UNILATERAL AND CENTRAL PROJECTION OF SYMMETRY VARYING IN SPATIAL ORIENTATION

CARLOS E. ROLDAN

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A Thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

Department of Psychology
Memorial University of Newfoundland

July 1975

St. John's Newfoundland

ABSTRACT

Ss made rapid perceptual judgments about tachistoscopically presented line patterns. These were symmetrical or asymmetrical, with axis of symmetry appearing in vertical, horizontal, and oblique orientations. The patterns could also be shown centrally or to either the right or left of fixation. Ss pressed a button for YES if the patterns displayed symmetry and another button for NO if the patterns were not symmetrical. Regardless of whether the patterns projected to both or entirely to one visual half-field, reaction-time (RT) was found to vary uniformly as a function of the orientation of the patterns. Overall RT's were shortest for vertically oriented patterns, and longest for those shown about the horizontal and oblique axes. This in turn confirmed the salience of left-right symmetry over symmetry appearing in other spatial orientations. The general pattern of results was consistent with the notion that the perception of symmetry is mediated by processes which serve to align the input stimuli into congruence with a stable internal representation of symmetry.

ACKNOWLEDGEMENTS

It never ceases to amaze me how ten books, survivors of a defunct Greek civilization, have so much influenced and permeated our thinking.

I would like to extend my respect, love, and gratitude to Mike Sherrick, Ted Rowe, and Graham Skanes, for their invaluable formative advice and unselfish generosity. I could not have hoped for a better group of men to work with, share with, and dream with, at this formative period of my life.

I am very grateful to Jim McCloskey for many hours of shop talk about symmetry perception, form perception, and evolution. His unique "What do you mean by that?" attitude, and his aplomb can justify the existence of any psychological laboratory. Gordon Rowe, Buck Weaver, Terry Kenny, and many other equally admirable peers have made this year the more rewarding.

I am most grateful to my wife Christina for being so wonderful to me. Her understanding of my needs, patience, and her incredibly lucid mind have at all times been the complement to my own thoughts and actions.

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INTRODUCTION

Mach (1898) long ago drew attention to symmetry, in particular symmetry about the vertical axis, as an especially salient feature of visual patterns. Initially, Mach had observed that bilateral symmetry was especially noticeable, while symmetries in other orientations were much less so. With regard to up-down symmetry for example, (i.e., symmetry about the horizontal axis), he noted the up-down symmetry existing between a landscape and its reflection in water might often go undetected (Mach, 1898, p. 94).

Since Mach's initial interest, the perceptual salience of left-right symmetry over symmetry appearing in other orientations has been experimentally confirmed (Corballis and Roldan, 1975; Goldmeier, 1937; Julesz, 1971; Rock and Leaman, 1963). But reliable a finding as the salience of left-right over up-down symmetry is at a purely experimental level, our understanding of why this is so is still unclear. More important the implications that knowledge about the processes mediating the perception of symmetry might have on our more general understanding of the processes mediating pattern discrimination, or form perception have not until recently received detailed examination (Julesz, 1971).

The relative importance of symmetry perception becomes apparent when the phenomenon of form perception is first considered. It will become clear, as we go along, in what fundamental ways the processes that mediate the perception of symmetry and those mediating the perception of form are generally related. We know that organisms at various levels of the phylogenetic scale, including the primates and man, perceive forms; this must be so if they are at all able to discriminate one shape from another. The early work of Klüver (1933) and Köhler (1927) revealed great similarities among the perception of monkeys, apes and man. Forms which were functionally equivalent for the apes also appeared similar to man as well. Lashley's (1929) investigation of form discrimination in the rat, also revealed more similarities than differences between primates and rodents. The differences were quantative. If Lashley's rats failed to transfer reaction (generalize the stimulus) to negative (complemented) patterns of the simplest kind, a transfer which is possible for monkey and man, the latter in turn display great difficulty in discriminating more complex stimuli (i.e. faces and photographs) from their negatives (Julesz, 1971). Both rats and humans are poor in transfer to rotated figures; and while a diamond and a square shape are distinctly different, it is only by considerable abstraction that we are able to regard the shapes as identical.

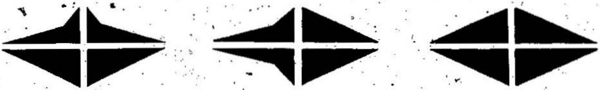
It is interesting that the problem of how we recognize rotated figures is very much relevant to the problem of the salience of left-right symmetry over symmetry occurring in other orientations. The heuristic here is that most perceptual invariances, particularly recognition of form, are processes very hard to understand, while symmetry perception is more amenable to analysis and its study very useful in elucidating the other perceptual invariances. Conventional pattern discrimination tasks have proven too complex and difficult for appropriate quantification and have not led to a coherent theory of form perception (Zusne, 1970). Attempts to quantify discrimination in precise terms have, however, revealed the symmetry extraction properties of the visual system as an important component of pattern discrimination. Two main lines of research have employed as stimuli randomly generated polygons (Anderson and Leonard, 1958; Attneave and Arnoult, 1956; Polidora and Thompson, 1964), or random-dot textures (Julesz, 1962, 1966). The findings of a large number of studies (see Michels and Zusne, 1965; Brown and Owen, 1967) have revealed an extensive variety of perceptual parameters of compactness, jaggedness, skewness, rotation, etc. each in turn being highly correlated with low-order moments of interior angles, side length, perimeter and area measures, etc. The problem of determining which of these parameters is actually used by _Ss_ is further complicated because of shifts in human attention. These attentional shifts taken in conjunction with the large number of parameters used has drastically complicated the development of a psychophysics of form. Recent work by Thomas (1967) points to a new direction of emphasis that may prove fruitful. Using multidimensional scaling of random polygons he was able to show that as a first approximation a two-dimensional shape of complexity and symmetry underlies the perception of form.

Empirical Evidence for the Salience of Left-Right Symmetry

Geometrically, a figure is said to be symmetric if it remains unchanged after it has been subjected to one or several symmetry operations such as, for example, rotation and/or reflection (Yaglom, 1962). A form may therefore be 'richer' or poorer' in symmetry depending on how many types of symmetry operations can be performed on it without affecting either: (a) The amount of information in the pattern, or (b) the way this information is distributed along its contours (Zusne, 1970). In this context, for any shape we observe that reflection might be possible along any number of axes. Some shapes, when a mirror is placed vertically on the plane in which they lie, will remain unaltered in any one position of the mirror, that is, they will be symmetric about one axis. The familiar shape A is an example of one-fold symmetry. A shape such as B also remains unchanged if reflected in a mirror, in this case, however this is so only when the mirror is placed above or below it. The first pattern is said to be left-right symmetrical only, the second up-down symmetrical only. In terms of rotation, the letters S, H, I and X possess two-fold symmetry, since they remain unaltered when subjected to reflections about the vertical and horizontal axes, or to a 180° rotation. In this same sense an equal-arm cross '+' displays four-fold symmetry since it is not altered in any way by four different axial reflections, or 180° rotations. The ultimately symmetrical shape therefore, is represented by a circular shape which remains thus regardless of the axis of reflection and/or rotation. Generally, studies investigating the salience of left-right symmetry have sampled the stimuli from patterns exhibiting symmetry about only one axis.

The perceptual salience of left-right over updown symmetry is a phenomenon generalizable to a large number of different classes of visual stimuli. The effect has been observed using amorphic shapes (Mach, 1897), composite geometrical forms (Goldmeier, 1937; Rock and Leaman, 1963), very complex random-dot and random-line displays (Julesz, 1969, 1971), histoforms (Fitts, Weinstein, Rappaport, Anderson and Leonard, 1956), simple-dot patterns (Corballis and Roldan, 1975), and even in such highly familiar stimuli as the letters A and B (Fox, 1975). We know from Mach's (1898) demonstrations of the phenomenon that the salience of left-right over up-down symmetry does not require specific practice with a class of bilaterally symmetrical patterns found in everyday interaction with the world. Mach was able to show that the particular identity of a shape was not affected in any obvious way if the shape was mirror reflected about the vertical axis, the phenomenal similarity being as striking as when these were repeated side by side. Mach also found that the shared similarities between such element pairs was lost if one was rotated 90^{0} with respect to the other, or if by juxtaposition one of the elements was so arranged as to be the up-down mirror-image of the other.

Goldmeier (1937) interpreted Mach's observations of the changes in phenomenal similarity between the shapes as being the outcome of having shifted the orientation of the axis of symmetry from the vertical to the horizontal. Goldmeier was more explicitly concerned with the effects on phenomenal similarity between forms that changes in their orientation might produce. In one of his experiments designed explicitly to contrast vertical symmetry with horizontal symmetry, Goldmeier required his subjects to choose from among two patterns, one symmetrical about the vertical axis only, the other symmetrical about the horizontal axis only, the one most similar to a standard pattern, which was a composite of the other two, so arranged as to exhibit symmetry about <u>both</u> the vertical and horizontal axes. Goldmeier's patterns are illustrated in Figure 1. The clear finding of this experiment



(a) (b) (c)

Figure 1. Patterns such as those used by Goldmeier (1937). The standard (c) exhibits symmetry about both the vertical and horizontal axes, while patterns (a) and (b) are symmetrical only about the vertical and horizontal axis respectively.

was that subjects overwhelmingly chose the symmetrical vertical version over the symmetrical horizontal version as being most similar to the standard. Goldmeier went on to show that this effect did not depend on the patterns *per se*, rather subjects base their decisions on the *phenomenal* vertical orientation of the patterns. When the three patterns were rotated sideways 90° thus reversing the symmetric relations between the patterns and the standard (i.e., the vertical symmetric version becomes symmetric about the horizontal, and *vice versa*) the results were also reversed for the patterns. Overall, the subjects chose the phenomenal vertical symmetric arrangement as most similar to the standard. Goldmeier concluded from these findings that the phenomenal qualities of symmetry depend in a very important way on spatial orientation.

Rock and Leaman (1963) later replicated Goldmeier's effect using his variation on the method of paired comparisons and the same stimuli. Rock and Leaman were able to show that the effect obtained by Goldmeier could also be obtained when the subject's head was tilted sideways 45°, so that both the vertical and horizontal axes were equally inclined with respect to the subject's retina rather than with respect to the gravitational coordinates of the environment. Rock and Leaman concluded from findings such as these, that the salience of vertical symmetry did not depend on retinal projection to the visual system; rather it was a matter of where the subject perceived the true vertical to be.

Fitts, Weinstein, Rappaport, Anderson and Leonard (1956) using precisely quantifiable metric figures, or so called histoforms, found recognition latencies for left-right symmetrical patterns, in a memory task, to be considerably shorter than recognition latencies for comparable up-down symmetrical patterns. Three possible interpretations were advanced by Fitts et al (1956) in order to explain this effect. The first of these, later favored by Rock and Leaman (1963), appeals to the special significance we might have learned to attach to left-right symmetry since it is so common a feature of our everyday environment. This interpretation appears inadequate, however, since response latencies to the relatively more infrequently met oblique symmetries were found to be shorter than those to symmetries about the horizontal (Corballis and Roldan, 1975). The second theory, normally referred to as the bilateral symmetry theory, has received the most attention due to its far reaching implications. The bilateral symmetry theory views the salience of left-right symmetry arising as a natural outcome of evolution instead of specific learning alone, it posits more explicitly that the effect can be attributed in some fundamental way to the structural bilateral symmetry of the nervous system (Corballis and Roldan, 1974, 1975; Julesz, 1971; Mach, 1897). Lastly, the third interpretation was made in reference to the greater facility in responding to peripheral details in the lateral rather than in the vertical areas of the visual field. This last interpretation has received almost no attention. This is partly attributable to the fact it was not explicitly elaborated further, and partly because it actually forms a subset of the more general bilateral symmetry account.

The Bilateral Symmetry Theory

Mach (1897) reasoned left-right reflecting of his random amorphic shapes was as similarity-preserving as left-right repetition of the shapes because these kinds of pattern arrangements gave rise in the brain to the same or similar sensations (Mach, 1897, p. 53, his italics). Of a figure symmetrical with respect to the median plane of the body, he argued, each half of the figure stands in the same relation with each half of the visual system, i.e., each eye. Thus, it was the one-to-one correspondence between each half of a bilaterally symmetrical pattern and each half of the visual apparatus that determined the similarity between the mirror-image halves. We know now that it is the visual fields rather than the eyes which are mapped symmetrically in the two halves of the brain: the left visual field projects solely to the right visual cortex, and the right visual field to the left visual cortex. This is so regardless of which eye is viewing (Polyak, 1957).

Julesz (1971) has recently extended Mach's observations and pursued a similar line of reasoning. In his complex computer-generated textures the perception of symmetry can occur even when exposures are very brief provided that the fixation point of the eyes coincides with the axis of symmetry of the patterns. This finding suggested to Julesz that the perception of symmetry in his patterns depends on the structural symmetry of some projection area in the brain, given the structural symmetry in neural anatomy around the center of the fovea, and on a point-by-point comparison process linking such loci.

Anatomically, the separation of ipsilateral from contralateral fibers along the optic nerve results in a cleavage line that clearly transects the center of the fovea (Polyak, 1957, p. 330). Given, therefore, that a left-right symmetrical pattern is fixated centrally on its axis of symmetry, the inference that the point-by-point comparison process envisaged by Julesz involves comparison between homologous symmetric points on both sides of the visual cortex is justified (Corballis and Roldan, 1974). In support of this notion Julesz cited a clinical observation made by Brindley and Lewin (1968) who were able to evoke visual phosphenes in a blind patient by directly stimulating her visual cortex. At one stage, unilateral stimulation produced a phosphene in one visual field, then with increased stimulation their patient reported the appearance of a new phosphene at the mirror-image location in the opposite field.

The comparison process suggested by Julesz might be mediated by the corpus callosum since it is known to contain at least some fibers that are homotopic, or connect symmetric points in either side of the brain (e.g. Cumming, 1970), except for the fact that the neurophysiological evidence for the visual system is mostly contrary to this notion. Sperry (1962) has noted, for example, that callosal connections between the visual (i.e., occipital and inferotemporal) areas of the cortex seemed exceptional in that they did not join mirror-image points. Hubel and Wiesel (1967) later confirmed this to be the case in the visual system of the cat. Also in the cat, Berlucchi and Rizzolatti (1968), have shown from single cell recordings that line orientation is preserved (rather than mirror-reversed) in the connections between the visual cortices. Gross, Rocha-Miranda and Bender (1972) have observed, furthermore, that visual properties of neurons in the infero-temporal cortex of the monkey indicate heterotopic rather than homotopic commisural connections. It seems, moreover, that the connections between the visual cortices might serve a rather limited perceptual function. For one thing, they appear to represent only a narrow vertical strip of the visual field, symmetrical about fixation; inter-hemispheric perceptual exchange clearly occurs over a much wider area of the visual field (Gazzaniga, 1970). The primary role of the callosal connections between visual cortices has been suggested to be that of mediating perception in depth of objects in central vision (Blakemore, 1969).

In this context, Corballis and Deale (in preparation) have remarked that if the commissures connecting the visual areas of the cortex seem to be organized so as to functionally preserve left-right orientation in the transmission of spatial information between the hemispheres, this is to be expected since in animals with overlapping visual fields continuity and left-right equivalence between the two half-fields must be preserved (Corballis, Miller and Morgan, 1971). In animals with non-overlapping visual fields, Corballis and Beale note this might not anatomically be the case. In certain fish and in some birds, such as the pigeon, optic fibers decussate naturally at the optic chiasm, each eye projecting solely to the contralateral hemisphere. For animals with eyes placed thus, any movement across the visual field of an eye would be interpreted as movement in the front-back plane. Front-back equivalence in this case would necessitate left-right reversal of perceptional information in interhemispheric transfer, since movement from back to front across the left visual field would be left to right movement in contralateral projection, and across the right visual field motion from back to front would be a right to left movement. Front-back equivalence would therefore be mediated through homotopic mapping between the visual areas. Julesz thought it may be the residual of this homotopic mapping process which explains the perception of symmetry in his briefly exposed patterns; more generally, the perception of symmetry in higher animals including man. "Perhaps it is the remainder of the front-back movement symmetries that animals with non-overlapping fields experience" (Julesz, 1971, p. 133).

Elsewhere, discussing binocular depth perception, Julesz (1968a) argues that this process is a fairly late one in evolution, arising after some favorable bodily changes occurred. Through the recession of a protruding snout or beak, the visual fields began to overlap and with the development of head movements and the accompanying complex movements of eye-coordination, a course registration between the two monocular views was possible. The advantages of depth perception probably outweighed in time the loss of panoramic vision for some animals. They could now perceive the spatial location of objects in the environment vividly as an independent sensation. If this is the case for man, one would therefore expect Julesz's homotopic comparison process to be located in an area much more primitive than that relegated to binocular vision; the perception of symmetry in his patterns involving perhaps structures at a subcortical level instead (Corballis and Roldan, 1974). Gazzaniga (1970) has suggested that some kinds of visual interhemispheric integration may occur at a level beyond that of the visual cortices, possibly in the inferotemporal regions. Support for the notion that there may be a subcortical system linking the visual areas in homotopic fashion comes from observations of commissurotomized patients (Trevarthen, 1970; Trevarthen and Sperry, 1973).

Trevarthen has written:

> "With lines set in motion asynchronously about a pivot at the fixation point (commissurotomized) subjects have confused mirror-symmetry for diagonal alignment when asked to signal when the two halves of the display are "in line". A diagonal alignment sloping across the whole field is felt to be unbalanced and is reset to make a symmetrical ∧ or ∨ configuration. A number of comparable misjudgments indicate that the commissurotomized subjects find it easier to judge when the two visual fields are perceived to be horizontally 'balanced' or mirror-symmetric over the vertical meridian" (Trevarthen, 1970, p. 34).

It may prove advantageous at present to remain skeptical until more is known behaviorally about the various kinds of neural mapping of information that may be operative in information integration across the vertical meridian. Discrimination reaction-time involving left-right mirror image and left-right repeated patterns have shown that whereas the former are usually judged more rapidly this effect depends on whether the Ss treat the patterns "wholistically" or as two distinct patterns (Sekuler and Staller, 1975; Corballis and Roldan, 1974). Sekuler and Staller have shown that if subjects discriminate non-mirror pairs as <u>same</u> and mirror-image pairs as <u>different</u> they are clearly faster at responding <u>same</u>. But if for a comparable group of subjects one reverses the labels assigned to the stimuli then the subjects are faster at responding "same" to mirror-image stimuli.

Corballis and Roldan (1974) also found similar labeling effects if their subjects used the labels mirror-same or symmetrical/asymmetrical. Spatial separation between the pairs of stimuli was also found to affect the results. These experiments suggest that the salience of left-right mirror-images over left-right repeated stimuli depends on whether the subjects deal with the two halves of a one-fold symmetrical pattern separately or as a whole. In this respect, Hock (1976) has suggested that two types of processing underlie same/different judgments. Using left-right repeated and symmetrical dot patterns he noted a structural process that organizes detailed parts of a stimulus into a well formed integrated whole and another strictly analytic process that decomposes the stimulus into features before the patterns are compared. Selective attention for orthogonal elements has also been shown to be an important factor in predicting shorter latencies for <u>same</u> over <u>different</u> judgments (Garner and Morton, 1969; Garner and Felfoldy, 1970; Pomerantz and Garner, 1973).

It is tempting to draw an association between these findings and heterotopic and homotopic comparison processes.

Unfortunately, there is at least one obstacle to this. In viewing a left-right symmetrical pattern the points to be compared are always an equal distance apart from the axis of symmetry; in left-right repeated patterns the points to be compared are always half the pattern's distance away, a geometrical property which cannot be overlooked (Corballis, Miller and Morgan, 1971). In this sense Julesz (1971) has noted that the perception of symmetry in his patterns is drastically favored for elements close to the axis of symmetry. When these are removed the remaining symmetric relations are no longer apparent.

Pattern Orientation and Symmetry Extraction

Julesz (1971) did not believe that a homotopic comparison process was the only mechanism for the perception of symmetry in visual patterns. He was aware that in simpler more cohesive patterns such as the random shapes used by Mach, one does not require symmetrical projection on the fovea in order to perceive symmetry. Indeed, subjects are able to perceive symmetry in simple dot patterns even when these are flashed within a single half-field, so that primary projection is entirely to one hemisphere (Corballis and Roldan, 1974). In viewing simple, low spatial resolution patterns, Julesz suggested that the symmetric relations might be extracted, and at some stage, invariant forms encoded by some unspecified central process beyond any strict dependence on the structural symmetry of the visual projection systems.

Mach (1897) had also realized that we can perceive symmetry when the axis of symmetry is not vertical, his explanation differed however:

> "...if the plane of symmetry diverges considerably from the median plane of the observer---the affinity of form is recognizable only by turning the figure round or by an intellectual act" (Mach, 1897, p. 107, his italics).

This is, one might perceive symmetry in patterns appearing in different spatial orientations by first mentally rotating the patterns to the vertical.

Mach did not restrict this reasoning to the perception of symmetry appearing in different orientations, but generalized this idea to the recognition of forms and object shapes viewed in other than their normal orientation. In this sense, he is worth quoting:

> "Two figures may be geometrically congruent, but physiologically quite different, as is shown by the two adjoined squares, which could never be recognized as the same without mechanical and intellectual operations" (Mach, 1897, p. 106).

Mach's adjoining squares are illustrated in Fig. 2. When an actual physical rotation of the figures is not possible, or if cocking of the head is not permitted, one might suppose that Mach's notion of "intellectual operations" refer to mental

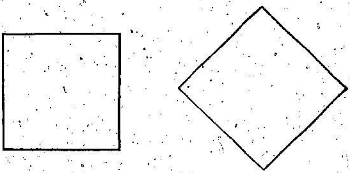


Figure 2. Mach's adjoining squares.

operations involving the representational rotation of one of the figures into congruence with the other. Moreover, note the implicit assumption that mental rotation could actually serve to align the <u>physiological</u> representation of a figure with its actual "upright" stored representation in memory, or in the case of symmetry perception that these intellectual operations would eventually serve to align the physiological representation of a pattern with the anatomical vertical meridian of the brain.

Mach's assumption seems more reasonable today since there is recent evidence which suggests we are able to perform mental transformations, mostly rotations, of perceptions or images. The most convincing experimental evidence that we can perform such mental transformations, has come from the work of Roger N. Shepard and his colleagues. In an initial study, for example, Shepard and Metzler (1971) showed their subjects pairs of perspective line drawings depicting three dimensional same or mirror-image block arrangements. Subjects' task was to judge whether the two figures were the <u>same</u> or <u>different</u>. The time normally taken by subjects to make judgments of sameness was found to be a monotonically increasing function of the angular difference between the portrayed orientations of the objects. From this result and from the subjects' introspective reports, these authors inferred that their subjects performed the task by mentally rotating one of the patterns in three dimensional 'space' to match it to the other. In subsequent studies, Cooper and Shepard (1973) and Cooper (1975) have shown that if encouraged to do so, people are able to perform mental rotations to map a stimulus against an internally generated percept or image. In deciding, for example, whether a random shape or a letter from the alphabet is the 'same' with respect to itself shown in different orientations, or 'different' with respect to its rotated miror-image version, the subject corrects for angular discrepancies by mentally rotating the input stimuli to match the upright internal representation. Cooper and Shepard (1973), Shepard and Chipman (1970) and Shepard, Kilpatrick, and Cunningham (1975) suggest from these findings that there exists some degree of isomorphism between an external stimulus and its internal representation (see also Arbib, 1972). Moreover, the internal physiological representation of a rotated mental image might be the same, in at least some respects as the internal representation that would have been generated by the rotated stimulus itself.

Corballis and Roldan (1975) have recently examined Mach's hypothesis that the perception of symmetry in patterns whose axis of symmetry is other than vertical with respect to the median plane of the observer is accomplished by mentally rotating the patterns into congruence with this anatomical axis. These authors presented their subjects simple dot patterns that were either symmetrical or repeated across a straight line. The axis of symmetry (indicated by the line) could be shown vertical, horizontal or in oblique orientations with respect to the median plane of the head. The subjects' task was to decide as quickly as possible whether or not each pattern was symmetrical about the line. Their results showed RT to vary as a function of the orientation of the line. Mean RT's were shortest for the vertical, somewhat longer for the oblique and longest for the horizontal orientations of the patterns. These results held even when the subjects were told in advance the orientation of the patterns suggesting that subjects are unable to rotate mentally an abstract general frame of reference. When the subjects tilted their heads 45° to either side of the vertical so that an oblique pattern would then project vertically on the retina, RT's were significantly faster to the retinal rather than the gravitational vertical patterns. This last finding was contrary to the findings of Rock and Leaman (1963) discussed earlier, and those of other studies on perceptual judgments as a function of head tilt (Attneave and Olson, 1967; Rock and Heimer, 1957) which suggest that perceptual judgments are usually made in the framework of gravitational rather than retinal coordinates. Corballis and Roldan (1975) suggest, however, that subjects may actually have a choice about the reference coordinates they will use in one or another situation.

When not instructed otherwise it is reasonable to suppose that subjects might base their judgments about orientation on gravitational coordinates to some extent, depending on the actual degree of body tilt (Rock, 1973). For example, whereas Attneave and Olson (1967) found that associations to lines of different orientations were normally invariant with respect to gravitational coordinates, Attneave and Reid (1968) later showed that subjects could easily base their decisions on retinal rather than gravitational coordinates if explicitly encouraged through instructions to do so. If indeed subjects are able to mentally correct for changes in the retinal projection of a shape from one instance to another, it is therefore possible to interpret Rock and Leaman's (1963) data as further evidence for the notion that subjects mentally rotated the patterns to the phenomenal vertical (Corballis and Roldan, 1974). Rock (1973) has pointed out in this respect that if for whatever reason we fail to perceive the axis of symmetry as phenomenally vertical, the symmetry in a pattern may not be noticed. In Figure 3(a) under conditions in which we are not 'set' to look for an axis of symmetry the symmetry in the shape may not be noticed. Contrast this effect with Figure 3(b) in which the symmetry is at once noticeable. Tilting of the page or tilting our head 45° may shift this effect from one pattern to the other, or not, depending entirely on what mental 'set' we choose to adopt.

Figure 3. Geometric shapes in which symmetry might or might not be noticed (after Rock, 1973).

How is it then that we are able to recognize patterns appearing in orientations other than usual? Rock (1973) has argued that we are able to do so by first invoking processes, akin to those studied by Shepard and Metzler (1971), whereby an abstract non-verbal description of the input is mentally rotated into congruence with its internally stored "upright" representation. Rock points out, however, that in instances in which not only the elements comprising a pattern have to be rotated, but also the exact spatial relations between these, the mental correction systems may become overtaxed. In identifying more or less familiar inverted faces or in attempts to read inverted script the correction processes may not be completely successful, thus impairing in some important sense the perception and subsequent recognition of the stimuli (Rock, 1973; p. 65).

Corballis and Roldan (1974) unlike Julesz have argued that if the perception of symmetry in Julesz's briefly exposed patterns does not occur spontaneously unless one fixates on the axis of symmetry, this might simply reflect that the patterns are simply too complex and formless to be mentally subjected to transformations involving mental rotation or translation. Rather than suggest that the salience of left-right symmetry in Julesz's patterns depends on fundamentally different principles from that in simpler more coherent patterns, these authors have argued that homotopic point-by-point comparison processes might possibly mediate the perception of symmetry, the difficulties in perceiving spontaneously the symmetry in a pattern being essentially a function of the successful application of mental correction processes.

It is still possible therefore to suppose along with Mach and Julesz that the perception of symmetry is mediated by mental processes which serve to align the patterns so that eventual symmetrical representation and homotopic point-by-point comparison is realized in the brain. If this is true, the salience of left-right symmetry in patterns for which mental rotation and adjustment is fairly easy might be predicted under conditions of stimulation in which projection of the patterns is to both hemispheres or restricted entirely to one. Under unilateral presentation condition, barring acuity effects, it should perhaps be expected that latencies in pattern discrimination be longer than those for patterns projected bilaterally. This discrepancy would in turn be consistent with the notion that patterns, where necessary, may also be adjusted by a 'centering' process (Corballis and Roldan, 1974). The aim of the experiment reported here therefore was simply to obtain response latency measures of the time taken by Ss to judge symmetry as a function of the orientation of the stimuli and under conditions of stimulation in which the patterns projected centrally to both hemispheres of the brain, or under conditions in which projection was solely to one hemisphere.

METHOD

The subjects were shown line patterns that were either symmetrical or repeated about an unmarked axis. This axis could vary in orientation from trial to trial. The patterns could also be shown centrally to to the left or right of fixation. Subjects' task was to decide as quickly as possible after each exposure whether or not the pattern was symmetrical.

Subjects

The subjects were 6 men and 6 women. All were right-handed, and reported normal or corrected vision. Subjects ranged in age from 17 to 25 years.

Stimuli

From two basic half patterns four different patterns were constructed. Each of these half patterns was made up of four randomly connected but not intersecting straight lines Each half pattern was either reflected (symmetry) or repeated (asymmetry) about the vertical axis. From this vertical axis the patterns could be shown in 8 different orientations in 45° steps from 0° through 315°. Each of these 32 stimuli were also presented to the right and left visual fields giving a total of 96 patterns. The patterns were photographed and the negatives mounted on 2 x 2 slides. Each pattern appeared white on a black background and subtended at eye level 1°30' of arc. When the patterns appeared to the right or left of fixation, the angular distance between the point of fixation and the central axis of the patterns was 1°10' of arc. Positive photocopies of a few representations of the slides are shown in Figure 4.

The patterns were shown in eight different orientations, but since there was no marked distinction between what could be the top and bottom of a pattern, there were effectively only four orientations represented by clockwise rotations of 0°, 45°, 90°, and 135° from the vertical. The patterns were rear-projected onto a translucent screen. A fixation point was set permanently on the screen.

Procedure

The S sat at the table about 1 m. 17 c. from the screen on which the patterns were to be shown. The patterns were shown at eye level and S was instructed to keep his head in an upright position throughout the experimental session. S was also instructed to rest the index finger of each hand on a response button and to press one button if the pattern shown was symmetrical, the other if it was not. Half of the Ss responded to symmetry by pressing YES with their right hand, the remaining six subjects did so with their left hand.

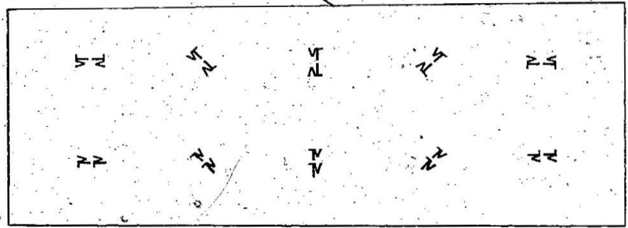


Figure 4. Positive photocopies of a few representations of the slides. The set of stimuli represented in the top row are symmetrical patterns with unmarked axis of symmetry appearing in vertical, oblique, and horizontal orientations. The bottom row illustrates the asymmetrical versions also in 45° clockwise rotations from vertical, the 225°, 270°, and 315° versions used in the experiment were not included. The stimuli were also shown to the right and left of fixation. The stimuli represented here correspond to central fixation conditions of stimulation.

Whenever an asymmetrical pattern was shown S was to press the NO response button.

The patterns were randomly shown with the constraint that no more than three consecutive presentations of either symmetry or asymmetry would occur. Also stimulation to either half-field was restricted to no more than two consecutive trials.

Each trial was initiated by a 500 msec. warning tone followed 1 sec. later by a 150 msec. exposure of a pattern. The S was instructed to fixate on a small fixation point set centrally on the screen and to hold fixation until the time a response was made. Reaction-time (RT) was measured from the onset of the stimulus.

Each S was given a number of sample trials to familiarize him with the equipment and task and then was given 20 monitored trials under the experimental conditions. During this training session the S was encouraged to make an attempt at maximizing speed in responding without at the same time sacrificing accuracy (see Appendix). These practice trials were not considered in the data analysis. After this short introduction to the task, the S was given 576 trials lasting 7 sec. each. After every 192 trials the Ss were given a short rest period. This treatment effectively divided the experimental session into three equal length blocks of trials. Carryover effects due to practice in performing the task were minimized by assigning two Ss in each hand dominance condition to each of three different presentation orders according to a Latin Square design.

RESULTS

Errors. Whenever S pressed the YES response button with in effect S should have pressed the NO button instead and vice versa, the response was considered an error and the corresponding RT measure for that trial was not considered in the analysis. Seven percent of the 6912 trials administered to the subjects in the experiment were errors. Although not of primary interest, the actual number of errors for each S, for each type of YES/NO judgment of symmetry, in each of the three visual field presentation conditions, and for each orientation of the patterns were counted and submitted to analysis. Figure 5 illustrates the mean number of errors averaged across the twelve subjects for YES/NO judgments in each of the three visual fields of presentation and for each orientation of the patterns. Rank tests (Ferguson, 1971, p. 331) revealed errors for both YES/NO judgments and for the three visual field presentation conditions combined to vary in frequency as a function of the orientation of the patterns ($p < .01$). Errors were most frequent when the patterns were shown in oblique orientations ($p < .01$). Otherwise, errors were homogeneously distributed among YES/NO decisions and visual field presentation conditions.

Reaction Times. Mean RT's for correct responses only were computed individually for each YES/NO judgment of symmetry, for each hand dominance condition, for each visual

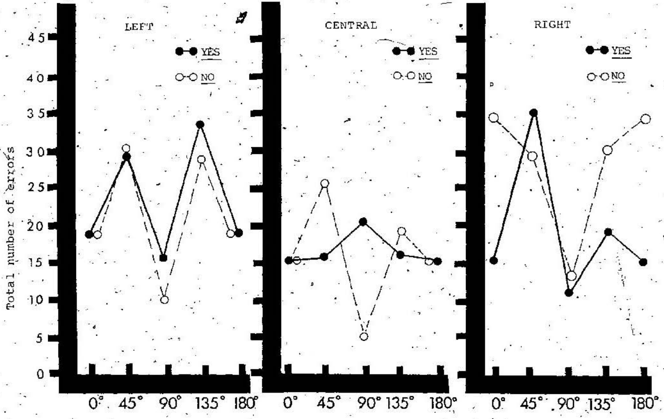


Figure 5: Total number of errors plotted as a function of the visual field of presentation, pattern orientation, and YES/NO judgments of symmetry. (Note: In this and all appropriate graphs the 0^{o} data points are repeated at 180^{o} in order to complete the function).

field of presentation condition and for each $\underline{S}$, as indicated in the Appendix, and these submitted to Analysis of Variance (see Table 1). Analysis of Variance revealed two significant main effects. Mean RT's for YES judgements of symmetry were more rapid than those for NO judgements of symmetry, $F\ (1,10) = 9.98,\ p < .05$, also RT was found to vary significantly as a function of the orientation of the patterns, $F\ (3,30) = 13.52,\ p < .01$. Response latencies were quickest for patterns shown about the vertical, and slowest for patterns appearing about the horizontal and oblique axes. Mean RT's are plotted as a function of the orientation of the patterns in Figure 6. Multiple comparisons using the Newman-Keuls method revealed no significant differences between the oblique and horizontal orientations of the patterns. In all comparisons, RT's for vertical patterns were the quickest ($p < .05$).

Three two-way interactions also reached significance. The interaction of Visual Field X Judgement, $F\ (2,20) = 14.12$, $p < .01$, is illustrated in Figure 7. Multiple comparisons using Newman-Keuls procedure revealed YES judgements to be quicker than NO judgements of symmetry only when the patterns were shown to the left and centrally about fixation ($p < .01$).

Table 1

Summary Table of Analysis of Variance
for mean reaction-time measures as
a function of Handedness, Visual Field,
Judgment, and Orientation of the stimuli.

Source	Denominator	df num	df den	MS	F
Within Subjects					
Visual Field (F)	FxS	2	20	6402.535	2.31
Judgment (J)	JxS	1	10	63754.25	9.98*
Orientation (O)	OxS	3	30	48747.46	13.52***
FxJ	FxJxS	2	20	12138.06	14.12***
FxO	FxOxS	6	60	3296.604	2.51*
TxO	JxOxS	3	30	6005.625	4.21*
FxJxO	FxJxOxS	6	60	1636.062	1.02
Between Subjects					
Handedness (H)	S	1	10	13373.7	0.45
Subjects (H)			10	298851.2	
HxF	FxS	2	20	4341.465	1.57
HxJ	JxS	1	10	5159.562	0.81
HxO	OxS	3	30	7769.227	2.16
FxS			20	2771.053	
JxS			10	6389.641	
OxS			30	3604.644	
FxJxS			20	859.7026	
FxOxS			60	1314.552	
JxOxS			30	1425.927	
HxFxJxO	FxJxOxS	6	50	461.2891	0.29
FxJxOxS			60		

*** $p < .001$
** $p < .01$
* $p < .05$

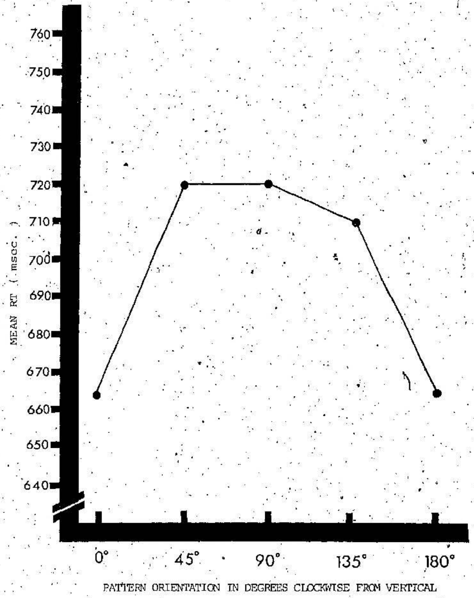


Figure 6. Illustration of Orientation main effect.

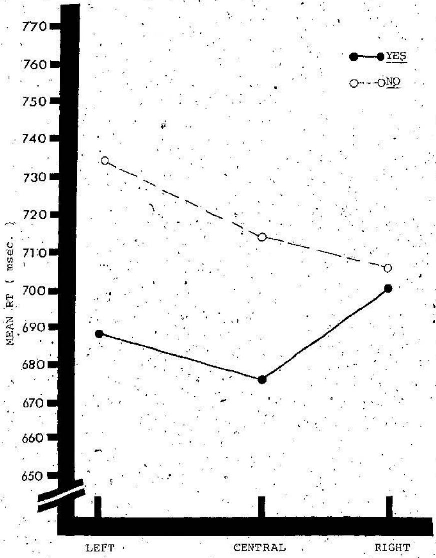


Figure 7. Illustration of Visual Field X Judgment interaction.

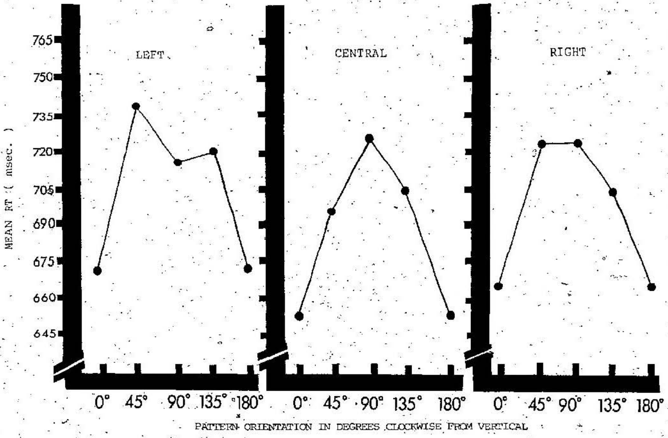


Figure 8. Illustration of Visual Field X Orientation interaction.

The two-way interaction between Visual Field and Orientation, $F(6,60) = 2.51$, $p < .05$, illustrated in Figure 8, and the Judgement by Orientation interaction, $F(3,30) = 4.21$, $p < .05$, illustrated in Figure 9, can both be considered significant unless one adopts the conservative degrees of freedom recommended by Greenhouse and Geisser (1959) for testing repeated-measurement effects. Figure 8 shows that in all visual presentation conditions, mean RT's are seen to vary as a function of the orientation of the patterns in a fairly uniform manner. The largest discrepancy between the three curves arises from the marked increase in response latencies for obliquely oriented patterns flashed to the right and left of fixation. The correspondingly marked increase in the frequency of errors for obliquely oriented patterns might be considered in conjunction here. The longer RT's for the 45° orientations of the patterns in the left and right visual field presentation conditions might reflect some perceptual difficulty other than the orientation of the patterns *per se* as is suggested by the greater number of errors for the obliques. In the case of the Judgement by Orientation interaction, multiple comparisons by Newman-Keuls procedure revealed significant ($p < .05$) latency differences between YES and NO judgements of symmetry for all

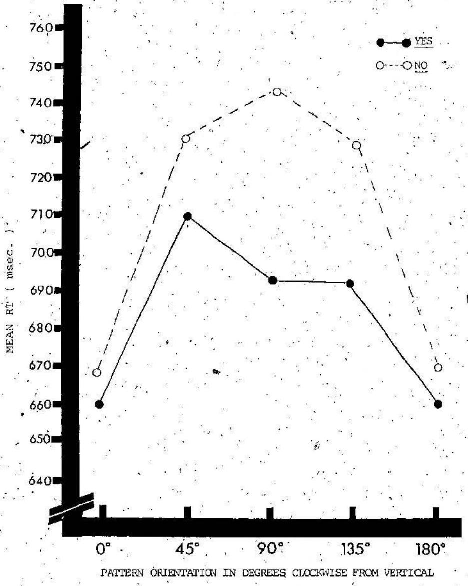


Figure 9. Illustration of Judgment X Orientation interaction.

orientations of the patterns except for those shown about the vertical. Although at present no obvious interpretation for these findings is available, any conjectures must be tempered by a strong possibility that these interactive effects were attributable to random variations in the data.

All other main and interactive effects considered in the Analysis of Variance failed to reach significance.

DISCUSSION

Although there are some minor discrepancies in the unilateral presentation conditions, the general pattern of results indicated that Ss were fastest at making judgments of symmetry when the patterns were vertical, and slowest when these were shown in oblique and horizontal orientations. Moreover, this same pattern of results was found generally to be fairly uniform over the three visual field presentation conditions. This in turn is consistent with the notion originally attributable to Mach (1897) that Ss submit the patterns to mental transformations involving rotation and correction before extracting the symmetry features. It is conceivable therefore that a homotopic comparison process such as the one envisaged by Julesz (1971) might indeed mediate the perception of symmetry in all visual displays. The limitations in detecting symmetry in his briefly exposed complex random-dot textures might perhaps reflect unsuitable input to such a symmetry extraction mechanism (Corballis and Roldan, 1974).

Before turning to some more theoretical considerations, let us first examine the pattern of results. Indeed, mean RT's were found to vary as a function of the orientation of the patterns confirming once more the salience of left-right symmetry. Moreover, these results replicate those of Corballis and Roldan (1975) when line rather than dot patterns are used, and under conditions in which neither the axis of symmetry of the patterns is conspicously indicated, nor eye movements likely. More important perhaps was the finding that <u>YES</u> judgments of symmetry were faster than <u>NO</u> judgments of symmetry when the patterns were flashed centrally on fixation as well as to the left visual field, but not significantly so when projection of the patterns was entirely to the right visual half-field. This finding is in contrast with that of Corballis and Roldan (1974) who found no such field effects under similar conditions of stimulation. It is important to notehowever, that in their experiment all patterns were presented vertically, and furthermore, <u>Ss</u> responded by using different labels for the patterns. Their own results in effect showed instructions to be a significant factor in speed of discrimination. That hemispheric asymmetries are found with respect to the way <u>YES</u>/<u>NO</u> judgments of symmetry are made is intriguing but perhaps not surprising since the results are in a direction predicted by more general findings suggesting specific functional hemispheric asymmetries in processing visual material (Gazzaniga, 1970). In particular, the use of the labels <u>YES</u>/<u>NO</u> might have facilitated responding to the patterns when these were projected to the left hemisphere but not so when the patterns were processed by the right less 'verbal' hemisphere.

The finding that overall <u>YES</u> judgments of symmetry were faster than <u>NO</u> judgments of symmetry is not particularly important since it is reasonable to suppose Ss responded NO only after having first checked the presence of symmetry in the patterns.

Contrary to the finding of Corballis and Roldan (1974) RT was found to be independent of the visual field to which the patterns were projected. This in turn does not provide direct support for the notion that Ss mentally 'center' the patterns before extracting the symmetric relations. The results of this experiment do not disprove this interpretation however, since the separation of the patterns from the point of fixation of the eyes reported by these researchers was considerably greater than the separation reported here. It may well be that minimizing acuity effects, which was the aim here, also reduced the magnitude of any such 'centering' effect. Though not significant there was a hint that unilateral RT's were longer, as might be noted in perusal of the curves in Figure 8.

Although there was some reason to suspect that an 'oblique' effect (Apelle, 1972) was present in the unilateral presentation conditions it is not clear why this effect did not generalize as well to centrally fixated patterns. A possible alternative interpretation is more likely if one considers visual acuity properties of the fovea. It is possible that in spite of efforts to restrict projection of the patterns to the fovea, by presenting the patterns as near as possible to the point of fixation yet entirely to either side, Ss might have an occassion misperceived part of the patterns. A relatively small number of trials such as these might have been sufficient to bias responses towards uncertainty and error. Nevertheless, it should be noted that this 'oblique' effect was not manifest in the three-way interaction between the field of presentation, the type of judgment, and the orientation of the stimuli, thereby indicating that the type of judgment by orientation pattern was independent of the visual field of presentation.

The perception of symmetry then appears to be a phenomenon partly attributable to a very primitive information extracting mechanism possibly involving one-to-one mapping between the hemispheres of the brain, and partly to some other higher order processes of abstraction and representation which permit an eventual suitable input to this system (Corballis and Roldan, 1975). The particular attributes of the latter seem to involve in a sense mental 'set' or expectancies about the symmetry characteristics of the patterns. This apparently is true if we are ever to notice symmetry appearing in orientations other than usual (Rock, 1973). In another sense there seem to be capacity limitations in the effectiveness of such correction processes when the relationships between elements in complex patterns are important in order to permit effective discrimination (Rock, 1973).

As was noted in the Introduction, the study of symmetry extraction processes might prove heuristically very useful in the study of other more complex perceptual invariances. Apparently, the orientation effects found in this and previous studies (Corballis and Roldan, 1975) are not restricted to the perception of symmetrical patterns only, since similar effects are readily obtained when the Ss are instructed to judge the same stimuli as same/YES for repeated half-patterns, or same/NO for symmetrical half-patterns (Corballis and Roldan, in preparation). That is, the effects might be shown to generalize to many classes of stimuli.

The elucidation of symmetry extraction processes might be further pursued along two more general lines of reasoning. Firstly, the parameter of complexity found to underlie most form discrimination (Thomas, 1967) might be effectively manipulated to purposes of mental correction limit estimations. Secondly, one might pursue the investigation of those perceptual parameters which actually facilitate or hinder alternatively the perception of symmetry. Visual masking techniques and specific attentional or 'set' demands might go a long way in elucidating the other perceptual invariances as well.

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APPENDIX

INSTRUCTIONS

The set of instructions given to each S were tailored to each one individually. The general format did not vary much however from the instructions given below:

"This is an experiment in which you will be required to judge the presence or absence of symmetry in visually presented patterns. You are to respond accordingly. If the pattern shown briefly to you is symmetrical, please press with the index finger of your (right or left) hand the button assigned for YES it is symmetrical. If the pattern shown briefly on the screen is not symmetrical press with the index finger of your other hand the NO it is not symmetrical button. You will be given 192 trials and then you will have a short rest. Each trial begins when you hear this tone, immediately fixate on the dot set centrally on the screen. One second after the occurrence of the tone signal you will be shown a pattern on the screen. Once you can tell whether the pattern is symmetrical or not press as quickly as possible the corresponding YES/NO button. Do not attempt to respond so quickly that you will sacrifice your accuracy. During practice try and find your optimum speed".

APPENDIX

Table 1

Mean reaction time in msc. for individual subjects in the CENTRAL presentation condition YES - (symmetry), NO = (asymmetry), O = Orientation in 45° clockwise rotations from the vertical.

	Subject	YES O_1	YES O_2	YES O_3	YES O_4		NO O_1	NO O_2	NO O_3	NO O_4
RH YES	1	724	727	644	752		655	708	765	806
	2	554	607	617	667		626	743	653	685
	3	647	699	778	688		750	796	763	702
	4	617	685	611	676		629	641	699	740
	5	607	644	653	604		598	685	651	681
	6	603	626	588	610		549	647	751	673
RH NO	7	602	670	571	600		623	675	676	647
	8	801	780	1126	909		981	940	1031	943
	9	559	578	596	608		578	604	637	630
	10	623	633	701	679		572	557	757	638
	11	533	607	602	555		610	680	656	674
	12	851	908	872	814		821	860	938	920
Overall YES Means		643	680	696	680	Overall NO Means	666	711	748	728
Overall YES/NO Means		654	695	722	704					

APPENDIX

Table 2

Mean reaction time in msec. for individual subjects in the LEFT VISUAL-FIELD presentation condition YES - (symmetry), NO = asymmetry), O = Orientation in 45^{0} clockwise rotations from the vertical .

	Subject	YES O_1	YES O_2	YES O_3	YES O_4	NO O_1	NO O_2	NO O_3	NO O_4
RH YES	1	700	805	652	659	714	824	740	771
	2	635	736	593	823	689	782	798	869
	3	678	684	652	723	720	757	775	778
	4	624	654	604	635	649	745	692	697
	5	618	771	681	675	651	673	643	730
	6	564	677	595	569	575	748	677	618
RH NO	7	571	715	588	691	650	672	682	644
	8	895	939	1000	938	909	952	1062	1053
	9	559	592	562	550	560	616	667	651
	10	654	699	689	571	601	653	623	620
	11	593	574	571	561	638	692	691	731
	12	849	919	844	858	817	859	891	881

Overall YES Mean	661	730	668	687	Overall NO Mean	681	747	753	753
Overall YES/NO Mean	671	739	711	720					

APPENDIX

Table 3

Mean reaction time in msec. for individual subjects in the RIGHT VISUAL-FIELD presentation condition YES = (symmetry), NO = (asymmetry), O = Orientation in 45° clockwise rotations from the vertical.

	Subject	YES O_1	YES O_2	YES O_3	YES O_4	NO O_1	NO O_2	NO O_3	NO O_4
RH YES	1	719	759	749	701	645	737	677	706
	2	662	677	649	732	665	732	757	756
	3	725	691	674	741	687	755	816	730
	4	615	678	637	579	608	755	664	680
	5	634	657	677	683	606	652	647	646
	6	557	627	620	606	563	668	638	639
RH NO	7	617	722	643	664	596	749	655	639
	8	948	974	1048	953	929	1018	1053	1057
	9	600	639	615	667	558	594	668	585
	10	605	640	765	676	579	601	621	575
	11	612	615	617	643	606	653	652	643
	12	800	911	863	808	878	867	895	801
Overall YES / Overall NO	Mean	674	715	713	704	659	731	728	704
Overall YES/NO	Mean	667	723	720	704				