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Article

Symmetry Modulates the Amplitude Spectrum Slope Effect on Visual Preference

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Abstract: Within the spectrum of a natural image, the amplitude of modulation decreases with spatial frequency. The speed of such an amplitude decrease, or the amplitude spectrum slope, of an image affects the perceived aesthetic value. Additionally, a human observer would consider a symmetric image more appealing than they do an asymmetric one. We investigated how these two factors jointly affect aesthetic preferences by manipulating both the amplitude spectrum slope and the symmetric level of images to assess their effects on aesthetic preference on a 6-point Likert scale. Our results showed that the preference ratings increased with the symmetry level but had an inverted U-shape relation to amplitude spectrum slope. In addition, a strong interaction existed between symmetry level and amplitude spectrum slope on preference rating, in that symmetry can amplify the amplitude spectrum slope's effects. Such effects can be described by a quadratic function of the spectrum slope. That is, preference is an inverted U-shape function of spectrum slope whose intercept is determined by the number of symmetry axis. In addition, the interaction between the two factors is manifested as the modulation depth of the quadratic function.

Keywords: amplitude spectrum; image statistics; complexity; aesthetics; phase

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1. Introduction

Aesthetic experience is essential for the quality of human life. Philosophers, psychologists, and artists have been searching for the essence of aesthetic experience for centuries (Redies et al., 2007). Recently, psychologists and neuroscientists have approached this issue from the properties of the images and their links to the functions of the visual system. The studies analyzing the image statistics of artworks in the Fourier domain (Graham &Field, 2007, 2008; Redies et al., 2007, 2008) showed that when averaged across orientation, the amplitude at different spatial frequencies, f, falls proportionally as frequency increases. This can be represented by a function f^k on logarithmic axes, in which the exponent parameter $-k$ is called the spectrum slope. Since this is parallel to a known characteristic of natural scenes (Burton &Moorhead, 1987; Field, 1987; D. J.Tolhurst et al., 2007), researchers have linked aesthetic experience to the evolutionary history of the visual system. That is, humans have an innate aesthetic preference for stimuli that depict the typical environment in which the human species evolved (Aks &Sprott, 1996; Orians, 1986; Spehar et al., 2003) since their visual systems are optimized to process this information (Párraga et al., 2000, 2005; David J.Tolhurst &Tadmor, 2000).

On the other hand, symmetry can also influence visual aesthetic preferences (Arnheim, 1974; Berlyne, 1971; Chien-ChungChen et al., 2011; Fechner, 1876; Martindale et al., 1990). Human observers generally prefer symmetric faces or bodies to asymmetric ones (Naini &Gill, 2008; Rhodes, 2006; Tovée et al., 2000). Such a preference for symmetry has also been found for abstract patterns that have no immediate biological significance (Berlyne, 1971; Eisenman, 1967; Enquist &Arak, 1994; Johnstone, 1994; Rhodes et al., 1998). Thus, such a preference should be induced by an image's properties, rather than the object it represents.

Chen et al. (Chien-ChungChen et al., 2011) investigated human aesthetic preferences for several kinds of images, including scrambled images and symmetric patterns with different numbers of symmetry axes. They found that the human aesthetic preference for symmetric patterns increased with the number of symmetry axes. However, they also noticed that the edges at symmetry axes led

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to an energy increment at high spatial frequencies and, in turn, a shallower spectrum slope for symmetric images. Other researchers have also noticed the co-occurrence between symmetric structures and fractal dimensions (Pickover, 1995), which is a linear function of the spectrum's slope. Hence, the preference for symmetric patterns may be an artifact of spectrum slope change.

In this study, we aimed to separate the spectrum slope from symmetry effects on aesthetic preference. With an iterative algorithm, we were able to control the exact spectrum slope of an image independent of its symmetry axis number, to separate their effects on aesthetic preference. If the preference for symmetry is an artifact, as mentioned above, we would expect that the preference for an image is solely determined by its spectrum slope, regardless of its symmetry axis number. Otherwise, the number of symmetry axes should affect preferences, as controlled by the spectrum slope. In this case, we should observe either an additive effect, if the effects of the two factors were independent from each other, or a modulation effect of symmetry on the relationship between spectrum slope and preference, if the two factors have an interaction.

2. Materials and Methods

3.1. Ethics statement

This study was approved by the Institutional Review Board of National Taiwan University (#201505EM020, approval date: July 21, 2015) and followed the guidelines of the Helsinki Declaration. Written informed consent was obtained from each participant.

3.2. Apparatus

The stimuli were presented on a 24-inch LCD monitor with 1920 (H) × 1200 (V) spatial resolution, controlled by a Macintosh computer via a Radeon 7200 graphics card, which provided 10-bit digital-to-analog converter depth. The LCD monitor was calibrated with a PhotoResearch PR655 radiometer for luminance. The display had a mean luminance of 8.85 cd/m^2 and mean chromaticity of (0.33, 0.33) in CIE 1931-xy coordinates. The monitor's refresh rate was 60 Hz. The viewing distance was set such that each pixel made up 1′ of visual angle. The experimental control and the stimulus generation were written in MATLAB with the Psychophysics Toolbox (Brainard, 1997).

3.3. Stimuli

The stimuli were grayscale scrambled images (Figure 1) with various spectral and symmetric properties. For each asymmetric stimulus, we first created a white noise spanned 8° (H) × 8 ° (V) visual angle, with the luminance of each pixel randomly drawn from a uniform distribution ranging from 0.51 to 135.94 cd/m^2. We then extracted the image's phase spectrum with a Fourier transform. We then paired this phase spectrum with a preassigned radially averaged amplitude spectrum with a predetermined slope and then applied inverse-Fourier transform to convert them back to an image. The spectrum slope of the image was from −2 to 0 with steps of 0.5.

We also used symmetric images with multiple numbers of symmetric axes. To create such image, we started with random dot images with a desired slope created using the procedure described above; then, we made symmetric versions of them with the following procedure: Let $f(r, \theta)$ be the luminance of a point on an image, where r is the distance from that point to the image's center and θ is the angle (in radiance) between the horizontal axis that passes through the image's center and the line connecting that point and the center. In the symmetric patterns, one part of the image is a reflection of another part about the symmetry axis. Hence, the luminance of a point $L(r, \Phi - \Delta\theta)$ on the image is the same as that of the point $L(r, \Phi + \Delta\theta)$, where Φ defines the orientation of the axis of symmetry and Δθ defines the angle difference between a pixel and the axis. For a pattern with n symmetric axes, $\Phi = k/n \times \pi + z$, where $k = 0, 2, \ldots, n - 1$, and z determines the orientation offset of the axis of symmetry. For instance, if $n = 1$, then z = 0 would give a horizontally symmetric pattern, while $z = \pi / 2$ would give a vertically symmetric one. In this experiment, we set $n = 1$, 2, 4, 8, and 16, in which $z = \pi / 2$ for $n = 1$ while $z = 0$ for other values of n, to create five types of symmetric patterns (from one to 16 axes). Since the rotation of square image would create a blank space and redundancy near the edge, we started with an image with size 11.67° (H) × 11.67° (V) and used the central 8° (H) × 8° (V) for the stimuli. We then reassigned the amplitude spectrum slope again to prevent the spectrum slope from changing due to the rotation and resizing operations.

The stimuli contained 30 types of image, which were combinations of five amplitude spectrum slopes and six types of symmetry levels. The five slopes were from −2 to 0 by steps of 0.5, while the six symmetry levels contained one asymmetric and five symmetric levels, of which the number of axes was one, two, four, eight, and 16.

We repeated the above procedure to create 50 sets of images for each of the 30 types of images. Hence, this experiment included a total of 1,500 images. Figure 1 shows examples of our stimuli.

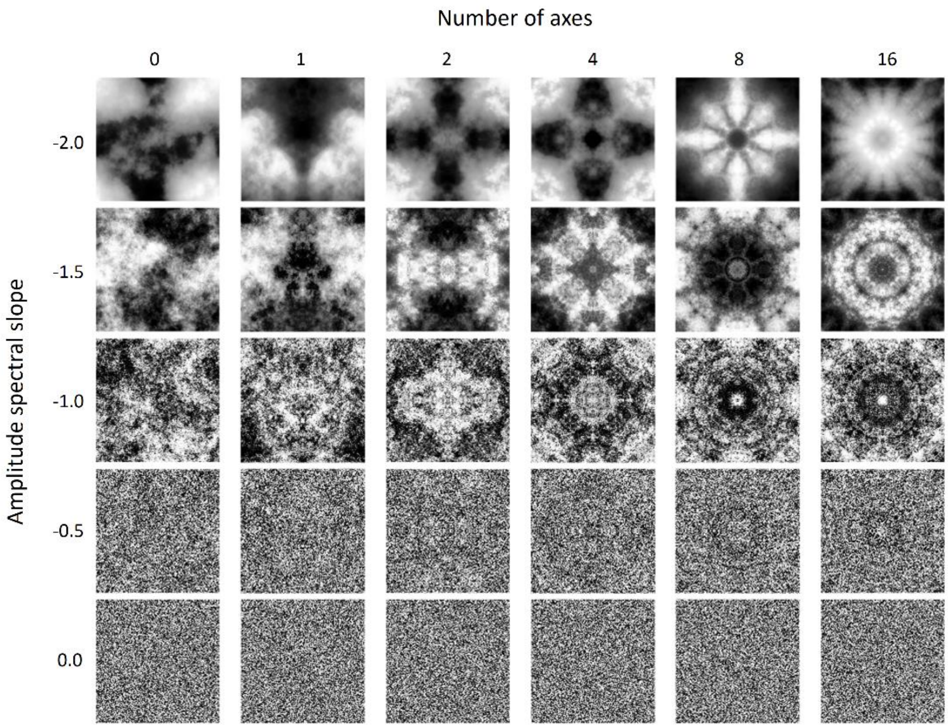

Figure 1. Sample of the stimuli. The stimuli are the combinations of different amplitude spectrum slopes (from 0 to −2) and numbers of axes (from 0 to 16). See text for details.

3.4. Producures

In each trial, a test stimulus was presented at the center of the display and remained there until the observer made a response. The observers were instructed to press a key to indicate, on a 6-point Likert scale, their aesthetic judgment to of test stimulus, in which 1 indicated *not beautiful*, 6 indicated *beautiful*, and the numbers between 1 and 6 indicated different degrees of beauty. The observers were instructed to use all of the numbers in their judgment to express their preference for all of the images in the stimulus set and to avoid making any judgments based on their personal experience with other images. This was aimed at encouraging the observers to anchor the extreme values of the Likert scale to the stimuli in this experiment, rather than to other images, whose aesthetic value might span a much greater range than our stimuli did. The intertrial interval (ITI) was 800 ms.

There were 20 blocks in this experiment, each containing one set of images randomly selected from 50 pregenerated image sets without repetition. The images of each block were randomly

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presented. In total, 43 participants participated in this experiment. The observers were recruited through Internet advertisements. All of the observers had corrected-to-normal (20/20) visual acuity.

3. Results

Figure 2 shows the preference ratings averaged across observers for all combinations of slope and symmetry level. The symbols stand for the data points, and the error bars represent the standard error (see figure caption). The smooth curve is the fit of the function described below.

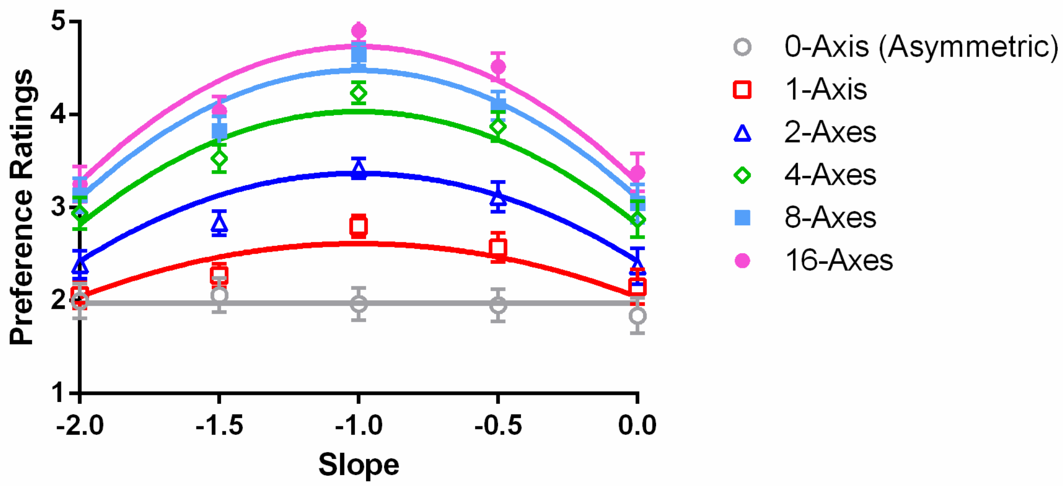

Figure 2. Preference ratings under different combinations of spectrum slope and number of axes. The gray symbols represent the data points for the asymmetric condition, red for one axis, blue for two axes, green for four axes, cyan for eight axes, and pink for 16 axes. The error bars are the standard error. The smooth curves are quadratic function fit.

The observers gave the lowest preference ratings to asymmetric images (the grey circles). The ratings increased with the number of symmetry axes in an image. This was consistent with Chen et al.'s study (Chien-ChungChen et al., 2011). At the same number of symmetry axes, the preference rating was an inverted-U function of spectrum slope that peaked at slope −1. A repeated measures two-way ANOVA, after Greenhouse–Geisser correction, showed an interaction between the number of symmetry axes and spectrum slope, $F(4.93, 206.86) = 22.33$, $p = .00$, $\eta_p^2 = .35$. The posthoc simple main effect analyses showed significant effects of number of axes for all of the five spectrum slope conditions (all *F*s > 36.28, all *p*s = .00, and all η_p^2s > .463). On the other hand, while a spectrum slope effect existed for all conditions with symmetric images regardless of the number of axes (all *F*s > 5.17, $p < .02$, $\eta_p^2 > .11$), no spectrum slope effect was found in the asymmetric condition, $F(1.56, 65.57) = .32$, $p = .67$, $\eta_p^2 = .008$. The main effects for number of axes, $F(1.54, 64.85) = 106.42$, $p = .00$, $\eta_p^2 = .72$, and spectrum slope, $F(1.40, 58.85) = 11.66$, $p = .00$, $\eta_p^2 = .22$ for slope, were also significant.

To further illustrate these effects, we plotted the preference rating difference and the corresponding effect size, measured as Cohen's *d*, between the 16-axis and zero-axis conditions as a function of spectrum slopes (Figure 3A) and between the −1 and 0 slope conditions as a function of the number of axes (Figure 3B). The former represents the axis effect at different slope conditions. The differential rating was from 1.26 to 2.94 ($m = 2.06$, $SD = 0.70$). The effect size was from 0.89 to 2.13 ($m = 1.52$, $SD = 0.52$), which was a very large effect. The latter represents the slope effect at

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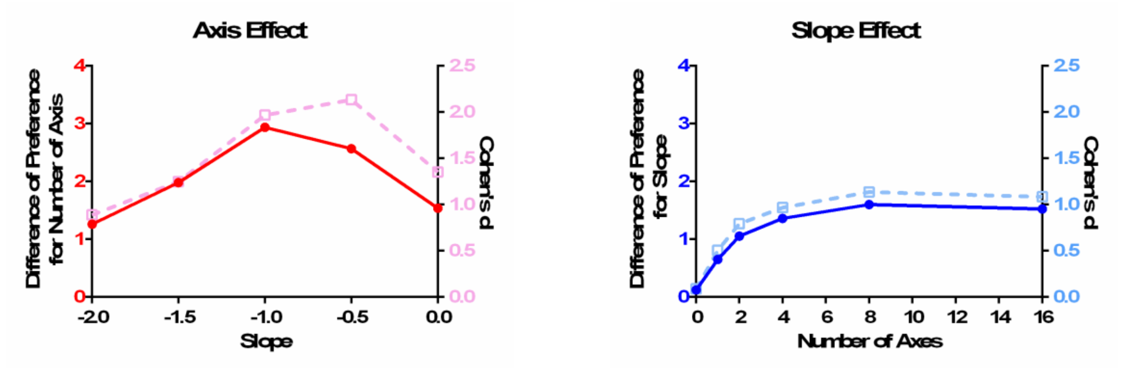
conditions with different numbers of axes. The differential rating was from 0.12 to 1.60 (m = 1.05, SD = 0.57), with an effect size from 0.09 to 1.14 (m = 0.76, SD = 0.40).



(**a**) (**b**)

Figure 3. Axis effect at different slopes and slope effect at different numbers of axes: (**a**) The red filled circles stand for axis effects at different slope conditions. The pink squares are the correspondent Cohen's d values. (**b**) The blue filled circles stand for the slope effects at different numbers of axes. The cyan squares are the corresponding Cohen's d values.

4. Discussion

In this study, we manipulated the spectrum slope and the number of symmetry axes to investigate the effects of amplitude spectrum and spatial structure on aesthetic preference. We measured the preference ratings of images with different combinations of spectrum slopes and numbers of axes. Overall, aesthetic preference increased monotonically as the number of symmetry axes increased but was an inverted-U-shaped function of amplitude spectrum slope. Furthermore, the effect of amplitude spectrum slope was enhanced as the number of symmetry axes increased. That is, symmetry modulated the amplitude of the spectrum slope effect on aesthetic preference.

Because the relationship between preference and spectrum slope had an inverted-U shape (Figure 2), we therefore used a quadratic function to fit our data. The function has a basic form $p = b (s - a)^2 + c$, where p is the preference rating, s is the spectrum slope, and b, a, and c are parameters that determine the shape, horizontal displacement, and vertical displacement of the function, respectively. The values of the parameters in the function are a function of the number of symmetry axes, and can therefore help with assessing its effects. The parameter c determines the function's vertical displacement. Its change therefore corresponds to an additive effect. Hence, if the effect of symmetry axis number was independent from that of spectrum slope, we should expect that only the parameter c would change with the number of axes. On the other hand, if the two factors had an interaction, we should expect that at least one of the parameters a and b would change with the number of symmetry axes because each could multiply s in the function to produce a modulation effect.

Both parameters b and c were exponential functions of the number of symmetry axes, n, while the parameter a was independent from n. Optimizing the curve fitting, we found that fixing a at −1, while $b = -1.56 \times \exp(-1 / n)$ and $c = 3.05 \times \exp(-1.56 / n) + 1.97$, provided an excellent fit to the data. The model accounted for 97.2% of the variance in the averaged data. The RMSE of the model, 0.15, is close to the mean standard error of the data (0.16).

The parameter $a = -1$ indicates that the observers most preferred images with a spectrum slope −1. This −1 slope is common among natural scenes (Burton &Moorhead, 1987; Field, 1987; D. J.Tolhurst et al., 2007). Hence, this may reflect the fact that human observers prefer stimuli whose image statistics resemble those of a typical natural scene (Burton &Moorhead, 1987; Field, 1987; D. J.Tolhurst et al., 2007).

The parameter b reflects the modulation magnitude of the quadratic function. Because $b = -1.56 \times \exp(-1 / n)$, this negative exponent function suggested a decelerating nature of the axis number effect (Figure 4A). That is, the greatest change occurred when the number of axes n was small and

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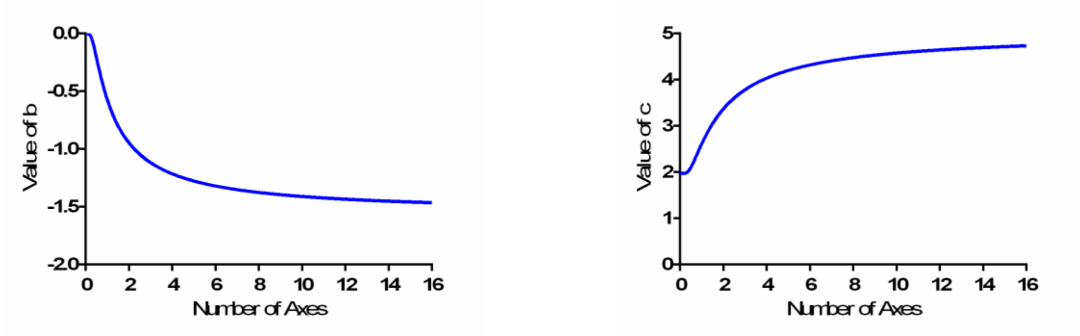
became asymptotic to −1.56 when n was large. In addition, the value of b was always negative. This gave us an inverted-U-shaped relationship between preference and spectrum slope for all numbers of axes (Figure 5), with preference rating p peaking at slope −1.



(a) (b)

Figure 4. The Effects of Number of Axes on Parameters b and c: (a) The parameter b decreased with the number of axes. (b) The parameter c increased with the number of axes.

The parameter c is the intercept of the quadratic function. Because c is also a function of n, it represents the symmetry axis effect by itself. The exponential function $c = 3.05 \times \exp(-1.56 / n) + 1.97$ is always positive (Figure 4B) and greater than the value p produced by $b \times (s - a)^2$. Therefore, parameter c makes the inverted U-shape functions below zero, which all peak at −1 (Figure 5), positive and with different peak values (Figure 2).

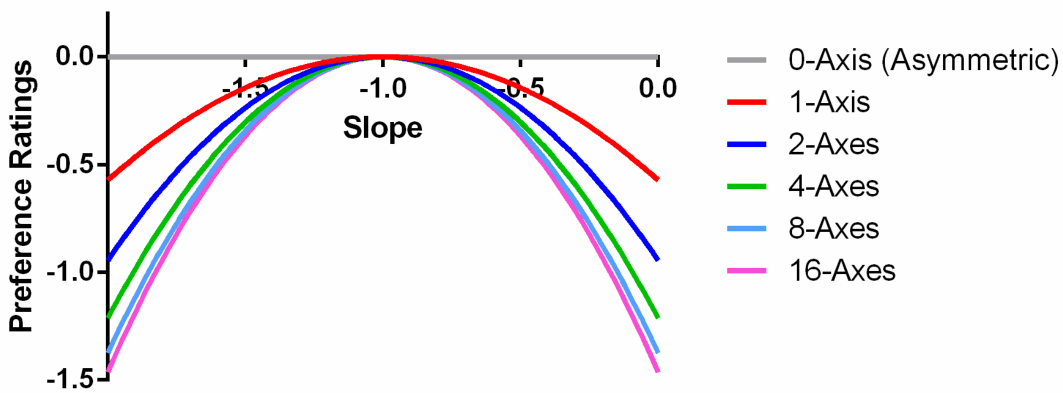


Figure 5. The effects of parameter b on preference ratings. When the parameter $c = 0$, the negative parameter b makes the quadratic functions for all symmetry axis conditions below 0.

To summarize, aesthetic preference is a quadratic function of amplitude spectrum slope, whose modulation depth (b) and intercept (c) are modulated by the number of symmetry axes. The quadratic part of the function can explain the inverted-U-shaped relation between preference and spectrum slope. The increment of the intercept with the number of symmetry axes mainly contributes to the increment of preference with the number of symmetry axes. The modulation depth's change with the number of symmetry axes, then, explains the interaction effect between spectrum slope and the number of symmetry axes on aesthetic preference.

Note that we did not find a slope effect in the scrambled image condition. This seems inconsistent with the previously reported inverted-U-shaped function between preference and spectrum slope [28,29]. This inconsistency may be due to the range of the images used in this and other studies. Because our stimuli contained both highly aesthetically appealing symmetric images and unappealing scrambled ones, the preference ratings for the latter could be compressed by the former. To test this hypothesis, we repeated our experiment with just asymmetric phase-scrambled images with spectrum slopes ranging from −2.5 to 0 by steps of 0.25. Similarly, the observers were instructed to use a 6-point Likert scale to indicate their aesthetic judgment of each image.

The preference ratings averaged across the 17 observers (aged 19 to 37 years) are shown in Figure 6. The red symbols represent the data points, and the error bars show the standard errors. The smooth curve is the fit of a quadratic function. As Figure 6 shows, the preference ratings became an inverted-U-shape function, as reported in previous results (Burton &Moorhead, 1987; Field, 1987; D. J.Tolhurst et al., 2007). A repeated one-way ANOVA, after Greenhouse-Geisser correction, showed that the spectrum slope had a significant effect on preference, $F(1.913, 30.614) = 7.71$, $p = .002$, $\eta_p^2 = .325$. The pairwise comparisons showed significant effects between medium slopes (−1.75 to −1.25) and shallower slopes (−0.5 to 0; all *ps* < .05). This result was fitted by the quadratic function $p = b(s - a)^2 + c$, where s is the spectrum slope, p is the preference rating, and a, b, and c are constants. We empirically found that the function $p = -0.78\ (s + 1.71)^2 + 3.73$ can fit our data well. This showed that the relationship between preference ratings and the images with different spectrum slopes was an inverted U-shape that peaked at about −1.7.

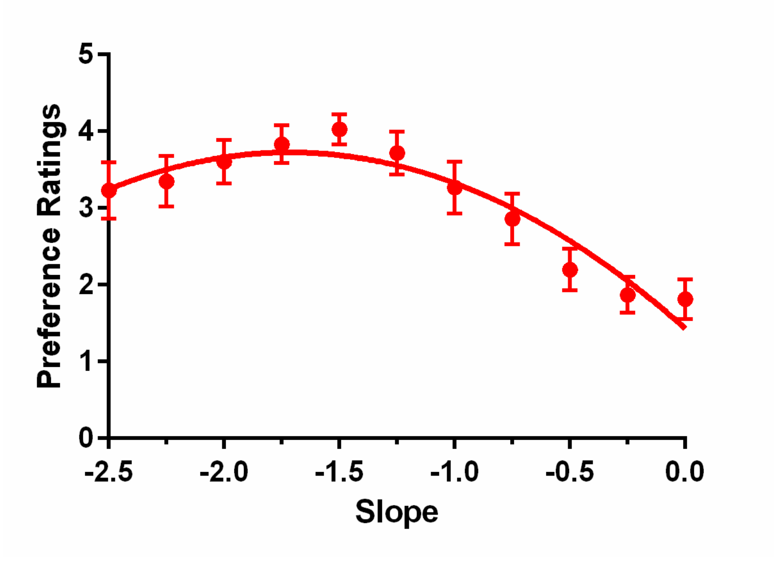


Figure 6. Preference ratings under different spectrum slopes. The red symbols indicate the data points for different spectrum slopes. The error bars are the standard error. The smooth curve is the fit of the quadratic function.

Thus, it is clear that when only phase-scrambled images are in the stimulus set, preferences are an inverted-U-shaped function of spectrum slope. However, when the stimulus set contained both symmetric and asymmetric images, symmetry dominated the aesthetic reference ratings; as a result, the preference ratings for the asymmetric images were always at the lowest level, regardless of the spectrum slope. This implies that previous research that only focused on the images' amplitude domain and claimed the importance of amplitude spectrum on aesthetic preferences had overestimated the role of amplitude spectrum. The symmetric structure, which was coded as the cosine component of the phase spectrum in the Fourier domain, has an enormous impact on aesthetics, as compared to amplitude spectrum.

Although image properties related to symmetric structure and spectrum slope usually co-occur (Chien-ChungChen et al., 2011; Pickover, 1995), our study showed that the two components of an image have individual impacts on aesthetic preferences. The amplitude spectrum slope's effects can be even amplified by symmetry. Hence, the spectrum slope's effects on aesthetic preference observed in the symmetric patterns are not completely due to the coincidence of spectrum slope changes as number of symmetry axes increases, as Chen et al. (Chien-ChungChen et al., 2011)

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claimed. The observed symmetry effect on aesthetics is not merely an artifact of the spectrum slope's effect.

Symmetry and spectral slope are processed differently in the visual cortex. Images with different spectral slopes produce differential BOLD activations in the cortical area V1, V2, and V3 (Isherwood et al., 2017; Olman et al., 2004) and different event-related potentials (ERPs) at around 100 ms (DeCesarei et al., 2013) or 175 ms and 250 ms (Blickhan et al., 2011) after stimulus onset. On the other hand, symmetric patterns produce greater BOLD activation than asymmetric ones do in the lateral occipital (LO), V3A, V4d/v, and V7 but not in the early visual cortical areas such as the V1 and V2 areas (Bona et al., 2014; Cattaneo et al., 2011; C.-C.Chen et al., 2007; Kourtzi, 2001; Sasaki et al., 2005; Tyler et al., 2005). The ERP waveform showed a sustained negativity starting around 200 ms after stimulus onset (Rampone et al., 2019). Thus, it should be clear that symmetry and spectral slope are handled by different brain mechanisms. Our results showed a substantial interaction between the two factors. This may suggest either a downstream mechanism that takes inputs from both mechanisms and can thus integrate these two pieces of information for making aesthetic judgments, or a profound link between these brain mechanisms.

5. Conclusions

In sum, our results showed that the both the amplitude slope and symmetry level influence human aesthetic preferences. The preference ratings increased as the symmetry level increased but had an inverted-U-shaped relationship with amplitude slope, consistent with previous studies. More importantly, we found that the relationship between amplitude slope and aesthetic preference was modulated by symmetry level. That is, symmetry level amplified the inverted U-shape function between amplitude slope and preference. The relation between spectrum slope and preference at different symmetry levels can be explained by a mathematical function, in which aesthetic preference is a quadratic function of amplitude spectrum slope whose modulation depth and intercept are modulated by the number of symmetry axes.

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Conflicts of Interest: The authors declare no conflict of interest.

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