Symmetry - A Review

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Abstract

Symmetry has been dealt with in a wide variety of fields in both art and science. Symmetry and asymmetry as aesthetic features have been used in architecture, sculptures and paintings. Symmetry and symmetric groups have been defined in mathematics [31]. Symmetry and it's compliment feature *Chirality* are basic properties of molecular structure that mediate chemical properties [29].
Though symmetry can be discussed in different aspects, in this paper psychophysical aspects of spatial visual symmetry are reviewed.

1 Preattentive Symmetry

Symmetry is a basic precategorical (preattentive) feature as are size, brightness, color, movement etc. That is, it is a fast processed feature (requiring less than 1 sec for detecting [10, 33]) and precedes processing of form shape and structure which are required for registration in short term memory and recall [2, 35, 14, 16]. HOWE [14] requested subjects to declare symmetry, if existed, in simple dot patterns which were visually displayed then masked. When display time was short, symmetry was detected but patterns could not be recalled. On longer display time, patterns were recallable, yet even when errors in reconstructing the patterns were made, the symmetric features were recalled correctly.

2 Goodness and Geometricity of Symmetry

Symmetry is an aesthetic feature which influences the gestalt perception of 'goodness' or 'geometricity' of an image or pattern. A series of experiments examine this influence [15, 14, 39]. The typical experiment is to request a subject to subjectively grade or scale a set of patterns in order of 'goodness'.
ZUSNE and MICHELS [39] requested subjects to order a given set of deformed pentagons in decreasing order of 'geometricity'. Results showed that all symmetric shapes preceded asymmetric ones.
In a similar experiment HOWE [15] requested subjects to grade patterns according to 'balance'. 'pleasingness', 'goodness', 'simplicity of organization' and dispersion. Symmetry had a direct effect on all except dispersion (with which symmetry is uncorrelated).
SZILAGYI and BAIRD [36] asked subjects to design patterns which are 'pleasing'. They found that subjects created symmetric objects with a preference for vertical symmetry.
In an earlier study ATTNEAVE [3] found that symmetric shapes are less 'complex'.
Another test examining symmetry as a basic and inherent feature is found in the work by GOLDMEIER [13]. He found that deformed objects which leave the symmetry intact are more similar to the original than minimaly asymmetrically deformed objects.

3 Saliency of Symmetry Types

Symmetry (in 2 dimensions) can be classified as

1. **mirror (reflectory) symmetry** - where an axis of symmetry exists and the two half-planes obtained are mirror images of each other.

2. **rotational symmetry** - where a single rotation point exists. Rotation of the pattern about this point by a fraction of a full cycle, aligns exactly with the original pattern.

Experiments [33] have shown that the reaction time (RT) for detecting symmetries of the rotational type is greater than RT for detection of mirror symmetries.

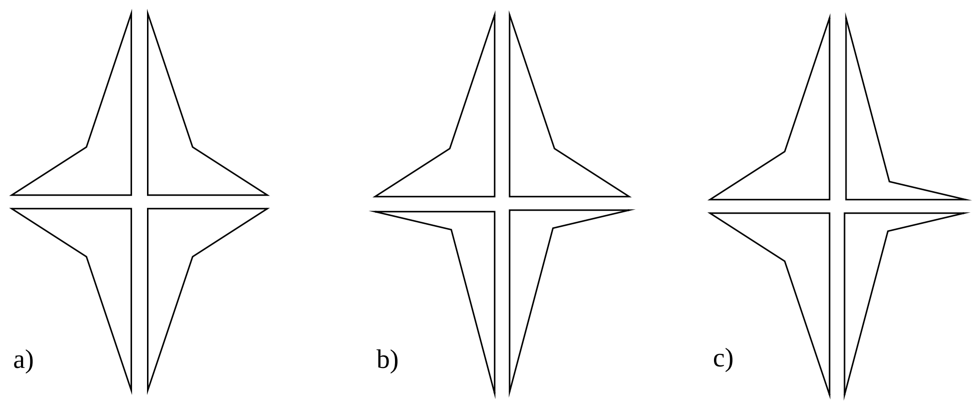

Figure 1: An experiment by Goldmeier showed that a pattern (a) deformed so that vertical symmetry is maintained (b) is more similar to the original than the same pattern deformed so that horizontal symmetry is maintained (c).

When discussing mirror symmetries, the question arises whether there is any difference in the perception of symmetry as a function of the angle of the symmetry axis.

3.1 Saliency of Vertical Symmetry

A collection of experiments show that vertical symmetry is the most salient and easily perceived of the possible axis of mirror symmetry [13, 32, 25, 11, 4, 1, 33].
GOLDMEIER [13] tested similarity in shapes. He requested subjects to decide which of two deformed shapes is most similar to the original. It was found that patterns deformed so that vertical symmetry is maintained (horizontal symmetry is broken) are more similar to the original than the same pattern deformed so that horizontal symmetry is maintained (see Figure 1). Following this work ROCK and LEAMAN [32] continued to examine the saliency of vertical symmetry perception. In a similar experiment, using abstract figures with both vertical and horizontal mirror symmetry, they too found that vertical symmetry maintaining (figures with distorted horizontal symmetry) had a clear superiority over horizontal symmetry maintaining.
BARLOW and REEVES [4] used random dot displays with a varying number of mirror-paired dots, The symmetry axis were of different angles. Subjects were to discriminate between 'symmetric' patterns and 'random' patterns. They found that at 80% paired dots and 20% random dots, vertical symmetry (symmetry axis at $0°$) had highest discriminability over horizontal ($90°$) and oblique ($45°$).
A similar experiment by MASAME [25] showed similar results.
ROYER [33] measured response time for detecting symmetry in patterns of dots in a square. It was found that RT for detection of vertical symmetry is shorter than horizontal and diagonal mirror symmetry which is shorter than RT for rotational symmetry detection.
Earlier works by JULESZ [18] and by CORBALIS and ROLDAN [11] also measured RT for vertical mirror symmetry as shorter than other angles of mirror symmetry.

4 Mental Rotation vs Template models of Symmetry Detection

Though there is agreement that vertical symmetry is most salient over any other angle of symmetry axis, there is still a controversy over the scaling of the other angles of symmetry axis (specifically vertical vs horizontal vs oblique axis of symmetry). This controversy corresponds to two models of symmetry perception:

1. **Template Model** - for each angle of symmetry axis (or rather for a range of angles around the vertical, horizontal and oblique axis) there is a template or simple mechanism which detects the symmetry in a pattern.

2. **Mental Rotation Model** - A single mechanism exists which detects symmetry (specifically detects vertical symmetry). All other mirror symmetries are detected by mentally rotating the pattern to align it's symmetry axis with the vertical, then processing it for (vertical) symmetry. The mental rotation is assumed to be linear in time as a function of the angle of rotation.

The mental rotation model supports a preference (and shorter RT for detection) of vertical symmetry over oblique symmetry, and oblique symmetry over horizontal symmetry (proportional to the angle of rotation between symmetry axis and the vertical). The template model, however, suggests no preference of one symmetry axis over the other (though preference for vertical over horizontal and horizontal over oblique is assumed due to frequency of those symmetries in the environment, which might strengthen the symmetry detection process).

Several experiments have been performed to test these two models [1, 18, 13, 4, 25, 33, 24, 34, 11].

4.1 Support for the Template Model

APPELE [1] described the 'oblique effect' in visual perception which indicates a preference (better detecting ability) of vertical and horizontal stimulus over oblique stimulus. Experiments support this effect in symmetry detecting tasks [18, 13, 4, 25, 33].
In an early work by GOLDMEIER [13] similarity in patterns was tested. It was found that an upright square is more similar to an upright rectangle than to a parallelogram. When these same shapes are tilted at $45°$ angle, the similarity of the square is greater to the tilted parallelogram than to the tilted rectangle (see Figure 2). These results are reasonable if the decreasing order of saliency of symmetry axis is vertical, horizontal and oblique. (since in the upright position the square and rectangle share vertical, horizontal and diagonal symmetries whereas the parallelogram shares only the diagonal symmetry. When tilted, the square and rectangle share diagonal symmetries whereas the parallelogram shares vertical symmetry with the square).
Further experiments by BARLOW and REEVES [4] and later by MASAME [25] used dot

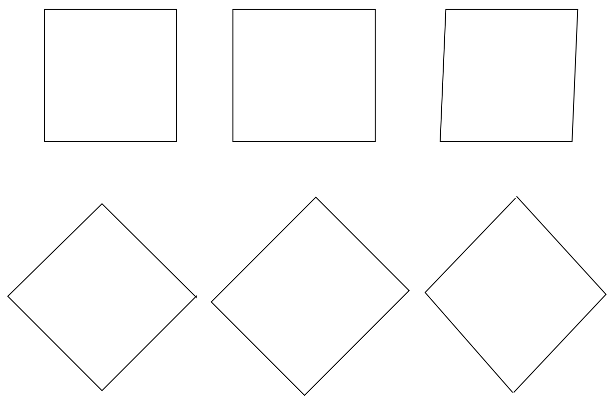

Figure 2: Goldmeier showed that an upright square is more similar to an upright rectangle than to a parallelogram (top row). However, when tilted, the square is more similar to the parallelogram than to the rectangle (bottom row).

displays with a varying number of mirror-paired dots. Subjects were to discriminate them from random. In one experimental set (experiment 3), 100 dots were displayed of which 80% were paired and 20% were random. Different axis of mirror symmetry were used. Results showed that detection was greatest for vertical symmetry (0°) followed by horizontal symmetry (90°) followed by oblique symmetry (45°).
Response time for detecting mirror symmetry of different angles in random dot patterns, was measured by JULESZ [18] to be in increasing order for vertical symmetry, horizontal symmetry and oblique symmetry axis.
In the systematic study by ROYER [33], all possible symmetries of dot patterns in a square were tested. RT for detecting symmetry in a pattern with horizontal (vertical) symmetry was much shorter than a pattern with diagonal symmetry.

4.2 Support for the Mental Rotation Model

As early as the beginning of the century the idea of mental rotation was suggested. MACH [24] and SACHS [34] concluded that rotated images are less similar to the original as the angle of rotation increases.
Studies have shown that object recognition can be modeled by mental rotation.
Support for the mental rotation model in detection of symmetry was given by CORBALIS and ROLDAN [11]. They used random clusters of six dots which were mirrored or repeated about an axis. This axis which was graphically displayed, was tilted at $0^\circ, 45^\circ, 90^\circ$ or 135°. Subjects were asked to detect the symmetric patterns (see Figure 3). Results showed that although there were only a few more errors in oblique symmetry detecting than in vertical and horizontal, the reaction time increased substantially as angle from the vertical increased (see Figure 4 center).

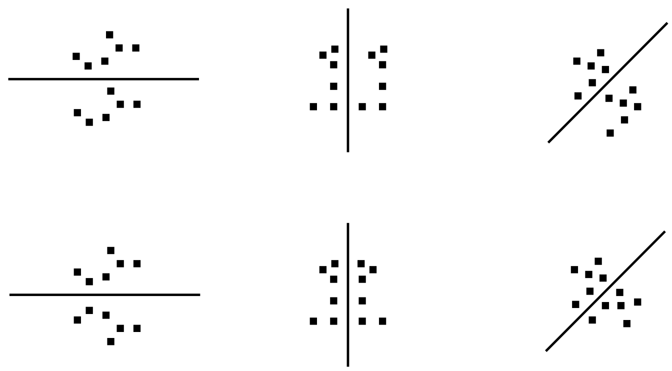

Figure 3: Corbalis and Roldan used random clusters of 6 dots, repeated or mirrored about an axis which was tilted at different angles.

These results support the mental rotation model.
In a further experiment subjects were to detect the same symmetric patterns with head tilted at 45° angle. Results showed that shortest RT is when angle of symmetry axis is equal to head tilt (45° or 135°) and largest when symmetry axis is perpendicular to head tilt (135° or 45°)(see Figure 4). Note that RT when head is tilted is not a phase shift of the results when head is upright. i.e. there is still some preference (shorter RT) for the absolute vertical (0°) over the absolute horizontal (90°)[1].

4.3 Discussion

Although the latter experiments support the mental rotation model, one must still consider the possibility that templates exist for symmetry detection at different angles, but are weaker at tilts further away from vertical which are less common. (though this does not explain why horizontal symmetry RT is greater than oblique). Further more, the process of symmetry detection might depend on scanning the axis itself in which case vertical scanning is 'easier' (i.e. less time consuming). This explanation is controversial since eye movements are not required for symmetry detection.

In the experiments of CORBALIS and ROLDAN [11] symmetry axis is shown explicitly, whereas in the template supporting experiments the symmetry axis was not shown. Missing symmetry axis might induce a search for the axis with initial search for the vertical and horizontal axis (which are more common and probable), so that detection of oblique symmetry is prolonged due to this serial search and not due to the symmetry detection process (mental rotation). Also, the GOLDMEIER experiments [13] used well known shapes (square, rect-

[1]This might be due to counter torsion of eyes (due to the Vestibular Occular Reflex which tends to rotate eyes counter to the direction of head movement) or due to the tendency to correct head position to upright. But these two explanations are insufficient to correct the results and some internal compensation for head tilt must be assumed

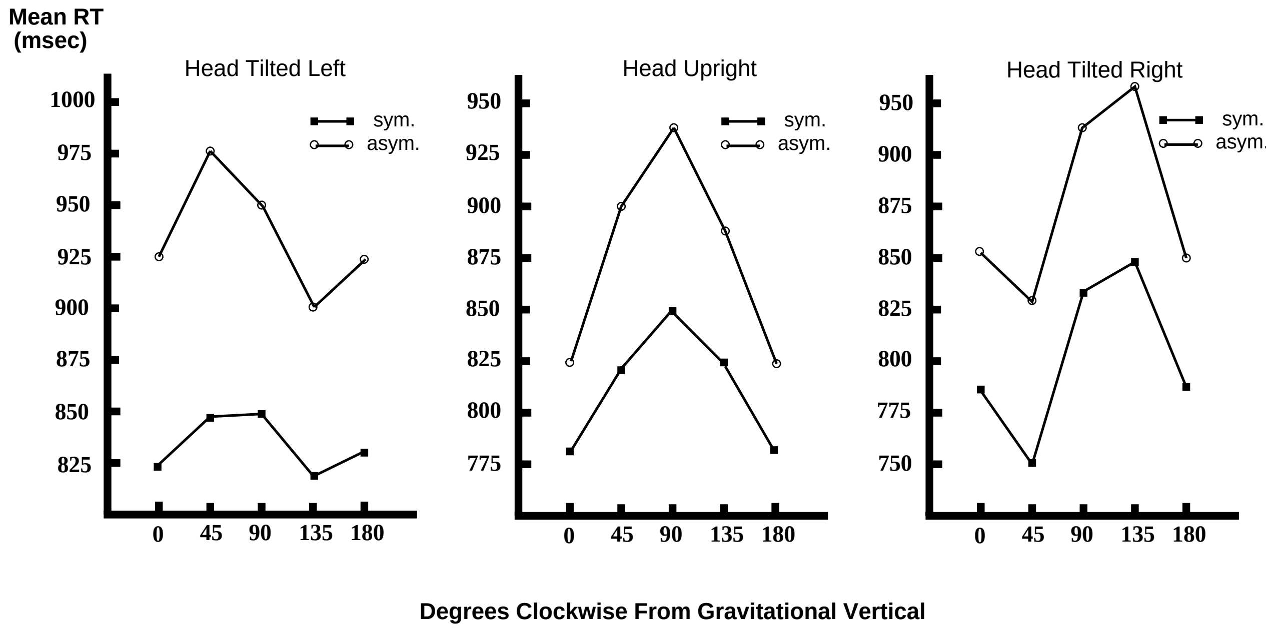

Figure 4: Results of the experiment by Corbalis and Roldan.

angles) which are usually not seen at other (tilted) angles.
This suggests that there is more than one strategy for symmetry detection, dependent on the stimulus and task.

5 Physiological and anatomical support for Symmetry processing

It is well known that the human visual system is bilaterally symmetric. Does this influence visual symmetry perception?

This question leads to a controversy regarding the coordinate system (the 'phenomenal' coordinate system) used while processing symmetry:

1. The 'phenomenal' coordinate system is aligned with the retinal coordinate system.

2. The 'phenomenal' coordinate system is aligned with the gravitational coordinate system.

In support of the former view, MACH [22, 23]thought that saliency of vertical symmetry was due to interactions between the symmetry of the pattern and the bilateral symmetry of the visual system. Following this, JULESZ [18] suggested that the underlying symmetric anatomy of the visual system is the basis for high frequency symmetry detection. i.e.

symmetry detection is performed by a point by point comparison based on neuroanatomy which is symmetric about the fovea. This means that detection of mirror symmetry in high frequency patterns, requires symmetric projection to the visual system.
This conclusion follows the results of experiments with random dot patterns where vertical symmetry was detected only when fixation point was on the symmetry axis. Symmetry in patterns with tilted axis or peripheral axis was not detected.
Further support for the retinal coordinate system is given by CORBALIS and ROLAND [11] where symmetry was detected in dot displays while head was tilted. Preference (shortest RT) was found for vertical symmetry in retinal coordinates.
In contrast, several experiments do not support JULESZ's theory of requiring symmetric projection in order to detect symmetry.
BARLOW and REEVES [4], using dot displays with varying number of mirror paired dots and symmetry axis displaced to right or left of fixation point, showed that although there is a decrease in performance, symmetry is detected.
MASAME [25] in a similar experiment found the same results.
Additional contradiction to the retinal coordinate view is given by ROCK and LEAMAN

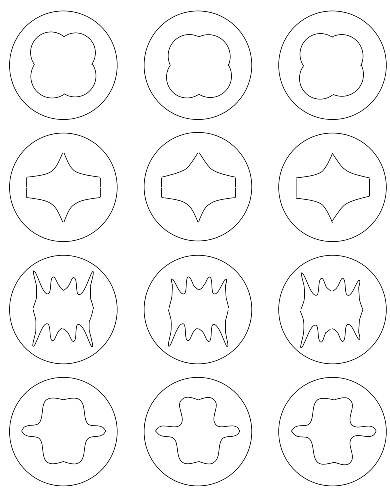

Figure 5: Abstract figures used by Rock and Leaman.
Original figures (left column) were distorted in their horizontal symmetry (center column) or their vertical symmetry (right column).

[32] who tested the saliency of vertical symmetry while changing the 'phenomenal' reference frame. They used abstract figures with both vertical and horizontal mirror symmetry. These figures were distorted once in their horizontal symmetry and once in their vertical symmetry (see Figure 5). Figures were displayed upright or at 90° tilt (which reversed affect of symmetry axis). Subjects were asked which of the distorted images was most similar to the original. The test was performed with head either upright or tilted at 45° angle. The test was preceded by a learning stage in which the phenomenal coordinate system was set. Results

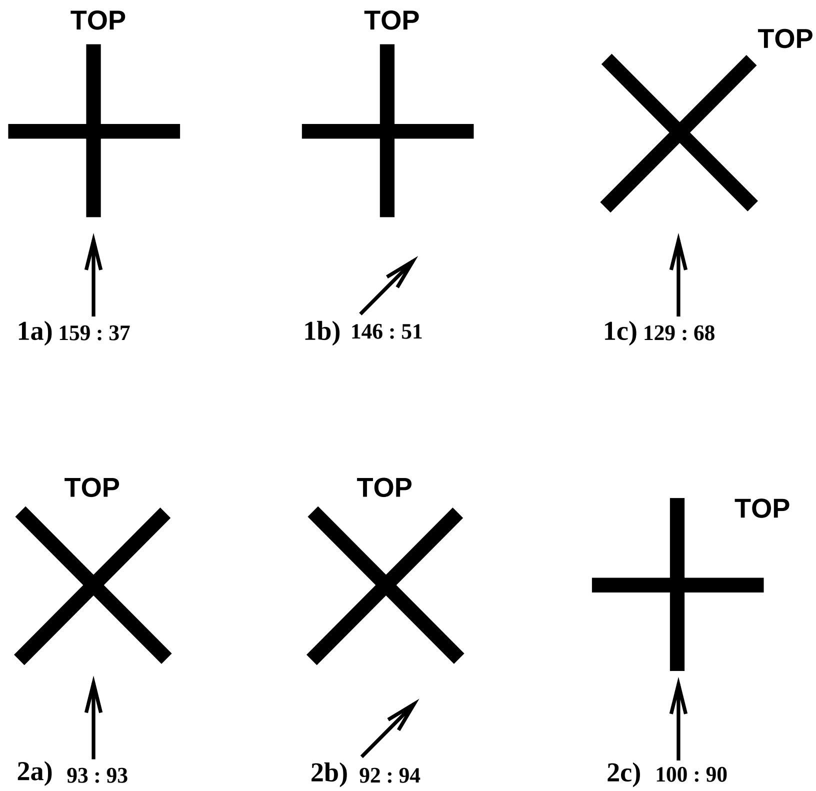

Figure 6: In the experiment by Rock and Leaman:
A comparison of case 2a and 2b - shows that retinal axis alone is ineffective.
A comparison of case 2b and 2c - shows that gravitational axis influences symmetry perception.
A comparison of case 2c and 1a - shows that phenomenal frame of reference influences symmetry perception

showed that when the phenomenal coordinates were aligned with axis of symmetry of the pattern, there was a preference for vertical symmetry regardless of whether the phenomenal vertical was aligned with the retinal vertical and/or the gravitational vertical(case 1a, 1b and 1c in Figure 6). When the phenomenal coordinates were not aligned with axis of symmetry of the pattern(symmetry axis were diagonal), there was no substantial preference of vertical symmetry over horizontal symmetry even when symmetry axis aligned with retinal vertical (case 2a and 2b in Figure 6). When both retinal and gravitational vertical were aligned yet both misaligned with the phenomenal vertical (case 2c in Figure 6), there was a slight preference for the vertical symmetry axis (though much less prominent than the control case 1a). These results showed that detection of symmetry is not based only on retinal coordinates or gravitational coordinates, but is a process dependent on the 'phenomenal' frame of reference as if the detection process includes a search and comparison of two 'sides' of the pattern.
CORBALIS and ROLDAN [11] state that it is reasonable to suppose that the phenomenal

coordinate system we use is normally gravitational (we see a stable world even when we move our head and eyes), yet given a limited processing time, initial fleeting impression is tied to retinal coordinates. The compensation for head tilt follows the receival and analysis of the retinal image. So, if a rapid decision is required, subjects may try to retain the retinal image so as not to slow the response by the correction process. This might explain the preference of retinal vertical over phenomenal and gravitational vertical in some of the experiments.
The symmetric anatomy of the visual system which favours retinal vertical symmetry might be used as the only detector of symmetry in complex (high frequency) patterns.

6 Is Symmetry inherent or learned?

Following the above controversy, the question of whether symmetry detecting is genetically inborn or learned, arises.
Following the course of evolution; when eyes were lateraly situated, forward motion induced symmetric stimulus. In addition, symmetry was necessary in behavioural aspects when detecting faces and animals facing us was a matter of survival. This and the fact that symmetry is very general and all types can be detected, supports the notion that symmetry detecting has evolved naturally and is genetically inherent.
The experiments of JULESZ [18] support symmetry detection as a physiological mechanism.

On the other hand, the mental rotation model and other experiments, show the robustness of symmetry perception and promote the idea that learning is part of the symmetry detection mechanism.

In the work by BORNSTEIN, FERDINANDES and GROSS [5] and later by BORNSTEIN and KRINSKY [6] it was shown that as early as 4 months, there is already faster processing of (habituation to) vertical symmetry compared to horizontal symmetry, oblique symmetry and asymmetric patterns. It was also shown, by FISHER, FERDINANDES and BORNSTEIN [12] and by BORNSTEIN and STILES-DAVIS [7] that at this early age, vertical symmetry can be distinguished from horizontal symmetry and from asymmetric patterns, however neither horizontal symmetry nor oblique symmetry can be distinguished from asymmetric patterns. They continue and show that up to 6 years of age, there is still better discrimination of vertical and horizontal symmetry from asymmetry, than discrimination of oblique symmetry from asymmetric patterns.
In experiments performed by MENDELSON and LEE [26], children were shown square patterns with a single symmetry axis (vertical, horizontal or diagonal) and of varying complexity (size of blobs). These subjects were asked to recognize a stimulus, displayed for a limited time, from a permanent array of patterns. Following the test, subjects were shown the aspects of symmetry appearing in the stimuli then retested. Results showed that at 7 years, subjects recognized all stimuli well, with a preference for vertical symmetry. At 6 years of age, subjects were aided in recognition by vertical, horizontal and diagonal symmetry. At

5 years, subjects were aided by vertical symmetry in all patterns, by horizontal symmetry in stimuli of high or medium complexity and by diagonal symmetry only in high complexity stimuli.
CHIPMAN and MENDELSON [9] showed that vertical symmetry influences complexity judgement, but horizontal and diagonal do not until age 7.

These experiments show that some initial symmetry perception exists, specifically the saliency of vertical symmetry, however learning is necessary for developing full symmetry perception including horizontal and oblique symmetries.

It is probably correct to assume (as in other feature detection mechanisms) that symmetry detection has a basis in anatomical and physiological mechanisms yet is supported and tuned by experience and learning.

7 The Process of Detecting Symmetry

All visual processing starts with the technical collection of the visual information, i.e. obtaining a projection on the retina. This is done during a constant fixation or fixations following saccadic motion, during a scanning process.
Does symmetry (as a feature of the stimulus or as a target for a visual task) affect the scanning and fixating process?
Further processing of symmetry must analyse and deal with several subproblems:

1. The type of symmetry (rotational or mirror).
2. The location of the symmetry axis or the point of rotation.
3. Measure of tilt of the symmetry axis (for mirror symmetry).
4. Measure of fraction of cycle which induces symmetry (for rotational symmetry).

7.1 Scanning Symmetry

Though symmetry can be performed without eye movement (even when symmetry axis is off fixation point as in [4, 18, 11, 10]), it is probable that some kind of internal scanning is performed, such as focusing of symmetry process or attention.
When, however, a pattern is displayed for free scanning, or a task is performed without limiting eye movement, the scan path can be recorded and measured.
Early work by YARBUS [38] and NOTON and STARK [28] showed that scanning an image included saccadic movements (short sharp eye movements which move eye from one fixation point to another) and stable fixations. Fixations were on locations in image of salient features (contours, corners etc.).

ZUSNE and MICHELS [39], in an early work found no relation between symmetry in polygons and eye scanning pattern.
Since then, however, several experiments have shown otherwise:
THOMAS [37] studied eye movements and fixations during subject viewing of Rochard cards (inkblot patterns). He found that fixations concentrated mainly on contours with a tendency to fixate more on one half of a symmetric image.
NOTON and STARK [28] Found the same results.
LOCHER and NODINE [21] used black shapes with increasing 'complexity' (number of sides). Some were symmetric and some asymmetric. They found that both number of fixations and their duration increased with complexity for both symmetric and asymmetric shapes. For symmetric shapes, fixations were concentrated on one half of the image only.
In a later work NODINE and LOCHER [27] used nonsense images, and again found that symmetry induced eye scanning of half the image.

Symmetry is a feature detected globally and from the periphery and is analysed early enough to influence and guide the scanning process.

7.2 Recognizing Different Types of Symmetry

In a systematic study bt ROYER [33], all possible symmetries of dots (or lines) in a square were displayed and RT for detection was measured. Symmetric patterns were classified (following the definitions in [31]) as:

G_m - horizontal,vertical and both diagonal mirror symmetries.
G_{HV} - horizontal and vertical mirror symmetries.
G_{DD} - both diagonal mirror symmetries.
G_H/G_V - horizontal or vertical mirror symmetry.
$G_{D+/D-}$ - a single diagonal mirror symmetry.
G_C - rotational (centric) symmetry (order 2).
G_{CC} - rotational (centric) symmetry (order 4).
G_a - asymmetry.

Results showed that there is an increase in RT for detection of symmetry in the following order:
for lines: G_m,G_{HV},G_{DD},G_{CC},G_H,$G_{D+/D-}$,G_C,G_a.
for dots: G_m,G_{HV},G_{DD},G_{CC},$G_{D+/D-}$,G_H,G_C,G_a.
(Following practice, results are of overall shorter RT, yet in same order as above except for ptterns of type
Vertical symmetry is thus more salient only among single-symmetries. Symmetry of type G_m (4-fold) and G_{HV} (2-fold) are most salient overall.

PALMER and HEMENWAY [30] suggest a hierarchical serial decomposition which might take place during the process of symmetry detection (see Figure 7).

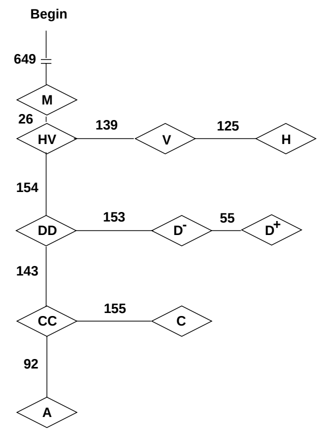

Figure 7: A hierarchical serial decomposition for symmetry detection suggested by Palmear and Hemenway.

7.3 Detecting Location and Tilt of Symmetry Axis

Additional serial search processing during symmetry detection is suggested during the search for the location of the symmetry axis and for it's tilt.
BARLOW and REEVES [4], studying symmetry in random dot displays with a varying number of mirror-paired dots, asked subjects to detect symmetry in patterns with symmetry axis displaced to the right or left of the point of fixation. Results showed that there is a decrease in discrimination as the axis of symmetry departs from the point of fixation. In a further experiment the display was divided into vertical 'strips'. The number of paired dots was varied in each strip separately. Results showed that discrimination deteriorated more for changes in the middle strips (closer to point of fixation) than for outer strips, and more for outer strips than for the inbetween strips.
BRUCE and MORGAN [8] found that changes in the pattern close to axis of symmetry is more important than changes distant to axis.
These results are in order if the symmetry axis is serially searched for from the center outward or from the center inward.

With regard to the detection of the tilt of the symmetry axis, the experiments mentioned in sections 4 and 5 and specifically the mental rotation model, suggest an additional serial process involved in symmetry detection.

7.4 Detecting Location of center of Rotational Symmetry and the Rotation Angle

No references were found dealing with the search for center of rotational symmetry not aligned with the fixation point. Neither were references for scaling of rotational symmetries as a function of their multiplicity (angle of rotation).

7.5 High vs Low Frequency Symmetry information - Hierarchy in Symmetry

JULESZ [18] found that mirror symmetry was undetectable in random dot patterns when axis of symmetry was off the fixation point. i.e. symmetry detection required symmetric projection onto the visual system. However, similar experiments with less 'complex' patterns did not give the same results [4, 25]. Although there was a decrease in symmetry detection when axis was lateral to the fixation point, in these experiments, symmetry was nonetheless detected.

JULESZ suggested that detection of high spatial frequency symmetry requires symmetric projection to the visual system whereas low spatial frequency does not. This can explain the difference in results between the above experiments.

To study further, the affects of frequency on symmetry perception, JULESZ and CHANG [19] designed random dot displays that were combinations of symmetric patterns of different spatial frequencies (by creating RD patterns of various spatial frequencies and superimposing them with weights).

Since spatial frequency channels occur before stereopsis [20] and stereopsis before symmetry [17], JULESZ and CHANG concluded that spatial frequency channels should occur before symmetry.

They used the following random dot patterns:

V - random dot pattern with vertical symmetry.

H - random dot pattern with horizontal symmetry.

V_{HP}, V_{LP} - random dot patterns with vertical symmetries passed through high pass filter and low pass filter respectively.

H_{HP}, H_{LP} - random dot patterns with horizontal symmetries passed through high pass filter and low pass filter respectively.

The display $0.5V + 0.5H$ (V display superimposed on H display with equal weights) gives a perception of random dots (i.e. no symmetry). At $0.7V + 0.3H$ vertical symmetry is perceived, and it is the only symmetry perceived. When RDs are passed through filters, the following results are obtained:

The display $V_{HP} + H_{HP}$ gives the same results as $H + V$ displays (where $0.6V_{HP} + 0.4H_{HP}$ is still seen as random and at different weights only a single symmetry is perceived). But in the display $V_{HP} + H_{LP}$ both horizontal and vertical symmetries are seen at the same time, though horizontal symmetry is a little stronger. (Note that for the same weighted combination but without filtering, vertical symmetry is stronger). For the display $V_{LP} + H_{HP}$ (above rotated) the perception of vertical symmetry is very much stronger than horizontal symmetry). $0.7V_{HP} + 0.3H_{LP}$ gives strongest perception of both horizontal and vertical symmetry (equal perception).

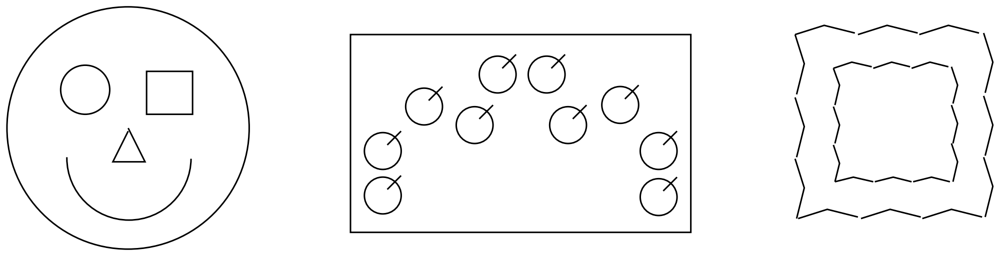

Figure 8: Examples showing global symmetries with local asymmetries.

The conclusions from these results are:

- Spatial frequency channels precedes symmetry.
- Low spatial frequencies have greater perceptual weight in symmetry, than high spatial frequencies.

7.5.1 Discussion

These results demonstrate that spatial frequencies influence symmetry perception. BARLOW and REEVES [4] suggested that instead of detecting symmetry in dot patterns by exhaustive pairing of dots, the image might be divided into paired regions and the number of dots in each region compared (i.e. comparing local dot density). This can be interpreted as low spatial frequency symmetry detecting.
This leads to an idea that symmetry detection uses low spatial frequencies for foveal guidance (see section 8.1 where only half of a symmetric image is scanned. i.e. information from the periphery, which is assumed to be of low spatial frequencies, guides the scanning process). Once the fixation is performed (following the low frequency guidance) the high frequency data can be symmetrically projected onto the visual system and analysed.
Again, this suggests that there are at least two different mechanisms dealing with symmetry, the low spatial frequency symmetry and the high spatial frequency symmetry.

The hierarchy in symmetry is expressed in another phenomenon where figures look 'over all' symmetric yet are actually (when focusing onto details) asymmetric (see Figure 8). This gives rise to the idea of global vs. local symmetry.

8 Further Questions

- Does the degree of a rotational symmetric pattern (i.e. the number of identical sections of the pattern) influence symmetry detection.
- How is symmetry detection affected when center of rotation (of rotationally symmetric patterns) is not at the fixation point.
- If low spatial frequencies serve to guide the scanning process, how is the scanning process affected when displays such as those used by JULESZ and CHANG [19] are used (where symmetry axis of low frequency is different than axis of high frequency data).

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