differ still in quality by virtue of their tapping implicit and explicit processes, respectively. The large body of evidence supporting the distinction between implicit and explicit memory processes (see Schacter, 1987) gives reason to believe that they might.

One finding that is consistent with this idea comes from Experiment 5. Previous research (Metzler & Shepard, 1974; Shepard & Metzler, 1971) suggested that when subjects judge whether two perspective views portray the same three-dimensional object, they perform the task by imagining the objects rotated in three-dimensional space. In contrast, in Experiment 5 there was some indication that backward alignment may also capitalize on an alignment that operates on the two-dimensional perspective drawings themselves. If this effect is found to be reliable, it may suggest a qualitative difference between explicit same responses and implicit backward alignment.

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