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VISUAL SYMMETRY PERCEPTION

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Summary

The aim of the present study is to review research relating to the visual perception of symmetry in humans and animals. In particular, data are presented for symmetry perception in infants, children, older people and in individuals with neurological or psychiatric disorders, while emphasis is given in exploring the concept of symmetry in relation to other cognitive processes and aesthetic judgments. Studies are also presented about the involvement of visual perception of symmetry in the perception of human faces, and an attempt is made in order to show the latest views on the physiological-neurological background and theoretical modeling approaches. In conclusion, despite methodological difficulties, the majority of current relevant studies show the importance of concentrating a particular type of symmetry: mirror symmetry around a visually hypothetical vertical axis.

Key words: visual symmetry perception, aesthetic judgments, cognitive mechanisms, neural basis

Introduction

Symmetry is part of the natural world that surrounds us.The concept of symmetry is borrowed from mathematics (geometry, book X of the Elements of Euclid) and studied in set theory (Carter, 2009. Miller, 1972), but it is vital in other disciplines, as is the case for the symmetry in physics {e.g. specular reflection (spatial symmetry) and spread acoustic and magnetic waves (radial symmetry)}, in chemistry {crystal structures and molecular structures (radial symmetry) and its isomers (symmetry position)}, and in biology {mainly in figures of living beings (bodies of plant and animal organisms with right-left symmetry around an axis) and radial shapes in nature (starfish, snowflakes, flowers, etc.)} (Darvas, 2007. Gould, 2004. Jaeger, 1917. Meshkov, 2009 . Nicholle, 1950. Rosen, 1975. 2009. Shubnikov & Koptsik, 1974. Weyl, 1952. Wigner, 1970). The preference for the scientific description of nature based on symmetry begins with Plato, who in "Timaeus", develops the theory that the building blocks of the universe are symmetrical polyhedra, corresponding to the elements of Empedocles (the tetrahedron for the fire, the cube for the earth, octahedron for the air, the dodecahedron and the icosahedron ether for the water).

Symmetry is fundamental for understanding both nature and art (Boas, 1955. Field & Golubitsky, 1992. Stevens, 1981. Redies, Hasenstein & Denzler, 2007. Voloshinov, 1996. Washburn & Crowe, 1988). Paleoanthropological studies report findings on symmetric construction of tools from various hominids, which perhaps evolved into aesthetic preference for symmetrical structures in humans (Hodgson, 2011. Saragusti et al., 2004. Toth, 1990).

Typical examples found in longitudinal and cross-cultural works of art reaffirm the above importance of symmetry: in painting (spatial symmetry, color symmetry), in sculpture (symmetry in the bodies of statues or friezes), in architecture (micro- and macro-level symmetry), in prose (repetition of words or phrases in literature-poetry and palindromes) and in music (with intact or transformed repetitions of musical motives both at the micro-level configurations, and at the macro-level). Thus, although initially the concept of symmetry relates to a special class of optical transformations (i.e., how to move an object in space), it should be clarified that it is not limited to objects in space (Hargittai & Hargittai, 1994. Tarasov, 1986). Synonym to symmetry is the concept of harmony, which describes the well-structured whole, which has a clearly defined structure both in its entirety, and to all its parts (Kaimakis, 2005) by stressing more the acoustic and musical, rather than the geometrical applications of symmetry (Wyle, 1952).

Of course, the perceptual systems, such as those of sight and hearing seem to differ fundamentally in nature, but that does not mean that they should be independently examined, because there are some general rules, which can apply to all of our senses (Bregman, 1990. Calvert, Brammer & Iversen, 1998. Cronly-Dillon, Persaud & Blore, 2000. Cronly-Dillon, Persaud & Gregory, 1999. Peeples, 2010. Rosenblum, 2010. Stein & Meredith, 1993). An example of a possible convergence in perception (visual and auditory) is symmetry.

Definition of symmetry and types of symmetry

Symmetry refers to the match of size, shape and position of interrelated parts of a whole with reference to a (visual or auditory) axis or a point. Symmetry is the property of an object or system to remain intact after a set of changes (transformations) (Ghyka, 1946). The property of being symmetrical in abstract visual forms includes the concepts of similarity and equality, in contrast with asymmetry, which is linked with the concepts of difference and inequality (VandenBos, 2002. Papadopoulos, 2005).

If we turn our attention to symmetries in the plane, i.e. the transformations that preserve equal geometric dis-

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tance (isometric), then we can define three types of transformations (transposition, rotation and mirroring), leading to four types of symmetry: a) translational symmetry (transposition of an object without rotating or mirroring), b) rotational symmetry (torsion of an object at a selected angle and center of rotation), c) mirror symmetry (reflectional / bilateral / mirror symmetry -projection of the image of an object as on a mirror). There are also more complex types of symmetry, such as d) the sliding mirror (glide-reflectional symmetry-substantially mirrored combination and transfer along the axis), and more complex combinations of the previous (Armstrong. 1988. Drivas , 2009. Stewart & Golubitsky, 1992. Weyl, 1952).

Symmetry perception in humans

The preference that humans show for symmetrical designs is mentioned for the first time by Aristotle in his work Metaphysics and a similar observation is made by Darwin in his book "The descent of man''.

The importance of symmetry as an organizational agent of human visual perception is emphasized in the field of experimental psychology (Baylis & Driver, 1995a. 1995b. Rock, 1983), during the early 20th century by the Gestalt school of psychology, which argues that people perceive objects more in organized groups i.e. formations, rather than as the sum of the individual parts (Koffka, 1935. Kohler, 1929). This organization of the human visual perceptual system is based on certain principles (such as proximity, similarity, symmetry, continuity and common fate). It has been shown experimentally that the similarity and proximity rather precede symmetry during processing of a stimulus (Labonté et al., 2002), but this does not restrict us to generalize the application of these principles and for auditory perception (Shepard & Levitin, 2002).

In general, symmetry perception in adults is automatic, does not demand and is achieved with great accuracy (Adams, Fitts, Rappaport & Weinstein, 1954. Arnheim, 1974. Barlow & Reeves, 1979. Belyne, 1971. Evans, Wenderoth & Cheng , 2000. Garner & Sutliff, 1974. Julesz, 1971. 1981. Koffka, 1935. Pomerantz, 1977. Quinlan, 2002. Tyler, 2002. Valentine, 1925. Wagemans, 1999. Wenderoth, 1994). In humans, however, it appears to be restricted to specific transformations in Euclidean two-dimensional space, such as transfer (transition symmetry), rotation (rotational symmetry) and mirroring (lateral or mirror symmetry), which we perceive mainly as repeats, rotations and reflections (Wagemans, 1997. Wyle, 1952).

Mirror (vertical axis) symmetry

Mirror (vertical axis) symmetry is the mirroring on a vertical y-axis on the points (x, y) for which f (x, y) = f (-x, y) is true (Mancini, Sally & Gurnsey, 2005. Tjan & Liu, 2005). The mirroring-reflection along a vertical axis is the type of symmetry, which is the most examined experimentally and it is considered the most important and easy to recognize for humans (Baylis & Driver, 1995. Beck, Pinsk & Kastner, 2005. Braitenberg, 1990. Deregowski, 1971. Enquist & Arak, 1994. Fisher & Fracasso, 1987. Fitts & Simon, 1952. Fitts & Simon, 1952. Fitts et al., 1956. Goldmeier, 1972. Grammer & Thornhill, 1994. Johnstone, 1994. Julesz, 1971. Kirkpatrick & Rosenthal, 1994 . Leyton, 1992. Masame, 1983. 1984. 1985. Munsinger & Forsman, 1966. Palmer & Hemenway, 1978. Pennisi, 1995. Szilagyi & Baird, 1977. Swaddle, 1999. Thomas, 1993. Thornhill, 1992. Thornhill & Gangestad , 1994. Tyler, 2002. Vetter, Poggio, & Bulthoff, 1994. Wagemans, 1995. 1997. Wenderoth, 1994). The mirrorings on the vertical axis are the easiest to identify (Mach effect), even when presented briefly for 10-160 ms (Barlow & Reeves, 1979. Carmody, Nodine & Locher, 1977. Corballis & Roldan, 1975. Julesz, 1981. Locher & Nodine, 1989. Palmer & Hemenway, 1978. Tyler, Hardage & Miller, 1995. Wagemans, van Gool & d'Ydewalle, 1992).

Our advantage to perceive mirrored points on the vertical axis directly and without conscious activation processes (such as attention) is evident compared to the reduced ability (reaction time) to detect repetitions or rotations (90o angles up to 180°) or mirror symmetry along other axes (horizontal or diagonal) (Carmody, Nodine & Locher, 1977. Corballis & Beale, 1976. Goldmeier, 1972. Herbert & Humphrey, 1996. Locher & Nodine, 1989. Locher & Wagemans, 1993. Mach, 1959. Rock & Leaman, 1963. Royer, 1981. Wagemans, 1997. Wenderoth, 1994. 1996. Zimmer, 1984). This preference for mirror (around vertical axis) symmetry is not confirmed by all researchers (Corballis, Miller & Morgan, 1971. Pothos & Ward, 2000). Finally, the preference for mirrored objects along y-axis appears to be true and for other primates, such as monkeys and it is associated with increased activation of the inferior (lower) temporal cortex (Rollenhagen & Olson, 2000).

Symmetry perception in infants and children

Symmetry perception in humans appears in infancy, and at the age of 4 months infants are able to distinguish the type of mirror symmetry around the vertical axis from other forms-types of symmetry (Baylis, 1998. Bornstein, Ferdinasen & Gross, 1981. Bornstein & Krinsky, 1985. Fisher et al., 1981. Humphrey & Humphrey 1989. Rhodes et al., 2002). The early occurring and potentially innate ability (Pinker, 1997) of familiarizing quickly with mirror symmetry along a vertical axis compared to horizontal symmetry or asymmetry is not accompanied by a preference for the vertical mirror symmetry (Fantz, Fagan & Miranda, 1975. Spears, 1964).

This preference appears interculturally after the age of 12 months (Bentley, 1977. Bornstein, Ferdinandsen & Gross, 1981. Boswell, 1976. Chipman & Mendelson, 1975. Deregowski, 1972. Paraskevopoulos, 1968). This could mean that although perception of vertical symmetry is innate or learned very early, the preference for this type of symmetry occurs later and is the product and/or relevant to previous experience (Bornstein, Ferdinandsen & Gross, 1981. Braine, 1978). The observed preference for symmetry in abstract designs in infants has not been fully confirmed for symmetrical human faces (Rhodes et al., 2002. Samuels et al., 1994).

Knowledge of school children and their performance in tasks examining visual symmetry varies in activities with different types and degrees of difficulty (Tuckey, 2005. Xistouri, 2007). The possibility of further familiarizing preschool and school age children with symmetry can be done either by encouraging the child to observe various objects, which are constructed based on symmetry (embroidery, ceramics, jewelry, etc.) (Hoyles & Healy, 1997. Tzekaki & Christodoulou, 2004) or by actual acts such as mirroring or folding (Knuchel, 2004. Seidel, 1998. Leikin, Berman & Zaslavsky, 2000. Servatius, 1997. Tzekaki, 1996).

Symmetry perception in the elderly

The only research that deals with age differences indicates that healthy young adults, middle-aged and older people recognize better mirror symmetry around a vertical axis, followed by recognition for horizontal and diagonal axis. But what differentiates young people (aged 19-39), middle aged (aged 40-60), young seniors (61-70) and older seniors (71-80) is the greater sensitivity (correct identification) of the first two groups over the last two, namely the elderly, for whom there is a statistically significant impaired performance (Herbert, Overbury, Singh & Faubert, 2002).

Symmetry and aesthetic judgments

Symmetry (with respect to different axes) is the major determining factor in aesthetic judgments (beauty), even in artificial two-dimensional objects (Eisenman, 1967. Eisenman & Gellens, 1968. Jacobsen & Hofel, 2001. 2002. 2003. Jacobsen, Schubotz, Hofel & van Cramon, 2006. Tinio & Leder, 2009). The complexity of the stimulus follows as predictor for judgments of beauty, but it is also influenced by the effect of familiarity with the stimuli (Tinio & Leder, 2009). The aesthetic preference for symmetry may be related to the easier and more effective processing of our cognitive-perceptual system for objects classified as symmetric (Reber, Schwarz & Wienkielman, 2004. Reber, Wienkielman & Schwarz, 1998).

Symmetry perception and other cognitive processes

Symmetry influences the separation of the object from the environment, and this happens because the symmetrical points of space tend to constitute a single object, while the non-symmetrical points are considered as background (Bahnsen, 1928. Driver & Baylis, 1992. Machilesen, Pauwels & Wagemans, 2009. Marshall & Halligan, 1994). Furthermore, judgments on the identity of ambiguous objects are influenced by symmetry perception in combination with other principles of morphological Gestalt theory (Hong & Pavel, 2002). Symmetry is therefore an important factor in the recognition process of three-dimensional objects (Herbert, Humphrey & Jolicoeur, 1994. Large, Macmullen & Hamm, 2003. Liu & Kersten, 2003. Pashler, 1990. Sekuler & Swimmer, 2000. Vetter & Poggio, 1994. Vetter, Poggio & Bultoff, 1994) and the recognition process of two-dimensional shapes (Dinnerstein & Wertheimer, 1957. Giaquinto, 2005. Marr & Nishihara, 1978. Palmer, 1985). Symmetry perception for objects that are symmetrical, apart from facilitating the identification process, it is also considered as a means of giving causal information to the observer (i.e. whether physical forces have been exerted on the objects in the past) (Leyton, 1992).

Symmetry is also contributing to the process of perception of the orientation of objects in space (Howard & Templeton, 1966. Szlyck, Rock & Fisher, 1995. Wagemans, 1993. Wilson, Wilkinson, Lin & Castillo, 2000. Wenderoth, 1997b), while the degree of easiness in detecting the symmetry axis of a shape tends to increase when the examined shape is enclosed by other shapes that have the same centerline direction (Palmer, 1985). It has also been suggested that symmetry perception can be done (and) independently of the perception of the orientation of objects. This means that we can recognize symmetrical objects regardless of their coordinates from us or from our past experiences with those objects from another perspective. This supports an object-centered approach to vision, rather than a viewer-centered approach (Enquist & Arak, 1994. Marr, 1982).

Symmetry perception requires a small amount of information, in the case of existence of couples of points near the symmetrical axis (vertical and/or horizontal) and not in the case of existence of corresponding symmetric couples of points in the rest of the two-dimensional surface area (Barlow & Reeves , 1979. Bruce & Morgan, 1975. Dakin & Herbert, 1998. Gurnsey, Herbert & Kenemy, 1998. Held & Richards, 1976. Jenkins, 1982. Julesz, 1971. Wenderoth, 1995. 2002).

Identifying symmetry is easiest when the axis of symmetry (usually vertical or horizontal) is in the center of the focus field of the observer (Barlow & Reeves, 1979. Locher & Nodine, 1989. Saarinen, 1988), thereby the automatic nature of symmetry varies when the stimulus is not in the center of our focus or when there are other disintegrating stimuli (Herbert, 2008. Saarinen, 1988). Of course, in some cases it may require an analysis-comparison of information, which may be placed in our broader visual field (Tyler & Hardage, 2002) and in particular near to the contours of objects (Barlow & Reeves, 1979. Carmody et al., 1977. Wenderoth , 1995. 2002). It is also confirmed by recording the eye movements of healthy individuals that there is a point-to-point procedure (non-automated process) or in other words comparison of points for complex visually presented stimuli (Herbert et al., 2006).

Generally, this lack of necessity for information for the entire visual area could be extended for the dimension of time. It seems that there is a variation in the ability to distinguish the orientation of the axes of symmetry when taking into account the time factor. Thus, for static presented visual stimuli (a stimulus per 853ms), compared to the same stimuli when presented dynamically (many different stimuli in sequential presentation for the same time-853ms), it appears that the second condition has an advantage – more correct responses by the participants (Niimi, Watanabe & Yokosava, 2008). It was also found that the observers' ability to perceive the existence of symmetry for the same stimulus (point group) remains unaffected even when given the parts of the image piece by piece and in a temporally asynchronous way (van der Vloed, Csatho & Van der Helm, 2007).

Symmetry is also very important for memory. Symmetrical objects have a better mnemonic encoding, recognition and recall (Attneave, 1955. Deregowski, 1972. Gibson, 1929. Kayaert & Wagemans, 2009. Stucchi et al., 2010). It is argued, however, that for the recognition of symmetry (for already known or new stimuli), we engage only short-term memory (by comparing the points of the stimulus) and not involving long-term memory (e.g., by activating old memories of similar stimuli and the indications that they were given as symmetric or non-symmetric) (Hogben, Julesz & Ross, 1976. Julesz, 1966). This contrasts with a survey (eight participants), which found that after training subjects, they respond faster (shorter reaction time) at the discretion of non-symmetrical than symmetrical stimuli (Leone et al., 2002).

The judgments of symmetry for 'easy' non-composite visual stimuli do not require the activation of attention (Barlow & Reeves, 1979. Locher & Wagemans, 1993. Wolfe & Friedman-Hill, 1992), but to identify more complex or elaborately designed symmetrical stimuli in space, greater involvement of the cognitive system is needed and the automatic nature of the processing is abolished (Barlow & Reeves, 1979. Foster, 1971. Royer, 1981. Wenderoth, 1997a).

People generally perceive the existence of symmetry even in non-symmetrical 'visual noise' (Barlow & Reeves, 1979. Dakin & Herbert, 1998. Rainville & Kingdom, 2002. Wagemans, van Gool, Swinnen, & van Horebeek, 1993). According to research data we tend to overestimate the high symmetry (symmetry effect), while we tend to underestimate the low symmetry (asymmetry effect) in natural stimuli (e.g. human faces which are never perfectly symmetrical, even though they are perceived as such), and in artificial visual stimuli (Carmody, Nodine & Locher, 1977. Freyd & Tversky, 1984. Garner, 1970. King, Meyer, Tangey & Biederman, 1976. McBeath, Schiano & Tversky, 1997). The overestimation/underestimation of the symmetry is affected by the ratio of symmetric to non-symmetric points given to stimuli (Csatho, van der Vloed & van der Helm, 2004).

People according to some surveys, generally detect small deviations from perfect symmetry (Gerbino & Zhang, 1991. Locher & Smets, 1992. Wagemans, van Gool, & d'Ydewalle, 1991. 1992. Wagemans, van Gool , Swinnen, & van Horebeek, 1993), but perhaps in line with other researchers judgments tend to be more sensitive to larger deviations from symmetry, and not in smaller ones, which raises questions about the just noticeable differences that our cognitive system can handle (Tjan & Liu, 2005). In any case the notion of symmetry is not of the "all or nothing" type. As examined in several studies it is a property of an object (when we judge it as symmetric or non-symmetric), but it can also be examined as a continuous trait (Masame, 1986. 1987. 1988. Zabrodsky & Algom, 2002).

The human perception of optical symmetry is different from the perception of colors, as color stimuli require extra attention investment and slowdown in reaction time (Morales & Pashler, 1999). Instead, it appears that the brightness of white and black spots over a gray background (and not the color) affect the ease of symmetry perception (Zhang & Gerbino, 1992).

Studies in animals

Apart from humans, studies demonstrate the ability of symmetrical visual stimuli perception in animals (which is true for dolphins, bees, pigeons and monkeys) (Anderson et al., 2005. Benard, Stach & Giurfa, 2006. Delius & Habers , 1978. Delius & Nowak, 1982. Giurfa, Eichmann & Menzl, 1996. Horridge, 1997. Lehrer, et al., 1995. Menne & Curio, 1978. Radesater & Halldorsdottir, 1993. Rensch, 1958. von Ferson, Manos, Goldowsky & Roitblat, 1992). The behavior of various animal species is affected by symmetry (Tyler, 1995), which plays a decisive role in choosing partners (e.g. preference for more mirror-like along the vertical axis, symmetrical faces and/or shapes on the bodies of other animals) (Fiske & Amundsen, 1997. Moller, 1992. Moller & Thornhill, 1998. Morris & Casey, 1998. Swaddle & Cuthill, 1994).

Symmetrical face perception in humans

Something similar to the preference of the more symmetrical faces and bodies in animals, holds true for humans (Berlyne, 1971. Cardenas & Harris, 2006. 2007. Grammer Fink, Juette, Ronzal & Thornhill, 2002. Grammer & Thornhill, 1994. Jacobsen & Hofel, 2002. Langlois & Roggman 1990. Little et al., 2001. Mealey et al., 1999. Penton-Voak et al., 2001. Perrett et al., 1999. Rhodes, Proffitt, Grady & Sumich, 1998 . Rhodes, Sumich & Byatt, 1999. Rhodes et al., 2001. Rhodes & Zebrowitz, 2002. Scheib, Gangestad & Thornhill, 1999. Thornhill & Gangestad, 1993. 1999. Tovee, Taske & Benson, 2000), but the preference for symmetrical faces is influenced by learning (Rentschler, Juttner, Unzicker & Landis, 1999. Washburn & Humphrey, 2001). Identifying symmetry in faces seems to happen more for normal photographs, rather than overturned, but this does not specify whether this ability is innate or perfectly learned (Rhodes et al., 2005). A neurally respective proposed region for the perception of symmetrical faces is OFA (occipital face area). The recognition of symmetry in any visual stimulus is linked to two other brain areas: MOG and IOS (middle occipital gyri and intraoccipital sulci) (Chen , Kao & Tyler, 2007).

Symmetry in pathological populations

Pathological presentation of mirroring letters occurs in children with dyslexia, who make systematic reversals of letters or syllables while writing (Kakouras & Maniadaki, 2005). Patients with frontal atrophy usually exhibit obsessions -verbal and visual- in the form of repeats (Bayles, Tomoeda & Kaszniak, 1985. Neary, Snowden, Northern & Goulding, 1988. Sandson & Albert, 1987) and patients with obsessive-compulsive disorder usually exhibit obsessions for symmetry of everyday objects (Hyman & Pedrick, 1999. Radomsky & Rachman, 2004). Patients who suffer from unilateral spatial neglect fail to indicate the middle of a straight line (the center of symmetry) (Martin, 1999), despite their intact ability to recognize symmetry axis for horizontal objects when they appear within the field they can perceive. They are also unable to recognize objects or vertical mirror reflections of real objects in the area of the visual field that they ignore (Driver, Baylis & Rafal, 1992. Priftis et al. 2003. Ramachandran, Altschuler & Hillyer, 1997).

Furthermore, patients with amblyopia (unilateral or bilateral decrease of the visual acuity caused by not using the eye during the neonatal period and infancy), make patients unable to understand the mirror symmetry (Levi & Saarinen, 2004), a similar difficulty occurs in patients with retinitis pigmentosa (namely progressive retinal degeneration) (Szleike, Seiple & Xie, 1995). Finally, people who use LSD or other hallucinogenic drugs or who suffer from seizures indicate strongly symmetrical hallucinations (Ermentrout & Cowan, 1979. Siegel, 1976).

Physiological background

The proposed neural basis for the perception of visually symmetrical stimuli initially involved the activation of area V1, which is sensitive to the detection of the orientation of a stimulus (Lee et al., 1995. 1998). Recent studies suggest increased activation in the extrastriate area of the visual cortex (Sasaki et al., 2005. Van der Zwan et al., 1998). The activation of the visual cortex only, and not other brain areas, should rather be interpreted as evidence that symmetry perception follows bottom-up processing (Sasaki et al., 2005). This is found using fMRI imaging in humans (activation of cortical areas V3A, V4, V7 and lateral occipital areas-LOC), and monkeys (Macaca mulatta, showing a much weaker activation compared to human areas V3A, V4 , V7 and TEO) (Sasaki et al., 2005. Tyler et al., 2005).

In this experiment the superiority of mirror symmetry perception to the vertical axis is confirmed, when symmetrical dots were presented on the horizontal axis (symmetry of the upper and lower half of the image), somewhat less activation appeared, compared to symmetrical dots along the vertical axis (left-right symmetry half of the image) (Rollenhagen & Olson, 2000). Also, this experiment reaffirms the preference for mirror symmetry compared to repetition-transfer (Bruce & Morgan, 1975. Corballis & Roldan, 1974).

A possible analogy of the previous monkey brain areas with similar centers in the human cortex could help elucidate the neural substrate associated with the concept of symmetry (Beck, Pinsk & Kastner, 2005). Of course, although it appears that the area V3A to be identical in humans and monkeys (Tootell et al., 1997), there is disagreement as to whether the other areas can be considered homologous or not (Kastner et al., 2001.Wade et al ., 2002). Another area proposed as relevant for the perception of symmetry is the central parietal region, which is located in front of the occipital lobe, and could be regarded as a topological extension (Croise et al., 2004. Jacobsen et al., 2006).

Models of symmetry perception

Despite the existence of many theoretical proposals for the mechanism of symmetry perception, so far there is no commonly accepted theory explaining the way that the visual system detects and responds to symmetric designs (Swaddle, 1999. Tyler, Hardage & Miller, 1995).

Some researchers suggest a general mechanism for identifying and coding of visual symmetry, which runs parallel for all objects of the visual field, while others reject this position and suggest serial comparison processing (Dakin & Herbert, 1998. Dakin & Watt, 1994. Huang, Pashler & Junge, 2004. Jenkins, 1982. Palmer & Hemenway, 1978).

The most popular model is the two-stage model, which argues that when observers are asked to distinguish a symmetrical pattern from a random pattern, then a rough analysis (which does not engage attention) occurs. But when subjects are asked to make more specific judgments (e.g. to distinguish perfect symmetries from symmetries characterized as slightly disturbed), then they activate processes of attention for "one-to-one" matching of points or point groups (Dakin & Hess, 1997. Gurnsey, Herbert & Kenemy, 1998. Palmer & Hemenway, 1978. Rainville & Kingdom, 2000. Royer, 1981. Tapiovaara, 1990. van der Helm & Leeuwenberg, 1996).

Currently there are five approach groups for the investigation of symmetry (Treder, 2010):

1) The Representational Models, which deal with the structures and relationships of the parts of the stimulus. They are based on mathematics and divided into two groups: the transformational approach (TA) and the holographic approach (HA). The first examines symmetries as geometric transformations (transposition, rotation and reflection) of point groups for which there is an inherent tension for preference and better processing (Garner, 1974. Palmer, 1983), while the second approach (holographic) stresses the importance of points towards the sets of points for symmetry perception (van der Helm & Leeuwenberg, 1996. 1999).

2) The Process Models try to identify the processing steps to be taken in the optical input to allow the representation of symmetry, indicating a point-to-point examination of the stimulus (Jenkins, 1983. Wagemans et al. , 1993). Similar models have been proposed, which suggest dividing the space into smaller cells that contain individual dots (as in Voronoi diagrams) (Barlow & Reeves, 1979. Dry, 2008).

3) Due to lack of experimental data on Neural Models, there is no satisfactory biological approach. Nevertheless, the importance of vertical symmetry is naively suggested that may arise from the vertically symmetrical organization-architecture of the visual cortex (Mach, 1950. Julesz, 1971), but this does not explain the success in recognition of other forms of symmetry around different axes. In addition to the above, there are two types of hybrid models that draw elements from the procedural models and neural models.

4) The Spatial Filtering Models are essentially procedural models, but whose proposed hypothetical neural processes are possible, which means that it is likely to occur at the biological level (Dakin & Watt, 1994. Gurnsey, Herbert & Kenemy, 1998. Poirer & Wilson, 2010).

5) Finally, models of Artificial Neural Network Models come from the field of computing. The ANN suggest that the preference of different species for symmetry and the automation of its localization is a by-product of the image recognition process (Enquist & Arak, 1994. Osorio, 1996). According to them the acquired-learned symmetry recognition is due to early experience with objects that are oriented in the vertical or horizontal axis (Latimer, Joung & Stevens, 1994).

The architecture of these networks is the classic one, i.e. elementary processing units in the network (computational nodes-neurons) which interact with each other at synapses, having specific synaptic weights. These systems after a training phase with visual stimuli, learn to identify symmetries. Besides the use of neural networks in the IT field, research aims at the identification of symmetry with the use of algorithms, which involve the processing of specific information, such as the outlines of the shapes or sets of points (Atallah, 1985. Bowns & Morgan, 1993. Burton, Kollias & Alexandridis, 1984. Parry-Barwick & Bowyer, 1993. Sun, 1995. Marola, 1989. Wolter, Woo & Volz, 1985. Yen & Chan, 1994). Certainly, researchers that follow this approach for the study of symmetry do not have the same objective as the experimental psychological research, as they aim to create systems that will successfully detect symmetry, without care about finding and simulating the actual processes of human perception (Latimer, Joung & Stevens, 1994).

Methodological considerations

It should be noted that despite the extensive literature on the study of visual perception of symmetry, the reported research methodologies vary greatly. As a result, it is almost impossible to compare them as they involve different animal species and for research on humans there are only small samples of participants in the published articles, the age of whom varies mainly in the range of 18-30. There are also methodological differences in the way and time of presentation of the stimuli. Some researchers use human faces (Tjan & Liu, 2005), others use symmetric patterns with dots inside non-symmetrical groups of dots (Barlow & Reeves, 1979) and others study geometric shapes (Freyd & Tversky, 1984) in two-dimensional or three-dimensional space. Still the fact that surveys are cross-sectional and not longitudinal is a potential methodological drawback, as we do not have a full picture of the visual and acoustic development on the concept of symmetry. Finally, there is limited or non-existent theoretical and research literature on auditory perception of symmetry transformations in music, which are similar to the visual transformations. This lack of research on acoustic symmetry perception deprives us the chance of conducting a complete comparative analysis, by applying the three basic geometric transformations to both senses.

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