The time required to prepare for a rotated stimulus

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Average time required to determine whether an alphanumeric character was presented in its normal version or in its mirror image was measured from 500 msec to 1,000 msec as the angular departure from upright increased from 0 to 90°.

However, when the Ss already knew the identity of the upcoming character and when advance information as to its orientation was available for 1,000 msec, the reaction time was reduced to about 400 msec regardless of the orientation of the test stimulus. In this case, Ss claimed that they could prepare for the rotated stimulus by imagining the normal version of the designated character rotated to the indicated orientation and that they could then rapidly test for a match against the ensuing stimulus.

Shepard and Metzler (1971) have reported that reaction time for determining whether pairs of perspective line drawings depict objects of the same three-dimensional shape increases linearly with the angular difference between the orientations of the two objects. On the basis of the marked linearity of the reaction-time functions as well as the introspective reports of the Ss, Shepard and Metzler argued that the Ss "mentally rotated" a representation of one object into the other in order to check for matching of the two mentally rotated objects.

In two further experiments, Shepard and Khan measured the amount of time required to respond discriminatively to a single rotated stimulus with a natural, preferred orientation (see Shepard, in press). In the first of these further experiments, Ss were presented with a rotating alphanumeric character in various tilted orientations and were required, for each, to determine whether the presented character was the "normal" or the "backward" (i.e., mirror-image) version of that character as generally seen in printed form. Reaction time was found to be a monotonically increasing function of the angular departure of the rotated stimulus from the standard upright orientation. This finding led Shepard and Khan to suggest that Ss carried out a mental rotation in order to make the "normal"-"backward" discrimination. However, this task—unlike the one studied by Shepard and Metzler—required that an internal representation of the visual test character be mentally rotated into congruence with a representation of the normal upright version of that alphanumeric character was tested in a long-term memory.

In both of the experiments mentioned above the tilted stimulus corresponding to the normal representation that the Ss was presumed to be mentally rotated was externally displayed throughout the trial. The question naturally arises as to whether a similar task could be carried out in preparation for an upcoming rotated test stimulus. In the second experiment by Shepard and Khan, Ss were again required to decide whether a rotated alphanumeric character as "normal" or "backward," but this time they were allowed to advance information about the orientation of the test stimulus prior to its actual visual presentation.

When advance information was given (in auditory form) concerning both the identity and the orientation of the ensuing test stimulus (e.g., "the letter R at 4-00 o'clock position"), the function relating reaction time and orientation of the test stimulus remained considerably the same as that for Ss, but for some Ss, became positive and horizontal. This finding suggests that Ss were able to mentally rotate the presentation of the rotated alphanumeric character by using the advance information to generate a mental image of the appropriate character and then rotate this image into the appropriate orientation. When presented with the actual test stimulus the Ss could make the required discriminative response almost rapidly, regardless of the orientation of the test stimulus. This was supported by the fact that the normal and the backward versions at an orientation of 120° deg is illustrated on the right in Fig. 1.

All stimuli, including test characters and advance information, were displayed vertically within the same circular aperture in the field of a tachistoscope. Fig. 1 illustrates the horizontal orientation of advance information as to the identity and the orientation of the test character [R] when it was to appear at an orientation of 120° deg. Identity information consisted of an outline drawing of the nominal uppercase version of the ensuing test character. Orientation information consisted of an arrow drawn through the center of the circular field and pointing to the position of the test character in the block on the top of the test character was about to appear.

Advance information cues always preceded the test character, and in such a way that both identity and orientation information were presented. The identity cue always preceded the orientation cue. The alphanumeric characters which served as identity and test stimuli subtended a visual angle of about 15° deg.

Fig. 1. Sequence of visual display on a trial of Type B. Each successive display immediately follows the preceding within the same circular field.

METHOD
Subjects
The eight Ss, five males and three females, were students and staff at Stanford University.

Stimuli
The test stimuli were all symmetrical upper-case letters (A, B, C, D, E, F, H, K, L, M, N, O, P, S, T, U, V, W, X, Y, Z), and three Arabic numerals (2, 5, 7), which could be displayed in either their normal or their backard versions. Six characters and one numeral were presented in each of six equally spaced orientations around the circle, in 45° steps with angle of rotation measured in clockwise from the normal upright orientation. The task was always to discriminate the normal versions of the six characters from the backward or mirror-image versions of two of the letters and the numeral. The letters and the numeral versions at an orientation of 120° deg is illustrated on the right in Fig. 1.

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Experimental Conditions and General Design
Each S was tested under eight experimental conditions. The two types of test stimuli (normal and rotated) were presented as a pretest stimulus and the duration of advance information was varied. The number of these conditions for each of the eight individual Ss is given in Table 1. Although not separately plotted, all of the points plotted on the graph were based on data from the two pretest stimuli and the duration of advance information for all test stimuli orientations and all experimental conditions.

All of the points plotted in Fig. 2 and independent of the exceptions of the points for 360 deg, which are the result of a separate analysis of variance, were significant at the 0.05 level of confidence. All other data were significant at the 0.01 level of confidence.
Consider first the uppermost reaction-time function, labeled "N" in Fig. 2. In Condition N, no advance information concerning either the identity or the orientation of the upcoming test stimulus was provided. In the absence of advance information, reaction time is a sharply increasing function of angular departure of the test stimulus from the standard upright orientation. Note the remarkably symmetrical shape of the function about 180 deg. This indicates that a given angular departure from upright results in an approximately equal increase in reaction time for both clockwise and counterclockwise rotations.

The marked dependence of reaction time upon departure of the test stimulus from upright, illustrated in Fig. 2, conforms well to the results obtained earlier by Shepard and Kline. Following them and, originally, Shepard and Metzler (1971), we interpret this monotonicity increasing function as supportive of the notion that Ss "mentally rotate" an internal representation of the visual test stimulus in order to determine whether that stimulus is normal or backward version. (In this case, the determination is presumably made by comparing the mentally represented character of the test character with a representation of the normal version of that alphanumeric character stored in long-term memory.) We attribute the concave-upward monotonic increase in reaction time (taller than linear in the results of Shepard and Metzler) to the fact that alphanumeric characters (unlike three-dimensional nonse square shapes) have a psychologically unique upright orientation. For a fuller discussion of possible sources of nonmonotonicity, see Cooper and Shepard (in press).

Consider next the set of reaction-time functions for the Type B conditions, in which information concerning both the identity and the orientation of the upcoming test stimulus was provided in advance of the presentation of the test stimulus itself. The curves labeled "B-100", "B-460", "B-700", and "B-1000" in Fig. 2 show the joint effect of orientation of the test stimulus and duration (in milliseconds) of advance information concerning that orientation upon reaction time. When advance information is to the identity of the upcoming test character is presented for 2,000 msec, followed by only 100 msec of orientation information (Condition B-100 in Fig. 2), the reaction-time function—though about 100 msec lower—has essentially the same shape as that of the function obtained when there was no advance information (Condition N). It is evident from Fig. 2, however, that as the duration of the orientation information is increased (Conditions B-460, B-700, and B-1000), the relationship between reaction time and orientation of the test stimulus becomes weaker. Indeed, when the duration of orientation information is presented for 1,000 msec, reaction times are short and virtually constant for all orientations of the test stimulus.

An analysis of variance performed on the group data for these four Type B conditions confirms the statistically reliable a four-way analysis of variance (by Durations by Orientations by Normal vs Backward Versions) was done with the four-way interaction used as the error term. All main effects were highly significant (P < .001). The sources of variance and the associated Fs were: "Ss," F = 147.25, df = 7,105, "duration," F = 260.94, df = 3,105, "orientations," F = 176.97, df = 310, "versions," F = 81.48, df = 1,105. All two-way interactions with the factor "Ss" were also significant (P < .001). "Ss by Durations," F = 133.39, df = 21,105, "Ss by Orientations," F = 18.45, df = 35,105, "Ss by Versions," F = 8.65, df = 1,105. The only other two-way interaction to achieve statistical significance was that of Durations by Orientations (F = 18.88, df = 15,105, p < .001). This interaction, of course, corresponds to the flattening of the reaction-time function with increasing duration of orientation information. None of the three-way interactions approached statistical significance. Analysis of variance done on the data of each S individually yielded essentially the same results.

The central finding—that the monotonic increase in reaction time with departure of the test stimulus from upright diminishes, and finally disappears, with increasing advance information duration—coexists nicely with our notions concerning the process of preparing for a rotated stimulus. If, as we suggested above, Ss prepare for a tilted stimulus by mentally rotating an internal representation of the preassigned character from the upright position into the preassigned orientation, then this process of preparatory mental rotation should take longer to complete as the orientation designated in the advance information departs further from the upright position. When this process of preparatory rotation has been fully completed for a given orientation indicated in advance, then reaction time to the actual test stimulus, when presented at that orientation, should be as short a reaction time to a stimulus which has not been rotated. (Presumably, if the S is fully prepared in the manner described above, the orientation character is a "template" against which to compare the visual test stimulus.)

However, when this preparatory rotation has not been fully completed in advance of the presentation of the test stimulus, then an increase in reaction time to that stimulus should result. For, in that case, additional mental rotation must be carried out after the actual test stimulus has been presented as a result of the normal backward discrimination to be executed gradually. The flatness of the B-1000 reaction-time function presented in Fig. 2 indicates that this process of preparatory rotation can be completed for all angular departures from upright with a 1,000-msec duration of the orientation cue. When the duration of the orientation cue is reduced to 700 msec, the predicted increase in reaction time occurs, especially for test stimuli presented at larger angular departures from upright. With orientation information durations of 400 and 100 msec, very little preparatory rotation can be carried out and reaction times are longer for all test-stimulus orientations.

The reaction-time data presented in Fig. 2 relate well to the introspective reports. The Ss claimed that they did attempt to prepare for the presentation of the test stimulus in these Type B conditions. A mental image of the character designated by the identity cue and then rotating this mental image into the orientation designated by the orientation cue. Most Ss reported that the condition in which 2,000 msec of identity information was followed by 1,000 msec of orientation information provided enough time to rotate a mental image of the anticipated stimulus up to a normal angular departure of 180 deg from the upright position. In the condition in which the duration of the orientation cue was reduced to 700 msec, they claimed that they often had insufficient time to rotate the mental image to 180 deg. With further reductions in the duration of the orientation information, rotations of 120 and even 60 deg became difficult. The shortest orientation information duration (100 msec) Ss claimed, generally allowed for no preparatory rotation before the onset of the actual rotated test stimulus. (The fact that the curve for B-1000 in the overall has a lower overall height than does the curve for N is to be attributed to the fact that Ss did have some advance information in Condition B-100 and so required less time to process the test stimulus before initiating a rotation. It does not indicate that there was no advance rotation.)

The Ss also said that, under the longer duration conditions, their preparatory mental image of the designated character was sufficiently well defined, even after mental rotation, to be used as a kind of "template" against which to compare the actual visual test stimulus. A comparison of the shapes of the B-1000 and C reaction-time functions shown in Fig. 2 lends support to these introspective claims. Recall that in Condition C the advance information cue consisted of an outline drawing of the normal version of the upcoming character, which had already been externally rotated into the appropriate orientation, while in Condition B-1000 the preparatory image had to be generated and mentally rotated by the S himself. Two analyses failed to indicate any significant difference in the shape of the B-1000 and C reaction-time functions. An analysis of variance indicated that the interaction between "conditions" and "orientations" was nonsignificant (F < .05) and, when the independent variable was taken as 0 to 180 deg departure from upright in either direction, a t test for the difference between the means of the test conditions was not significantly different. A reaction-time function for Conditions B-1000 and C was also nonsignificant (t = 1.02, df = 7). Nonetheless,
the B-1000 function is slightly above the C function in overall height by about 20 micra for all orientations. Possibly the preparatory internal representation was slightly more vivid in Condition C as a result of the fact that complete information as to identity and orientation had been available for 3 sec prior to the onset of the test stimulus in this condition, but for only 1 sec in Condition B-1000.

SUMMARY AND CONCLUSIONS

When Ss are required to determine whether a tilted alphanumeric character is normal or backward, given no advance information about the test stimulus itself, they mentally rotate an internal representation of the test character, after it has been presented, into the standard upright position and compare this representation with a permanently stored representation of the normal upright version of that character. Evidence for this conclusion derives from the marked increase in reaction time with increasing angular departure of the test character from the upright orientation (Condition N in Fig. 2).

However, when Ss are given advance information as to the identity and orientation of the upcoming test character for an adequate amount of time, they can prepare for the presentation of the tilted test stimulus by carrying out a purely mental rotation of a mental image of the anticipated character in advance of its actual presentation. The virtually flat reaction-time function that results when identity information is followed by a full 1,000 micra of orientation information (Condition B-1000 in Fig. 2) provides strong support for this conclusion.

When the duration of the advance orientation information is reduced below the full 1,000 micra, this preparatory mental rotation usually cannot be full completed for large angular departures from upright in general; the shorter the duration of the advance information, the smaller the angular departure from upright over which preparatory rotation can be completed. The dependence of reaction time upon angular departure of the test stimulus from the upright position for short durations of orientation information and, especially, the weakening of this dependence as the duration of the orientation information increases (Conditions B-1000, B-400, and B-700 in Fig. 2) provide support for this conclusion.

Finally, the similarity flat shapes of the reaction-time functions obtained under Conditions B-1000 and C (in Fig. 2) and the introspective reports of the Ss support the following conclusion: For purposes of speed, comparison against the ensuing test stimulus with a representation that the S constructs and retains on the basis of separately presented cues as to identity and orientation (Condition B-1000) is virtually as effective as an untransformed memory image of the extremally rotated character itself (Condition C).

REFERENCES


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Sex composition and group performance in a visual signal detection task

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Forty-eight Ss (24 males, 24 females) were run in groups of 4 on 720 trials of a 16-alternative forced-choice visual signal detection task requiring both individual and group decisions. Four types of groups were formed: all male, all female, mixed-sex (males and females combined), and mixed-sex (males and females combined and mixed). No differences in performance between all-male and all-female groups, and mixed-sex groups had poorer performance, with mixed-sex groups having significantly lower sensitivity than heterosexually-sexed groups. The results were interpreted as indicating that heterogeneity of groups with regard to sex interacts with seating pattern in affecting performance, probably due to the formation of information coalitions between-like-sex group members when the seating pattern encourages such coalitions.

A programmatic series of studies of visual signal detection determined that scanning strategies were similar for most individuals, both male and female (Clement & Hasking, 1971; Clement & Schierer, 1971). It was found that group performance in four-person groups was superior to individual performance, but was not as good as predicted by a model in which information from individuals was combined in an independent fashion (Clement, 1973). Although this last study used only male Ss, prior findings indicated that task was sex-specific, and thus groups of female Ss would be expected to perform in a similar manner. However, this speculation was not supported by empirical data extending investigation to the possible effects of Sex on group performance, three types of groups could be considered: all-male all-female, and mixed groups.

Mixed groups, in turn, could contain differing proportions of males and females and could differ as well in terms of the seating patterns (proximity and position) among males and females in the group.

Mixed groups, by definition, are heterogeneous in their composition. Studies of group heterogeneity and its effect on performance generally have dealt with personality or peer performance factors (e.g., Hoffman, 1955; Goldman, 1967; McEogin, 1968), but few have included sex as a variable in studies of such things as problem-solving tasks (Hoffman & Weiss, 1963; Kent & Goodman, 1969) and jury deliberations (Strodtbeck & Mann, 1956). In the latter studies, the usual assumption has been that obtained sex differences are derived from differences in motivation and culturally determined role expectations—perhaps of more importance on the part of males (e.g., Leung & Yancey, 1963). No evidence has been obtained that males or females typically perform in a superior fashion on test-specific tasks. Aside from such tests, sex composition of groups has been used frequently as a variable in small group performance studies. It might be expected that mixed groups would show some of the effects previously attributed to group heterogeneity, but the effect of sex heterogeneity per se probably would be much less than that of heterogeneity due to personality and other differences.

One factor in small group performance receiving more study has been that of proximity or seating relationships. Such studies have usually focused on leadership roles and their development (e.g., Davenport, Brooker, & Minto, 1971). Those members of a group who are seated near each other might be expected to communicate more (Hare & Miles, 1963), and this could lead to increased cooperative behavior as well as to facilitation of leadership roles (Sommer, 1962). All-male and all-female groups would not differ in the respect that there would be no sex-related proximity relationships to affect communications and leadership functions. However, mixed groups might be expected to show some such effects, particularly if the seating arrangement were one which tended to emphasize like-sex grouping.

Another potential factor which might influence small group performance would be coalition formation by sex in mixed groups. In cooperative kinds of tasks, the formation of coalitions is rather unexpected. However, if coalitions were formed, the task would take on some aspects of a competitive rather than a cooperative situation, and performance might be expected to suffer (e.g., Deutsch, 1949). Such coalitions might form as a result of sex differentiation (Strodtbeck & Mann, 1956) or some other sex-related behavior which influences communication—object choices (Parten, 1933; Smith, 1944; Jones, 1951). Coalition formation based upon sex would be more likely to form when such things as proximity or seating patterns would encourage them (Hare, 1962). For example, a four-person mixed-sex group with two males and two females could be seated in the order male-male-female-female or in the order male-female-male-female. The former arrangement would be expected to emphasize and encourage sex grouping.

This study compared the performances of four types: