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Aesthetic Preference for Polygon Shape

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Abstract

Abstract shapes can vary in how much they are preferred by observers, but the key factors are still not well understood. In Experiment 1, observers rated the attractiveness of octagonal polygons that varied in contour length but had approximate constant area. Thus, the shapes differed in compactness. Shapes with partial symmetry were judged to be more attractive as were those with greater total contour length. In a second experiment, participants judged polygons with different numbers of concavities but with constant contour length. Shapes with more concavities were considered more attractive. The data demonstrate a preference for greater complexity—both in terms of contour length and as changes in the number of concavities.

Keywords

aesthetic judgment, beauty, polygons, shape perception, shape contour, concavity/convexity

Contour Variation and Perceived Beauty of Polygon Shape

Polygons and Art

Although simple, polygons have long been considered an art form, starting from their use by the Ancient Greeks, and have been incorporated into fine art and design throughout all of recorded art history. As a famous example, the Platonic solids are polyhedra whose faces are regular polygons, and their aesthetic beauty

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and symmetry have fascinated artists for thousands of years. Contemporary examples include architectural friezes and surface pattern design as found in textiles, craftwork, and all forms of decorative ornamentation.

Polygons and Complexity

It is difficult to say what makes a shape complex. More complex shapes may be defined as those having more contour or a greater number of parts (Friedenberg, 2009). Alternatively, shapes that are less redundant may be more complex. Symmetry is a form of redundancy so asymmetric shapes ought to be more complex than symmetric ones. Another issue regards the difference between the objective complexity of a pattern that can be manipulated and measured more easily and subjective complexity that is an observer's internal representation of how complex the pattern is. The internal representation is probably not always identical to the external. Subjective complexity can in turn be broken down into perceptual and cognitive complexity. The perceptual type may be influenced more by stimulus features like part and part arrangements. The cognitive type may be more influenced by cognitive labels or associations (Nicki & Moss, 1975).

The study of visual preference for simple geometrical shapes has a long history. For example, in his pioneering work, Fechner (1876) used rectangles and ovals to test the idea that a specific aspect ratio is preferred (the so-called golden ratio). From a theoretical standpoint, later researchers began to investigate order and complexity and the role these factors play in determining aesthetic judgment. Birkhoff (1932) theorized that forms with more order and less complexity were considered more pleasing. His aesthetic measure (M) was a function of order (O) divided by complexity (C) expressed mathematically as $M = O/C$. He published a set of 90 polygons with associated M values that were determined empirically. The characteristics that he found contributed to perceived beauty in this set were vertical and radial symmetry, balance and conforming to a vertical/horizontal grid. Birkhoff's theory emphasizes order over complexity and therefore is biased toward simple shapes.

Birkhoff's proposal, however, has failed to hold up against subsequent empirical testing (Nadal, 2007; Nadal, Munar, Marty, & Cela-Conde, 2010). As a result Eysenck (1941) formulated a different formula to predict preference, expressed as $M = O \times C$. This formula acknowledges that complex aspects of form can also contribute to beauty. Using a subset of Birkhoff's polygons, he performed a factor analysis and determined those attributes that correlated with preference. These included symmetry, angles close to 90° or 180°, and number of nonparallel sides. Additional correlated variables included equilibrium, repetition and, of special note for the current study, compactness.

Munsinger and Kessen (1964) presented polygons to participants that varied in the number of turns. They found an inverted U-shaped function in which preference peaked at intermediary levels of complexity, with exceptions for shapes that were recognizable or symmetric. Day (1967) found an increase in pleasantness judgments for polygons up to 28 sides that was then followed by a gradual decrease, again supporting the notion that observers prefer moderately complex stimuli. Eisenman and Gillens (1968) found that observers like complex symmetric forms that have elements of simplicity to them, such as symmetry, but also with elements of complexity, such as an increased number of vertices.

Boselie and Leeuwenberg (1985) created a coding scheme to describe polygons and how they produce a pleasing aesthetic response. Their code takes line-angle pairs and applies operators, like number of iterations, to them. To illustrate, in their code, a square would start with a line length and a 90° angle that would then be iterated four times. This square would be judged as attractive because it has only two free parameters in the code: line length and angle. Their formula for aesthetic appeal is $M = R–P$, where R is a set of additional regularities and P the number of free parameters from the code. In their view, a polygon is maximally pleasing when it has the shortest code in their scheme that can describe it, an idea with strong connections to information theory. Katz (2002) mentions some of the shortcomings of the coding model and provides an alternative. He devised a neurally inspired pattern recognition process that breaks polygons down into their component primitives like lines and then reconstructs more complex features.

Based on this research, we can see that complexity is a multidimensional concept. Symmetry, number of sides, side length, number of vertices, vertex angles, and other properties can all contribute to shape complexity and impact upon aesthetic judgments. In the current study, we single out two aspects of polygons for investigation. The first is compactness. Compactness can be measured as the ratio of the contour length to the area of a polygon. The second factor we investigate is the number of concave angles in polygons. We discuss these in greater detail later.

Polygons and Compactness

In previous work, we have shown that observers prefer triangles that are more compact (Friedenberg, 2012). We attributed these results to the *perceptual instability hypothesis*, which states that shapes perceived as more fragile will be judged less attractive. For instance, an elongated right triangle may seem less beautiful if it is viewed with the point down (as opposed to the base down) because it looks as if it will fall over or break more easily. These judgments may be evolutionarily related to perceptual affordances (Gibson, 1986) because unstable objects are either difficult to use or cannot be used.

If compactness is a dominant aesthetic factor, it ought to be preferred not just in simpler shapes like triangles but also in random polygons with a larger number of sides. Random polygons are more complex and irregular. They need not have perfect symmetry or distinct elongation axes. As such, they are more representative of natural forms like animal shapes but can still be manipulated with some degree of precision. The purpose of this study is to see if compactness can be generalized to this larger category of shapes. If so, it would provide further support for the perceptual instability hypothesis.

One way to manipulate compactness is to vary external contour length while holding internal area roughly constant. This can be done in polygons by varying the extent to which contour alternates about a fixed radius from the pattern center. The first consideration is that the *n*-sided polygon that has the largest area relative to its perimeter is a regular polygon with *n* sides, in which all angles are equal in size and all sides are equal in length. Any area-preserving deviation from strict regularity necessarily increases the length of the external contour. The closer the vertices that define the contour of such a polygon remain to this radius, the shorter its perimeter will be relative to its area and the more compact the form will be. The farther they vary from this radius, both closer to the center inward of the radius or outward away from it, the longer its perimeter will be relative to its area and the less compact it will be. In the latter case, the form can be seen to *develop* parts and features that make it more diffuse and spread out.

We define compactness (C) as the ratio of the area (A) to the contour length (L), expressed as $C = A/L$. When A is large and L is small, C is high and the shape is compact. When A is small and L is large, C is lower in value and the shape is diffuse. The measure L/A is the inverse of compactness and measures how much a shape's contour meanders over space. Later in this article, we see if these values, expressed in terms of perimeter and area, will correlate with observer preferences. Compact forms are those with few or small extensions. Dispersed forms are those with many or large extensions and parts. To use biological examples in the former case, we would have a clam because it has a shell that is rounded, curving back on itself with very little feature variation. In the latter case, we have an octopus because each of the eight tentacles deviates far from the main body. Examples of polygons that vary in compactness are shown in Figure 2.

Our study is unique in that it is one of very few to investigate properties that seem directly tied to complexity, namely perimeter length and number of concave vertices. Our work therefore extends the notion of complexity to include these two shape parameters and supports earlier findings in the literature that show a complexity preference.

Experiment 1

In Experiment 1, we varied the compactness of octagonal polygons, generated as described earlier, to investigate what effect this may have on visual preference for these shapes. If compactness has a strong influence, we would expect compact forms to be rated as more beautiful. In contrast, forms that are less compact

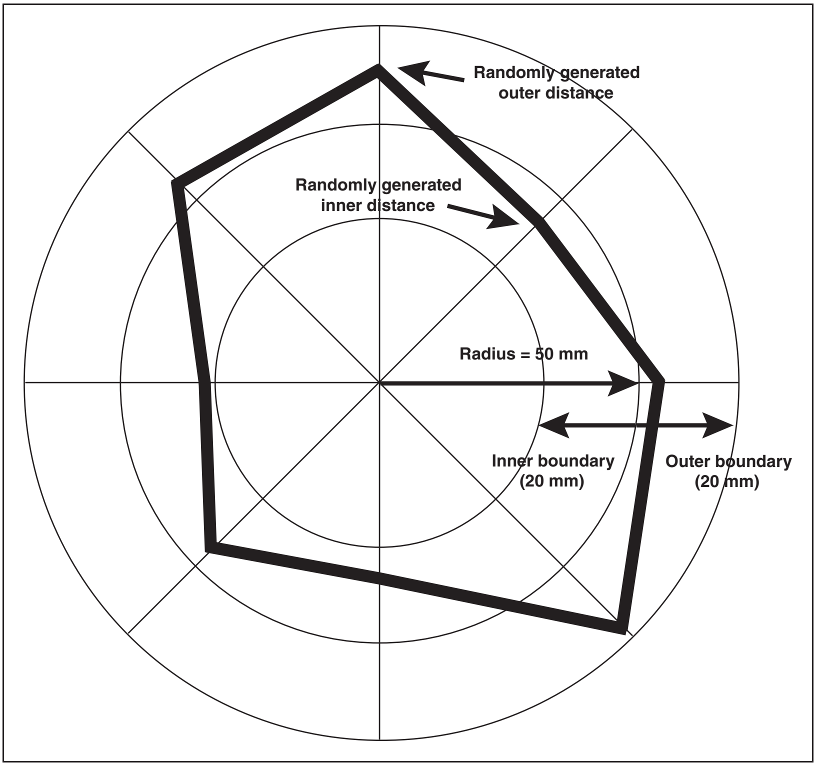

Figure 1. Polygons in Experiment 1 were created following these steps: (a) Choice of one of eight axes. (b) Choice of vertex placement on axis as away or toward pattern center. (c) Random generation of a distance toward or away from radius within a range determined by the condition. (d) Repeat for all axes. (e) Connect adjacent vertices with a straight line. Only the straight contour lines were visible to participants.

should be less attractive. In terms of complexity, compact shapes can be considered as simple because there is less contour as a proportion of the area. Consequently, diffuse shapes are more complex because they contain a greater amount of contour relative to their area.

Method

Participants. Twenty-one undergraduates from Manhattan College in New York participated for extra course credit. There were five males and 16 females. Average age was approximately 20 years. All vision was normal or corrected to normal.

Stimuli. Each pattern was presented in the center of a computer monitor with a diagonal screen length of 43 cm. Average contour distance from the center of the

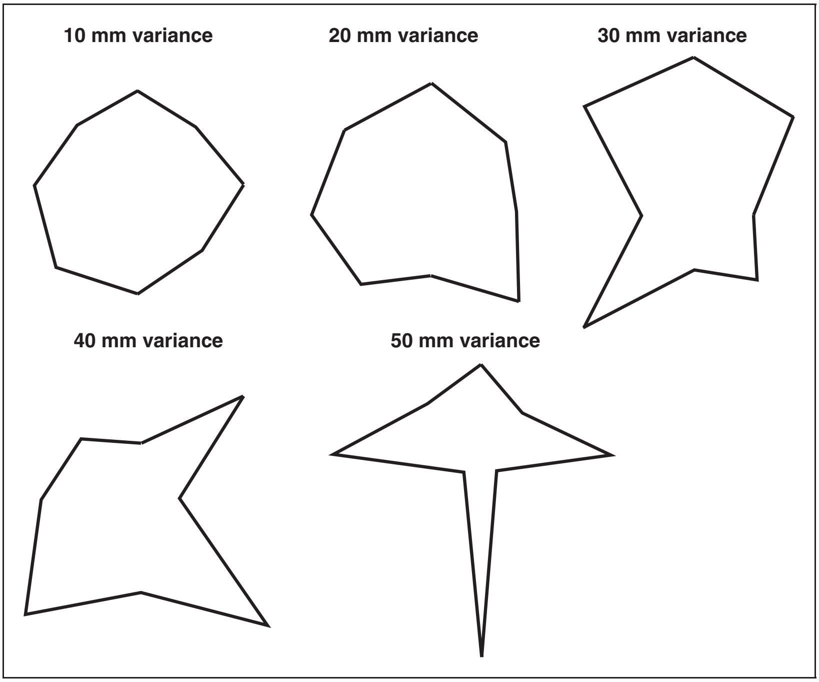

Figure 2. Examples of polygons from each of the five contour variance conditions in Experiment 1.

screen was 50 mm, subtending 5° visual angle. The stimuli averaged out to be 100 mm in width, subtending 10° of visual angle. Viewing distance was about 45 cm. The contour lines appeared in black on a white background and were 0.5 mm in width.

We generated contours in five steps. First, one of eight random orientations was chosen. These orientations dissected the circular region into 45° intervals starting at vertical (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°). These orientations correspond to a vertical, a horizontal, and a left- and right-oblique axis. A direction either toward or away from the pattern center was then selected. Third, a distance from the baseline radius was next generated. The distance ranged from 1 to X millimeters, where X was 10, 20, 30, 40, or 50 millimeters depending on the condition. A vertex was placed by this amount toward or away from the origin along the given axis. Once this was performed for all eight orientations, the successive vertices were connected with straight lines to form the polygon (see Figure 1).

Contour length was determined as the range relative to the radius about which each point could lie. Range in this sense refers to the size of the radii outward and inward from the fixed starting radius within which the contour could fall. If this range were small, say 10 mm, then the points stayed close to the

50 mm circular radius and when joined produced a more compact shape. If this range were larger, say 50 mm, then the points could vary significantly in either direction from the radius and when joined produced a more spread out and jagged shape.

Because each direction either outward or inward was random, the vertices varied on average equally both toward and away from the center. This maintained a relatively constant polygon area across all of the shapes. Figure 2 depicts examples for each of the five contour variance conditions. Because these polygons are constructed in this constrained manner, they are not true simple polygons but should be referred to as semirandom or irregular simple polygons.

Procedure. Participants completed a consent form and read a set of typed instructions. They were then verbally instructed to rate the perceived attractiveness of each irregular simple polygon according to their own subjective standard. They were told to equate attractiveness with beauty or pleasantness (i.e., not to think of sexual attraction) and that the judgments were subjective, meaning there was no right or wrong answer. There are many terms used in the aesthetics literature to infer perceived beauty, among them are *attractiveness*, *pleasantness*, and how *interesting* a pattern is. In our two studies, we used the term *attractiveness*, but it was clearly explained to participants that we were equating attractiveness to beauty in a general or abstract sense and not how it would be applied solely to human figures. After the experiment, participants completed a survey in which they were asked to provide reasons for why they liked or did not like the patterns.

Ratings were made using a numerical one to seven (1–7) scale, with higher numbers corresponding to higher perceived attractiveness. Each observer indicated their response by pushing one of these seven numbers on the numeric keypad. If they pushed any other key, the trial would fail to advance. Participants were allowed to view each pattern as long as they wished.

The primary variable of interest was contour variance. Increases in this variance produced increases in contour length and correspondingly made shapes less compact. There were five levels of variance ranging from 10 to 50 millimeters (10–50 mm) in 10 mm increments. Ten unique irregular simple polygons were generated for each of these five conditions resulting in 50 unique patterns per block. There were four blocks in an experiment and a total of 200 trials. The 50 unique polygons in each block were presented every time in new random orders. A complete experimental session lasted about 20 minutes.

Results

The distribution of the ratings data was approximately normal and so was not transformed. A Kolmogorov–Smirnoff test for the normality of the response distribution showed the data did not deviate from normal assumptions ($D = 0.15$ at a 0.01 cutoff value). There were a small number of trials on

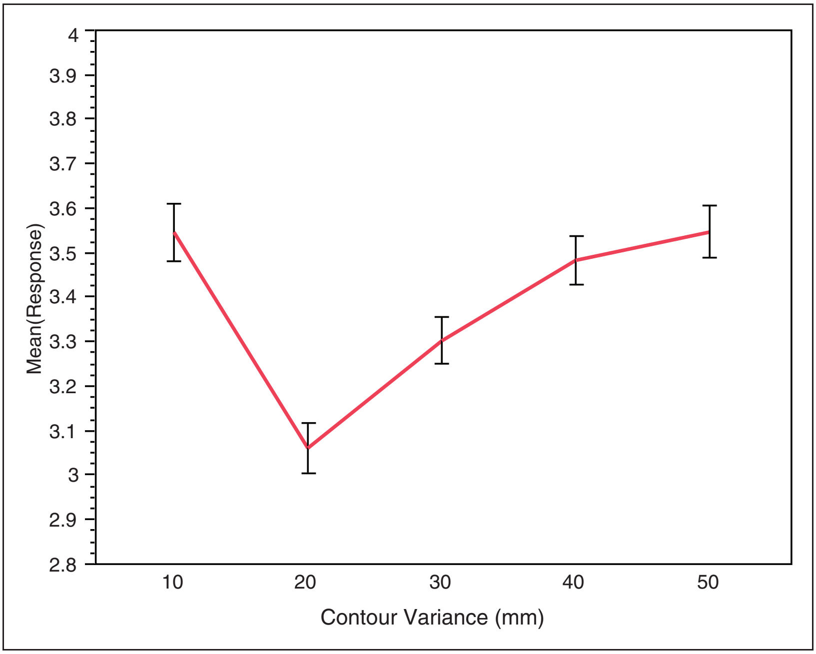

Figure 3. Mean attractiveness ratings and standard error bars (±1 *SE*) for each level of contour variance in Experiment 1. Polygons with longer contours are rated higher in perceived beauty.

which participants took longer than 4 seconds to respond. These were considered as outliers and deleted. They constituted less than 1% of the data. The cutoff point for eliminating outliers in both this and the next experiment were 0.5% of the data. These responses occur mostly at the beginning of the study and so indicate an adjustment to the task. Outliers at other points throughout the experiment are believed to reflect a lapse in attention or fatigue. Comparison of the results with and without these outliers does not affect the result.

Figure 3 shows means and standard error bars for each level of contour variance. A one-factor analysis of variance was performed on the rating scale data. The effect of contour variance was significant, $F(4, 100) = 13.37$, $p < .01$. There were higher ratings for the 10 mm and 50 mm variance conditions, showing that these were more preferred. In addition, there was a regular increase in ratings from 20 mm to 50 mm. This effect appears to be linear, but only within this range with the 10 mm condition excluded.

In addition, we correlated responses with perimeter (P) and with perimeter divided by area (P/A). Ratings do increase with an increase in perimeter length, $r(39) = .54$, $p < .01$ and with a decrease in compactness, $r(39) = .62$, $p < .01$. Both of these analyses were performed with the 10 mm contour variance condition removed. We believe these shapes are being judged using a different process as they are all convex and quasi-symmetric. This is explained in the discussion section later. Figure 4 shows the scatterplots for these two correlations.

One of the problems with using polygons in psychological research concerns meaningfulness and familiarity. If a polygon looks like an object an observer may have seen before, it could bias increased liking (Hekkert, Thurgood, & Whitfield, 2013). To investigate this possibility, participants completed a survey after they had finished the experiment. One question on the survey asked whether they thought any of the polygons looked familiar to them and if so which ones. Many of the participants reported experiencing familiarity, but it was only to a small number of polygons out of the total set. We removed the data for these polygons from the dataset and reanalyzed. The pattern of results were unchanged so we conclude that familiarity was not a serious confound.

Discussion

Surprisingly, our results show the opposite of the compactness prediction. Participants rated less compact polygons as more attractive. There was a distinct preference for polygons with increased contour relative to area. This increase in contour length makes the shapes more complex so preference in these forms was for greater complexity. Greater contour length equates with greater complexity, as there is simply more of a shape present. It is perhaps the simplest quantitative measure of complexity. Note that our rating function does not indicate a build up to a peak followed by a decrease, that is, there is no inverted U-shaped function. It is possible that the peak could be outside the range that was tested. Additional research with greater variance and number of sides would be necessary to discover any such peak.

Not all of the conditions were part of an increasing trend. Shapes with the smallest contour variance in this experiment were judged relatively high in attractiveness. In these polygons that we used, there are only convex angles, and the shapes resemble regular octagons. These patterns are globally quasi-symmetric. Axes drawn through their vertices approximate reflective symmetry axes, meaning that one-half of the pattern divided along these lines and folded over will somewhat match the remaining half.

These polygons have approximate eightfold rotational symmetry. A rotation of the entire shape by 45° clockwise or counterclockwise will cause the pattern to roughly superimpose upon itself. Symmetry, whether reflective, rotational, or translational, is found in the arts of all cultures and as such is generally considered beautiful (Stevens, 1981). Symmetric faces (Fink, Neave, Manning, & Grammer, 2006; Rhodes, 2006) and symmetric bodies (Bertamini, Byrne, & Bennett, 2013; Tovée, Tasker, & Benson, 2000) are judged as more attractive. Symmetric patterns that are regular are also high in figural goodness. They are simpler or have high redundancy and form better gestalts (Nucci & Wagemans, 2007).

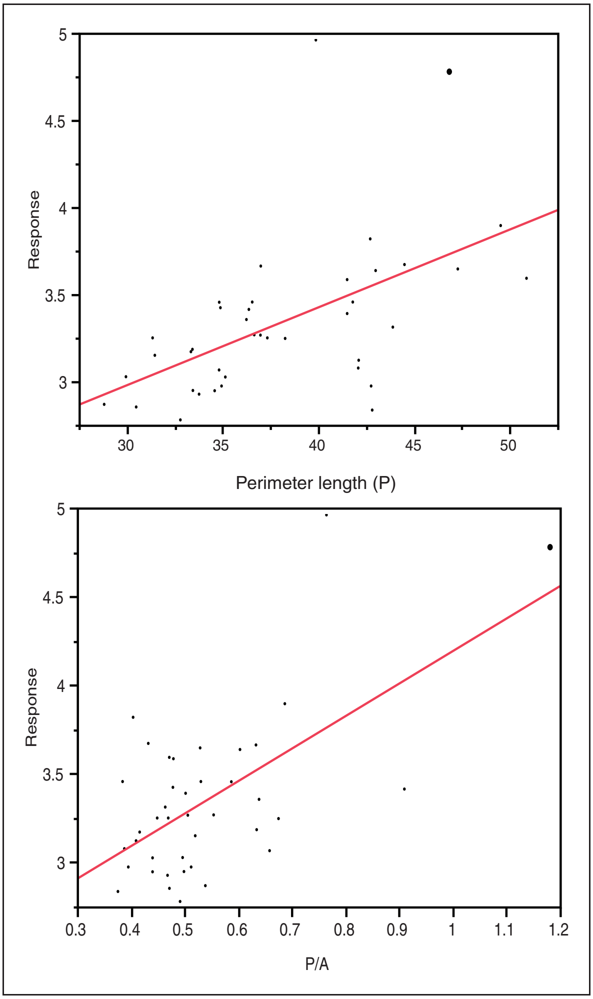

Figure 4. Scatterplots showing the relationship between response ratings and polygon perimeter length and between responses and perimeter length divided by area. As P/A increases, compactness decreases.

If symmetry or regularity can account for the smallest deviation case, how do we account for the upward trend for the remaining conditions? One explanation concerns local feature salience. Increased contour variance lengthens the distance between adjacent points on the polygon so that the straight lines connecting them are longer. Perceptually, this makes the features sharper and thus more noticeable in appearance. There is a controversy in the literature on whether sharp or smooth forms are preferred. Initial findings suggested that curved forms appear less threatening and are thus rated more attractive (Bar & Neta, 2006). Subsequently, it has been found that there is a preference for smooth but also for more complex and spikey objects (Phillips, Norman, & Beers, 2010).

Experiment 2

In the first experiment, variation was introduced in the form of additional contour. Polygons with similar areas, but longer outer contours were preferred, with the exception being those that were regular and symmetric. One aspect of contour complexity is polarity, which is whether features are convex or concave. When the vertex between two lines is convex, it forms a protrusion away from the inside of the pattern. When the vertex is concave, the feature becomes an indentation toward the inside of the pattern.

In this second experiment we set out to explore the role that convexity and concavity play in determining perceived attractiveness for polygons, we ask the question: Do the number of concavities and convexities in a polygon contour affect aesthetic judgment? If observers prefer more complex stimuli, as they seem to in terms of contour length in Experiment 1, then we can predict they will also prefer polygons with greater feature variety. More specifically stated, polygons with a greater number of contour polarity shifts should be preferred. In the next study, we generate octagons that vary in the number of times they switch between concave and convex features while holding contour length constant. Although Experiment 1 focused on contour length, which is a quantitative estimate, Experiment 2 will focus on contour change, a qualitative estimate.

Method

Participants. A total of 15 Manhattan College undergraduates participated in the study. They received extra course credit for doing so. There were two males and 13 females. Average age was 20. Vision was normal or corrected to normal.

Stimuli. In our notation, we use a lowercase v to designate a concave vertex and a lowercase x to designate a convex vertex. An octagon can contain between zero and four (0–4) concavities. For the zero case, we again have a quasi-symmetric polygon (denoted xxxxxxxx). There is only one instance with a single vertex (vxxxxxxx). There are three sequences of octagons with two concavities (vxxxvxxx, vxxvxxxx, vxvxxxxx), two sequences with three concavities (vxvxxvxx, vxvxvxxx), and one with four (vxvxvxvx). An example from each of these conditions is shown in Figure 5.

Polygon contours varied within a donut-shaped region whose inner boundary was 30 cm (3° visual angle) from the screen and whose outer boundary was 90 cm (9° visual angle) from screen center. These distances are thus comparable with those in the first experiment. Vertex coordinates were generated randomly for

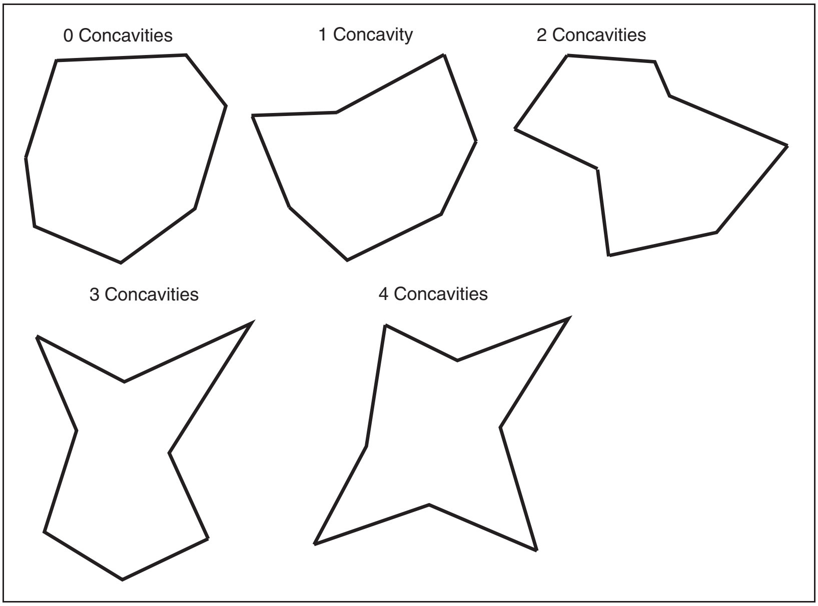

Figure 5. Examples of polygons for each of the eight concavity conditions in Experiment 2.

each axis. These points were then connected to form the polygon. Patterns were generated until we obtained 10 examples for each polarity sequence.

Procedure. The procedure was identical to that in Experiment 1. Participants viewed each polygon and rated their attractiveness on a 7-point scale with higher numbers indicating higher perceived attractiveness. Participants were given as much time as needed to make a judgment. Response times were measured from stimulus onset to response termination.

There were 10 different examples for each of the eight conditions with a total of 80 unique stimuli per block. An experimental session consisted of four blocks, yielding a total of 320 trials. Order of presentation for the 80 polygons was randomized in each block. Participants took about one-half hour to complete the study.

Results

All responses that took longer than 3.5 seconds were considered outliers and removed from analyses. These were far less than 1% of the data. Ratings were normally distributed and were not transformed. The Kolmogorov–Smirnoff test showed the distribution did not deviate from normal ($D = 0.15$ at a 0.01 cutoff value). We conducted a one-way analysis of variance with contour polarity as the factor and ratings as the dependent measure. The effect of

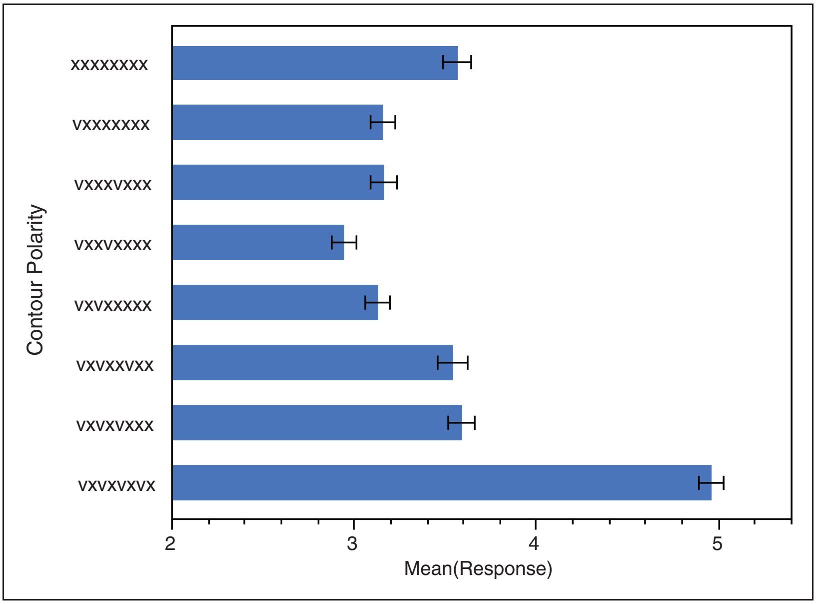

Figure 6. Mean attractiveness ratings and standard error bars (± 1 *SE*) for each polarity sequence in Experiment 2.

contour polarity was significant, $F(7,\ 112) = 77.52$, $p < .01$. The means and standard errors for the eight conditions are depicted in Figure 6.

The all-convex polygons this time received only moderately high scores. Unlike the first experiment, they were not the highest rated. Polygons with a single or a double concavity as a group scored the lowest. Those with three concavities were liked second best, and those with four concavities were liked the most.

These effects can be more clearly seen in the derived variable of polarity shifts, where we pool together conditions containing a given number of shifts regardless of sequencing. The overall effect portrayed in Figure 7 shows a dip for polygons with one or two concavities and an increased liking for those with three and four. The all-convex and the three concavity cases are about equal. As was the case in the first experiment, we deleted data corresponding to familiar polygons. This left the basic pattern of results unchanged so we concluded that meaningfulness of the stimuli was not a confounding variable.

Discussion

In this experiment, we find that observers prefer polygons with a greater number of concave vertices. These vertices are the location where two protruding features abut one another. They signal a change in the direction of a contour. As such, they add valuable information to a shape description and so are likely to

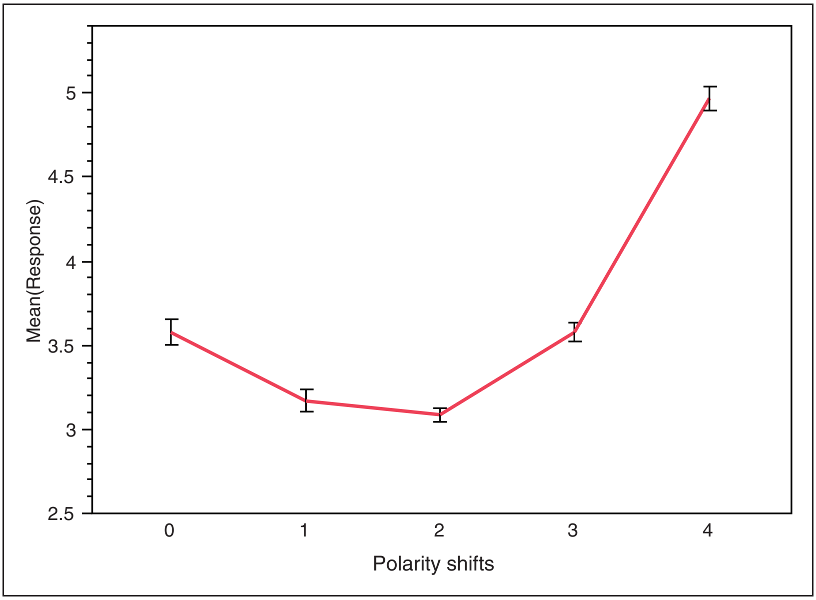

Figure 7. Mean attractiveness ratings and standard error bars (±1 *SE*) for number of polarity shifts in Experiment 2. Those patterns with a greater number of concave vertices are judged higher in perceived beauty.

increase the perceived complexity of the shape. We infer from the ratings that our participants may prefer them for these reasons.

The use of the term *concavity* can be applied to shapes with curved contours as well as those with straight edges. Because our concave features are with straight edges only, we cannot necessarily generalize our results to curved shapes. We have already mentioned that participants seem to judge straight and curved shapes differently (Bar & Neta, 2006). This is an interesting avenue for future work as straight-edged objects are typically artifacts and human-constructed while curved objects are more often part of the natural world, a technological versus biological difference.

The three and four concavity patterns do suggest a positive trending function, but as we did not include patterns with more concavities, it is difficult to tell if this upward trend continues. In future work, we plan to test patterns with a greater number of polarity shifts. As with contour length, there may be a peak response to contours with a larger number of alternations after which ratings could level off or decrease.

General Discussion

We report two experiments in which we tested aspects of irregular polygons that can explain visual preference. In Experiment 1, we found that attractiveness ratings for octagonal polygons increased as the variable length of their outer contours increased. The data suggest that observers prefer shapes with longer contours when their total area is held approximately constant. Longer contours in these patterns results in greater feature salience: The protrusions and intrusions of the contour about the center become more noticeable. Less contour variation produces more globally rounded and compact forms, while greater variation results in more alternating and extended forms. We would like to emphasize that terms like *salience* and *elongation* as we have been using them here are our own interpretations of the results.

The results of Experiment 1 run counter to the hypothesis that observers prefer more compact shapes. This idea had been proposed on the basis of earlier findings where more compact triangles with shorter contours were preferred (Friedenberg, 2012). In that study, it was suggested that compact forms are preferred because they are perceived as less fragile: what we call the perceptual instability hypothesis. So how do we reconcile these findings? In the previous study, the patterns were triangles and an increase in contour length corresponded to an increase in elongation based on ratings and preference data. It is possible that this factor contributed to the sense of instability because longer and narrower objects can teeter and fall over more easily. Hypothetically, they can also be broken into pieces more easily.

Importantly, this argument does not apply to the current stimuli. An increase in contour length here did not change the object's overall elongation and so did not seem to affect perceived instability. With the random polygons in the current experiments, there were noticeable increases in the length of a feature or portion of the total contour. Measurement estimates show that these angular features jutted out at most by 40% of total shape length. This is a local rather than global change in elongation, however, and appears to contribute less to perceived instability.

In Experiment 2, we introduced a different type of manipulation of the polygon. Rather than varying feature length, we varied feature type. Features here were defined as convexities. For octagons, there were eight concave/convex feature sequences ranging from no concavities to four concavities. Polygons with no concavities were moderately preferred, perhaps because they are quasi-symmetric. Polygons with one or two concavities were preferred least, while those with three and four were preferred most. The general trend of these results suggests that participants prefer patterns with the greatest amount of variety.

In summary, we can make several statements. First, contour length impacts on aesthetic preference when area is held approximately constant. Observers consistently judge polygons with longer contours as more attractive, at least within the range of our stimuli. Second, contour variation affects aesthetic preference. Polygons with a greater number of contour alternations were judged as more attractive with our stimuli. Third, the results for the patterns used here do not support the perceptual instability hypothesis, most likely because our polygons lack a salient global axis.

There are several possibilities for future work. One could create polygons with global axes, either symmetric or elongated and vary their orientation and length. Polygons with longer axes may be judged as less attractive in congruence with an object fragility account. One could also vary local feature salience either in isolation or in conjunction with global axes, in effect *pitting* these two forces against each other to see how and if they interact. Total object complexity could additionally be manipulated by increasing the number of sides in a polygon beyond the eight-sided figures we use here or by increasing the degree to which contour wanders relative to our patterns. There may a point at intermediate complexity levels where aesthetic judgments peak and then fall, thus exhibiting the so-called inverted U-shaped function.

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