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Transformation processes upon the visual code

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Seven experiments investigated whether orientation-dependent latency functions for the visual code resemble those observed in studies of mental rotations of visual images. The subjects were required to perform "same-different" classifications of two simultaneously presented letters. The dependent variables considered were reaction time (RT) and accuracy. Experiments 1, 2, 4, 5, and 6 showed that subjects could correctly classify two different letters on the basis of the visual code without preceding transformations. Experiments 1, 2, and 7 showed orientation-dependent effects for "same" responses. It appeared, however, that orientation functions for the visual code were clearly different from those previously observed for visual images. In addition, the findings of Experiments 4, 5, and 6 indicated that a frame that jointly rotated with the disoriented letters could eliminate the orientation-dependent effects for "same" responses. Experiment 7 showed that the results of Experiments 4, 5, and 6 must be attributed to the structural characteristics of the frame and not to a directional cue. The results of Experiment 3 seemed to demonstrate that transformations did not occur when the subjects used the phonetic code to classify the letters. Overall, the results of the seven experiments were considered to provide a demonstration of the importance of the distinction between the operations on visual images and those on the visual code.

Human observers can classify as "same" two simultaneously presented familiar shapes irrespective of their size, position, and orientation; that is, they can rapidly compensate for differences at the level of retinal projections. Contingent features are thought to be corrected to eliminate irrelevant stimulus properties and facilitate the matching of the stimuli. However, the manner in which the operations of correction are achieved has yet to be determined. It has been proposed (Larsen & Bundesen, 1978; Rock, 1973) that observers can adopt the strategy of transforming mentally a visual image of the type extensively studied by Shepard and his collaborators (see review in Shepard, 1975). However, other authors (Besner & Coltheart, 1975, 1976; Posner, 1969) have suggested that correction depends upon operations that take place at an earlier stage and involve the visual code.

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Several studies (Shepard, 1975) have reported that the time required to determine whether two visual patterns are the same in shape increases monotonically, and approximately linearly, with the angular difference between the orientations of the patterns. This finding has led to the notion that observers rotate mentally the visual image of one of the two stimuli into congruence with the other prior to comparing them for a match or a mismatch in shape. Central to this notion are the hypotheses that (1) the operation of mental rotation is an internal analogue of the process that occurs when the rotation of an external object is perceived, and (2) that during mental rotation the internal process passes through a trajectory, that is, a series of intermediate stages which have a one-to-one correspondence to the intermediate stages in the external rotation of the object (Cooper, 1976; Cooper & Shepard, 1973a).

In a number of mental rotation studies, the timing of stimulus presentations often allowed from 1 to 2 sec to generate a visual image of sufficient clarity to be used for subsequent transformations (Cooper

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& Podgorny, 1976; Cooper & Shepard, 1973a, 1973b). In addition, the figures to be judged were always very similar, since reflections of the same pattern were used as the different pairs (Cooper, 1975; Cooper & Shepard, 1973a; Corballis, Nagourney, Shetzer, & Stefanatos, 1978; Corballis, Zbodroff, Shetzer, & Butler, 1978; Shepard, 1975), and the observers were required to discriminate between a stimulus and its mirror image, not between entirely different stimuli.

Posner (1978, chaps. 2 and 3; see also Posner & Rogers, 1978) has reviewed data establishing that when the subjects are visually shown alphabetical letters, two different internal codes are formed. One represents the visual code of the letter, and the other its phonetic recoding. These two codes yield two isolable processing systems. When the two letters are physically identical, they are classified as *same* on the basis of the visual code, whereas when they share only the same name they are matched on the basis of the phonetic code.

Posner has also stressed the importance of the conceptual distinction between the visual code and a visual image and between operations upon a visual image and the visual code. The generation of a visual image is accompanied by subjective reports of imagery and demands attention, whereas the visual code is formed automatically and without clear awareness by the observer. Correspondingly, while operations upon a visual image are relatively slow, operations upon the visual code occur very rapidly.

When familiar shapes are presented simultaneously, observers are able to classify them almost immediately and effortlessly; thus, the visual code rather than the visual image might be the internal representation upon which the operation of normalization takes place. This hypothesis would gain support if the time course of the normalization process were different from that observed for the rotation of visual images. In other words, the question is whether the quasi-linear relationship between angular difference in orientation and response latency is also observable when the two comparison stimuli are simultaneously present and have different shapes.

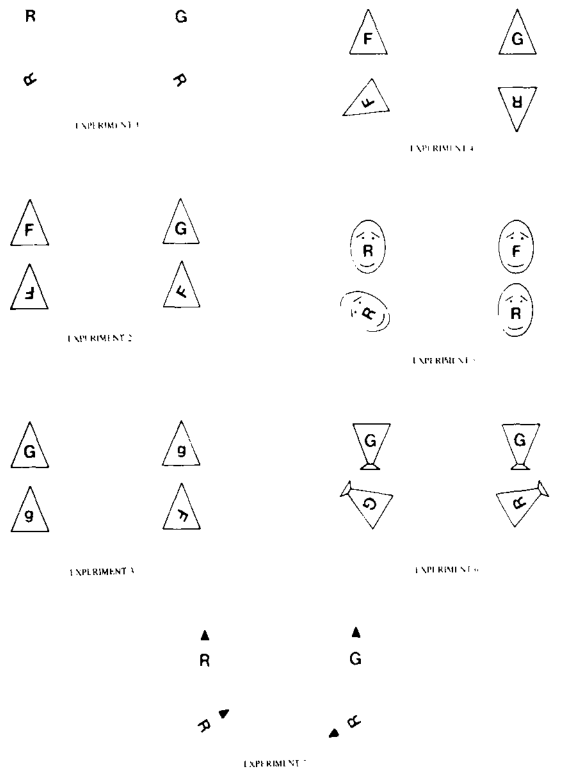

Figure 1. Examples of the stimuli.

EXPERIMENT 1

Experiment 1 consisted of a simultaneous "same-different" letter classification task. The letter pairs were either physically identical or different. Therefore, observers could perform the task on the basis of the visual code.

Method

Subjects. Twelve students (six males and six females) in the age range of 19-25 years took part in the experiment. All were right-handed and had normal or corrected vision. They were paid for participating in the experiment.

Stimuli. The stimuli (see Figure 1) consisted of pairs of black uppercase forms of F, G, and R (taken from MECANORMA 22-28.C) on a white background. Photographic negatives (35 mm) of each pattern were mounted in slide holders for tachistoscopic projection on a back-projection screen. The letters were placed one above the other in a vertical arrangement. The upper letter always appeared in the standard upright position (0 deg orientation), whereas the second letter of the pair could be drawn in six different angular orientations from 0 to 300 deg in 60-deg steps of clockwise rotation. The three "same" pairs were presented five times in the six different orientations so that 90 "same" stimuli were projected. Thirty-six "different" pairs were obtained by pairing each letter with one of the other two in six different orientations. Since each "different" pair was presented twice, 72 "different" stimuli were projected. The stimuli subtended a visual angle of about 7.9 deg when both letters appeared in the standard upright position. Each letter was 3.4 deg high while the spacing between the two letters of a pair subtended 1.1 deg of visual angle.

Procedure. In the test session, the subject maintained a constant head position by leaning his/her forehead against a headrest and placing the chin on a chinrest. The subject faced a translucent screen at a distance of 60 cm. An acoustic signal (800 Hz for 1 sec) prompted the subject to fixate a central point on the screen. Half a second after the warning signal, a slide was projected for 100 msec. The interval between two presentations was 5 sec.

The stimulus intensity was 45 cd/m², and the luminances of the ambient light and fixation field were 21 and 20 cd/m², respectively. The subject was instructed to respond by pressing one of the two keys with the right or left index finger as quickly as possible and to try to avoid errors. The keys were on a response panel positioned in front of the subject and in a central position just below the fixation mark on the screen. Half of the subjects (three males and three females) used the right hand for "same" responses and the left hand for "different" responses, whereas the other half had the reverse assignment. Pressing the key stopped one of two electronic millisecond counters that were started at the beginning of the 100-msec exposure period. The stimuli were projected onto the center of the screen through a Kodak Carousel equipped with an electronic shutter. Each subject was tested during one 60-min session. Formal testing began after about 80 informal practice trials, during which the subjects became acquainted with the experimental situation and learned to press the correct key in response to "same" and "different" pairs. The data collection session consisted of 162 experimental trials divided into two blocks of 81 trials separated by a 5-min rest period. Stimuli were presented in a random sequence. No feedback was given to the subject.

Results

Table 1 shows overall mean correct RTs and percentages of errors for "same" responses as a function of the degree of orientation of the lower letter. The mean latencies are shown as a function of angular orientation in Figure 2.

A three-way analysis of variance was carried out on correct "same" RTs. When an error occurred, the RT for the cell was estimated from the remaining correct RTs in the block according to the formula suggested by Winer (1971). The factors were angular orientation, type of letter, and presentation (first to fifth presentation of each letter in each orientation). The main effects were significant—$F(6,66)=23.49$, $p < .001$, $F(2,22)=9.82$, $p < .001$, and $F(4,44)=7.98$, $p < .001$, for orientation, type of letter, and presentation, respectively. These effects remain significant even if one adopts the reduced degrees of freedom ($df=1,11$) recommended (Myers, 1972) for testing repeated measures. The three letters yielded different response latencies—543 msec for F, 590 msec for G, and 610 msec for R. RTs decreased from the first to the last presentation—627, 598, 596, 549, and 556 msec. No other source of variability attained statistical significance.

Four F ratios were performed on mean RTs to test linear, quadratic, cubic, and quartic trends (Myers, 1972). The significance of the trends was tested with $\alpha=.01$ in order not to exceed the overall value of α for the corresponding source of variability in the analysis of variance. The linear and quadratic trends were significant—$F(1,11)=23.89$, $p < .001$, for the linear trend, and $F(1,11)=44.14$, $p < .001$, for the quadratic trend.

A one-way analysis of variance was carried out on errors and showed a significant effect of angular orientation [$F(6,66)=5.59$, $p < .001$] even with reduced degrees of freedom.

In the above-mentioned analyses, the results for the upright orientation were included twice, once as 0 deg and once as 360 deg. Since this procedure is questionable (see Discussion below), the analyses were replicated considering only five orientations, that is, 60, 120, 180, 240, and 300 deg. In the case of mean correct RTs, the main effects of orientation [$F(4,44)=6.05$, $p < .001$], type of letter [$F(2,22)=6.46$, $p < .01$], and presentation [$F(4,44)=5.62$, $p < .005$] were significant, even when conservative degrees of freedom are employed. The letter F (560 msec) showed the fastest RTs, followed by the letters G (614 msec) and R (626 msec). RTs improved from the first to the fifth presentation—639, 636, 610, 568, and 565 msec. No other source was significant. The linear and quadratic trends were again significant [$F(1,11)=23.89$, $p < .001$, and $F(1,11)=10.09$, $p < .01$, respectively]. In the case of errors, the analysis of variance did not show a significant effect of orientation.

Four one-way analyses of variance were conducted on correct RTs and errors for "different" responses (see Table 2 and Figure 3). The orientation main effect was not close to statistical significance in any analysis ($F < 1$ for both RT analyses).

Discussion

A preliminary point that must be discussed concerns the opportunity of including the upright position in the analyses. Previous studies have shown that this orientation yields the fastest RTs even if the subjects are not required to rotate the letters mentally (see Ambler & Proctor, 1976; Cooper & Shepard, 1973a; Egeth & Blecker, 1971; Kolers & Perkins, 1969). It seems that congruence with an overlearned familiar orientation favorably affects the encoding

Table 1
Overall Mean RTs (in Milliseconds) and Mean Percentages of Errors (PE) for "Same" Responses as a Function of Angular Orientation of the Lower Letter

	Angular Orientation (in Degrees)													
	0		60		120		180		240		300		360	
Experiment	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
1	530	2.2	602	12.2	608	8.3	615	2.8	598	5.0	571	4.4	530	2.2
2	564	2.8	616	5.6	648	6.7	654	3.9	628	10.0	609	9.4	564	2.8
3	807	7.8	872	7.2	883	13.3	897	9.4	871	8.3	879	7.2	807	7.8
4	585	1.7	611	3.3	619	2.2	582	3.9	610	1.7	605	5.0	585	1.7
5	767	8.9	793	11.1	850	10.0	787	6.6	816	9.4	785	5.0	767	8.9
6	703	4.4	776	6.6	786	3.8	810	5.5	751	2.2	782	5.5	703	4.4
7	615	4.4	654	12.7	695	16.1	707	21.6	700	14.4	659	11.6	615	4.4

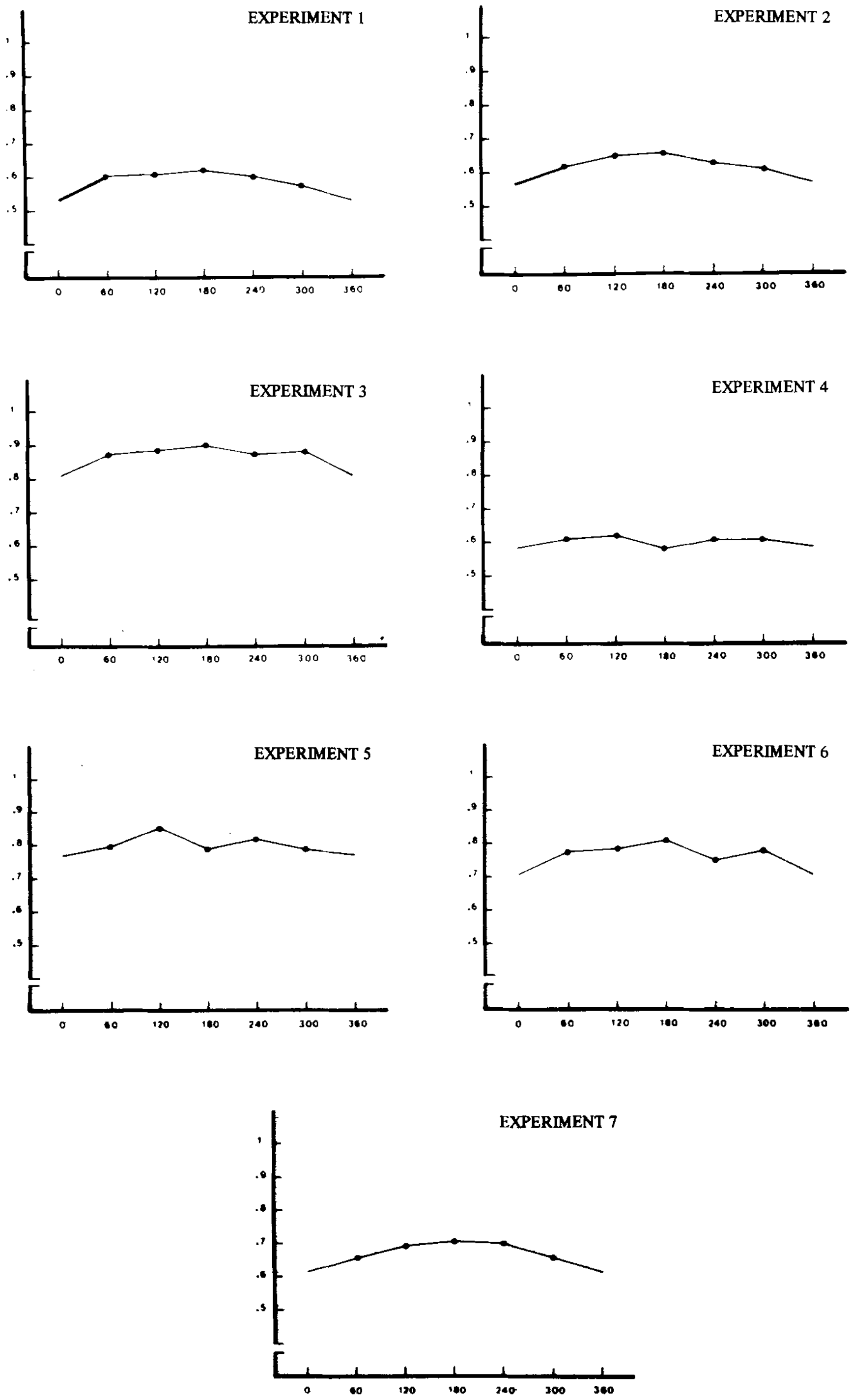

Figure 2. Mean RTs for "same" responses as a function of the degree of angular orientation of the lower letter in a pair.

time common to every stimulus irrespective of any subsequent process of transformation. Therefore, by including twice (0 and 360 deg) the results for the upright orientation, we could have forced on the data a quadratic trend attributable not to a rotational transformation, but to a different orientation-dependent process. Furthermore, central to the idea of a mental rotation is the notion of a trajectory, that is, a one-

Table 2
Overall Mean RTs (in Milliseconds) and Mean Percentages of Errors for "Different" Responses as a Function of Angular Orientation of the Lower Letter

	Angular Orientation (in Degrees)													
	0		60		120		180		240		300		360	
Experiment	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
1	641	2.0	643	6.2	639	7.6	635	3.4	660	2.7	643	.6	641	2.0
2	645	.0	673	.0	675	1.3	658	.0	682	1.3	653	.0	645	.0
3	1005	14.6	959	3.8	1009	10.0	991	9.7	900	11.1	1000	12.2	1005	14.1
4	627	2.0	633	3.4	654	2.7	639	1.3	631	3.4	627	.0	627	2.0
5	803	5.7	802	3.4	862	9.7	833	8.3	837	4.5	810	7.6	803	5.7
6	774	1.7	790	2.0	780	1.3	790	4.5	816	5.5	809	5.5	774	1.7
7	698	6.9	694	2.2	704	6.2	739	.6	743	8.3	668	1.8	698	6.9

to-one correspondence between all the intervening stages of the hypothesized internal rotation and those of an actual external rotation.

If a mental rotation is actually performed, it must be shown by a quadratic trend even when the data for 0 deg are not considered in the analysis. The significance of the quadratic trend with and without the upright orientation seems to indicate that the observers have adopted a normalization process of the disoriented letter similar to that of mental rotation shown for visual images.

However, this conclusion is in contrast with the striking difference between previous estimates of mental rotation rates of visual images, which were in the range of 250-400 deg/sec (see, e.g., Cooper & Shepard, 1973a; Corballis, Nagourney et al., 1978), and that of the present experiment (2,640 deg/sec), which was much higher. Such an estimate of rotation rate is implausibly high and poses a difficult problem for interpreting the processes of normalization observed here in terms of rotation of visual images. Moreover, the time-course of mental rotation has been shown to be fairly constant in speed across orientations, even when, as in the case for familiar stimuli with a preferred upright position, rotation functions tend to depart from linearity (Cooper & Shepard, 1973a; Corballis, Zbodroff, & Roldan, 1976). On the contrary, in the present experiment, the difference in latency between the upright orientation and its adjacent orientations was always much learger than the differences between any other pair of orientations.

It must also be stressed that "different" responses showed no evidence of an angular orientation effect. Even though it is known that distortions have less marked effect upon negative decisions, or "different" responses, than upon positive decisions, or "same" responses (Corballis et al., 1976; Corballis, Zbodroff et al., 1978; Egeth & Blecker, 1971), it seems difficult to find a satisfactory explanation for this discrepancy within the framework of mental rotation of a visual image. Previous studies on visual images (Cooper 1976; Cooper & Shepard, 1973a; Corballis, Nagourney et al., 1978; Corballis et al., 1976; Shepard, 1975) have always found that response latency was an increasing function of the angular difference between the two comparative stimuli for both same and different responses. Accordingly, it has been found (Bundesen & Larsen, 1975; Larsen & Bundesen, 1978) that the time necessary to classify as "same" or "different" two shapes increased linearly as a function of the size ratio of the figures for both types of responses, when the transformation rate suggested the use of visual images. On the contrary, those studies of mental size scaling (Besner & Coltheart, 1975, 1976; Santee & Egeth, 1980) in which the operations of normalization were presumably based on the visual code found that response latency varied systematically as a function of the amount of size disparity only in the case of "same" responses.

A significant linear trend was present in both analyses. This trend is attributable to the fact that RTs to the left orientations (i.e., 240 and 300 deg) tend to be consistently faster than those to the corresponding right orientations (60 and 120 deg). This finding is not without precedent in a simultaneous letter classification task (Simion, Bagnara, Bisiacchi, Roncato, & Umiltà, 1980, Experiment 2) and seems to suggest a visual scanning effect, for example, a left-to-right scanning linked to reading habits.

Corballis, Nagourney et al. (1978) suggested that the introduction of an explicit frame of reference surrounding the comparison stimuli can be effective for manipulating the visual cues according to which the operation of normalization takes place. Following this suggestion, it was decided to carry out a variation of Experiment 1 in which the letters were enclosed in a triangular frame. In this way, we hoped to simplify the operation of normalization by making the horizontal and vertical cues more conspicuous.

EXPERIMENT 2

This experiment followed the same method as Experiment 1 with the single exception that the two letters to be compared were enclosed in two identical

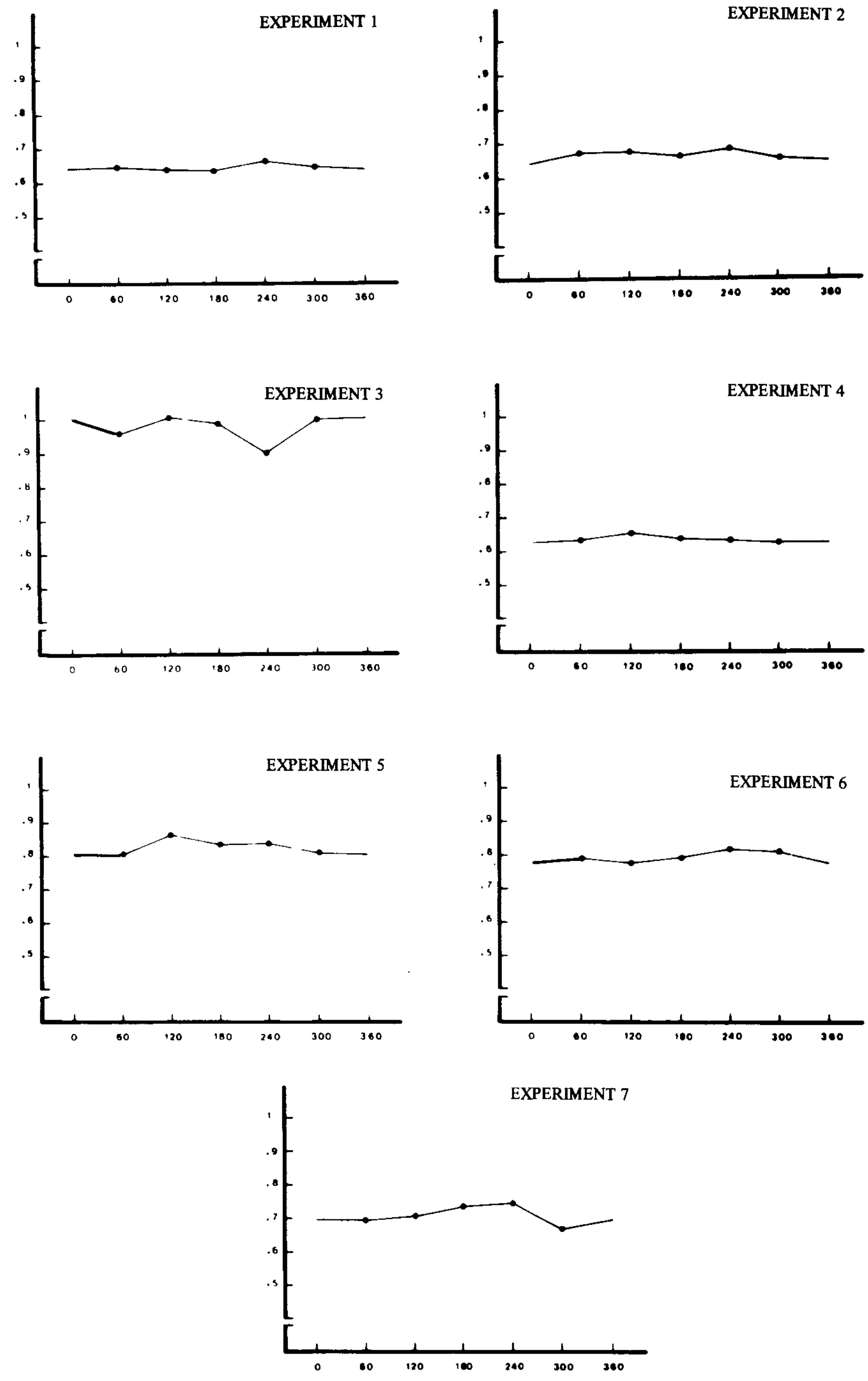

Figure 3. Mean RTs for "different" responses as a function of the degree of angular orientation of the lower letter in a pair.

isosceles triangles (see Figure 1). The two triangles were always presented with the vertex in the upright position.

Method

Stimuli. The letters were identical to those of Experiment 1. Each letter was centered in an isosceles triangle, the base and the height of which subtended 3.4 and 4.6 deg, respectively.

Subjects. Twelve students (six males and six females), selected as before, took part in the experiment. None had participated in Experiment 1.

Procedure. The procedure was identical to that of Experiment 1.

Results

Tables 1 and 2 show overall mean correct RTs and percentages of errors for "same" and "different" responses, respectively. The mean latencies for "same" and "different" responses as a function of angular orientation of the rotated letter can also be seen in Figures 2 and 3. The correct RTs and errors were submitted to the analyses already described for Experiment 1. With the upright orientation, "same" RTs showed significant main effects due to orientation [$F(6,66) = 39.51$, $p < .001$] and type of letter [$F(2,22) = 14.72$, $p < .001$] even with reduced degrees of freedom. RTs were fastest for the letter F (589 msec) followed by G (569 msec) and R (653 msec). The other sources were nonsignificant. Only the quadratic trend attained statistical significance [$F(1,11) = 89.59$, $p < .001$].

Without the 0-deg orientation, "same" RTs showed significant main effects of orientation [$F(4,44) = 9.59$, $p < .001$], type of letter [$F(2,22) = 16.64$, $p < .001$], and presentation [$F(4,44) = 3.09$, $p < .05$]. The first two were significant also with reduced degrees of freedom. The letters yielded different RTs—606, 612, and 680 msec for F, G, and R, respectively. RTs were faster at the end than at the beginning of the session—668, 631, 619, 627, and 620 msec. No other source was significant. Only the quadratic trend reached significance [$F(1,11) = 27.18$, $p < .001$]. The errors showed no significant difference in the two analyses. In the case of "different" responses, no source of variability was close to significance in any analysis ($p < .20$ for the RT analysis).

Discussion

The results of Experiment 2 confirmed those of Experiment 1 in showing that "same" responses are emitted after normalization of the rotated letter, whereas "different" responses do not require a similar process. Also, in this experiment, the rate of rotation (2,312 deg/sec) was much higher than any previously estimated for visual images. Such a replication confirms the apparent discrepancies between the results of the present experiments and those of previous studies on mental rotation. The only effect of the triangular frame was to eliminate those scanning strategies which probably yielded the linear trends in Experiment 1.

In both Experiment 1 and Experiment 2, the two comparison letters were either identical in shape or different. Therefore, they could be easily compared on the basis of the visual code. Experiment 3 was aimed at showing whether visual transformations for "same" responses take place when the two letters of a pair must be compared on the basis of the phonetic code.

EXPERIMENT 3

Experiment 3 followed the method of Experiment 2, with the single exception that the two comparison letters always had different shapes. That is, one member of each pair was uppercase and the other member was lowercase. Thus, the "same-different" decision could be made only on the basis of the names of the two letters.

Method

Subjects. Twelve students (six males and six females), selected as before, took part in the experiment. None had participated in Experiment 1 or Experiment 2.

Stimuli. Examples of the pairs of letters are given in Figure 1. The letters were at the same distance as the capitals in the preceding experiments. The triangular frame was identical to that of Experiment 2.

Procedure. The procedure of Experiment 1 was followed.

Results

Overall mean correct RTs for "same" and "different" responses, along with percentages of errors, are shown in Tables 1 and 2; RTs are also shown in Figures 2 and 3. RTs and errors were submitted to one-way analyses of variance with angular orientation as the only factor. RT data were again tested for linear, quadratic, cubic, and quartic trends. In the case of "same" responses with the upright orientation, there was a significant main effect of orientation [$F(6,66) = 4.13$, $p < .005$], which became nonsignificant when conservative degrees of freedom were adopted. Only the quadratic trend was significant [$F(1,11) = 99.84$, $p < .001$]. However, when the upright position was omitted, the main effect of orientation was not significant ($F < 1$). No significant source of variability was found for error analyses.

In the case of "different" responses, there was a significant main effect of orientation, both with and without the upright orientation [$F(6,66) = 6.11$, $p < .001$, and $F(4,44) = 7.02$, $p < .001$, respectively], which was also significant with reduced degrees of freedom. The only significant trend was the cubic one when the upright orientation was not included [$F(1,11) = 16.76$, $p < .01$]. The errors were not affected by the orientation of the letters.

Discussion

In the previous experiments, in which the two letters were presumably classified on the basis of the visual code, there were highly significant quadratic trends for "same" responses. Evidence in favor of a visual transformation is the fact that the quadratic trend was present even when the upright orientation was omitted. In that case, the quadratic trend could not be attributed to a faster encoding time for right-side-up letters. By the same line of reasoning, the lack of a significant quadratic trend in the present experiment for "same" responses without the 0-deg orientation could be considered as evidence against a visual transformation prior to phonetic comparison. The opinion that the subjects in the present experiment used a different process of comparison is also suggested by the observation that RTs in Experiment 3 were much longer than the RTs in Experiments 1 and 2.

The significant quadratic trend observed for "same" responses when the upright orientation was included could result simply from the greater speed and automaticity of visual encoding of the letter presented in that position. As already noted, this advantage for the upright orientation might be due to the fact that highly familiar shapes such as letters have an overlearned characteristic orientation. The fact that the 180-deg orientation yielded the slowest RTs makes this explanation seem more convincing than one (Attneave & Olson, 1967; Attneave & Reid, 1968; Olson & Hildyard, 1977) that would attribute this effect to congruence with the primary vertical axis. The effect of the privileged upright position should have been stronger in the present experiment, in which the process of visual encoding was more demanding inasmuch as the observers had to process six shapes (i.e., the uppercase and lowercase forms of G, F, and R) instead of three (i.e., the uppercase forms of the same letters) as in the two previous experiments. However, faster and more automatic visual encoding of upright letters should have been equally effective for "different" pairs, which was apparently not the case (see Table 2 and Figure 2) even though an orientation-dependent effect was found for "different" responses. In fact, there was only a significant cubic trend and the upright orientation did not show the fastest RTs.

It is conceivable (Chase, 1978; Theios, 1973, 1975) that the identification of a visually presented letter, that is, the labeling of a highly familiar visual shape, implies at least two different stages of information processing. The first stage can be characterized as a stage of visual encoding that yields the actual shape of the visual object. The second stage is based on an acoustic representation of the name of the visual object stored in long-term memory and implies a phonetic encoding. In a "same-different" task with letters that can be physically identical or different, the process of comparison usually takes place at the first stage. As shown by Experiments 1 and 2, the effects of visual transformations are apparent at the stage of visual matching. When the task also requires a "same" response for letters that have different shapes, the process of comparison must take place only at the second stage. As shown by Experiment 3, in this case only an effect of the upright orientation is present, whereas the effects of normalization disappear for the other orientations. Thus, it seems that phonetic encoding and phonetic matching can be performed independently of the actual orientation of the visual shape. However, the matching process is clearly much faster when both letters are in the upright orientation. The observation that when the comparison of the two letters depends on the phonetic code no operation of normalization is required corroborates previous findings (Corcoran & Besner, 1975; Santee & Egeth, 1980) which report that pairs of letter and geometrical figures that are only nominally equivalent show no effect of relative size manipulation.

Many investigators (Chase, 1978; Pachella & Miller, 1976; Stanovich & Pachella, 1977) divide input processing into an encoding and a comparison phase. This view is not inconsistent with the possibility that visual encoding and phonetic encoding take place in series, whereas visual comparison and phonetic comparison are independent and take place in parallel. What Experiments 1, 2, and 3 seem to show is that orientation-dependent visual transformations play a role in visual comparison, as is presumably the case also for size normalization (Posner, 1978), but not in phonetic comparison.

EXPERIMENT 4

Assuming that normalization processes take place at the level of visual comparison, it would be interesting to determine whether this is always the case. In the following experiments, we have tried to show that when the process of comparison involves the visual code there are circumstances in which it can take place without prior transformations.

It has already been shown (Cooper, 1976; Cooper & Shepard, 1973a, 1973b; Shepard, 1975) that the ordered relationship between RTs and angular orientation disappears when advanced information is given about the orientation of the ensuing stimulus. The most likely explanation of this finding suggests that the orientation cue allows the observers to perform a mental rotation on a generated visual image before the presentation of the stimulus. In fact, the regression of latency on angular orientation is lost only if sufficient time elapses between presentation of the cue and presentation of the stimulus.

Corballis and his associates (Corballis, Nagourney et al., 1978; Corballis & Roldan, 1975; Corballis et al., 1976) have demonstrated that mental rotations are not always performed with reference to the gravitational coordinates. Although they have found that RTs are dependent primarily on retinal coordinates for detection of symmetry of unfamiliar dot patterns (Corballis & Roldan, 1975), they have later established that RTs depend primarily on environmental coordinates for discrimination between standard and reversed versions of familiar alphanumeric characters (Corballis, Nagourney et al., 1978; Corballis et al., 1976). These authors have suggested that corrective rotations might depend on a variety of factors, including the type of the judgments, the instructions, and the nature of the stimuli.

All these studies have dealt with mental rotation of visual images. In view of the distinction between the visual code and a visual image, it seems pertinent to ask whether there are factors that can influence the visual transformations shown in Experiments 1 and 2. Minsky (1975) has discussed the role of frames on perception, suggesting which structural factors can influence visual transformations. According to him, a frame can be used to describe the structural invariants present in the display. If, then, pairs of disoriented letters are enclosed in frames the orientation of which is congruent with that of the letter, the comparison process should not require any orientation-dependent transformation. More specifically, we suggest that when the two disoriented letters maintain invariant relationships with their own frames and the two frames are identical, a comparison based on the visual code can take place without any previous process of normalization.

A similar idea was tested by Blount (Note 1). He studied size normalization; the type of frame manipulation employed was whether pictorial depth cues were present. When they were not, the usual normalization effect was obtained. However, when the depth cues made physically different forms appear to have the same size, normalization did not occur.

The following experiment was aimed at testing this hypothesis. It followed the method of Experiment 2 except for the fact that the triangular frame was jointly oriented with the rotated letter.

Method

Subjects. A group of 12 students (six males and six females) were tested. The subjects were selected in the same way as before. None had participated in the previous experiments.

Stimuli. The same pairs of letters as in Experiment 2 were employed. The upper letter was centered in a triangular frame, and both the letter and the triangle were in the upright orientation (0 deg). The lower letter was centered in an identical triangle, the vertical axis of which had the same orientation as the vertical axis of the letter (see Figure 1).

Procedure. The procedure was the same as that of Experiment 2.

Results

Tables 1 and 2 show the mean correct RTs and percentages of errors for "same" and "different" responses. Mean correct RTs are also shown in Figures 2 and 3 for "same" and "different" responses, respectively. As in Experiment 3, latencies were subjected to four analyses of variance separately for "same" and "different" responses with and without the upright orientation. No source of variability attained statistical significance ($p > .20$). Analyses of errors also showed no significant effects.

Discussion

The lack of any significant trend strongly supports the notion that when the two comparison letters maintain invariant relationships with their triangular frame, no transformation is needed. Irrespective of their specific orientations, the two letters share the same relationships with their own frames and thus the observers can base the comparison on the structural invariants, which are the same for both stimuli. It seems worth noting that the rotated frames eliminated even the great advantage of the upright position.

In the present experiment, "same" responses were given to identical letters; therefore the comparison could be performed on the basis of the visual code. Since the rotated frame apparently had the effect of eliminating the transformations found in Experiments 1 and 2, in which the comparison also took place through the visual code, it can be suggested that the frame acted at the stage of visual comparison. In Experiments 5 and 6, we tried to extend the foregoing findings to other frames.

EXPERIMENTS 5 AND 6

Experiments 5 and 6 varied the method of Experiment 4 by employing different frames—a cartoon face in Experiment 5 and a schematic drawing of a glass in Experiment 6.

Method

Subjects. Two groups of 12 students (12 males and 12 females) took part in the experiments. The subjects were selected in the same way as before. None had participated in previous experiments.

Stimuli. In Experiment 5, the stimuli were cartoon faces composed of two facial features and one capital letter arranged in an oval frame. Each feature was always presented in the same location with respect to the oval frame containing it (see Figure 1). The capital letters were identical to those employed in Experiment 1. In Experiment 6, the stimuli were schematic glasses obtained by substituting, for the vertex of the isosceles triangles of Experiments 2, 3 and 4, a small isosceles trapezoid. A capital letter was presented in the center of the frame (see Figure 1). Again, the capital letters were those already employed in the previous experiments. Also, the size of the stimuli was the same as in Experiments 1 and 2. Both in Experiment 5 and Experiment 6, the orientation of the frame was congruent with the orientation of the rotated letter.

Procedure. The procedure of Experiments 5 and 6 exactly replicated that of Experiment 1.

Results

Tables 1 and 2 and Figures 2 and 3 show the results of Experiments 5 and 6. Mean correct RTs and errors were subjected to the statistical analyses already described for the two previous experiments.

The results for the two experiments were so similar that they can be described together. For faces with the upright orientation, there was a significant main effect due to angular orientation for "same" responses [$F(6,66) = 3.97$, $p < .005$]; this was not significant with reduced degrees of freedom. For glasses, the effect was also significant [$F(6,66) = 10.00$, $p < .001$], as it was with reduced degrees of freedom. Quadratic trend was significant for faces [$F(1,11) = 9.49$, $p < .001$] and for glasses [$F(1,11) = 18.32$, $p < .001$]. When the upright position was omitted, no significant effect was found ($p > .20$).

In the case of "different" responses, neither the analysis with the upright orientation nor that without it yielded any significant effect ($p > .20$).

Error analyses did not show significant results for either "same" or "different" responses.

Discussion

The results of Experiments 5 and 6 are only partially confirmatory of those of Experiment 4. Experiment 4 showed that the rotated triangular frame had eliminated any orientation-dependent effect. The lack of significant effects in the present experiments when the upright orientation was omitted seems to confirm that observers were not performing transformations prior to visual comparison. However, with both frames, a fairly consistent quadratic trend was brought about by the inclusion of the upright orientation. As we have pointed out in the discussion of Experiment 3, this quadratic trend might be attributed to faster and more automatic encoding of the letters presented in the privileged upright position. But, again, such an explanation would seem to imply an identical finding for "different" pairs that the data clearly failed to show. Despite these discrepancies, however, overall the results of Experiments 5 and 6 confirmed the impression that the rotated frame allowed the observers to perform the letter comparison task on the basis of the visual code without a preceding process of normalization.

In Experiments 4 and 5, the RT functions for both "same" and "different" responses showed a clear, though nonsignificant, dip at 180 deg. This trend might be attributable to the use of vertically symmetrical frames. However, such an interpretation is contradicted by the lack of the effect in Experiment 6, in which a frame equally symmetrical along the vertical axis was employed.

Although the present experiments were performed to test whether a frame had an effect on the comparison of two disoriented letters, a much simpler explanation could be given in terms of directional cues. The three frames used were symmetrical along the vertical axis and had a distinctly marked top-bottom direction. Thus, they could indicate clearly the orientation of the enclosed letter. The rotated frame could also be likened to a landmark feature (see Hochberg & Gellman, 1977) that provides direct information about orientation. As already noted (in the introduction to Experiment 4), directional cues seem to be effective only when the observers are given enough time to perform a mental rotation of the visual image of the stimulus before it is actually shown. In the present experiments, the directional cue was instead given simultaneously with the rotated letter and the observers should not have been able to generate a suitable visual image. In fact, the present series of experiments was aimed at studying transformations based on the visual code as opposed to mental rotations of internally generated visual images. In any case, the best way to decide whether a directional cue can explain the results of Experiments 4, 5, and 6 seems to be by a condition in which a simultaneous directional cue is given without any frame. The following experiment was directed at disentangling the effect of the rotated frame from that of the directional cue.

EXPERIMENT 7

This experiment followed the method of Experiments 4, 5, and 6, but in this case the frame was replaced by an arrowhead, corresponding to the top vertex of the triangle of Experiment 4, which rotated jointly with the letter.

Method

Subjects. A group of 12 students (six males and six females) were tested. The subjects were selected in the same way as before. None had participated in the previous experiments.

Stimuli. The pairs of capital letters to be compared were identical to those of Experiment 1, with the exception that on the top of each letter a small arrowhead was printed. Its location corresponded exactly to the top vertex of the triangle in Experiment 4.

Procedure. The procedure was the same as that of Experiment 1.

Results

The mean correct RTs and percentages of errors for "same" and "different" responses as a function of angular orientation of the rotated letter can be seen in Tables 1 and 2 and in Figures 2 and 3.

The two one-way analyses of variance carried out on mean correct RTs for "same" responses showed a significant effect of angular orientation both with [$F(6,66) = 18.42$, $p < .001$; significant also with reduced degrees of freedom] and without [$F(4,44) = 4.46$, $p < .01$; nonsignificant with reduced degrees of freedom] the upright orientation. In both cases, there was only a significant quadratic trend [$F(1,11) = 83.48$, $p < .001$, and $F(1,11) = 16.27$, $p < .01$, respectively]. A significant orientation effect was found also for errors when the upright orientation was considered [$F(6,66) = 5.18$, $p < .01$; significant also with conservative degrees of freedom]. The two analyses of variance carried out on mean correct RTs for "different" responses showed a significant main effect of angular orientation. This effect was significant with reduced degrees of freedom even when the upright orientation was omitted [$F(6,66) = 5.58$, $p < .001$, and $F(4,44) = 6.34$, $p < .001$]. Again, in both cases, the only significant trend was the quadratic one [$F(1,11) = 10.02$, $p < .01$, and $F(1,11) = 25.72$, $p < .001$]. Significant orientation effects were found for errors even when reduced degrees of freedom were employed [$F(6,66) = 5.52$, $p < .01$, and $F(4,44) = 7.73$, $p < .001$].

Discussion

The results of Experiment 7 for "same" responses were like those of Experiment 2 and showed a very clear-cut effect of angular orientation. Also, in this experiment, the rate of rotation was much too high (i.e., 2,180 deg/sec) to be accounted for in terms of rotation of a visual image.

However, "different" responses in Experiment 7 showed an orientation-dependent effect that was absent in Experiment 2. Kroll, Kellicut, Berrian, and Kreisler (1974) found that an irrelevant feature of the comparison letters (color, in their study) affected the time-course of matches only when the attention of the observers was deliberately called to that dimension. It is conceivable that in Experiment 7 the arrowhead called the attention of the observers to orientation, bringing about an orientation-dependent effect for "different" responses. The notion that the two arrowheads acted as interfering directional cues is supported by the remarkably high error rates found when the stimuli comprising arrowheads pointing toward different directions had to be classified as "same."

It seems that the results of Experiments 4, 5, and 6 must be attributed to the structural characteristics of the frame and not to a directional cue. On the other hand, the results of Experiment 2 had shown that transformations cannot be prevented by simply enclosing the disoriented letter in a fixed frame. When the triangle did not rotate jointly with the letter, the observers had to perform a transformation in order to classify correctly two identical letters. A fixed pattern cannot be considered a suitable frame, since the spatial relationship between the enclosing pattern and the letter are not invariant. We have shown that a rotated frame does not function as a directional cue; however, directionality is but one of the many properties defining a frame. It would be interesting to determine whether any of these properties or any combination of them account for the disappearance of the orientation-dependent effects.

CONCLUSION

Central to the present study was the distinction between the operations on the visual code and those on visual images. It is well-known (Shepard, 1975) that processes of mental rotation can be performed on internally generated visual images. It is also well established (Posner, 1978) that normalization processes can involve the visual code. We have tried to determine whether the orientation functions for the visual code resemble those observed in studies devised to investigate the mental rotation of visual images. It appears that orientation functions for the visual code differ in many ways from those for visual images.

An apparent discrepancy concerns "different" responses. In the case of visual images, orientation functions for "different" or negative responses were like those for "same" or positive responses in showing a linear or quasi-linear relationship between latency and angular difference of the comparison stimuli. In contrast, in the case of the visual code, no orientation-dependent effect was found when the observers correctly classified two different letters. The only exception occurred when an arrowhead presumably called attention to orientation (Experiment 7). Thus, it seems that observers could correctly classify two different patterns on the basis of the visual code without any preceding transformation.

The lack of any evidence of normalization processes for "different" responses seems to be a typical finding of those studies in which the nonrelevant physical disparities presumably can be corrected at the level of the visual code. Two explanations have been proposed to account for the effect of nonrelevant stimulus properties on "same" but not on "different" decisions (Besner & Coltheart, 1975, 1976; Santee & Egeth, 1980). "Different" judgments would not be sensitive to irrelevant disparities, since they are mediated by an analytic process, whereas "same" judgments are determined by a holistic process which is sensitive to irrelevant disparities. Alternatively, it has been proposed that the relevant dimension is examined prior to the irrelevant one and that the process terminates as soon as a difference is found on the relevant dimension. However, this second explanation seems to imply that RTs for "different" judgments will be faster than those for "same." This was clearly not the case in the present study, even though the unbalanced probability of occurrence of the decisions could have played a role in slowing down "different" responses.

Orientation-dependent effects were apparent only when the observers correctly classified as "same" two identical letters (Experiments 1, 2, and 7). However, even if we restrict our attention to "same" responses in Experiments 1, 2, and 7, we may note that the orientation functions observed differ sharply from those found in previous studies on mental rotation of visual images. First, the estimates of rotation rates in the present study were so high as to render implausible the view that the visual transformation was the mental rotation of a visual image. Second, there was always a much larger difference in latency between the upright orientation and the two adjacent (60 and 300 deg) orientations than between any other pair of adjacent orientations, whereas the previous studies had shown that the time taken to rotate a pattern mentally is more or less constant along the entire trajectory. In addition, those studies which have found a departure from linearity have also shown that mental rotation became relatively slower as the orientation departed from the standard upright position and especially so when it was close to 180 deg from the upright. In the present study, the opposite proved true.

Also, the finding that a frame that jointly rotates with the letter eliminates any orientation-dependent effect, even for "same" responses, is difficult to reconcile with previous findings on mental rotation. Cooper and Shepard (1973a) and Corballis and Roldan (1975) have shown that observers cannot rotate mentally an abstract frame of reference in preparation for some stimulus of known orientation, even though they can adjust their frame of reference in advance of a stimulus to compensate for head tilt (Corballis et al., 1976; Corballis, Nagourney et al., 1978). These last studies simply showed that the upright orientation can be defined either according to retinal coordinates or according to gravitational axes. However, mental rotation has always the same time-course, independently of the coordinates that define the upright orientation. The findings of Experiments 4, 5, and 6 suggest that observers utilized the invariant relationships between the letter and its frame to accomplish the match on the basis of the visual code without previous transformations.

In conclusion, the difference between the operations on the visual code and those on visual images can be summarized as follows. (1) "same" and "different" judgments are likely to be mediated by two different processors (one holistic and the other analytic) in the case of the visual code, whereas they are presumably mediated by the same holistic processor in the case of visual images. (2) The holistic processor for the visual code operates at a much faster rate and almost automatically in comparison with that for visual images, which requires effort and attention. (3) Only the system that processes the visual code can use the structurally invariant features provided by a frame.

On the other hand, it must be pointed out that the existence of a time-consuming normalization process is not the only possible explanation of the orientation-dependent effects found for "same" responses in Experiments 1, 2, and 7. An alternative explanation can be given in terms of the criterion shift model put forward by Besner and Coltheart (1975; see also Santee & Egeth, 1980) for the interpretation of similar findings when the irrelevant dimension was size. According to this model, a "same" analyzing mechanism operates on a hierarchy of perceptual tests. When a difference is detected along an irrelevant dimension, a rise in the criterion for a "same" decision is considered to take place. Therefore, the observed increase in "same" RTs can be explained by assuming that greater irrelevant differences result in greater criterion shifts. The normalization and criterion shift hypotheses are clearly alternative, and both can account for the orientation-dependent effects found in the present study.

The data of Experiment 3 suggest that no normalization process or, alternatively, no criterion shift occurred when the observers used the phonetic code to match the two letters. In fact, although there was a clear advantage for letters that were both in the upright orientation, there was no evidence of an increase in latency with angular departure from the vertical for other orientations.

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