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# Affine Geometry, Visual Sensation, and Preference for Symmetry of Things in a Thing - Article

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**Abstract:** Evolution and geometry generate complexity in similar ways. Evolution drives natural selection while geometry may capture the logic of this selection and express it visually, in terms of specific generic properties representing some kind of advantage. Geometry is ideally suited for expressing the logic of evolutionary selection for symmetry, which is found in the shape curves of vein systems and other natural objects such as leaves, cell membranes, or tunnel systems built by ants. The topology and geometry of symmetry is controlled by numerical parameters, which act in analogy with a biological organism's DNA. The introductory part of this paper reviews findings from experiments illustrating the critical role of two-dimensional design parameters and shape symmetry for visual or tactile shape sensation, and for perception-based decision making in populations of experts and non-experts. Thereafter, results from a pilot study on the effects of fractal symmetry, referred to herein as the *symmetry of things in a thing*, on aesthetic judgments and visual preference are presented. In a first experiment (psychophysical scaling procedure), non-expert observers had to rate (scale from 0 to 10) the perceived beauty of a random series of 2D fractal trees with varying degrees of fractal symmetry. In a second experiment (two-alternative forced choice procedure), they had to express their preference for one of two shapes from the series. The shape pairs were presented successively in random order. Results show that the smallest possible fractal deviation from "symmetry of things in a thing" significantly reduces the perceived attractiveness of such shapes. The potential of future studies where different levels of complexity of fractal patterns are weighed against different degrees of symmetry is pointed out in the conclusion.

**Keywords:** Visual symmetry; affine projection; fractals; visual sensation; aesthetics; preference

## 1. Introduction

Brain evolution has produced highly specialized processes which enable us to effectively exploit the geometry of visual perceptual space. Some data suggest that the human brain is equipped with an in-built sense of geometry (e.g. Amir *et al.*, 2012; Amir *et al.*, 2014), which is a key to conscious knowledge about specific object properties and associations between two-dimensional projections and their correlated three-dimensional structures in the real world (e.g. Biederman, 1987; Wilson & Wilkinson, 2002; Pizlo *et al.*, 2010; Li *et al.*, 2013). These associations favour structural regularities and, above all, symmetry (Li *et al.*, 2009; Li *et al.*, 2013). Thus, it is not surprising that symmetry plays an important role in conceptual processes and the design geometry of complex spatial structures, and is abundantly exploited by engineers and architects. The use of the symmetry of curvature, for example, dates back to the dawn of building shelter and vernacular architecture, which relies, by the nature of the materials and construction techniques used, almost entirely on symmetrical curves (Figure 1, left). In the middle ages, descriptive geometry was used for the planning and execution of building projects for which symmetric curves were the reference model, as in the design of arched hallways and corridors (Figure 1, middle). In the last century, the Spanish designer and architect Gaudi exploited the same kind of geometry for the design of the *Sagrada Familia* in Barcelona (Figure 1, right) and many of his other fabulous structures, which can be appreciated by taking a walk through the Guëll Park, or by visiting the Guëll museum in Barcelona.

46 **Figure 1.** The importance of the symmetry of curves for human endeavour dates back to the dawn of  
 47 building shelter and to vernacular architecture (left). Symmetric curve geometry is currently used in  
 48 contemporary free-form architecture (middle), which has been much inspired by the Spanish  
 49 architect Gaudi, who largely exploited symmetry of curvature for the design of the hall and  
 50 archways of the *Sagrada Familia* in Barcelona (right).



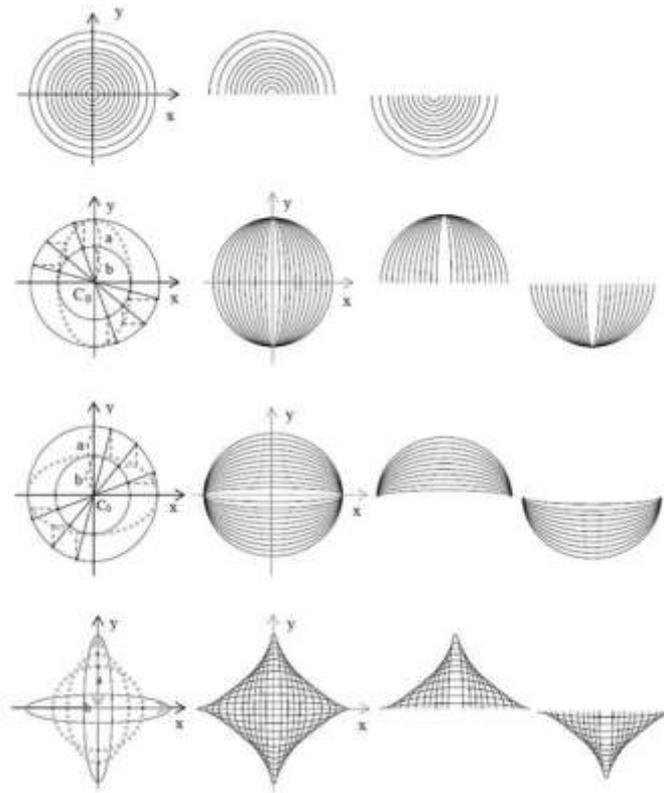
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 53 Gaudi's structures were largely inspired by nature, which abounds with curved shapes and  
 54 features (see also Ghyka, 1946), and our perception uses these features as cues to shape or object  
 55 recognition and image interpretation (e.g. Stevens 1981a and b; Foley *et al.*, 2004; Dresp, Silvestri and  
 56 Motro, 2007; Dresp-Langley 2013, 2015; Mustonen *et al.*, 2015; Strother, Killebrew and Caplovitz,  
 57 2015). In biology, curvature guides physical, chemical, and biological processes, such as protein  
 58 folding, membrane binding, and other biophysical transformations (Grove, 2009). The  
 59 representation and cognition of curvature ranges from the biochemical level of living organisms  
 60 capable of sensing this property in their near or distant physical environments (Hatzakis, 2009) to  
 61 perceptual properties extracted from physical stimuli by the human brain (Dresp, 1998; Bonnet and  
 62 Dresp, 2001; Dresp and Fischer, 2001; Dresp and Langley, 2005; Dresp-Langley and Durup, 2009;  
 63 2012), the ultimate product of evolution. In terms of a mathematical property of the physical world,  
 64 curve symmetry can be directly linked to affine geometry (see also Gerbino and Zhang, 1991).

### 65 1.1. Affine geometry and visual sensation

66 In affine geometry, curves derived from circles and ellipses share certain properties, the circle  
 67 being a particular case of the ellipse. Projective geometry permits generating symmetric curves from  
 68 ellipses by affinity with concentric circles (Figure 2). Their perception is grounded in biology in the  
 69 sense that most natural objects can be represented in 2D as symmetrically curved shapes with  
 70 Euclidean properties of ellipses. Studies comparing between visually perceived curvature by experts  
 71 in geometry (architects and design engineers) and non-experts (Dresp, Silvestri and Motro, 2006),  
 72 using symmetric curves derived from concentric circles by affine projection have shown that their  
 73 perceived magnitude is determined by a single geometric parameter, the curves' *aspect ratio*. The  
 74 perceptual responses to such curves are independent of both expertise and sensory modality, given  
 75 that tactile sensing by sighted blindfolded and congenitally blind observers produces the same  
 76 results (Dresp-Langley, 2013). The symmetry of the curves, however, is a critical factor to these  
 77 geometry-based perceptual responses (Dresp-Langley, 2015). The *aspect ratio* relates the height  
 78 (*sagitta*) to the width of a curve, and in symmetric curves of variable size but constant *aspect ratio*  
 79 directly taken from concentric circles (no projection by affinity), perceived curvature is also constant,  
 80 in both vision and touch. This observation is directly linked to the phenomenon of scale-invariance  
 81 in visual curvature discrimination (cf. Whitaker and McGraw, 1998) and in the detection and  
 82 recognition of shapes in general (cf. Pizlo, 1994).  
 83

84 **Figure 2.** Projective geometry permits generating symmetric curves from ellipses by affinity with  
 85 concentric circles. Their perception is grounded in biology in the sense that most natural objects can  
 86 be represented in images as symmetrically curved shapes with the Euclidean properties of ellipses.  
 87 Symmetric curves yield visual and tactile sensations of curvature which increase exponentially with  
 88 the *aspect ratio* of the curves (e.g. Dresp-Langley, 2013; 2015)

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### 91 1.2. Reflection and rotational shape symmetry

92 The role of reflection symmetry in visual perception was pointed out by Gestalt psychologists at  
 93 the beginning of the 20th century (Bahnsen, 1928; Koffka, 1935) as a major factor in shape perception.  
 94 It refers to specific transformations by transition of points in Euclidean space resulting in mirrored  
 95 representations. Axial symmetry (e.g.), which results from point-by-point mirroring across an axis ( $f$   
 96  $(x, y, z) = f(-x, y, z)$ ), is an important factor in visual recognition (e.g. Braitenberg, 1990; Beck, Pinsk &  
 97 Kastner, 2005; Tjan & Liu, 2005). Reflection or mirror symmetry is detected fast (Barlow and  
 98 Reeves, 1979; Wagemans, et al., 1991), in foveal and in peripheral vision (Barrett et al., 1999). Vertical  
 99 mirror symmetry facilitates face recognition by human (e.g. Thornhill & Gangestad, 1999) and  
 100 non-human primates (Anderson et al., 2005), and is used by the human visual system as a  
 101 second-order cue to perceptual grouping (Machilsen et al., 2009).

102 Rotational symmetry of shape plays an important role in architecture and design (e.g. Arnheim,  
 103 1969). The design of complex modern spatial structures is a domain of contemporary relevance.  
 104 Visual-spatial experiments on expert architects as well as novices have shown that perceiving the  
 105 rotational symmetry of partial shapes which constitute the simplest possible *tensegrity* (*tensile*  
 106 *integrity*) structure (Figure 4) is an important part of our understanding how they are put together.  
 107 Only once this symmetry is perceived by the expert or novice, will he/she be able to draw the  
 108 structure from memory into axonometric or topological reference frames provided to that effect  
 109 (Silvestri, Motro, Maurin and Dresch-Langley, 2010). Tensegrity structures have inspired current  
 110 biological models (e.g. Levin, 2002), from the level of single cells to that of the whole human body.  
 111 They possess what Mandelbrot (1982) called "fractal consistency across spatial scales", or "fractal  
 112 iterations", like those seen in large trees that appear composed of many smaller trees of the same  
 113 structure.

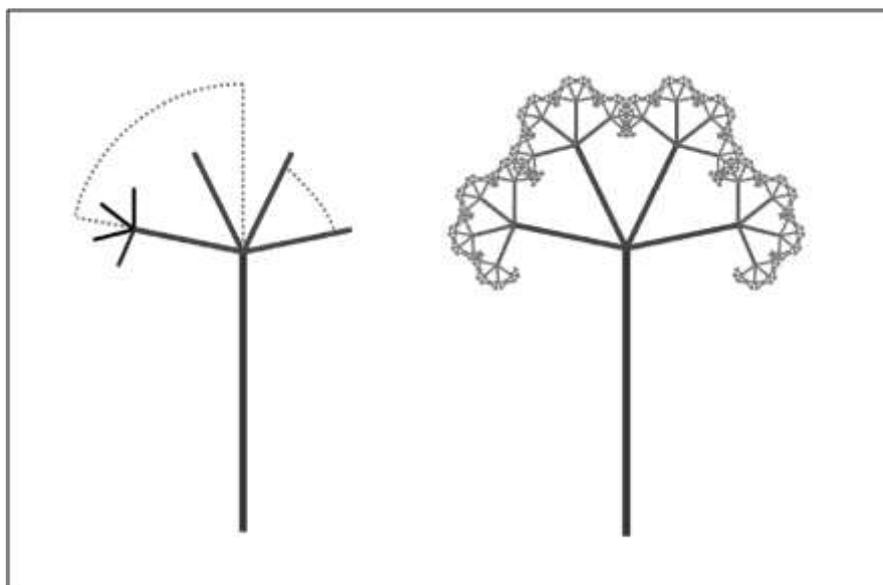
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### 115 1.3. Nature-inspired design and the symmetry of "things in a thing"

116 Fractal geometry is also inspired by nature (Mandelbrot, 1982), with its many symmetric visual  
117 structures like those found in cells, trees, butterflies and flowers. A fractal may be defined as a  
118 complex whole (object or pattern) that has the same structural characteristics as its constituent parts.  
119 The structural symmetry that results from fractal iterations may be described as the *symmetry of*  
120 *things in a thing*. The radial symmetry of a sunflower is a choice example of fractal symmetry as it  
121 exists in nature. Behavioural studies have shown that various animal species are naturally attracted  
122 to two-dimensional representations of objects exhibiting flower-like radial symmetry (Lehrer *et al.*,  
123 1995; Giurfa *et al.*, 1996). In complex 3D fractal trees, single fractals ("things") have a symmetrical  
124 counterpart within the whole structure (*the thing*), which may possess radial symmetry, reflection  
125 symmetry and manifold rotational symmetries, like many objects in nature (plants, snowflakes, etc.)  
126 are bound by both reflection and rotational symmetry, and exhibit multiples of one and the same  
127 shape (*things*) repeated in all directions.

128 Nature-inspired design occupies an important place in contemporary graphic art, and  
129 symmetry has been identified as a major defining feature of visual beauty, compositional order, and  
130 harmony. Symmetry directly determines aesthetic preferences and the subjectively perceived beauty  
131 of two-dimensional visual images and patterns (Eisenman, 1967; Berlyne, 1971; Jacobsen *et al.*, 2002,  
132 2003, 2006; Tinio & Leder, 2009), and symmetrical visual patterns are also more easily remembered  
133 and recognized (Deregowski, 1971, 1972; Kayert & Wagemans, 2009) compared with asymmetrical  
134 ones. Sabatelli *et al.* (2010) suggested that natural and artistic creative processes rely on common,  
135 possibly fractal, transformations. Fractal transformations may describe iterative transitions from  
136 simplicity and order (symmetry) to complexity and chaos (asymmetry). Again, fractal trees seem to  
137 be a pertinent example here, where simple 2D mirror trees (Figure 3) with reflection and/or radial  
138 symmetry open an almost infinite number of possibilities for adding complexity through further  
139 transformations leading to complex projections of 3D structures with multiple rotational symmetries  
140 (not shown here).

141 **Figure 3.** Fractal geometry and affine geometry share principles of projection in Euclidean space.  
142 Fractal trees, inspired by nature (Mandelbrot, 1982), may be defined as complex wholes where every  
143 part repeats itself across multiple fractal iterations, producing *symmetry of things in a thing*. In the  
144 simple fractal mirror-tree shown here, concentric circles are the mathematical basis for describing  
145 structural regularities with vertical reflection (mirror) symmetry, which has been identified as a  
146 major determinant of the visual attractiveness of image configurations (e.g. Eisenman, 1967).



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Whether nature-inspired fractal design appeals to our senses in the same way as the real objects found in nature remains an open question. However, on the basis of previous findings summarized

151 here above, we may assume that the *symmetry of things in a thing* in fractal design plays a decisive role  
152 in our perception of their aesthetic content and thereby influence certain preference judgments.  
153 Given the multiple levels of complexity of fractal objects, trying to address this question requires  
154 starting with simple examples. For this pilot study here, we created a series of fractal mirror trees  
155 based on geometric transformations as shown in Figures 2 and 3. In two psychophysical  
156 experiments, one using a subjective aesthetic rating procedure, the other a preference judgment  
157 design, we tested whether the subjective attractiveness of such trees is affected by different degrees  
158 of violation of symmetry, from an almost imperceptible lack of mirror detail to massive asymmetry.

## 159 2. Materials and methods

160 The experiments were conducted in accordance with the Declaration of Helsinki (1964) and  
161 with the full approval of the corresponding author's institutional (CNRS) ethics committee.  
162 Informed written consent was obtained from each of the participants. Experimental sessions were  
163 organized following conditions of randomized, trial-by-trial free image viewing using a computer  
164 with a keyboard and a high resolution monitor. 15 mirror tree images were generated using a  
165 comprehensive vector graphics environment (Adobe Illustrator CC) and computer shape library.

### 166 2.1. Subjects

167 30 observers, ranging in age between 25 and 70 and unaware of the hypotheses of the study,  
168 participated in the experiments. All subjects had normal or corrected-to-normal visual acuity.

### 169 2.2. Stimuli

170 The stimuli for the two experiments were generated on the basis of 15 images of fractal trees  
171 (Figure 5) drawn in a vector graphics environment (Adobe Illustrator CC) using simple principles of  
172 2D geometry, as shown here above in Figure 3. Five of these images (Figure 4, top row) were mirror  
173 trees with vertical reflection symmetry and perfect *symmetry of things in a thing*. Five of them (Figure  
174 4, middle row) were imperfect mirror trees in the sense that their vertical reflection symmetry  
175 excluded one of the elementary parts, which was not mirrored on the right side of the tree. In the  
176 remaining five, asymmetrical images (Figure 4, bottom row), elementary shapes "growing" on the  
177 branches of the left side of the trees were not mirrored on the right side. The luminance contrast  
178 between figures and backgrounds was constant in the 15 images (same RGB (200, 200, 200) for all  
179 figures, same RGB (20, 20, 20) for all backgrounds). The height of a fractal tree on the screen was 10  
180 cm, the widest lateral expansion in the vertical direction of any given tree was 4 cm.

### 181 2.3. Task instructions

182 In the aesthetic rating experiment, subjects were instructed to rate the beauty of each of the  
183 fifteen individual images on a subjective psychophysical scale from 0 (zero) for "very ugly" to ten  
184 (10) for "very beautiful". In the preference judgment experiment, subjects were instructed to  
185 indicate whether they spontaneously preferred the left or the right of an image pair. Hitting the  
186 response key initiated the next image pair. Half of the subjects started with the rating experiment,  
187 the other half with the preference judgment experiment.

### 188 2.4. Procedure

189 Subjects were seated at a distance of 1 meter from the screen and looked at the center of the  
190 screen. The images were displayed centrally and presented in random order. In the aesthetic rating  
191 experiment, each of the 15 images was presented once to each of the 30 subjects. In the preference  
192 judgment experiment, each image from a group of five was paired with its counterpart from the two  
193 other groups of five and spatial position in a pair (left/right) was counterbalanced (Figure 5).

194 **Figure 4.** Stimuli from the aesthetic rating and visual preference experiments described herein.  
195 Fifteen images of fractal mirror trees were designed using some of the principles of transformation

196 shown in Figures 2 and 3. The first five trees (top) possess perfect *symmetry of things in a thing* across  
 197 the vertical axis. In the next set of five (middle), the smallest of fractal details is missing on the right.  
 198 The remaining five trees (bottom) are asymmetrical.



199 This yielded 30 image pairs with 20 presentations for each single figure (10 times on the left,  
 200 and 10 times on the right). The image pairs were displayed in random order and each pair was  
 201 displayed twice in an individual session, yielding 60 preference judgments from each of the 30  
 202 subjects. Individual responses were coded and written into text files, which were imported into the  
 203 data analysis software for further processing. The intervals between stimulus presentations were  
 204 observer controlled. They typically varied from one to three seconds, depending on the observer,  
 205 who initiated the next image presentation by striking a given response key ("1" for "left", "2" for  
 206 "right") on the computer keyboard.  
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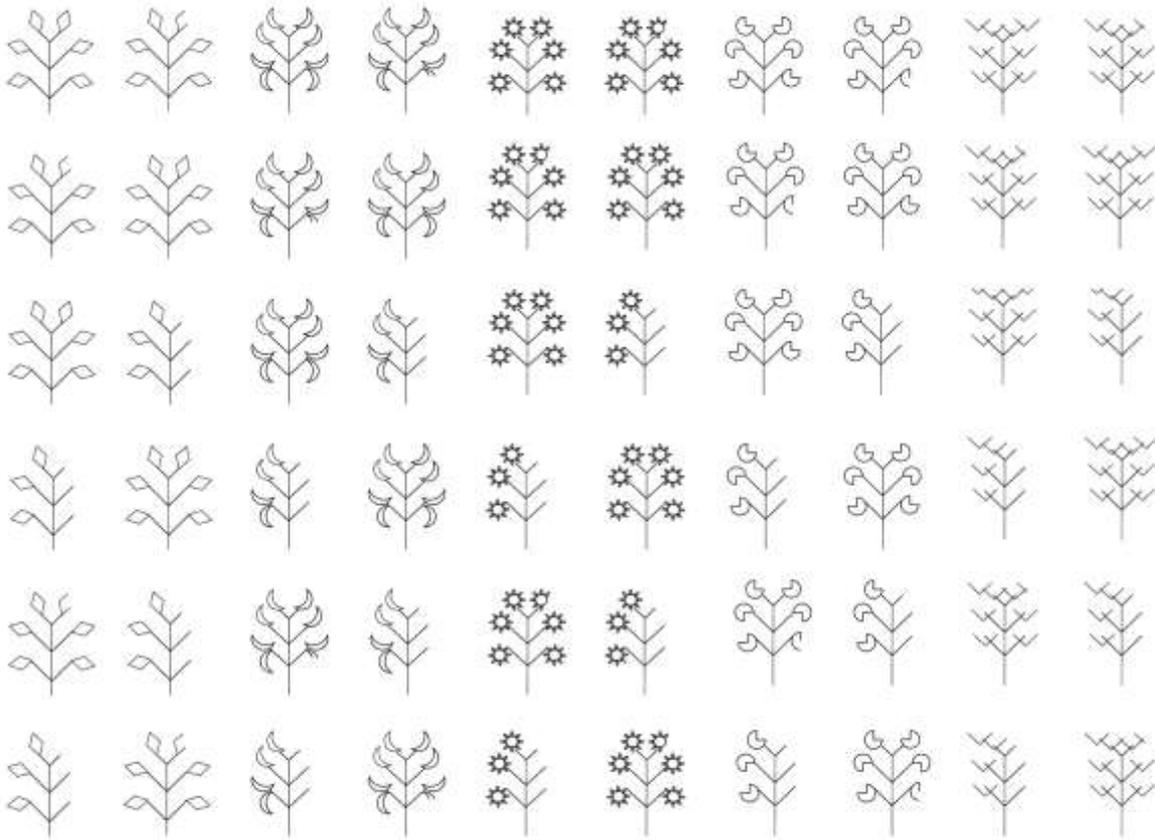
### 209 3. Results

210 The raw data from the two experiments were analyzed using *Systat 11*. Data plots showing  
 211 medians and variances of the rating distributions were generated. Means and their standard errors  
 212 of the subjective aesthetic ratings and the total number of "preferred" responses from the preference  
 213 judgment task were plotted for comparison between figure types. One-way analyses of variance  
 214 testing for statistical significance of differences in means observed for the three figure types:  
 215 'symmetrical', 'single detail missing on right' and 'asymmetrical' were performed.

#### 216 3.1. Subjective aesthetic ratings

217 The medians and variance of the subjective aesthetic ratings between zero and ten produced by the  
 218 30 subjects in response to the 15 images were plotted as a function of the three-level figure type factor  
 219 (Figure 5). With five figures per factor level and 30 individual ratings per figure, we have a total of  
 220 150 observations for each level of this factor, and a total of 450 observations. The distribution of  
 221 observations satisfies criteria of normality and equality of variance for further parametric testing,  
 222 outliers were not removed from the dataset.

223 **Figure 5.** 30 image pairs with 20 presentations for each single figure (10 times on the left, and 10  
 224 times on the right). The image pairs were displayed in random order and each pair was displayed  
 225 twice in an individual session, yielding 60 preference judgments from each of the 30 subjects..



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One-way ANOVA signaled a significant effect of figure type on raw data for subjective beauty ratings ( $F(2, 449)=79.47$ ;  $p<.001$ ). The differences between the means, plotted here in terms of the average subjective rating and its standard error for each figure type (Figure 6), reveal that perfectly symmetrical figures score higher for subjective beauty than figures with a detail missing ( $t(1, 149)=7.15$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison), and that figures with a detail missing score higher than asymmetrical figures ( $t(1, 149)=5.42$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison). The largest difference in average aesthetic ratings is observed between symmetrical and asymmetrical figures ( $t(1, 149)=12.57$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison). When average beauty ratings are plotted as a function of the individual figures (Figure 7), we see that none of the three figure types produced an average score in the extremes ("very beautiful" or "very ugly"). The five symmetrical ones (1 to 5 on the x-axis) produced average ratings between '5' and '8', the five with a small detail missing on the right (6 to 10 on the x-axis) produced average scores between '4' and '6', and the five asymmetrical figures (11 to 15 on the x-axis) scored between '3' and '4' on average.

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### 3.1. Preference judgments

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The total number of times each figure of the 15 was chosen as "preferred" in a pair of images in the preference judgment task was counted. One-way ANOVA on the total number of preferences for a figure of each type ( $N=5$  per factor level) signaled a significant effect of figure type on preference ( $F(2, 14)=368.12$ ;  $p<.001$ ). The differences between means, plotted here in terms of the average number of "preferred" and its standard error for each figure type (Figure 8), reveal that perfectly symmetrical figures yield larger preferences than figures with a detail missing ( $t(1, 4)=19.00$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison), and that figures with a detail missing yield larger preferences than asymmetrical figures ( $t(1, 4)=7.28$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison). The largest difference in number of "preferred" is observed between symmetrical and asymmetrical figures ( $t(1, 4)=26.28$ ;  $p<.001$ ), *post hoc* Holm-Sidak comparison). When the total number of "preferred" responses is plotted as a function of the 15 individual figures (Figure 9), we see that the five symmetrical figures (1 to 5

252 on the x-axis) produced almost identical high-preference totals, while the other figures produced  
253 more variable ones in the lower preference range.

#### 254 4. Discussion

255 As illustrated by examples from the introduction here above, shape sensation and perception  
256 can be related to affine design geometry (e.g. Bahnsen, 1928; Koffka, 1935; Braitenberg, 1990; Gerbino  
257 and Zhang, 1991; Dresch-Langley, 2015). Similarly, the topology and geometry of fractal objects may  
258 be controlled by a few simple geometric parameters, as in the fractal mirror trees that were used as  
259 stimuli here. The term "fractal" was first introduced by Mandelbrot (1982) based on the meaning  
260 "broken" or "fractured" (*fractus*), with reference to geometric patterns existing in nature. The findings  
261 from this study here show that the smallest "fractal" deviation from perfect *symmetry of things in a*  
262 *thing* in basic mirror trees (any computer shape library can generate them) with vertical reflection  
263 symmetry when no fractals are removed, significantly diminishes subjectively perceived beauty and  
264 visual preference. These results confirm previous observations from aesthetic perception studies  
265 using different two-dimensional configurations (Eisenman, 1967; Berlyne, 1971; Jacobsen *et al.*, 2002,  
266 2003, 2006; Tinio & Leder, 2009). Perfectly symmetrical trees also produced the strongest consensual  
267 results, for both subjective aesthetic ratings and visual preferences, while the ones with a small detail  
268 missing and the asymmetrical trees produced more disparate data, indicating higher uncertainty  
269 (i.e. less confidence) in the subjects' perceptual responses.

270 In nature, it is indeed difficult to find things which do not have at least one axis of mirror or  
271 reflection symmetry, such as palm trees and sunflowers or broccoli and snowflakes (cf. Mandelbrot,  
272 1975), for example. Also, most human beings are basically symmetric around the vertical axis when  
273 standing up, and it is therefore almost unsurprising that our aesthetic preferences would mostly go  
274 for symmetrical objects (see also Tinio & Leder, 2009, on massive familiarization). However, results  
275 from earlier studies (Eisenman & Gellens, 1968) lead to suggest that things may not be that simple  
276 when complexity and symmetry are weighed against each other, and when socio-cultural factors are  
277 brought into the equation. Personality and creativity (Eisenman and Rappaport, 1967; Arnheim,  
278 1969; Cook and Furnham, 2012) have been identified as two such variables, and highly creative  
279 individuals may have a stronger tendency to prefer asymmetrical objects, especially when these  
280 exhibit high levels of complexity, as in the case of fractal objects with multiple rotational symmetries,  
281 for example. As pointed out previously (Sabatelli *et al.*, 2010), symmetry and asymmetry coexist in  
282 many natural and human processes, and the critical role of symmetry in art has been well  
283 demonstrated; the complementary role of asymmetry maybe less . Fractal objects offer new perspectives for  
284 research on complementary aspects of symmetry and asymmetry in processes of increasing complexity,  
285 including processes of visual perception.

286 Fractals are different from other geometric figures because of the way in which they scale across  
287 multiple iterations, yielding increasingly complex repetitive structures which are symmetrical by  
288 nature. Fractal symmetry is also referred to as *expanding symmetry* or *evolving symmetry*, especially if  
289 replication is exactly the same at every scale, as in a detailed pattern that repeats itself across  
290 multiple fractal iterations. For the visual scientist, this opens many perspectives as it permits the  
291 finely controlled manipulation of each and every shape detail in a given configuration and thereby  
292 allows to create visual stimuli where variations in complexity and symmetry can be effectively  
293 weighed against each other in further studies.

#### 294 5. Conclusion

295 The visual attractiveness of 2D fractal design shapes closely depends on the *symmetry of things in*  
296 *a thing* in configurations with simple geometry, as shown in this pilot study here on the example of a  
297 few very basic fractal mirror-trees. In these simple displays, the smallest "fractal" deviation from a  
298 perfect *symmetry of things in a thing* is shown to have significantly negative effects on subjectively  
299 perceived beauty and preference judgments. These findings are to encourage further studies, using  
300 more sophisticated fractal design objects with increasingly large number of fractal iterations,  
301 producing more and more complex 2D mirror designs and shapes with increasingly multiple

302 rotational symmetry in 3D. Such design objects are ideally suited for a numerically controlled  
 303 manipulation of the smallest of details in the *symmetry of things in a thing*, perfectly tailored for  
 304 investigating complex interactions between symmetry and complexity in their effects on visual  
 305 sensation and aesthetic perception.

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