Recognition of forms rotated in depth: A test of the information type theory¹

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The present study aims at testing if the information type theory (Takano, 1989) is able to explain form recognition in the case of depth rotation. As in standard mental rotation experiments, 43 undergraduates were asked to judge whether two solid forms were the same or different. One of them had been rotated around a vertical axis. The theory predicted that reaction time should increase monotonically with angular disparity between the two forms when their difference was defined by orientation-bound information whereas reaction time should be unrelated to angular disparity when their difference was defined by orientation-free information. The results confirmed these predictions. It is concluded that an object-centered coordinate system (Marr & Nishihara, 1978) is unnecessary to explain recognition of forms rotated in depth; it can be explained in terms of either orientation-free information or combination of orientation-bound information and mental operation to adjust it.

Key words: form recognition, mental rotation, depth rotation, information type theory, object-centered coordinate system.

The purpose of the present study is to test the information type theory proposed by Takano (1987, 1989) to see if it is capable of explaining recognition of a form rotated in depth. The information type theory asserts that the form of an object can be recognized without an object-centered coordinate system (Marr, 1982; Marr & Nishihara, 1978) even when viewpoint has changed.

Marr argued that representation of a form based on a particular viewpoint or a viewer-centered coordinate system (Marr, 1982; Marr & Nishihara, 1978) is too unreliable to recognize the form when it is seen from a different viewpoint. The proposed object-centered coordinate system which is intrinsic to

each object is not bound to a particular viewpoint, and thus allegedly serves as a reliable basis to recognize its form regardless of viewpoint change. However, form recognition is sometimes susceptible to viewpoint change (e.g., Rock, 1973; Shepard & Cooper, 1982). This cannot be explained by the object-centered coordinate system theory. It was once suggested that recognition of a form is always accomplished by mentally rotating its viewer-centered representation when the viewpoint has changed. Unfortunately, this alternative is unable to explain the cases in which mental rotation is not carried out (Corballis & Nagourney, 1978; Corballis, Zbrodoff, Shetzer, & Butler, 1978; Eley, 1982; White, 1980).

The information type theory (Takano, 1987, 1989) has provided an integrated explanation for both the case where form recognition is affected by viewpoint change and the case where it is not. The theory assumes four types of information that are used to construct representation of a form in the human visual system. *Identity information* specifies an

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elementary component of a form. *Combination information* specifies how to conjoin elementary components. *Absolute orientation information* specifies orientation of an elementary component. *Relative orientation information* specifies orientational relationship between elementary components. The former two types of information are orientation-free (i.e., insusceptible to orientational change, which is virtually equivalent to viewpoint change as far as the relationship between the viewer and the form is concerned), whereas the latter two types are orientation-bound (i.e., susceptible to orientational change). They determine orientation on the basis of a *subject-centered coordinate system* (or a *subjective frame*), which corresponds to a viewer-centered coordinate system that is used to construct internal representation of a form.³ When the viewer attempts to recognize the form later, the subjective frame coincides with a viewer-centered coordinate system employed at the time of recognition if the viewpoint is identical to that taken when the initial representation was constructed; otherwise, the subjective frame and the viewer-centered coordinate system do not coincide. Incidentally, orientational change or viewpoint change can be defined by their difference.

Takano (1989) provided empirical evidence to verify the basic assumptions of the information type theory, but his data were concerned solely with orientational change in a picture plane around a z -axis.⁴ Typically, the human visual system has to cope with orientational change in depth around a y -axis because the human moves roughly in horizontal directions on the terrestrial surface. Accordingly, it is indispensable to test the

predictions of the information type theory as to the case where a form is rotated in depth, in order to see if the theory is valid in ordinary form recognition.

In the case of depth rotation, what information is classified into what information type is not the same as in the case of picture plane rotation. In the latter case, for example, such pieces of information as length or curvature of a line segment and an angle between two line segments are physically invariable in two-dimensional projection of a form⁵; hence they can be encoded as orientation-free information. In the case of depth rotation, on the other hand, they are physically variable; hence they have to be encoded as orientation-bound information. Nevertheless, the classificatory framework per se remains valid in the case of depth rotation because there are still some formal features that are not affected by depth rotation (Takano, 1987). Whether curvature of a line segment is zero or not, for example, is physically invariable as far as a generic view is concerned⁶; hence it can be encoded as orientation-free information. Therefore, the information type theory is expected to make proper predictions concerning form recognition in the case of depth rotation as well if the classification into the information types is adequately modified.

In the standard setting of a mental rotation experiment with depth rotation, the predictions made by the information type theory are as follows: When the difference between a

³ The subjective frame may not correspond to the viewer-centered coordinate system if the latter is determined solely by retinal orientation, for the former can be affected by other factors as well (see Takano, 1989).

⁴ A frontal-parallel plane is supposed to be defined by a horizontal x -axis and a vertical y -axis, with a z -axis perpendicular to this plane.

⁵ Strictly speaking, they are invariable only when rotated on a "genuine frontal surface" (see Takano, 1989, Footnote 7). Ordinarily, however, magnitude of variation is small enough to be ignored when rotation is conducted on a picture plane.

⁶ There are accidental views where a curved line becomes a straight line or even completely occluded. However, it is not necessary to take the accidental views into consideration in order to explain how correct recognition of a form is accomplished, for correct recognition is not possible at all given these views.

standard stimulus and a comparison stimulus is defined solely in terms of relative orientation information which is orientation-bound (i.e., when they are mirror-images of each other), correct form recognition is possible after conducting a mental operation that adjusts the relative orientation information in one of the stimuli so that it is directly comparable to that in the other. Under appropriate conditions, this operation is mental rotation (Shepard & Cooper, 1982; Shepard & Metzler, 1971), and reaction time to decide whether the two stimuli are the same or different is expected to be a monotonically increasing function of angular disparity between them.⁷ When the difference between the two stimuli can be defined in terms of either identity information or combination information which are both orientation-free, correct form recognition is possible without mental operations as above. Under appropriate conditions, reaction time is expected to be constant regardless of angular disparity.⁸ The following experiment was designed to test these predictions.

Method

Design

Three independent variables were manipulated. A between-subject variable, *Information Type*, had three levels: the Relative Orientation, Identity, and Combination conditions. A within-subject variable, *Angular Disparity*, had five levels: 0, 45, 90, 135, and 180 degrees counterclockwise around a *y*-axis when

viewed from above. Another within-subject variable, *Original Form*, had two levels; i.e., two forms were employed. A primary dependent variable was reaction time with error rate as a secondary dependent variable.

Subjects

Original Subjects consisted of 18 male and 18 female undergraduates. Final Subjects had the same composition, substituting seven subjects for four males and three females among Original Subjects, who made three consecutive errors for the same stimulus. The remaining 29 subjects were common between both groups of subjects. Although the data from Final Subjects are of primary concern, those from Original Subjects will also be presented. In either group, 12 subjects were randomly assigned to each condition of Information Type, with the constraint that the male/female ratio would be equal in every condition. All the subjects were right-handed and had visual acuity of .7 or above in terms of Landolt rings, with or without correction.

Materials

Two of the solid objects used by Shepard and Metzler (1971) were adopted as the original forms (see Figure 1). Metzler and Shepard (1974) found that the time needed to recognize orientation of an object was proportional to angular disparity. A cube in each original form was painted black to make it easy to recognize orientation, and thus to minimize the possibility that the time for recognition of orientation and the time for mental rotation are confounded.

Information Type was manipulated in the following way as shown in Figure 1: Some straight lines were replaced by curved lines in the Identity condition. The two ends pointing to opposite directions in each original form were transformed so that they point to the same direction in the Combination condition. The original forms were converted to their respective mirror images (or enantiomorphs) in the Relative Orientation condition.

⁷ The "appropriate conditions" refer to those in which alternative methods to adjust relative orientation information (see Takano, 1989, 1992) are harder to be applied than mental rotation.

⁸ The "appropriate conditions" refer to those in which orientation-free information is actually encoded and used. It may not be encoded as such (Takano, 1989); or mental rotation may be carried out by way of precaution if subjects are not sure that the encoded orientation-free information can be relied on for discrimination.

Figure 1. The two original forms and their variations presented to the subjects.

Figure 2. Examples of depth rotation: Original Form 1 with the modification in identity information.

The stimuli were produced in the following way: The two original forms and their corresponding variations in the three Information Type conditions were produced with a three-dimensional computer graphic program (Z's TRIPHONY Digital Craft). The same program was used to rotate each form around a y -axis and to make its two-dimensional projection (see Figure 2). All the projections were traced with drawing instruments to smooth out oblique lines. Slides were produced so that each contained two projections placed side by side. The left-hand projection was always either of the two original forms in 0 degrees, while the right-hand projection was either the same original form or one of its three variations in one of the five orientations. Forty slides were produced in all. Each

condition of Information Type required 20 slides, with *Same* 10 slides where the right and left projections were identical apart from orientational difference and 10 *Different* slides where they were different as to the corresponding Information Type. The slides were projected onto a screen so that each form would subtend about 5 degrees of visual angle; two forms in each slide were presented in an area of approximately 5×12 degrees of visual angle.

Apparatus

The slides were mounted in a random-access slide projector (Kodak S-RA2500) and rear-projected onto a translucent screen. An electronic shutter (GERBRANDS G1166S) was attached to the projector. When the ex-

Figure 3. Results: Reaction time as a function of angular disparity. C: The Combination condition. I: The Identity condition. R: The Relative Orientation condition.

perimenter opened the shutter by pressing a button on a control box (MUROMACHI special order), a timer (GERBRANDS DIGITAL MILLISECOND CLOCK) started. When one of two buttons placed side by side on a response box was pressed by a subject, the shutter was closed, the timer stopped, and one of two LED's on the control box indicated which button had been pressed. The head of the subject was fixed in a head-rest placed 82 cm away from the screen. An eye-sight test sheet (HANDAYA 3 m version) was used.

Procedures

The subjects were tested individually in a session of about 30 min. Visual acuity of the subject was tested first. Then the subject was seated in a chair holding the head upright in the head-rest with the index fingers on the response buttons.

Familiarization trials. The subject was told that the task was to decide whether two forms presented simultaneously were the same or different when angular disparity was ignored. Then all the 20 slides were shown in the following order: For one original form, the 10 slides were shown in ascending order from 0 to 180 degrees. For one orientation, a Same slide was shown before a Different slide. Original Form 1 (see Figure 1) was shown

first to one half of the subjects, while Original Form 2 was shown first to the other half. Takano (1989) found that subjects could fail to encode critical orientation-free information. In order to avoid such failure, the experimenter orally explained the difference between two forms when a Different slide was shown in 0 degrees: In the Identity condition, it was told that a straight part in the left-hand original figure was round in the right-hand figure. In the Combination condition, it was told that both ends of the left-hand original figure were pointing to opposite directions while those of the right-hand figure were pointing to the same direction. In the Relative Orientation condition, it was told that left and right was reversed in the right-hand figure just as the left-hand original figure was seen in a mirror. The subject was asked to press the right-hand button when both forms were the same and the left-hand button when they were different; a speeded response was not required. It was stressed that only these forms would be presented in the subsequent trials.

Practice trials. The subject was then given two blocks of practice trials. Every slide was presented once in a random order in one block. It was required to press an appropriate button as correctly and quickly as possible. Both accuracy and speed were equally

stressed. It was again stressed that the previously shown forms only would be presented. The subject was asked several questions as to important points in the instruction. When the subject made a wrong answer, correct information was provided. In each practice trial, the experimenter asked, "Ready?" and the subject answered, "Yes," if prepared. Then a slide was presented. The time between the onset of the slide presentation and the response was recorded in milliseconds along with the kind of the response. Every response was followed by an oral feedback as to its accuracy.

Test trials. After the subject's questions were answered, three blocks of test trials were given consecutively without rest. The construction of a test trial was identical to that of a practice trial, except that no feedback as to accuracy was provided. When an erroneous response was made on a slide, it was presented again following presentation of two slides randomly chosen from the same set of

the 20 slides, after all the three blocks of test trials had been given. This triplet of reassessment trials was repeated until three correct responses were obtained for every slide. The reassessment trials were not discernible from the test trials for the subject because all these trials were given consecutively.

Results

Basic data. Among Original Subjects, six in the Relative Orientation condition and one in the Combination condition made three consecutive errors on the same slide. They were replaced by seven new subjects to form Final Subjects. Every subject made three correct responses on each Same slide. The median of the corresponding three reaction times was used in the subsequent analyses to minimize influence of outliers. The medians were averaged across Final Subjects or Original Subjects for each combination of each level of the respective three independent

Table 1
Mean reaction times (ms) for the Same and Different slides in Original Subjects
and the Different slides in Final Subjects

Subject	Slide	Information		Angular disparity				
		Form	Type ^{a)}	0°	45°	90°	135°	180°
Original	Same	1	C	671	735	879	812	736
			I	579	592	572	634	585
			R	802	1 010	1 453	1 845	2 434
		2	C	596	677	684	672	647
			I	560	601	594	582	579
			R	883	1 208	1 742	1 967	2 531
	Different	1	C	657	638	758	901	708
			I	503	503	569	657	530
			R	1 315	1 033	1 917	2 124	2 307
		2	C	589	578	576	562	601
			I	548	595	612	633	547
			R	1 106	1 378	1 807	2 326	2 381
Final ^{b)}	Different	1	C	715	709	821	968	755
			R	1 318	1 094	1 942	2 637	2 502
		2	C	622	599	604	596	629
			R	1 041	1 445	1 933	2 257	3 098

^{a)} C: The Combination condition. I: The Identity condition. R: The Relative Orientation condition.

^{b)} In the Identity condition, the mean reaction times of Final Subjects were identical to those of Original Subjects because no subjects had been replaced.

variables. The reaction times for the Different slides were processed in the same way.

Results of the Same slides in Final Subjects. The information type theory predicted that reaction time would monotonically increase with angular disparity in the Relative Orientation condition whereas it would be constant regardless of angular disparity in the Identity and Combination conditions. As seen in Figure 3, the results of the Same slides in Final Subjects agreed perfectly with these predictions. Statistical analyses also confirmed the predictions. According to a three-way ANOVA with the three independent variables, both Information Type and Angular Disparity had significant effects, $F(2, 33)=32.644$, $p<.001$, and $F(4, 132)=18.689$, $p<.001$, respectively, while Original Form did not, $F(1, 33)=1.294$. Of particular interest was the interaction between Information Type and Angular Disparity; it was highly significant, $F(8, 132)=17.939$, $p<.001$. Among the other interactions, only the one between Information Type and Original Form was significant, $F(2, 33)=5.999$, $p<.01$. In order to locate the source of the significant interaction between Information Type and Angular Disparity, a trend analysis was conducted separately for each condition of Information Type and for each Original Form. The information type theory predicted that linear trend would be significant only in the Relative Orientation condition. The results confirmed this prediction. As for Original Form 1, linear trend was significant in the Relative Orientation condition, $F(1, 55)=66.042$, $p<.001$, while it was not in the Combination and Identity conditions, $F(1, 55)=.222$ and $F(1, 55)=.276$, respectively. As for Original Form 2 as well, linear trend was significant in the Relative Orientation condition, $F(1, 55)=29.459$, $p<.001$, while it was not in the Combination and Identity conditions, $F(1, 55)=.381$ and $F(1, 55)=.024$, respectively. In the Relative Orientation condition of Original Form 1, quadratic trend was also significant, $F(1, 55)=7.702$, $p<.01$.

Results of the Same slides in Original Subjects. Original Subjects gave essentially the same results as to the Same slides (see Table 1). A three-way ANOVA showed that both Information Type and Angular Disparity had significant effects, $F(2, 33)=37.381$, $p<.001$, and $F(4, 132)=44.107$, $p<.001$, respectively, while Original Form did not, $F(1, 33)=.011$. The interaction between Information Type and Angular Disparity was again significant, $F(8, 132)=39.490$, $p<.001$, as well as that between Information Type and Original Form, $F(2, 33)=3.449$, $p<.05$, with the other interactions nonsignificant. The trend analyses also gave the same results: As for Original Form 1, linear trend was significant in the Relative Orientation condition, $F(1, 55)=48.359$, $p<.001$, while it was not in the Combination condition, $F(1, 55)=.474$. The result of the trend analysis for the Identity condition was identical to that in Final Subjects because no subject was replaced in this condition. As for Original Form 2 as well, linear trend was significant in the Relative Orientation condition, $F(1, 55)=57.693$, $p<.001$, while it was not in the Combination condition, $F(1, 55)=.162$. No quadratic trend was significant in Original Subjects.

Results of the Different slides. In the case of the Different slides, angular disparity cannot be defined strictly because two different forms do not coincide by any rotation, especially when they are mirror-images of each other. Therefore, the results of detailed analyses will not be presented although essentially the same pattern of results as in the Same slides was obtained (see Table 1).

Error rates. The mean error rate throughout the three test blocks was 3.98% for Final Subjects and 4.81% for Original Subjects. There was no tradeoff between reaction time and error rate.

Discussion

Interpretation of the results. As the information type theory predicted, reaction time

monotonically increased with angular disparity in the Relative Orientation condition. This result is also consistent with the finding of Shepard and Metzler (1971); it is implied that mental rotation was carried out to align orientation of two forms before same/different judgment was made. In the Identity and Combination conditions, reaction time was unrelated to angular disparity. This is the first case in which monotonic increase of reaction time was not observed in the standard setting of mental rotation experiments with respect to depth rotation. It is implied that the differences in orientation-free information enabled the subjects to make same/different judgment without carrying out mental rotation as the information type theory predicted.

The modifications introduced into both original forms can be reasonably regarded as corresponding to the three information types assumed by the theory. In the Identity condition, the original forms and their variations were different in whether the curvatures of the particular line segments were zero or not. This difference is physically invariable in their two-dimensional projections during depth rotation as far as a generic view is concerned. The difference had to be perceivable because an accidental view was deliberately avoided in the present experiment. Thus it is classified as orientation-free information. It has already been confirmed that this difference is classified as elementary information (Takano, 1989; Treisman & Gelade, 1980; Treisman, Sykes, & Gelade, 1977). Therefore, the difference between zero curvature and non-zero curvature can be considered as identity information.

In the Combination condition, the original forms and their variations were different in whether the two ends were pointing in the same direction or opposite directions. This difference is physically invariable and perceivable in their two-dimensional projections during depth rotation. Thus it is classified as orientation-free information. This difference cannot be elementary information because it

does not belong to the limited set of features that have been confirmed to be encoded as elements. Although there is a report that a combination of line segments can be encoded as an element when they form Y- or arrow-junction in a three-dimensional object (Enns & Rensink, 1991), no evidence at all suggests that such global features as those used in the Combination condition are encoded as elements. Therefore, the difference employed in this condition can be considered as combination information.

In the Relative Orientation condition, the original forms and their variations were mirror-images. No difference in orientation-free information is involved between mirror-images. In addition, the left-right difference is physically variable and perceivable in their two-dimensional projections during depth rotation. Thus it is classified as orientation-bound information. The difference between mirror-images cannot be removed by any change in orientation of the whole object. Therefore, it cannot be absolute orientation information; it must be relative orientation information.

Alternative interpretations. First, it might be suspected that the replacement of the subjects affected the results. However, the results obtained from Original Subjects were essentially identical to those obtained from Final Subjects. It is therefore not conceivable that the results obtained from Final Subjects reflect the properties peculiar to those subjects who made relatively accurate judgment. Second, it might be suspected that the observed systematic relation between reaction time and angular disparity was produced by the familiarization procedure where all the slides were shown in the ascending order from 0 to 180 degrees. If this interpretation were to hold, however, monotonically increasing functions should have appeared in the Identity and Combination conditions as well since the same familiarization procedure was taken in these conditions. Finally, it might be suspected that the differences in the results

among the three Information Type conditions were produced by the differences among those conditions in the oral descriptions about the original forms and their variations. However, the descriptions simply confirmed the existing physical differences, and did not directly indicate judgmental strategies. Accordingly, it can be reasonably assumed that the differences in the results stemmed from the encoded physical differences (i.e., the information types).

Apparent inconsistency with a preceding study. Although the present results are consistent with past empirical findings with respect to form recognition, the study reported by Rock, Wheeler, and Tudor (1989) appears to be an exception at first glance. They presented irregularly winding wires and required the subjects to imagine how each wire would look if rotated around a y -axis by 90 degrees, to make recognition or written production of the resultant form. It was found that both recognition and production were extremely inaccurate. This sharply contrasts with the present study where the overall error rate was only 5% or so and fairly accurate recognition was made possible by invoking mental rotation in the Relative Orientation condition.

Those researchers denied the notion of mental rotation and proposed an alternative explanation that the widely observed increase in reaction time with angular disparity is a result of increasing difficulty of judgment. Unfortunately, this alternative explanation has at least two weak points: First, it does not provide a reasonable basis to account for the cases in which no increase in reaction time was observed regardless of increasing angular disparity around a z -axis (Corballis & Nagourney, 1978; Corballis et al., 1978; Eley, 1982; White, 1980). The results in the Identity and Combination conditions of the present study contradict their explanation more directly because rotation around a y -axis was used just as in their study. Second, their explanation cannot deal with Cooper's (1976) finding strongly suggesting that a

"mentally rotated" representation is actually passing through its intermediate trajectory (see Rock et al., 1989, Footnote 4).

Strictly speaking, the information type theory does not commit itself to the presence of mental rotation. It predicts merely influence of increase in angular disparity when mirror-image discrimination is required. Under appropriate conditions (see Footnote 7), the theory predicts that reaction time will increase monotonically with angular disparity, but it does not specify the process to generate this monotonic increase. Accordingly, the information type theory does not contradict the explanation by Rock et al. (1989) as far as the reality of mental rotation is concerned. Nevertheless, an attempt to accommodate their findings and the notion of mental rotation within the framework of the information type theory will be presented below.

Rock et al. (1989) have undoubtedly made clear the problem with a certain interpretation of mental rotation experiments, i.e., the interpretation that the spatial image of a three-dimensional object can be rotated in depth while preserving its precise form. However, their findings are perfectly compatible with another interpretation of mental rotation experiments. It first requires to recognize the fact that depth rotation, unlike picture plane rotation, gives rise to quantitative modifications in length of a line segment, an angle between line segments, and so on, in two-dimensional retinal projection. It further requires to assume that the capacity to simulate these quantitative modifications is severely limited in a mental device that carries out rotation of a spatial image.

According to this hypothesis, the results of typical mental rotation experiments requiring discrimination between mirror-images rotated in depth are explained as follows: It is easy to identify such features as are critical for correct discrimination in these experiments. There can be at least two reasons why it is easy; first, the solid objects (Shepard & Metzler, 1971) typically used in these experi-

ments have regular forms; second, the subjects repeatedly experience different views of an object from different viewpoints during many trials. At any rate, what have to be rotated to make mirror-image discrimination are only these critical features and their mutual orientational relationships⁹; quantitative modifications can be ignored. Suppose, for example, that Original Form 1 rotated by 180 degrees is rotated back to decide whether it is identical to Original Form 1 or its mirror-image (see Figure 1). What has to be rotated is simply the relative orientation between the end with two cubes and that with one cube. When the backward rotation has been completed, the end with two cubes is located to the right of the end with one cube, which indicates that this form is identical to Original Form 1, not to its mirror-image. Although these ends may shrink or stretch in particular ways during the rotation, it has nothing to do with mirror-image discrimination. Thus, depth mental rotation makes it possible to accomplish fairly accurate recognition (i.e., mirror-image discrimination) of three-dimensional forms though quantitative modifications may not be accurately simulated.

The findings of Rock et al. (1989) are explained as follows: In their experiments, it was not easy to identify critical features probably because the wire objects had irregular forms and their different views from different viewpoints were not actually experienced, as pointed out by those researchers. In addition, mental rotation of a few critical features was not sufficient to accomplish their tasks; appropriate quantitative modifications were indispensable. The irregularity of the employed forms might have made these modifications

still more difficult. Thus, accurate recognition was not made possible by mental rotation in their study.

This explanation within the framework of the information type theory is preferred to the explanation proposed by Rock et al. (1989) because the former does not share the aforementioned weak points of the latter: First, the cases in which reaction time does not increase with angular disparity can be explained in terms of reliance on orientation-free information. Second, Cooper's (1976) findings can be explained in at least two ways: mental rotation preserving precise form was possible because quantitative modifications were not needed in picture plane rotation employed in her study, or mirror-image discrimination could be performed on the basis of a few critical features that could be identified while experiencing different views of a form in different orientations.

Conclusion. It is now clear that an apparent contradiction between the results in Rock et al. (1989) and those in the present experiment as well as typical mental rotation experiments can be reasonably resolved within the framework of the information type theory. Then it is justified to conclude that the assumption of the object-centered coordinate system is not needed to explain successful recognition of a form rotated in depth. The subjective frame which is assumed in the information type theory provides a reasonable basis to explain the available data concerning depth rotation if combined with the use of orientation-free information or mental rotation of extracted critical features.

Incidentally, Okura (1992) has recently reported that rate of depth mental rotation is smaller when it is performed around a y -axis than when it is performed around an x -axis. It is implied that the former is easier. It is not surprising if this finding is reliable because the human visual system which typically moves around on the terrestrial surface has to cope more with y -axis rotations than with x -axis rotations.

⁹ The assumption that mental representation of a form can be reduced to a few critical features and their orientational relationships is consistent with a finding that complexity of a form did not increase rate of depth mental rotation (Yuille & Seiger, 1982).

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