The Study of Symmetry in Empirical Aesthetics

Marco Bertamini and Giulia Rampone

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Abstract and Keywords

Symmetry has attracted interest from many scholars, scientists, and artists over the centuries. It has been described as a key principle of aesthetics as well as a factor in perception of shape. We critically review the empirical evidence regarding the link between symmetry and aesthetics, between symmetry and beauty/attractiveness, and between symmetry and affect, and discuss possible mechanisms. We show that, although symmetry entails regularity and redundancy, there is no clear and strong link between beauty and simplicity. Also, although symmetry influences aesthetic judgments, it is difficult to isolate a neural correlate of this link, suggesting that spontaneous aesthetic responses to symmetry are not elicited in the brain unless people are explicitly processing symmetry aesthetically. Finally, we show that preference for symmetry lies on a continuum from a universal tendency to prefer symmetry to obsessive need for order and balance.

Keywords: Symmetry, mirror symmetry, reflection, aesthetics, beauty, affect

Symmetry has a central role in many fields. It has been studied formally in mathematics, but we can see its application also in art, religion, and ornamentation. Early thinkers, like Plato, were fascinated by symmetry. Although he did not discover what we now know as Platonic solids, he based a whole philosophy on them in the treatise *Timaeus*. There are five Platonic solids, which are polyhedra constructed by a set of identical polygonal faces: tetrahedron, cube, octahedron, dodecahedron, and icosahedron. Alternatively, using more than one type of face one can generate the 13 Archimedean solids (like the truncated icosahedron of a typical football with white hexagons and black pentagons). Aristotle also mentions symmetry as a form of beauty in his *Metaphisica*. The fascination continued through the centuries. Since the 19th century the treatment of symmetry has been based on *group theory* in physics and mathematics, and the underlying symmetry transformations can be thought of as operations. Based on this analysis we can then find, for example, that the icosahedron has 120 symmetries.

Our discussion will focus on patterns in two dimensions. Within the Euclidean plane there are four types of rigid transformations that preserve metric properties: translations, rotations, reflections, and glide reflections. These transformations form a symmetry group. For example, the human face is an example of reflection, and the pattern of footprints in the sand is a glide reflection, a combination of a reflection and a translation (Figure 1). For patterns that repeat along one dimension there are seven types (known as frieze patterns) and for patterns extending over two dimensions there are 17 types (known as wallpaper patterns) (Grünbaum & Shephard, 1987).

Why is symmetry so interesting to so many people? Mathematicians, such as Hermann Weyl, have noted the close link between symmetry and beauty ("Beauty is bound up with symmetry," Weyl, 1952, p. 1), and more recently Ian Stewart has titled a book *Why Beauty Is Truth: The History of Symmetry* (Stewart, 2007) (words taken from a poem by Keats). Symmetry can be seen as a form of research strategy used by modern physicists (Zee, 2007). Biologists have also expressed great interest in symmetry. For instance, Darwin mentions symmetry specifically as a type of ornament in sexual selection (Darwin, 1882). In terms of artists, we could mention the fascination of M. C. Escher with the Moorish architecture of the Alhambra in Granada, and in particular with its mosaic patterns (Figure 1). In 1936 Escher traveled to Spain and he spent days making detailed drawings of the patterns and tessellations, which then figured in his own work.

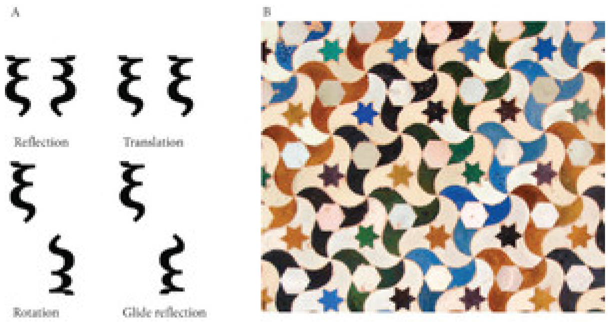

Figure 1. (A) The four rigid transformations in the Euclidian plane. (B) A digitally enhanced pattern from Alhambra. This is one type of wallpaper pattern, and its formal code is p3 because it has three different rotations of order three (120°), but no reflections or glide reflections.

Studies of symmetry perception have confirmed that symmetry can be detected quickly and efficiently (Barlow & Reeves, 1979; Julesz, 1971), and influences the salience of a pattern (Mach, 1886; Wenderoth, 1994), speed of responses (Bertamini, Friedenberg, & Kubovy, 1997; Royer, 1981), eye movement exploratory behavior (Locher & Nodine, 1987), and arousal as measured by skin conductance changes (Krupinski & Locher, 1988). For reviews, see Wagemans (1995), Treder (2010), or Bertamini and Makin (2014). In the case of Locher and Nodine (1987) and Krupinski and Locher (1988), the stimuli used were abstract paintings manipulated to add symmetry. With respect to memory, people tend to reproduce symmetric shapes more accurately and to make shapes more symmetrical than the original (Attneave, 1955; Perkins, 1932). Symmetric shapes appear also as more familiar (Brodeur, Chauret, Dion-Lessard, & Lepage, 2011). In summary, it is well established that symmetry is salient and can be detected efficiently by humans and other animals. Neurophysiological studies have also found strong and widespread activation in visual regions in response to presentation of symmetric patterns (for a review, see Bertamini, Silvanto, Norcia, Makin, & Wagemans, 2018).

Symmetry in Visual Arts

Scruton (2009) distinguished four types of beauty: human beauty (attractiveness), natural beauty, everyday beauty, and artistic beauty. We can find examples of symmetry for each of these categories, in the human body, in flowers, in architecture and design, and in recognized traditional and modern artworks. In the case of visual art, the role of symmetry is widespread, and we can find examples across the centuries and in all cultures (Arnheim, 1974; Deregowski, 1972; Washburn & Crowe, 1988).

A famous example of an explicit attempt to incorporate balance and symmetry is Leonardo da Vinci's *Vitruvian Man* (c.1490). It illustrates how human proportions are captured by simple geometrical forms, in particular a circle and a square. Da Vinci is elaborating the ideas of Marcus Vitruvius Pollio, a Roman author and architect from the 1st century BCE. In his book *De architectura* he discusses how important proportions that must guide architecture (in the broad sense) come from the human body. For example, with arms and legs outstretched the body can be placed inside a square and a circle and the navel is the center. Because da Vinci had familiarity with anatomy, in his drawing the arms are raised just as high as the top of the head and the navel is at the center of the circle, but not the square. He also deliberately chose a posture that was not perfectly symmetric, with the feet for example pointing in different directions. This shows that although symmetry can be found in the human body, one can overstate the regularity of the human proportions. It also shows that often artists contrast an overall symmetry with local deviations from regularity. The key proposal in *De architectura*, however, is that what we find pleasing derives from aspects of our physical body (Figure 2).

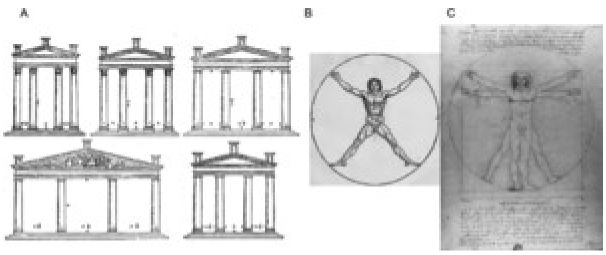

Figure 2. (A) The five types of temples listed by Vitruvius, in which spacing between columns is given as multiples of column width. (B) The body of a man inside a circle. These illustrations come from a translation of *De architectura* published in Venice in 1590. (B) Leonardo's *Vitruvian Man* (circa 1490), which is anatomically more accurate.

In addition to da Vinci, other Renaissance artists were fascinated by and wrote about symmetry. Albrecht Dürer included an acute rhombohedron (truncated on its axis of symmetry) in *Melancolia I* (1514) (Ritterbush, 1983), but also wrote a book on *Symmetry of the Human Body* (published posthumously in 1532).

Many authors have pointed out that we should not confine the study of preference for symmetry to established art forms. As noted by Gombrich (1979) humans like to surround themselves with symmetric objects and patterns. It is interesting that the two major figures in psychology of art of the 20th century, Gombrich and Arnheim, published books that, for all their differences, refer indirectly to symmetry in the title: *The Sense of Order* (Gombrich, 1979) and *The Power of the Centre* (Arnheim, 1982).

Symmetry and Complexity

It is necessary to consider symmetry together with complexity. This issue is central to work of early theoretical discussions in Birkhoff (1884–1944) and in the writing of Berlyne (1960). Birkhoff (1884–1944) was an American mathematician who developed a keen interest in aesthetics. He discussed the role of order, unity, or harmony and suggested that beauty is a direct function of order but decreases with complexity. Symmetry was part of what he referred to as order. He created a set of abstract stimuli and we show two examples in Figure 3. These are #1 and #90 in the series (Birkhoff, 1933). These stimuli were later employed in many studies by other researchers with mixed results. For example, Eysenck (1941) noted that some observers preferred simpler shapes and other preferred the more complex shapes.

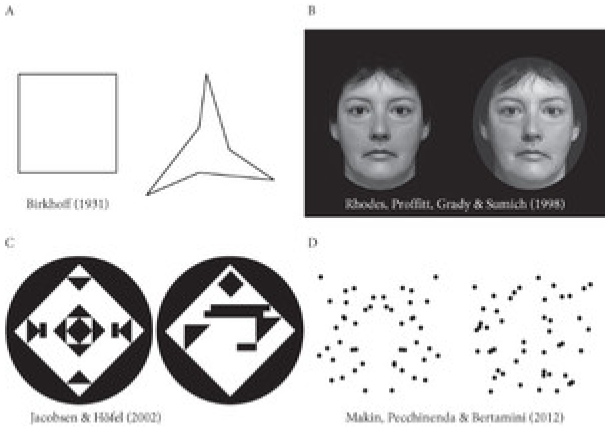

Figure 3. Example of stimuli used in studies of preference for symmetry. (A) These are two examples from a set of 90 created by Birkhoff (1933). They vary in order and complexity (as defined by Birkhoff). The one on the left has high order and low complexity, and the opposite for the example on the right (they are the first and the last in the original set of 90). (B) Faces manipulated so that the one on the left has perfect symmetry (courtesy of Gillan Rhodes; see Rhodes et al., 1998). The focus of this work was on perceived beauty and attractiveness. (C) Abstract patterns used by Jacobsen and Höfel (2002), symmetry and asymmetry. (D) Abstract patterns used by Makin, Wilton, Pecchinenda, and Bertamini (2012), bilateral symmetry and asymmetry.

Berlyne (1960) defined visual complexity in terms of three dimensions: the number of elements, their dissimilarity, and the regularity or irregularity of their arrangement. The presence of symmetry affects the level of objective as well as perceived complexity, something notoriously hard to quantify (Donderi, 2006). One can say that the number of nonredundant elements is reduced. For example, for bilateral symmetry one half of the configuration and a coding of symmetry are sufficient to describe the whole pattern. Various studies have noted how symmetry plays a role in perceived complexity of patterns (e.g., Berlyne, Ogilvie, & Parham, 1968; Chipman, 1977). In perception, the role of the number of transformations that generate a pattern of dots has been shown to predict the subjective "goodness" of that pattern (Garner, 1970). A different approach not based on transformations comes from structural information theory of perception (Leeuwenberg & van der Helm, 2013). Other authors, like Schmidhuber (1997), have claimed that art is based on minimal algorithmic complexity (Kolmogorov complexity).

The concept of symmetry is also closely linked to that of balance. This terminology has a long tradition, and a theoretical discussion can be found in Arnheim's book *The Power of the Centre* (Arnheim, 1982). Arnheim focuses on composition, and the fact that there is always a balance between centric and eccentric forces. This allows Arnheim to break away from a rigid interpretation of order, although it does not provide formal measures that can be used empirically.

Early Experimental Work

Fechner cites symmetry ("symmetrie") approximately 50 times in his book (Fechner, 1876). He uses it as a clear example of visual preference, mentioning the kaleidoscope and the human body as examples. He also lists symmetry together with the golden section as examples of forms that we find pleasant independently from any learned association.

Eisenman (1967) and Eisenman and Rappaport (1967) used abstract shapes and asked participants to select the preferred ones. The stimuli in both studies were the same and included nine asymmetric and three symmetric polygons. The symmetric stimuli were taken from the set introduced by Birkhoff (1933). Eisenman concluded that there was a clear tendency to select symmetric shapes as preferred. Combined with the finding that complex shapes were never selected, this was seen as evidence against a preference for complexity, although only the preference for symmetry was replicated by Eisenman and Gillens (1968). In addition, the paper also suggests that there are individual differences and more creative people may prefer asymmetry to symmetry (see also Eysenck & Castle, 1970).

Eysenck developed a model that differed from Birkhoff's, and tried to support this empirically. He concluded that although order (including symmetry) was a key factor for visual preference, complexity was likely to contribute, and the two factors would interact in a multiplicative way (Eysenck, 1968). Eysenck was also a pioneer of cross-cultural studies of aesthetics. Two studies compared British and Egyptian samples using some Birkhoff stimuli. Symmetry had a similar influence in both cultures. This comparison has recently been replicated by Bode, Helmy, and Bertamini (2017) using abstract stimuli made with black-and-white matrices (see also Makin, Helmy, & Bertamini, 2017).

Preference for symmetry using abstract shapes (polygons) was confirmed by the experiments carried out by Munsinger and Kessen (1964). They concluded that symmetry contributed to preference because it reduced complexity and increased meaningfulness (something observers also rated).

We have already mentioned that Locher and Nodine (1987) and Krupinski and Locher (1988) used paintings manipulated to be more or less symmetric and measured eye movements and skin conductance. It is interesting that hedonic value was in their case reduced by symmetry. This is likely to be a result specific to these stimuli, and the fact that the symmetry was artificial and a deviation from what the artists had created. With respect to type of stimuli, in addition to abstract patterns and artworks, one study tested dynamic configurations (Wright & Bertamini, 2015). These dynamic stimuli were created as symmetric or random configurations of lines. Each line had a local rotation, and the configuration underwent a global transformation: translation, rotation, expansion, horizontal shear. Results confirmed a preference for dynamic symmetric patterns. Expansion was the preferred global dynamic transformation, and shear was the most disliked.

Finally, it is interesting to note that infants as young as 4 months old can discriminate symmetry (Humphrey and Humphrey, 1989), but there is no clear evidence of actual preference for the more symmetric patterns (Bornstein, Ferdinandsen, & Gross, 1981) or faces (Rhodes, Geddes, Jeffery, Dziurawiec, & Clark, 2002) at this age. Recently, Huang, Xue, Spelke, Huang, Zheng, and Peng (2018) have drawn explicit attention to this dissociation between perception and preference for symmetry in infants. Preschool children, when they start to draw, often use symmetry in their drawings, especially rotational symmetry for flowers (Villarroel, Merino, & Antón, 2019).

More Recent Studies and Models

Fechner (1876) had introduced three methods: choice, use, and production. Although production has not been employed as much as the others it can be very informative. Westphal-Fitch, Oh, and Fitch (2013) gave participants an open-ended production task and a computer interface that constrained the generation of rectangles or complex patterns. They concluded that framing and local symmetries affected what people produce.

New techniques to study preference have also been developed. For example, Makin, Bertamini, Jones, Holmes, & Zanker (2016) used a gaze-driven evolutionary algorithm technique. An eye-tracker identified patterns (phenotypes) that were good at attracting and retaining the gaze of the observer. Resulting fitness scores determined the parameters (genotypes) used to create the next generation of patterns. This procedure tests whether people automatically evaluate symmetry without explicit instruction. When participants looked for symmetry, there was an increase in genes coding for symmetry. When participants looked for the patterns they preferred, there was a smaller increase in symmetry, indicating that people tolerated some imperfection. There was no increase in symmetry during free viewing.

In Leder et al.'s model of visual aesthetic judgment, symmetry is placed among other factors within the early perception analysis stage (Leder, Belke, Oeberst, & Augustin, 2004; see also Leder & Nadal, 2014). In this sense this formal aspect of the stimulus comes before later processing of factors like familiarity, prototypicality, and semantics. A large body of work has focused on symmetry and attractiveness, including the relationship between symmetry and prototypicality. This will be discussed in the following section.

If we look at ornamentation in different cultures, it is easy to find many examples of the use of symmetry (Brain, 1979; Gröning, 2002). This could be a strategy to signal biological fitness. Cárdenas and Harris (2006) tested the rating of attractiveness of human faces and added decorations that varied in symmetry. The addition of symmetric designs to asymmetric faces increased their attractiveness, and conversely the addition of asymmetric designs to symmetric faces decreased attractiveness.

Tinio and Leder (2009) studied the influence of familiarization on preference for symmetry and complexity. They found that massive familiarization generated contrast effects for complexity: participants familiarized with simple stimuli judged complex stimuli more beautiful and vice versa. This contrast effect was not present for symmetry, which appears to be more stable.

In an influential paper, Ramachandran and Hirstein (1999) claimed that artists deploy certain rules or principles to titillate the visual areas of the brain. One of these principles is symmetry. The argument relies on the evolutionary logic mentioned later, but they expand the idea. Symmetry, as a property of living organisms, is an early-warning system and grabs attention to facilitate further processing. It is therefore useful because it is geared toward discovering interesting object-like entities in the environment. Given these premises they say that “it is hardly surprising that we have a built-in aesthetic preference for symmetry” (p. 27).

Of the eight laws of aesthetic experience listed by Ramachandran and Hirstein (1999), in addition to symmetry there is a phenomenon known as “peak shift.” This is relevant as one can argue that it applies to symmetry preference. In animal learning, after training with a stimulus, an animal may respond more strongly to the exaggerated version of the training stimulus. For example, if an animal is trained to choose a rectangle over a square the response may be stronger for rectangles that are more elongated than the stimulus used at training. In a study by Jansson, Forkman, and Enquist (2002) chickens were rewarded with two slightly asymmetric crosses that were mirror images of each other. After training, the animals preferred a novel symmetric cross to the asymmetric training stimuli. That is, the preferred stimulus was not the one that they had been rewarded with, but one that was novel but symmetric. The authors conclude that preference for symmetry arises as a consequence of generalization and without any link to quality of the signal.

Hypothesis About Why Symmetry is Linked to Beauty

One popular theory about symmetry and preference is based on an evolutionary hypothesis. During development organisms will deviate from symmetry when they are affected by genetic and environmental stresses. This process produces fluctuating asymmetry, and the degree of asymmetry is a proxy for quality of an individual and, in particular, quality of a mate (Watson & Thornhill, 1994). This role of symmetry in perceived attractiveness is supported by evidence that symmetry in faces and bodies affects preference (Bertamini, Byrne, & Bennett, 2013; Little & Jones, 2003; Little, Jones, & DeBruine, 2011; Perrett, Burt, Penton-Voak, Lee, Rowland, & Edwards, 1999; Rhodes, Proffitt, Grady, & Sumich, 1998), and symmetry as a factor in mating has been documented in many species. Møller and Thornhill (1998) conducted a meta-analysis on data from 42 species and concluded that there is a moderate significant negative relationship between fluctuation asymmetry and mating success.

Although testing symmetry separated from averageness is difficult, Rhodes, Sumich, and Byat (1999) confirmed that symmetric faces are attractive by statistically controlling for averageness. Jones et al. (2001) report evidence in support of the hypothesis that symmetry is a signal of genetic fitness. They found that attractiveness is mediated by a link between judgments of facial symmetry and of apparent health. The literature on attractiveness is vast and we cannot provide an exhaustive review here. We will just mention one last recent paper (Lewis, 2017) because it has demonstrated preference for symmetry in faces under naturalistic conditions (three-dimensional faces presented under rotation and with asymmetric lighting).

However, there is evidence that symmetry is preferred even when it does not serve any biologically relevant function, and as we have seen many studies have used abstract patterns (Eisenman, 1967; Humphrey, 1997). Even in animal work, mating is not the only factor. For example, bees are attracted to flower-like symmetric patterns (Lehrer, Horridge, Zhang, & Gadagkar, 1995; Rodríguez, Gumbert, Hempel de Ibarra, Kunze, & Giurfa, 2004) and chicks prefer symmetric seeds (Clara, Regolin, & Vallortigara, 2007).

As an alternative view, preference for symmetry may be a byproduct of general properties of the sensory networks (Enquist & Johnstone, 1997; Jansson, Forkman, & Enquist, 2002), and the process of object recognition that needs to be robust to position and orientation changes (Enquist & Arak, 1994). It has been shown that trained networks prefer symmetric patterns because these patterns are close to the average of the training patterns, whether symmetry was present or not in the training set (Johnstone, 1994). This can explain the tuning of the visual system to symmetry but in itself it does not explain preference. To explain preference, one needs to assume that what is processed efficiently is also liked. This link has been made explicitly by various authors (Cavanagh, 2005; Latto, 1995; Zeki, 1999). In Latto's definition an aesthetic primitive is "intrinsically interesting, even in the absence of narrative meaning, because it resonates with the mechanisms of the visual system processing it" (Latto, 1995, p. 68). In this respect, symmetry lends itself as the ideal example of an aesthetic primitive. Other authors have developed the idea of a link between aesthetics and efficient coding by the brain (Redies, 2008).

Another hypothesis, also related to the existence of a tuning of the visual system to symmetry but more indirectly, is known as the fluency hypothesis. Fluency is the subjective ease with which a stimulus is processed. It has been proposed that fluent processing has a positive hedonic value, and that the fluent processing of symmetry directly produces a positive response (Reber, Schwartz, & Winkielman, 2004; Winkielman & Cacioppo, 2001). One possibility is that preference for symmetry is a form of affective misattribution due to the ease of processing symmetric objects (Pecchinenda, Bertamini, Makin, & Ruta, 2014).

It should be stressed that these hypotheses are not exclusive, and that they all capture some aspect of the phenomenon.

Evidence That Symmetry is Not Always Preferred to Asymmetry

Some authors have criticized the simplistic assumption that symmetry is always linked to beauty. For example, McManus (2005) has argued that there is always a tension between symmetry and asymmetry.

Although the examples of symmetry in art are widespread, it has been pointed out that symmetry is more important in Western culture than for instance in Japanese culture, which values asymmetry and irregularity (*fukinsei*) (Zeki, 2013).

Despite the many claims about the fundamental role of symmetry in aesthetics, the evidence provides some important qualifications. As a category, there is evidence that symmetry is linked with positive valence, as evidenced for instance by the implicit association test (IAT) (Bertamini, Makin, & Rampone, 2013; Makin, Pecchinenda, & Bertamini, 2012; Mastandrea, Bartoli & Carrus, 2011). The IAT measures the strength of association between the category symmetry (represented by abstract patterns) and the category positive valence (represented by words). The strength of this association can be taken as an indirect, and implicit, measure of preference. However, preference measured by IAT does not always match the preference expressed explicitly, in particular in the case of rotational symmetry (Makin, Pecchinenda, & Bertamini, 2012). Bertamini, Makin, and Rampone (2013) confirmed an implicit association between symmetry and positive valence; in addition symmetry was associated with arousal, and with simplicity.

Although these implicit measures are interesting and confirm that people tend to think of symmetry in positive terms, they do not test the idea of a direct positive experience as a result of processing of symmetry. A more direct test of fast affective responses is provided by affective priming. Bertamini, Makin, and Pecchinenda (2013) report a series of experiments in which abstract symmetry was used as a prime, following by words that could have positive or negative valence. Here the evidence is that there is no automatic priming by symmetry of positive words. However, priming can take place under some conditions, in particular when the symmetry category is processed (Bertamini, Makin, & Pecchinenda, 2013).

Pecchinenda et al. (2014) used a priming task that involved reading the target words aloud, and they measured voice onset latency. When the word is read, this response is unique to each target. This has the advantage of avoiding Stroop-like mechanism interference at the response stage. There were faster vocal responses to positive target words preceded by symmetric patterns. In their final experiment, they used the affect misattribution procedure (AMP). The AMP is a variant of the affective priming paradigm in which symmetric and random patterns are presented incidentally, and the targets are unfamiliar and neutral. Results showed that the positive affect elicited by the brief presentation of symmetry (75 ms) was (mis)attributed to the targets (Chinese pictograms).

In the context of the link between symmetry and attractiveness, the evidence is not entirely univocal (see Rhodes, 2006, for discussion and evaluation). For humans and other animals, attractiveness is not always associated with symmetry. In particular there is mixed evidence for a role of symmetry in animal mating strategies (e.g., Dufour & Weatherhead, 1998; Palmer, 1996). With respect to facial attractiveness, some studies found evidence of reduced attractiveness for perfect symmetry, for example using computer generated faces (Zaidel & Deblieck, 2007). Scheib, Gangestad, and Thornhill (1999) and also Zaidel and Hessamian (2010) tested attractiveness of faces when only half of the face was visible. They found that images of half faces were rated as beautiful as the full faces.

Because symmetry is a nonaccidental property, it is associated with the presence of an object (Bertamini, 2010; Tyler, 1995). As we have seen symmetry is preferred across a range of different objects, familiar and abstract. In a recent study, Bertamini, Rampone, Makin, and Jessop (2019) interleaved male faces, female faces, polygons, smoothed versions of the polygons, flowers, and landscapes. For each category there were symmetric and asymmetric stimuli. Participants expressed a rating of beauty and also rated the salience of symmetry (in a separate block of trials). Landscapes that were artificially made to appear symmetric were liked less than the original landscapes, suggesting that symmetry is expected to belong to individual objects and not to scenes.

A recent study (Leder et al., 2019) investigated another factor: the role of art expertise on evaluations of beauty of patterns with different degrees of symmetry and complexity. Unlike the nonart experts, art experts (artists and art-historians) preferred simple and asymmetric shapes. This preliminary evidence suggests that we should update the view of a universal preference for symmetry by recognizing some mitigating factors (e.g. context, culture, personality traits, expertise). We should, however, make a distinction between explicit rating of preference and more indirect measures. Weichselbaum, Leder, & Ansorge (2018) found that art expertise did not alter the preference for symmetric over asymmetric patterns when measured with the IAT.

Moreover, in the study by Bertamini et al. (2019), within the category where symmetry was liked less than asymmetry (landscapes), the analysis of the modified stimuli (half of the total stimuli) showed that salience of symmetry was nevertheless correlated positively with preference.

In summary, in this section we have listed some examples of the literature that provide important counterexamples to a simple equation between symmetry and aesthetic beauty; for example, in different cultures, between symmetry and positive affect, depending on the measure of positive affect used, and between symmetry and attractiveness.

Neurophysiological Evidence

As we have seen a fundamental aspect of symmetry is its role in vision. There is agreement that a brain network in ventral extrastriate visual regions of the occipital cortex (but not of the primary visual areas) is tuned to symmetry (for a review, see Bertamini et al., 2018). Functional magnetic resonance imaging (fMRI) work has identified enhanced activation in these areas (Sasaki, Vanduffel, Knutsen, Tyler, & Tootell, 2005; Tyler et al., 2005), and electroencephalogram (EEG) work has showed negative deflection (e.g., Makin, Wilton, Pecchinenda & Bertamini, 2012) for symmetric configurations, compared with random. One question is whether this symmetry-related activation plays any role in determining the affective status of symmetry, and whether this role can be identified at the neural level.

Neural correlates of the link between symmetry and beauty were first explored by Jacobsen and Höfel (2001, 2002, 2003; see also Höfel & Jacobsen, 2003). The authors measured event-related potentials (ERPs) and aimed to identify indexes of judgments of beauty using abstract patterns that contained either symmetry (*beautiful* judgment-driving factor) or random configuration (*not beautiful* judgment-driving factor). They measured ERPs to the stimuli in descriptive (i.e., report whether the stimulus is symmetric or not) versus aesthetic evaluative judgments (i.e., rate how much you like the stimulus) in a trial-by-trial cueing task design, using binary responses (beautiful, not beautiful; symmetric, not symmetric). While early perceptual components (P1, N1) were present in all conditions, indicating visual processing of the stimulus, the two judgment types gave different later ERP responses. Evaluative judgments tasks led to early frontal negative deflection (Fz, 300–400 ms) for stimuli judged as *not beautiful*, and right lateralized late positivity (C4, 440–880 ms) in the evaluative task compared with the symmetry judgment task. Importantly, a response to symmetry vs. random was only evident in the symmetry categorization task, as a sustained negative deflection over parieto-occipital areas. This sustained visual analysis did not occur under the aesthetic judgment task. However, Jacobsen, Klein, and Löw, (2018) re-analyzed these data using different analysis parameters and showed an enhanced negativity to the symmetric stimuli also during evaluative aesthetic judgments. An fMRI study (Jacobsen, Schubotz, Höfel, & Cramon, 2006) provided similar results. Symmetry judgments triggered activation of regions related to visuospatial analysis, while aesthetic judgments elicited activation within fronto-temporal regions (although *beautiful*-judged stimuli elicited higher activation in both areas involved in aesthetic judgments (fronto-median) and areas involved in symmetry judgment (left intraparietal sulcus).

The dissociation, both in time (different response latency) and space (different neural generators), between the two types of tasks suggests aesthetic judgment of beauty may not originate from the mere processing of symmetry, despite the fact that both symmetry discrimination and aesthetic evaluation relied on the same stimulus feature. The same stimulus can be processed differently depending on the type of task.

In an original design, Höfel and Jacobsen (2007a) looked at the effect of misreporting a judgment (i.e., saying “no” to respond “yes”). Both true and false judgments triggered the earlier fronto-central negativity for *actual* not-beautiful patterns, while the right lateralization of the late positivity amplitude was cancelled when false judgments were made. The posterior sustained negativity for symmetry was not affected by the validity of the responses. The same authors (Höfel & Jacobsen, 2007b) then explored the role of performing an active judgment, as opposed to engaging in mere contemplation, on these ERP responses. Participants performed either an *aesthetic contemplation* or a *mere viewing* task. In both cases they did not make any explicit judgment. In both tasks there was no fronto-central ERP deflection, and the late positive potential was only present during the contemplation task. The sustained posterior negative ERP (index of symmetry processing) was always present.

Together these findings show that the recruitment of fronto-central networks underpins processes of self-reflection and subjective evaluation and is contingent on the *intention* to perform a judgment about the aesthetic quality of the pattern. A visual analysis of the stimulus characteristics is necessary (i.e., parieto-occipital deflection) but it is not sufficient to elicit aesthetic processing.

It is possible that abstract configurations contain information to make a *cold* judgment of symmetry, but this is not sufficient to elicit a spontaneous aesthetic experience (Makin, 2017). By contrast, faces are biologically and socially relevant stimuli. Neural correlates of face attractiveness have been recorded, although they are mainly associated with reward (e.g., Winston, O'Doherty, Kilner, Perrett, & Dolan, 2007). Other studies showed that attractive faces did not elicit any spontaneous response unless beauty was intentionally assessed (Roye, Höfel, & Jacobsen, 2008; Schacht, Werheid, & Sommer, 2008).

A strategy to identify an ERP index of the automatic association between symmetry and beauty/positive valence is the use of implicit measures. Rampone, Makin, and Bertamini (2014) used an affective picture–word interference task, with a word (positive or negative) superimposed on a pattern (symmetry or random). They investigated whether and how visual processing of symmetry is influenced when processing valence. When participants classified the valence of the word (and ignored the pattern underneath), the symmetry-related parieto-occipital negativity was recorded only for *positive words–symmetry* pairs but not for *negative words–symmetry* pairs. The authors proposed that preattentive tuning of the visual system to symmetry was enhanced when processing positive-valenced words, a similar conclusion to that drawn by Jacobsen et al. (2006).

Other electrophysiological measures have been used to index neural correlates of aesthetic experience. For example, electromyography (EMG) detects spontaneous affective responses. The activation of zygomaticus mayor (ZM—or smiling muscle) signals a positive emotional response (Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008) and fluently processed stimuli (Cannon, Hayes, & Tipper, 2010; Winkielman & Cacioppo, 2001; Winkielman, Halberstadt, Fazendeiro, & Catty, 2006). Stimuli with negative valence, on the other hand, activate the corrugator supercilii (CS or frowning muscle) (Lishner, Cooter, & Zald, 2008). Gerger, Leder, Tinio, and Schacht (2011) used abstract patterns (asymmetric/symmetric) and faces (attractive/unattractive). They found that symmetric patterns and faces elicited higher ZM activations whereas unattractive patterns and faces elicited higher CS activations. Moreover, abstract patterns elicited fluency-related effects (greater ZM activation for longer stimulus presentations). In a 2AFC discrimination task (symmetry vs. random) Makin, Wilton, Pecchinenda, and Bertamini (2012) observed greater ZM activation for symmetry. However, in a second experiment, participants categorized the target with a dichotomous response (yes to symmetry, no to asymmetry for one group, the opposite for another group). Interestingly, ZM activation was stronger for trials that required a yes response, irrespective of target identity. In line with the aforementioned studies (Jacobsen & Höfel, 2007b; Jacobsen et al., 2006) this study showed that processing symmetry per se does not produce a positive response as measured by (neuro)physiological measures. What is true is that symmetry is spontaneously categorized as target (or *figure of interest*), unless other task requirements are present, and this categorization has positive effects, measured for example by the ZM response.

Clinical Evidence

Preference for symmetry, order, and balance may be an adaptive natural behavior, but in some cases it can be manifested in extremes forms, becoming a marker of maladaptive compulsive behaviors.

Preoccupation with symmetry and ordering/arranging is one of the symptoms of obsessive compulsive disorder (OCD) (Lochner et al., 2016; Radomsky & Rachman, 2004). Symptoms include an obsession with symmetry and regularity in the physical environment, and a need for arranging elements in balanced and orderly structures. OCD individuals can experience a tormenting sense of dissatisfaction and *incompleteness* when things in the physical world are perceived as *not just right* (NJR-Experiences) (Coles, Frost, Heimberg, & Rhéaume, 2003). Incompleteness is a discomforting sense that involves all sensory modalities and is caused by a deficit in the ability to integrate emotional experience and sensory feedback in guiding behavior (Summerfeldt, 2004).

The need for symmetry and order lies on a continuum from healthy behavior to a clinically impairing behavior and can be measured in the nonclinical population. There are scales to measure OCD symptoms in the general population, in particular the *Symmetry, Ordering, and Arranging Questionnaire* (SOAQ, Radomsky & Rachman, 2004) assesses beliefs and behaviors associated with ordering and arranging, while the *NJRE Questionnaire* (*Revised*; Coles, Frost, Heimberg, & Rhéaume, 2003) assesses the intensity of subjective not-just-right experiences. High scores on these scales are related to high levels of discomfort when in disorderly environments (Coles, Heimberg, Frost, & Steketee, 2005), which can impact completion of ordinary tasks (Radomsky & Rachman, 2004).

A recent study investigated aesthetic preference for symmetry in individuals with OCD-like *incompleteness* traits (Summerfeldt, Gilbert, & Reynolds, 2015). Participants performed two aesthetic tasks on novel abstract stimuli, in which symmetry was either the primary (Assessment of Preference for Balance task, BT; Wilson & Chatterjee, 2005), or the secondary (Maitland Graves Design Judgment Test, DJT) dimension. Participants were asked to make objective estimates of the aesthetic value of an object (i.e., judge the degree of harmony and balance of the image) or to report their aesthetic preference (i.e., judge liking for the image). High scores on *incompleteness* traits and self-perceived symmetry-related concerns and behaviors (SOAQ scores) were associated with greater preference for symmetry (although there were no differences in the ability to estimate objectively the aesthetic value of the stimulus).

It is possible that strong preference for symmetry may result from a need to correct for sensory-emotional dysregulations. Summerfeldt et al. (2015) proposed there may be a link between the *perceptual fluency* account of preference for symmetry and the nature of this behavior. OCD individuals may show accentuated need for easily processed visual cues that can facilitate the achievement of a satisfactory sensory-emotional state.

Other studies have looked at EEG/ERP markers for preference for symmetry in OCD symmetry-related traits (Evans et al., 2012; Evans & Maliken, 2011). *Oddball tasks* have been shown to elicit atypical cortical activity in patients with OCD. Typically, processing a rare (oddball) stimulus elicits a positive component over centro-parietal areas (electrode Pz) that peaks around 300 ms from stimulus onset (P300). In OCD patients, P300 has a more pronounced amplitude and earlier onset. In one study (Evans et al., 2012) participants performed an oddball task with two sets of stimuli. One set consisted of alternating images of symmetric (parallel) and asymmetric (displaced) lines. A control set consisted of alternating blue and red colored spheres. Results showed stronger sensory conflict (i.e., more positive peak and faster latency of the P300) for oddball asymmetric stimuli in participants showing greater preference for symmetry and order. Similar results were observed in children with typical arranging compulsions (Evans & Maliken, 2011). These results suggest that greater sensitivity for oddball asymmetry may reflect a reaction to the occurrence of not-just-right experiences. A preference for organization is associated with several disorders, but present in the general population as well. Langeslag (2018) measured ERP responses to objects arranged with various degrees of organization (sorted by shape and color from totally organized to totally disorganized). Participants rated the displays in terms of valence (i.e., pleasant/unpleasant feeling) and arousal (i.e., calming/arousing feeling); their *desire for order* and *organization behaviors* were also measured. There was a linear inverse relationship between level of disorganization and pleasantness (totally disorganized were least pleasant); no differences were observed with arousal. ERP measures showed a frontal negativity (at electrodes Fz, Cz) at 200–400 ms for the totally disorganized displays compared with organized, slightly disorganized, and control images. It is interesting that this negativity resembles the early frontal negative deflection (Fz, 300–400 ms) for stimuli judged as *not beautiful* observed with symmetric patterns (Höfel & Jacobsen, 2003; Jacobsen & Höfel, 2002, 2003). However, ERP amplitude did not correlate with valence ratings in this study.

Other clinical evidences of a bias toward symmetry have been found in patients with body dysmorphic disorder (BDD) (Lambrou, Veale, & Wilson, 2011) and autism spectrum disorder (Perreault, Gurnsey, Dawson, Mottron, & Bertone, 2011). Potentially, some of these common symptoms can be reunited under a similar endophenotype that involves an augmented perceptual sensitivity to symmetry and regularity.

Conclusion

Interest in symmetry is widespread and symmetry has been studied in many fields, from empirical aesthetics, evolutionary psychology, and psychology of art to neuroscience. Many thinkers, including early Greek philosophers, have linked symmetry with beauty. Empirical work has also produced a large literature. In general observers do like symmetry in novel and abstract configurations, in objects, and in the human body.

One issue that is central to this literature is how symmetry relates to complexity. Symmetry can be understood as regularity and redundancy, and this redundancy can be used for encoding of shape information. However, there is no clear and strong link between beauty and simplicity. For example, what makes bilateral symmetry more salient than rotational symmetry may have to do with visual perception, but not with the properties of the two transformations (both rigid transformations in the plane).

Although symmetry drives aesthetic judgments, it is difficult to isolate a neural correlate of this link. It seems that a spontaneous aesthetic response to symmetry (in abstract and unfamiliar stimuli) is not elicited in the brain unless people are explicitly processing symmetry aesthetically.

Finally, preference for symmetry, order, and balance lies on a continuum ranging from a universal tendency to prefer symmetry to pathological obsessive compulsion. It seems that dysfunctional perceptual mechanisms may play a role in excessive preferences for symmetry in disorders such as OCD, BDD, and autism. This area of research, however, is still in its infancy.

Symmetry will continue to be a central topic in empirical aesthetics as it is a paradigmatic tool to study order and complexity, and to test hypotheses about the potential adaptive function of certain patterns of preference.

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Marco Bertamini

Marco Bertamini, Department of Experimental Psychology, University of Liverpool, UK

Giulia Rampone

School of Psychology, University of Liverpool, UK