Aesthetic Issues in Spatial Composition:

Effects of Vertical Position and Perspective on Framing Single Objects

by

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Abstract

Aesthetic preference for the vertical composition of single-object pictures was studied through a series of two-alternative forced-choice experiments. The results reveal the influence of several factors, including spatial asymmetries in the functional properties of the object and the typical position of the object relative to the observer. With asymmetric side views of objects, people generally prefer objects typically located below the observer's viewpoint (e.g., a bowl or swimming stingray) to be below the center of the frame and objects typically located above the observer's viewpoint (e.g., a light fixture or flying eagle) to be above the center of the frame. In addition, people generally prefer symmetric views of those same objects from directly above or directly below to be closer to the center of the frame. We suggest that these results can be unified by the hypothesis that people prefer the object's "affordance space" to be centered within the frame.

A classic problem facing virtually anyone who attempts to create an aesthetically pleasing two-dimensional image is how to compose it within the confines of a simple rectangular frame. Despite the pervasiveness of this challenge and more than a century of investigation, beginning with Fechner (1871, 1876), little is known scientifically about the factors that actually influence people's preferences for spatial composition. There is no dearth of admonitions and advice in the literature on the aesthetics of spatial composition from artists and art theorists who espouse their own ideas about what people *should* like (e.g., Bell, 1914; Greenberg, 1961), but comparatively few scientific studies have been undertaken to determine what people actually do like, especially concerning the issue we address here: the vertical placement of an object within a frame.

Before delving into this specific topic, however, it will be useful to consider briefly our approach to the scientific study of aesthetic response. Most people presume that aesthetics is the study of how people respond to art and that aesthetics is therefore necessarily about people's response to art objects. In our view, however, aesthetic response is a complex, multidimensional aspect of human experience that depends on many things – biology, culture, past history, and present context, to name a few – but always includes a bipolar evaluative dimension related to pleasure/displeasure that occurs in response to virtually all visual stimulation, not just art (see Palmer, Schloss & Sammartino, 2012). It tends to arise spontaneously in its most extreme forms ("Ah! I love it!" or "Ugh! I hate it!"), but it can also be brought to consciousness by certain contexts (e.g., going to an art museum or shopping for home decor) and tasks that focus the viewer's attention specifically on it (e.g., being asked which of two images one prefers in a perceptual experiment).

Art, in contrast, is a subset of human artifacts that have been specifically created to evoke aesthetic experiences in the creator and/or other viewers. The question of what features beyond this minimal characterization are required for an object to be considered art – aesthetic intent, emotional arousal, free play of the imagination, novelty, meaning, etc. – is a controversial one that has engaged philosophers from Plato, Aristotle, and Kant to the present day without producing any clear consensus (see Shimamura & Palmer, 2012, for several contemporary views). Its consideration is beyond the scope of the present article.

The relation between art and aesthetics, at least as we consider them here, is much weaker than usually supposed. One might try to define it by supposing that art constitutes the set of objects that characteristically produce positive aesthetic experiences in viewers, but a moment's reflection shows at least two fundamental problems. First, although positive aesthetic responses often arise from viewing art objects, they also produce neutral and even negative aesthetic responses in many viewers, a good example being Duchamps's famous urinal entitled "Fountain." Second, most people have positive aesthetic responses to many objects, including certain flowers, people, and landscapes, that do not qualify as art simply because they are not human artifacts.[1]

A variety of previous studies have demonstrated that spatial composition within a rectangular frame matters in the aesthetic impact of visual images. Most have concentrated on the "balance" of images: how its elements are arranged horizontally within the frame. This is partly because of the emphasis placed on balance by art theorists (e.g., Arnheim, 1974, 1988) and

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[1] Even though the images we created are framed visual artifacts about which viewers make aesthetic judgments, we do not claim them to be art, because our intent was only to study viewers' aesthetic responses scientifically rather than to provide the viewer with aesthetic experiences for their own sake. We do claim that viewers have aesthetic responses to them, however, and that they can make reliable discriminations of aesthetic preference among them.

partly because of the productive analogy with gravitational balance in physics. For example, McManus, Edmondson, and Rodger (1985) made explicit use of the physical metaphor by asking participants to move a fulcrum horizontally under an image until it was visually "balanced." Participants viewed works of art as well as abstract displays of one or two red, green, or blue squares. Overall the art works were balanced near the center of the frame, with more images balanced slightly left of center, and position was the most important factor. More recently, McManus, Stöver, and Kim (in press) tested a quantified version of a balance theory proposed by Arnheim (1954, derived from Ross, 1907), using a physicalist model of pixel "weight," in which black is maximally heavy and white maximally light. The data from observers' balance judgments did not support the model, however.

Locher and colleagues have examined horizontal balance by analyzing a free creative process (Locher, Stappers, & Overbeeke, 2003; Locher, Cornelis, Wagemans & Stappers, 2001), eye movements (Nodine, Locher, & Krupinski, 1993), and discriminations between original and altered compositions (Locher, Stappers, & Overbeeke, 1999). For example, design students created compositions from variously shaped cut-outs (circles, squares, rectangles, and leaves) and were videotaped in the creative process to assess the role of spatial and/or physical balance. In the overwhelming majority of compositions, the physical weight was roughly evenly distributed around the center (Locher, et al., 2001, 2003). Subsequently, Locher, Overbeeke and Stappers (2005) examined the perception of balance in six abstract paintings by Piet Mondrian together with variations of those paintings in which the colors (red, blue, and yellow) were interchanged. They found that Mondrian's originals were all judged to be balanced near the center, whereas the manipulations were generally perceived as less well-balanced. No data on aesthetic preference or response were collected, however, and the elements of the images were abstract and meaningless.

In contrast, recent research on spatial composition of pictures containing meaningful objects has revealed systematic discrepancies from balance. Palmer, Gardner, and Wickens (2008) studied aesthetic preferences for spatial composition within rectangular frames by varying the horizontal placement of a single object. Consistent with a preference for balance, they found that people systematically preferred a vertically symmetrical, forward facing object to be centered in the frame (the “center bias”). Inconsistent with a preference for balance, however, they also found that people systematically prefer an asymmetrical left-facing or right-facing object (e.g., a side view of a dog) to be located distinctly off-center, such that the object faces into, rather than out of, the frame (the “inward bias”).[2]

Leyssen, Linsen, Sammartino, and Palmer (2012) extended these results by studying pictures containing two meaningful objects. Using ranking, two-alternative forced choice (2ACF), and method of adjustment tasks, they consistently found strong semantic biases: observers preferred images in which related objects were horizontally close together (e.g., a wine bottle and a cake; a bottle of dish soap and a sponge) and unrelated objects were far apart (e.g., a wine bottle and a sponge; a bottle of dish soap and a cake). Somewhat surprisingly, these

[2]The well-known "rule of thirds" compositional heuristic may seem consistent with this inward bias, but it is not sufficient to account for other results. The rule of thirds states that the focal object should be placed at one of the four points of intersection created when the frame is divided into equal thirds horizontally and vertically (e.g., Smith, 1797; Field, 1845). It clearly implies that the subject should not be placed at (or even near) the center of the frame either horizontally or vertically, but at or near the third-points, which are distinctly off-center. Nevertheless, the maximal preference for forward-facing symmetrical objects is clearly at the center (Palmer, Gardner, and Wickens, 2008), thus contradicting the primary tenet of the rule of thirds.

semantic relatedness effects were much more robust than balance effects, which were seldom evident when semantic effects were strong.

Other work on aesthetics and spatial composition has taken an observational approach by analyzing existing corpora of paintings in various ways. For example, Tyler (1998a, 1998b, 2007) found that one of the two eyes in non-profile portraits of human faces almost always lies along or very close to the vertical midline of the frame. McManus and Thomas (2007) found no corresponding preference for an eye to be centered in a 2AFC task, however, using pairs of portraits of the same person, one with an eye centered in the frame and one with neither eye centered. An observational result inconsistent with balance arose in analyzing the spatial properties of paintings and drawings of single animals in medieval bestiaries (Bertamini, Bennett & Bode, 2011). Objective measurements of such images revealed a bias analogous to Palmer et al.'s (2008) inward bias: there was reliably more space in front of the animal's head than behind its tail.

In contrast to this body of research on horizontal composition and balance, we know of no prior research that has addressed preferences for spatial composition in the vertical dimension. We used a methodological and theoretical framework similar to our previous research on horizontal composition of single-object pictures (Palmer et al., 2008) to understand compositional biases in single-object pictures when the only factor that varied was the object's vertical placement.

General Methods

Participants. Participants in all four experiments were students at the University of California, Berkeley, who were naïve to the purpose of the experiment, received partial course credit in their undergraduate psychology course, and gave informed consent.

Procedure. Participants viewed pairs of images on a computer screen from approximately 60 cm. They were instructed to look at each screen and to press either the left or right mouse button to indicate which of two images they preferred aesthetically. They proceeded through the trials at their own pace and were given breaks at appropriate intervals.

Stimuli. Each trial consisted of a pair of colored images on a neutral gray background depicting the same object at different vertical positions within the frame. Stimulus displays were prepared using Adobe Photoshop and were presented in randomized order by programs written in Presentation software (www.neurobs.com).

Experiment 1: Objects Supported by a Horizontal Plane Below Eye Level

We began by studying a nearly pure side-view of a ceramic bowl resting on a table-like horizontal surface as a canonical single-object scene in which the vertical position of the object might vary. Such a scene is, in effect, a two-object scene, because explicitly or implicitly, the vertical position of the horizontal edge of the supporting surface must be considered as well as that of the focal object itself. In this initial exploratory study, we simplified the image set by always placing the horizontal edge of the supporting surface at the middle of the object, which was located at one of five equally spaced heights, with the third position being at the center of the frame.

We also varied the aspect ratio of both the frame and the object, creating a wider (dish), neutral (bowl), and taller (vase) version of the same object (see Figure 1A) within a horizontal or vertical frame (see Figures 1B, 1C). The frames were equal in area but varied in aspect ratio: 4:3 for the horizontal frame and 3:4 for the vertical frame. The objects were also approximately equal in area but varied in aspect ratio: 2:1 for the dish, 1:1 for the bowl, and 1:2 for the vase, respectively. We expected people to prefer compositions in which the aspect ratio of the frame was most similar to the aspect ratio of the object, with the caveat that there might be an overall bias toward the horizontal frame shape due to familiarity. Each object shape was compared to the same object in both frame shapes to detect possible interactions in preference between the aspect ratios of the object and frame.

Methods

Participants. There were 12 participants, whose mean age was 19.3 years.

Design. The experiment consisted of 420 trials, resulting from the pairwise combinations of the same object (dish, bowl, or vase) located at each of 5 vertical positions within both of the frame shapes, balanced for screen position (i.e., the permutations of ten items – one of the objects at the five positions in the two frame shapes – chosen two at a time, for each of the three objects). The five positions were located 20%, 35%, 50%, 65% and 80% of the distance from the bottom to the top of the frame (Figures 1B, 1C).

Displays. Stimulus displays were presented on a 19" monitor with a resolution of 600 x 800 px. Each screen consisted of a pair of colored images on a neutral gray background. The two different frame shapes (horizontal: 360 x 270 px; vertical: 270 x 360 px) were presented in the upper left (150 px above and 200 px left of frame center) and lower right quadrants (150 px below and 200 px right of frame center). The object was a ceramic bowl, which was photographed from a side-view perspective and rescaled into its different aspect ratios (100 x 50 px for the bowl, 75 x 75 for the cup, and 50 x 100 for the vase), with the texture on the bowl being reapplied at the original aspect ratio such that any resulting textural irregularities on the surface of the bowl were corrected (see Figure 1A).

Results and Discussion

The percentage of trials on which each given image was chosen in all of its 2AFC comparisons is plotted in Figure 2 for the two frame shapes. These data were averaged over object shapes because there was neither a main effect of object shape ($F < 1$) nor an interaction between frame shape and object shape ($F(4,44) = 2.20$, $p > .13$).

There was a main effect of position ($F(4,44) = 59.02$, $p < .0001$), which had both a statistically significant linear ($F(1,11) = 90.35$, $p < .001$) and quadratic component ($F(1,11) = 9.55$, $p < .01$). The most preferred position was that second from the bottom, with the bottom-most position being chosen almost as often. These two positions were reliably preferred to the top two positions ($F(1,11) = 85.45$, $p < .001$). The slight preference for horizontal over vertical frames was not significant ($F(1,11) = 1.11$, $p = .32$), but there was a reliable interaction between frame shape and position $F(4,44) = 4.04$, $p < .01$, which is small, but evident in Figure 2.

The strong lower bias was a surprise, because we expected to find a center bias roughly analogous to our results with the horizontal placement of symmetrical objects. Several interpretations of this finding are possible. The *gravitational stability hypothesis* is that the lower bias might reflect a preference for the vertical position of the object and ground plane's far edge to be close to the bottom of the frame, where they would lend greater overall gravitational stability to the image (cf. Arnheim, 1974, 1988). The *ecological hypothesis* is that the lower bias is driven by the fact that bowls are usually located below eye level when humans observe them. Finally, the *functional asymmetry hypothesis* is that the present results are actually just the lower half of an inward bias in the vertical dimension, analogous to the inward bias in the horizontal dimension (Palmer, et al., 2008), which we interpret as being driven by asymmetries in the functional structure of the objects. The conjecture is that because the top of the bowl is functionally its most salient part – playing the crucial role in how substances are placed into and taken out of it – the top of the bowl is functionally analogous to the fronts of the objects we studied previously in the horizontal dimension (a person, a dog, a flower, etc.). If people prefer objects to "face into the frame" in the vertical dimension because of such functional asymmetries, then they should prefer the bowl to "face" upward into the frame, such that its top is closer to the frame's center than its bottom and there is more room above than below it. Even so, the lower bias we found in the present experiment is a good deal stronger than the inward biases we found with horizontal position, suggesting that some additional factor(s) may be at work. Note that these three hypotheses are not mutually exclusive: all might be involved to some degree in producing the strong lower bias we found for the bowl in Experiment 1. We address these and related issues in Experiments 2 and 3.

Experiment 2: Objects Supported by Horizontal Planes Above versus Below Eye Level

We explored the lower bias found in Experiment 1 by testing the three hypotheses just described – gravitational stability, ecological statistics, and/or functional asymmetries – through two manipulations in Experiment 2. First, we included a hemispherical light fixture, whose shape was similar to that of the bowl, but which was supported by attachment to an overhead (ceiling) plane. If gravitational stability is the crucial factor, people should prefer the light fixture to be at or near the bottom of the frame, just like the bowl. Both of the other two hypotheses predict a reversal of the vertical bias for the light fixture: it should be preferred when higher in the frame. Because the functionally salient part of the light fixture is the lower, light-emitting portion, the presence of a bias governed by functional asymmetry, analogous to that in the horizontal dimension, predicts that the fixture should be preferred at or near the top of the frame (i.e., an upper bias for an object that "faces" downward). And because light fixtures are usually located above human observers, the ecological hypothesis also predicts that it should be preferred toward the top of the frame. The latter two hypotheses cannot be distinguished in the present experiment, but we attempt to disentangle them in Experiments 3 and 4.

The second manipulation was decoupling the object's vertical position from that of the horizontal edge within the constraints imposed by gravitational support of the bowl by an underlying surface and of the light fixture by an overhead surface. By decoupling these two variables, we will be able to determine the extent to which the results of Experiment 1 might have been due to the height of the horizontal edge coinciding with the height of the bowl.

The bowl and light fixture were photographed, isolated, and placed at five equally spaced vertical locations in a frame that were consistent with attachment to a horizontal plane below or above them, respectively. There were also five possible positions of the horizontal edge. The five images of the bowl were similar to those in Experiment 1, except that the perspective was now slightly above it, and the horizon also varied in vertical placement (Figures 3A, 3B). The five images of the light fixture were constructed in a manner analogous to the images of the bowl in every respect except that the relative vertical positions of the fixture and the horizontal edge were reversed.

Method

Participants. There were 15 participants, whose mean age was approximately 19.7 years.

Design. There were 210 paired comparisons resulting from all ordered pairs of the fifteen possible images of an object (either the bowl or the light fixture) on each plane, taken two at a time. The colors of the plane of attachment and that of the back plane were counterbalanced within subjects, resulting in a total of 420 trials. Presentation of the two objects was blocked, and the order of the blocks was balanced across participants.

Displays. The bowl images were created by photographing the same ceramic bowl as in Experiment 1 from approximately 18° above the horizontal to make different placements of the horizontal edge plausible. It was then placed in a frame with a separately created background consisting of a single horizon edge. The different positions were generated by shifting the bowl and the horizon edge vertically in the frame. The light fixture images were created in the same way, except that it was photographed from approximately 18° below the horizontal. The five object and horizon were located as in Experiment 1, at 20%, 35%, 50%, 65% and 80% of the distance from the bottom to the top of the frame (See Figure 3A, 3B). The center of each object was defined as the center of the bounding box around the object.

Each screen consisted of a pair of colored images (480 x 360 px) positioned at the same 384-px height on the screen and separated by 100 px. The CRT monitor measured 18" diagonally, had a resolution of 1024 x 768 pixels, and a refresh rate of 85 Hz.

Results and Discussion

We computed the percentage of trials on which each image was chosen in all of its 2AFC comparisons. Because neither the order of object presentation (i.e., block order) nor the color of the attachment plane had any effect (all $Fs < 1.5$, $p > .10$), subsequent analyses were performed on the data averaged over these factors. The preference data are plotted separately for the bowl (Figure 3C) and the light fixture (Figure 3D) as a function of the height of the object relative to the frame (x-axis), the height of the horizontal edge relative to the frame (dashed curves), and the height of the object relative to the horizontal edge (solid curves).

The most obvious and important feature of these data is that the light fixture data are an almost perfect mirror image of the bowl data, with a remarkable correlation of +.98 ($p < .001$) between corresponding points of the two data sets: whatever is true of the bowl data is true of the fixture data, but with the height relations reversed. This pattern of near-perfect height reversal effectively rules out the gravitational stability hypothesis, which predicts no reversal.

If one considers only the data in which the vertical positions of the bowl and horizontal edge coincided (the top curve, labeled “0,” in Figure 3C), the lower bias for the bowl in Experiment 2 replicates the lower bias for the horizontally oriented frame in Experiment 1 (Figure 2) almost exactly ($r = +.92$). Moreover, if one considers the data from both the bowl and light fixture when they are at the same level as the horizontal edge (the top curves, labeled “0,” in both Figures 3C and 3D), the pattern looks quite similar to the results for the horizontal positions of objects reported in Experiment 2 of Palmer, Gardner, and Wickens (2008; Figure 4): There is an overall center bias that is strongly influenced by an inward bias toward objects “facing” into the frame. In the present case, we presume that the bowl “faces” upward and the light fixture “faces” downward because of vertical asymmetries in their primary functions. In analogy to the horizontal case, a functional bias predicts that people will prefer the location of the more functionally salient parts to be closer to the center of the frame, and indeed they do. The present data are therefore compatible with a functional bias in the vertical dimension. They are also compatible with an ecological height bias, however, because the bowl is preferred lower in the frame and is generally lower than a person’s viewpoint when looking at it, and the light fixture is preferred higher in the frame and is generally higher than a human’s viewpoint when looking at it. Both functional and ecological biases may contribute to the observed effects, of course. We return to this issue in Experiment 4.

We next examined effects due to the relation between the height of the horizontal edge and the height of the object. The clear pattern is that the most preferred image of both the bowl and the light fixture at each object height is the one in which the horizontal edge is at the same height as the object ($F(1,14) = 8.36$, $p < .05$) for images with the object at the horizon height versus the next closest horizon height). As the height difference between the object and horizon increases, the choice percentages decrease regularly, with the size of the decrease being highly correlated with the height difference between the object and the horizontal edge ($r = +.96$, $p < .001$). There is thus a robust "similar-height" bias toward preferring the object and horizontal edge to be at or near the same height and systematically decreasing for increasingly large distances between them, at least for these particular perspective views of these two objects.

Why might there be such a strong bias toward preferring the horizontal edge to be at or near the same height as the object? One possibility is that the depth relation between the object and the edge is most evident in these images, because part of the edge is actually occluded by the object. This possibility does not account for the monotonic decrease in preference for the other edge positions, however. Perhaps the most satisfying explanation for the entire pattern of results concerns the perspective from which the pictures of the objects were taken and the likely distance between the object and the far edge of the supporting surface. The present images were side views taken at an angle of about 18° from horizontal. The supporting surface would thus be greatly foreshortened, and its far edge would plausibly be relatively near the object in the projected image. For comparison, consider the images if the perspective on the objects had been pure side views or pure top (or bottom) views. In a pure side view, the far edge of the supporting surface would have to be at essentially the same height as the bottom (top) of the bowl (light fixture), and in a pure top (bottom) view the horizontal edge would likely be entirely out of the picture. This hypothesis could be tested by repeating the experiment with views of the same objects at different perspectives with the horizontal edges at different heights, but we leave this experiment for a future study.

We have argued that the lower bias effects shown in Figure 3 may have arisen from an inward bias in the vertical dimension analogous to the inward bias in the horizontal dimension: Pictures of objects that “face” upward and are supported by a horizontal plane below them are preferred when they are located below the center of the frame (i.e., a lower bias), whereas objects that “face” downward and are attached to an overhead plane are preferred above the center (i.e., an upper bias). It seems most likely that this occurs, analogously to the horizontal cases, because of functional asymmetries in the properties of the objects: Just as a person, car, or flower can “face” left (or right) in a picture, it seems plausible to claim that the bowl “faces” upward and the light fixture “faces” downward. However, unlike the horizontal cases, there are other confounding variables that prevent a definitive conclusion about the reason for the inward-facing pattern of preferences. First, bowls are typically located below the viewer, and light fixtures are typically located above the viewer. The upper and lower biases thus may be explained by the aforementioned ecological hypothesis: a bias for the height of objects within rectangular images to reflect the height of the depicted objects relative to an observer in the real world. Second, the bowl was viewed from slightly above, and the light fixture from slightly below. The observed inward biases therefore could result if people simply prefer objects seen from above to be low in the frame and objects seen from below to be high in the frame. We will refer to this as the *perspective hypothesis*. The next two experiments attempt to disentangle these possibilities.

Experiment 3: Perspective Effects for the Bowl and Light Fixture

In Experiment 3 we attempted to distinguish among these three explanations for the inward bias found in Experiment 2: the effects of functional asymmetries in the object, the effects of ecological height relative to a typical human viewpoint, and the effects of perspective view due to the angle of the camera relative to the object. We did so by measuring preference effects in the vertical position of pictures of the bowl and light fixture taken from five different perspectives sampled from a 90° arc around the object: 0° (pure side view), 18°, 36°, 54°, or 90° (directly) above the bowl and 0°, -18°, -36°, -54°, or -90° (directly) below the light fixture (see Figures 4A and 4B). By analogy with the horizontal effects reported by Palmer et al. (2008), a pure functional asymmetry ("facing") explanation predicts that the preference for low placement of the bowl and high placement of the fixture should be greatest for the pure side views (0°), where the projections of these objects are functionally most asymmetrical, should decrease monotonically as the angle increases from horizontal, and should be entirely eliminated for the 90° above (below) views, from which the images of these object are visually and functionally symmetrical when they directly "face" the camera. A pure ecological explanation implies that there should be no difference between the preferred height of an object depending on its perspective angle, because all that matters is where they are located in the world: All of the bowl images should be preferred equally low in the frame, and all the light fixture images should be preferred equally high. Finally, a pure perspective explanation – that pictures taken from above are preferred when the object is lower in the frame and those taken from below are preferred when the object is higher in the frame – implies that the perspective effects in the present experiment should be opposite those predicted from the functional asymmetry explanation: greatest from directly above (below), where the viewpoint is most completely from above (below) the bowl (light fixture), and eliminated for the pure side views, where the viewpoint is neither above or below. Again, note that these alternatives are not mutually exclusive and may combine to give various mixtures.

To avoid the possibly confounding variables introduced by having a horizontal edge in the images, we placed the objects on a horizonless colored background with a soft lightness gradient that ran along the horizontal axis (see Figure 4C). The objects again appeared at 5 different vertical positions within the frame (see Figure 4C).

Method

Participants. There were 17 participants, whose mean age was approximately 19.5 years.

Design. Twenty paired comparisons resulted from all ordered pairs of the five different vertical positions of the same perspective view of the object, taken two at a time, for each of the two objects (bowl and light fixture). The five perspective views of the two different objects (at ± 0°, ±18°, ±36°, ±54°, and ±90° from a pure side view) were never compared directly to each other, resulting in a total of 200 trials. The trials were blocked by object, so that half of the participants saw all of the light fixture trials first, and the other half saw all of the bowl trials first.

Displays. Each screen consisted of two colored images, measuring 450 x 600 px, placed on a neutral gray background. The images, shown in Figure 4, were placed at the same 450-px height on the screen and were separated by 300 px. The LCD monitor measured 19” diagonally, and had a resolution of 1440 x 900 and a refresh rate of 60 Hz.

Results and Discussion

The percentages of trials on which each view of each object was chosen as preferred at each vertical position in the frame are plotted in Figure 5A and 5B for the bowl and light fixture, respectively, as a function of the angle of the depicted perspective relative to horizontal. Consistent with the results of Experiment 2, there was an overall lower bias for the bowl ($F(1,16) = 21.11$, $p<.001$) (see Figure 5A) and an overall upper bias for the light fixture ($F(1,16)$

= 32.96, p<.001) (see Figure 5B), which resulted in a powerful interaction between object and vertical position ($F(4,64) = 32.51$, $p<.001$). Smaller, but still significant, interactions were present between perspective and position ($F(16,256) = 2.52$, $p < .001$) and among object, perspective, and vertical position ($F(16,256) = 3.61$, $p < .001$). No effect of block order or any of its interactions were statistically reliable (all Fs < 1.8, ps > .15).

The interactions between vertical position and perspective for the bowl (Figure 5A) and light fixture (Figure 5B) arise from seemingly complex differences in the slopes and curvatures of the preferences functions. The functions are relatively straight and steep for the 0° (side-view) perspectives, but transform gradually to the 90° (top/bottom) perspectives, which are inverted-U shapes that are still somewhat tilted, but much more symmetrical. The structure of these interactions can be captured quantitatively by examining the amount of variance accounted for by the linear and quadratic components of the functions, which together account for an average of 92% of the variance, ranging from 82% to 99.8%. Consistent with our previous work on horizontal preferences (Palmer et al., 2008), we interpret the linear trend as indicating the strength of an inward bias (i.e., the lower bias for the bowl and the upper bias for the light fixture) and the quadratic trend, which peaks at the central position, as indicating the strength of a center bias.

Figure 6 shows the proportion of variance explained by the linear and quadratic components for the bowl and light fixture as a function of perspective. As the perspective angle deviates from horizontal (0°) and the object's image becomes more symmetrical about a horizontal (image) axis, the linear variance decreases systematically and the quadratic variance increases systematically. This pattern is also characteristic of the horizontal preference functions: When the perspective view was strongly directed and asymmetrical about the relevant image axis (i.e., a pure side view), people strongly preferred the object to "face" into the frame, but when it was facing the viewer and symmetrical, people tended to prefer the object to be centered in the frame (Palmer et al., 2008). The present data thus strongly support a functional asymmetry hypothesis, because the inward bias is strongest for the purely side view, at which the object's functional asymmetry is maximal, and decreases monotonically with changes in perspective.

The data do not appear to support the perspective explanation that people prefer views from above to be low in the frame and those from below to be high in the frame, because this predicts the opposite pattern of results: a larger inward bias as the perspective deviates from horizontal (0°). It is logically possible, however, that a larger functional asymmetry component combines with a smaller perspective effect to produce the observed pattern. It is interesting that the linear component never disappears entirely, accounting for 30-50% of the variance even in the 90° perspective views from directly above the bowl and below the light fixture, so the existence of a perspective effect cannot be ruled out. This residual height effect is almost surely due to an ecological bias, however, for reasons discussed in Experiment 4, which further investigates the possible influences of perspective, functional asymmetry, and ecological factors.

Experiment 4: Flying Eagles and Swimming Stingrays

Experiment 4 investigated the upper and lower biases evident in Experiments 2 and 3 more extensively to shed further light on their possible causes. As just discussed, the findings from Experiments 1-3 seem to arise from functional asymmetries in the objects themselves plus ecological effects due to their typical location relative to the viewer and/or perspective effects of whether the object is viewed from above or below. One drawback of the bowl and light fixture is that, because they are supported by an opaque surface below and above them, respectively, not all perspective views are possible: the bowl cannot be viewed from below nor the light fixture from above. As a result, ecological effects are necessarily confounded with perspective effects: The bowl, typically located below the viewer and supported by a surface below it, is almost always seen from a vantage point at least somewhat above it, and the light fixture, typically located above the viewer and supported by a surface above it, is almost always seen from a vantage point at least somewhat below it.

To dissociate these effects, we studied preferences for vertical placement of two objects that could be viewed from any perspective angle, yet have characteristic positions above or below human observers: a flying eagle, which is typically located above human observers, and a swimming stingray which is typically located below human observers. By using such unattached objects, we were able to generate believable images from viewpoints that sampled a 180° arc around one side of the object – from directly above to directly below – for both an object that is typically located above the viewer and one that is typically located below the observer.

Two further issues are also addressed in this experiment: generalizing the results to objects radically different from a bowl and light fixture and eliminating the possibility of "demand characteristics" due to the same observers viewing both objects. Experiments 1-3 all used a bowl and light fixture as representative objects located below and above the observer, respectively, but it makes sense to replicate the results with other objects. If the causes of the effects observed in previous experiments are general, the same pattern of results should be found for the stingray and eagle, which are quite different from a bowl and light fixture. Experiments 2 and 3 also used fully within-participant designs, such that the same observers saw both the bowl and the light fixture images. Perhaps they preferred the bowl to be lower and the light fixture to be higher in the frame only because they saw both kinds of objects and felt pressured to make some kind of height distinction between them. In the present experiment, different participants made judgments about the eagle images and the stingray images to avoid this possibility.

Method

Participants. There were 24 participants, whose mean age was approximately 19.1 years.

Design. There were 20 paired comparisons that resulted from all ordered pairs of the five different vertical positions in the frame of the same perspective view of one object, taken two at a time, for each of the two facing directions (left and right). There were four perspective views of the two objects – directly-above (+90°), side-above (+45), side-below (-45), and directly-below (-90°) relative to a pure side view – which were never compared to each other, resulting in a total of 160 trials. (The pure side view was not included to reduce the number of trials, because we were most interested in the cases in which the perspective includes and upward or downward component.) To avoid demand characteristics resulting from seeing both the eagle and stingray images together, the object (eagle or stingray) was a between-subjects variable. Within each group, all trials were randomized.

Displays. Each screen consisted of two colored images (400 x 400 px) on a neutral gray background. The images were placed at the same 400-px height on the screen, and were separated by 200 px. The 3-D models of the eagle and the stingray were purchased from Content Paradise (www.contentparadise.com) and were arranged in Poser 6. Left-facing and right-facing versions of both objects were used. For the eagle, the directly-above and side-above images had a background of mottled green that resembled ground or grass, and the directly-below and side-below images had a background of sky and clouds on a bright day (Figure 7A). For the stingray, the directly-above and side-above images had a background of dark turquoise that resembled a view into deeper water, and the directly-below and side-below images had a background of a lighter turquoise that resembled a view toward the water's surface (Figure 7B). In side-above and side-below views of the stingray, a vertical lightness gradient was imposed on the background to imply deeper water below and lighter water above. The LCD monitor measured 20" diagonally, with a 1280 x 800 px resolution and a 60 Hz refresh rate.

Results and Discussion

Average percentages of trials on which each image was chosen over all of its 2AFC comparisons were analyzed separately for eagle and stingray conditions. Because the left/right facing direction of the eagle and stingray had no effect (Eagle: $F < 1$; Stingray: $F(4,44) = 1.10$, $p > .3$), the data were averaged over facing directions in all subsequent analyses. There was a significant overall interaction between perspective viewpoint and vertical position of the object for both the eagle, $F(12,132) = 5.23$, $p < .001$ (see Figure 7C), and the stingray, $F(12,132) = 4.80$, $p <.001$) (see Figure 7D), arising from distinct patterns of positional preference for different perspective views. The percentages of variance accounted for by the linear and quadratic components of these curves are graphed in Figure 8.

Consider first the results in the directly-above and directly-below perspectives. For neither the eagle nor the stingray did it matter whether the view was from directly above or directly below ($F(4,44) = 1.05, 1.11$, $p > .40, .30$, respectively), so these two conditions were averaged for further analyses. Both the eagle and sting ray show strong quadratic (inverted-U) components at these perspectives ($F(1,11) = 8.60, 7.84$, $p < .02, .02$, respectively), characteristic of the center bias we have previously found with preferences for the horizontal position of symmetrical views of objects (Palmer et al., 2008). In the present cases, however, there is also a linear component that we did not find in 2AFC preferences for the horizontal position of symmetrical objects: The eagle functions were tilted upward, indicating preference for higher placements ($F(1,11) = 11.23$, $p < .01$), and the stingray functions were tilted slightly downward, indicating preference for lower placements ($F(1,11) = 4.87$, $p < .05$). The facts that the sign of these linear components are positive for the eagle and negative for the stingray and that they do not differ for the directly above versus directly below conditions for either object strongly suggests that they arise from an ecological bias, which predicts a positive slope (i.e., upper bias) for the eagle and a negative slope (i.e., lower bias) for the stingray. If they were driven by a perspective bias due to looking upward or downward at the object, there should be an upper bias for the objects viewed from below and a lower bias for objects viewed from above, independent of which object was depicted. Clearly, this is not the case.

Both the side-above and side-below views also showed an upper bias for the eagle and a lower bias for the stingray, as evidenced by reliable linear components for both objects, though opposite in slope (eagle: $F(1,11) = 6.26, 42.25$, $p < .05, .001$; stingray: $F(1,11) = 13.75, 6.19$, $p < .01, .05$). In the case of the eagle, these two perspectives differed significantly from each other ($F(4,44) = 4.68$, $p < .01$), because the upper bias was stronger when the eagle was viewed from below than when it was viewed from above. The analogous pattern was evident in the linear x linear component interaction in the stingray data, with the stronger lower bias present for the view from below ($F(1,11) = 4.85$, $p < .05$). Given the ecological effects apparent in the views from directly above and below, the most consistent interpretation of these results is that the flying eagle images produced a strong ecological upper bias and a weaker inward bias, such that the side-below view (showing the eagle's belly) is preferred relatively higher in the frame than the side-above view (showing the eagle's back). As the graph in 7C shows, at positions that were 65% and 80% from the bottom of the frame, the side-below view of the eagle was more preferred ($F(1,11) = 11.50, 7.50$, $p < .01, .02$, respectively), whereas at positions 20% and 35%

from the bottom of the frame, the side-above view of the eagle was more preferred ($F(1,11)$ = 13.92, 4.85, $p < .01$, .05, respectively). Corresponding trends were apparent in the side-above and side-below views of the stingray, but the corresponding contrasts only trended toward statistical significance ($F(1,11)$ = 4.38, 3.70, $p<.07$, .08 for the 65% and 80% positions; $F(1,11)$ = 3.46, 4.03, $p<.09$, .08 for the 20% and 35% positions). This pattern suggests that, in addition to strong ecological effects, there may be either weak perspective effects or weak functional asymmetry effects in these conditions because the upper bias is slightly stronger for the eagle when looking up at it, whereas the lower bias is slightly stronger for the stingray when looking down at it.

At least two, and possibly three, factors thus appear to be at work in producing the pattern of preferences evident in this experiment. First, there is a strong overall upper bias for pictures of flying eagles to be located toward the top of the frame and a lower bias for pictures of swimming stingrays to be located toward the bottom. These effects are reflected in the linear components of the perspective views for both objects (see Figure 8) and are presumably due to the fact that flying eagles tend to be located above human observers in the world whereas swimming stingrays are typically located below human observers in the world. Second, there is a fairly strong center bias for the views from directly above and directly below, which is still evident in the side-above view of the eagle (and perhaps weakly evident in the side-below view of the stingray), and nearly absent in the side-below view of the eagle and side-above view of the stingray (see Figures 7C, 7D, and 8). This center bias is presumably due to the symmetrical structure of the eagle's and stingray's left and right sides. Third, there may be an additional, but smaller, upper bias for the side-below view of the eagle and lower bias for the side-above view of the stingray that is likely to be due to some asymmetry in function or visual salience between the top and bottom surfaces of the eagle and stingray. We cannot isolate this component statistically from the ecological bias, because both are reflected in the linear components plotted in Figure 8, but its weakness in the directly above and below views implies that it is unlikely to be due to perspective effects produced by looking upward and downward per se.

General Discussion

The four experiments just described explored people's aesthetic preferences for spatial composition in the vertical dimension for single-object pictures within a rectangular frame. The results were partly analogous to our previous findings on preference for horizontal composition (Palmer, Gardner & Wickens, 2008) in that they demonstrated the existence of center and inward biases. The inward bias in the vertical dimension differs from that in the horizontal dimension, however, in that it arises for different objects rather than different facing directions of the same object: a lower bias for a bowl and swimming stingray versus an upper bias for a light fixture and a flying eagle. The inward bias in the vertical dimension appears to arise from multiple relatively high-level factors, including what we call functional asymmetry effects, ecological effects, and possibly perspective effects.[3]

What we are calling functional asymmetry effects would arise because people's interactions with many objects are not equally distributed over the space surrounding them. The fact that fronts of objects are almost always more salient in interactions than their sides and backs can explain the inward bias found by Palmer, Gardner, and Wickens (2008) in the horizontal placement: people prefer the more salient functional parts of the object to be closer to the center. By analogous logic, the primary functions of a bowl concern the space inside and

[3] It is worth mentioning here that the rule of thirds fails to capture people's aesthetic preferences in the vertical dimension as well as in the horizontal dimension. The relevant facts in the vertical case are that the most extreme positions were chosen as the most pleasing and that perspective has an effect on preferred position (see Figs. 5, 7). Both results demonstrate that there is more to spatial composition than can be explained by the rule of thirds.

above it, because that is where objects and/or substances are placed into it and removed from it. The sides and bottom of the bowl are certainly important for its ability to contain those substances, to be moved from place to place, and to rest stably on a supporting surface, but the space above it seems to be far more salient, thus implying a vertical asymmetry in function. If there is a bias toward having the more salient parts and the area around them closer to the center of the frame, then a purely side-view of a bowl should be preferred when it is located toward the bottom of the frame. Note that there is no such functional asymmetry in a purely top-view of the same bowl, because the bowl is both physically and functionally symmetric with respect to the area of space depicted around its sides. These observations can explain the graded reduction in preference asymmetries as the perspective rises from a pure side-view to a pure top-view. Similarly, a ceiling-mounted light fixture's primary function is to emit light into the space below it. A purely side-view of such a fixture thus exhibits a distinct functional asymmetry in which the space below it is more important than the space above it. The space around a light fixture in a purely bottom-view, however, is both physically and functionally symmetric and should therefore not be systematically biased toward a lower or higher position. This is precisely the pattern we found in Experiments 3 and 4 for the percentage of variance accounted for by the linear components of the results (see Figures 6 and 8). It is not as obvious that there are corresponding functional asymmetries for eagles and sting rays, but there may be, given that the eyes of eagles are on its lower surface and those of sting rays on its upper surface. Alternatively, these surfaces may simply be more familiar due to the perspectives from which people normally see them.

A simpler and more elegant explanation of the results can be devised by positing the existence of what we will call an "affordance space" around an object that reflects the extent and/or importance of functions that take place in that region around the object, where "affordances" are the functions of an object that an observer can perceive from its visible structure (Gibson, 1977). If the affordance space around an object is asymmetrical, as suggested above, then what we are calling an inward bias may actually be understood as a center bias that operates on an asymmetrical affordance space that contains more surrounding area on the functionally more salient side(s). That is, if viewers implicitly prefer the affordance space around an object to be centered in the frame, and if that affordance space is asymmetrical with more space in front of horizontally facing objects (e.g., a person, chair, or vehicle), on top of "upward facing" objects (e.g., a bowl), and toward the bottom of "downward facing" objects (e.g., a light fixture), then at least some of the inward biases in both horizontal and vertical dimensions we have found may actually be understood as center biases operating on affordance spaces rather than as inward biases operating on the objective boundaries of the physical objects. We are currently devising ways to measure the shapes of affordance spaces for different objects empirically to find out whether the results conform to the inward biases we have found in aesthetic judgments of spatial composition.

Perspective height effects in aesthetic preferences refer to possible differences in the preferred vertical placement of an object within a frame that depend on the direction from which the object is viewed. Our hypothesis that such effects might exist arose from another possible explanation of the inward biases found in Experiment 2: people may tend to prefer an object typically viewed from above (e.g., a bowl) to be located below the center of the frame, and they may prefer an object typically viewed from below (e.g., a light fixture) to be located above the center of the frame. We investigated the implications of this possibility in more detail in Experiments 3 and 4, but the results posed several problems. First, the upper and lower biases in

Experiment 3 are clearly strongest when viewing objects from the side, weakening considerably as the perspective moves toward views from directly above and directly below (see Figures 5 and 6), where one would logically expect such perspective effects to be strongest. Second, when perspective effects were dissociated from ecological effects in Experiment 4, we found no difference between views of the same object (for either eagle or stingray) when viewed from directly above versus directly below (see Figures 7 and 8). Because any perspective effect would presumably have to be maximal at such contrasts between purely upward and purely downward views of the same object, we conclude that, despite its intuitive plausibility, the vertical component of the perspective viewing angle is not a significant factor in driving aesthetic preferences for vertical placement of a focal object within a picture.

Ecological effects are based on the fact that some objects tend to be located higher than the observer in the environment (e.g., flying eagles and light fixtures) and others tend to be located lower (e.g., bowls and swimming stingrays). It appears to cause strong and pervasive inward height biases in the present results in that people prefer the vertical position of an object within the frame to be consistent with the vertical position of the object relative to the observer: i.e., eagles and light fixtures to be high and bowls and stingrays to be low. Although the magnitude of this bias is presumably constant across perspective conditions in Experiments 3 and 4, the magnitude of the inward bias varies because it seems to combine with functional asymmetries. Palmer, Gardner, and Wickens (2008) did not find any corresponding ecological biases in the horizontal position of objects, presumably because objects do not have characteristic positions to the left or right of mobile human observers, who locomote on a horizontal ground plane in a three-dimensional terrestrial world.

The existence of ecological height effects in our data suggests that aesthetic preferences are driven to a considerable degree by how well the position of the focal object within the frame fits the observer's expectations about the position of such objects within corresponding environmental scenes. In this regard, the ecological effects we observed are consistent with "fluency" accounts of aesthetic preference (e.g., Reber, et al., 2004; Winkielman, et al., 2006), according to which people prefer images that are more easily (fluently) perceived.[4] It has been known for many years, for example, that people are faster and more accurate at recognizing objects in appropriate locations within otherwise coherent contextual scenes (e.g., Biederman et al., 1982; Palmer, 1975). In these previous studies, the appropriateness of the target object's position was defined in relation to other objects, such as a loaf of bread being located on a cutting board on a kitchen counter next to, say, a bread knife and a piece of cheese rather than perched atop a post in the front yard, as a mailbox might be. More recently, Estes et al. (2008) demonstrated ecological height effects on object recognition by showing that participants were faster at discriminating snakes from birds when the birds were high in the frame and the snakes were low than when the birds were low and the snakes were high. This pattern of results, in which subjective measures of aesthetic preference mirror objective measures of perceptual performance, thus supports the primary claim of fluency theory.

Additional evidence for a concordance between aesthetic judgments and recognition performance can be found for other compositional factors. In a pioneering study of "canonical perspective," Palmer, Rosch, and Chase (1981) demonstrated that everyday objects are more quickly and easily perceived from some perspectives than others. Khalil and McBeath (2006)

[4] We believe we are studying aesthetic response rather than everyday familiarity or fluency because we asked our participants to indicate their aesthetic preferences. This does not preclude the possibility that familiarity or fluency is relevant to understanding the causes of such aesthetic decisions, however.

later reported that more canonical views are also rated as more aesthetically pleasing than less canonical ones. Similar effects have recently been found to hold in the size domain. Konkle and Oliva (2011) have shown that people prefer pictures of objects of different sizes to be depicted in 2D images with corresponding differences in their depicted sizes relative to a surrounding frame: The image of a mouse, for example, should be smaller than the image of an elephant within the same-sized frame. Konkle and Oliva call this the “canonical visual size” effect. Linsen, Leyssen, Gardner, and Palmer (in press) have confirmed that this size preference holds for aesthetic judgments as well: People rate pictures of a butterfly as most aesthetically pleasing at a smaller size within its frame than they do for pictures of an elephant. Although we do not yet know of any corresponding studies of the effects of size on recognition performance measures, it seems plausible that similar results would be obtained: A mouse would be recognized more quickly and accurately if it its image is small within its frame and an elephant’s if its image is large, than in the reverse situations. Thus, it appears plausible that people’s aesthetic judgments will generally be higher under the same conditions in which their recognition performance is better. Indeed, the ecological height bias we have found for aesthetic judgments and the corresponding effects on recognition performance reported by Estes et al. (2008) seem to be due to the fact that an object’s perceptual representation includes information about its “canonical height” in the world relative to the viewer, analogous to canonical perspective (Palmer et al., 1981) and canonical size (Konkle & Oliva, 2011). This confluence of results, assuming it continues to hold, thus supports the fluency account of aesthetic response: people generally prefer the images in which the objects are most easily perceived and recognized.

We believe that the foregoing results, together with those we reported previously (Palmer, et al., 2008; Leyssen et al., in press), establish that systematic compositional biases other than simple balance effects are present in people's aesthetic judgments of framed images. We discovered these compositional biases by studying images of meaningful objects that we created for this purpose, but evidence for the horizontal biases are evident in suitably chosen corpora of paintings, drawings, or photographic images. Gardner et al. (2009) found evidence of the horizontal inward bias for single-object images in stock photography databases, and Bertamini et al. (2011) did so in paintings and drawings of animals in medieval bestiaries. We expect that similar corroboration of the present vertical compositional effects could be found in appropriate samples of photographs, paintings, and/or drawings, and we plan to do so in the future.

Before closing, we briefly turn to the deeper question of why such biases might exist. In the case of color aesthetics, Palmer and Schloss (2010) argued that color preferences perform an adaptive "steering" function, biasing sighted observers to approach objects that are likely to be beneficial and/or pleasant, and to avoid objects that are likely to be harmful and/or unpleasant. This explanation is satisfying from an adaptive, evolutionary perspective because acting in accord with such aesthetic preferences would be beneficial for the organism to the extent that the preferences are correlated with (i.e., carry predictive information about) what is "good" versus "bad" for the observer. It is not so obvious what adaptive function might be served by the compositional biases we have identified here: the center bias, the functionally asymmetrical inward bias, and the various ecological biases (for height in the picture plane, canonical perspective, and canonical size). An unavoidable problem for any adaptive theory of these biases is that they apply to framed, two-dimensional, visual depictions. Even in modern times, the compositions of rectangular, framed images seem to be largely irrelevant to people's lives, at least beyond art museums, interior wall decor, website design, and other aesthetic domains. To be more generally relevant, the domain to which these principles apply would have to be broadened to include more ecological behaviors.

One intriguing possibility is that the compositional biases we have found here and previously (Palmer et al., 2008) may be related to making optimal attentional movements, eye fixations, and head adjustments in actively exploring the world. People make thousands of eye and head adjustments every day to bring various ecological scenes, objects, and parts into view so that the observer can see them clearly for a wide variety of purposes, and many of these overt behaviors appear to be driven by prior covert attentional fixations (e.g., Rizzolatti et al., 1987). It therefore seems plausible that making attentional, eye, and head adjustments in the process of understanding a framed image that correspond closely to the attentional, eye, and head adjustments that an observer would make in a similar physical environment would facilitate comprehension. Among the most general and ubiquitous of vision's purposes is to identify the objects and assess their functions in relation to the observer's current plans and goals (i.e., their affordances; cf. Gibson, 1977). Perhaps the aesthetic effects we are finding in spatial composition are rooted in principles that the visual system uses to optimize the visual field for perceiving the environment more quickly and accurately. What exactly needs to be seen, of course, varies greatly from one task to another, but what we are calling the "default" task of object identification will surely be among the most important.

The general idea is that if the composition of an image within a rectangular frame is conceived as roughly analogous to the positional structure of objects within the visual field, it would be adaptive for people to make attentional and eye fixations that make the most important information about the most relevant objects most readily available in the image. The center bias would be related to the strong foveation of retinal receptors and the cortical magnification of information at or near the central area of the visual field. The functional asymmetry biases would similarly be related to putting the most important and informative regions of the image at or near the fovea. Ecological biases would be related to providing proximal image features that are consistent with distal object features, depicting objects from canonical perspectives, and at sizes and positions within the frame that mirror the corresponding properties of the depicted object.

There are differences between rectangular frames and the field of vision, to be sure. One is that the frame of a picture is explicitly visible whereas the boundary of the visual field is not, being defined merely by the absence of sensory experience. Another is that the shape of the visual field is roughly oval rather than rectangular. Such relatively minor differences aside, however, the "adaptive vision" hypothesis of such aesthetic effects provides a plausible, ecologically relevant rationale for why people might have such default biases. These ideas are as yet mere conjectures, of course, but that is always the starting point for the next round of empirical tests. At least they have the virtue of making a bridge between aesthetic preferences and adaptive aspects of real-world perception.

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Figure Captions

Figure 1. Representative displays from Experiment 1. Three objects – a bowl, cup, and vase (A) – were rendered at five positions within a horizontal frame (B) and a vertical frame (C).

Figure 2. Results of Experiment 1. The average percentage of trials in which the given image was preferred over all possible comparisons is plotted as a function of the position of the object in the frame for the horizontal frame (solid line, open circles) and the vertical frame (dashed line, filled circles).

Figure 3. Displays and results for Experiment 2. Systematic variations of object position and horizon position for the bowl (A) and the light fixture (B) result in analogous sets of images for the two objects. The percentage of trials in which the given image was preferred over all possible comparisons are plotted for the bowl in panel C and for the light fixture in panel D. The solid black lines connect the data points for which the object position was constant relative to the horizontal edge, the dotted lines connect the data points for which the horizon position was constant relative to the frame, and different horizon positions are designated by different symbol shapes.

Figure 4. Displays for Experiment 3. A bowl (A) and a light fixture (B) were photographed from five different perspectives, (0° to ±90° relative to a pure side view). Each object was then placed on a background at each of five different positions, as shown in panel C for the 0° view of the bowl and the -90° view of the light fixture.

Figure 5. Results of Experiment 3. The percentage of trials in which the given image was preferred over all possible combinations of the same view of the object is plotted for the five perspective views of the bowl (A) and the light fixture (B).

Figure 6. A stacked bar graph showing the percentage of variance in the data for the bowl and for the light fixture that are explained by a linear component (darker gray), and a quadratic component (lighter gray). Note that the patterns are similar for the two objects in terms of the deviation in perspective viewing angle from a pure side view (0°).

Figure 7. Displays and results of Experiment 4. Images of the flying eagle (A) and the swimming stingray (B) are shown from four different viewpoints: directly-above, side-above, side-below, and directly-below. The box surrounding each view is the drawn with the same line-type as in the graphs plotted in panels C and D. The graphs show the percentage of trials on which a particular image was chosen with the object at a particular position (x-axis) and from a given view (different lines) for the eagle (C) and the stingray (D).

Figure 8. A stacked bar graph showing the percentage of variance in the data for the eagle and for the stingray that is explained by a linear component (darker gray), and a quadratic component

(lighter gray). Note that the pattern is similar for the two objects in terms of the deviation in perspective viewing angle from a pure side view (0°).

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Figure 1

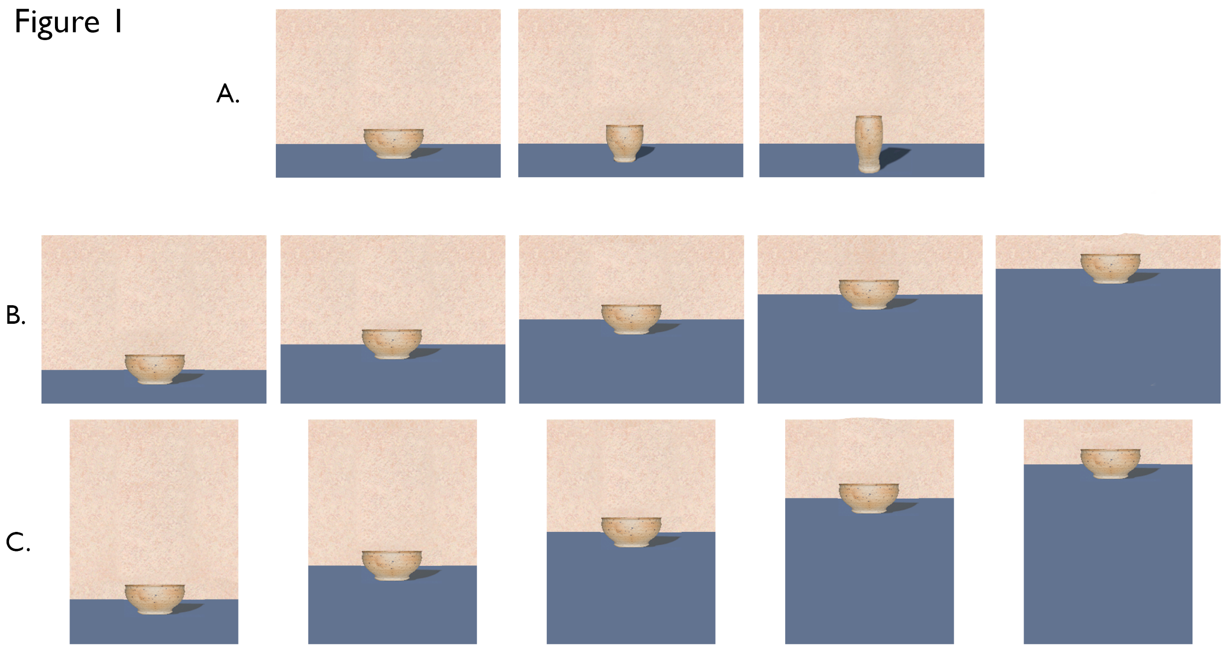


Figure 2

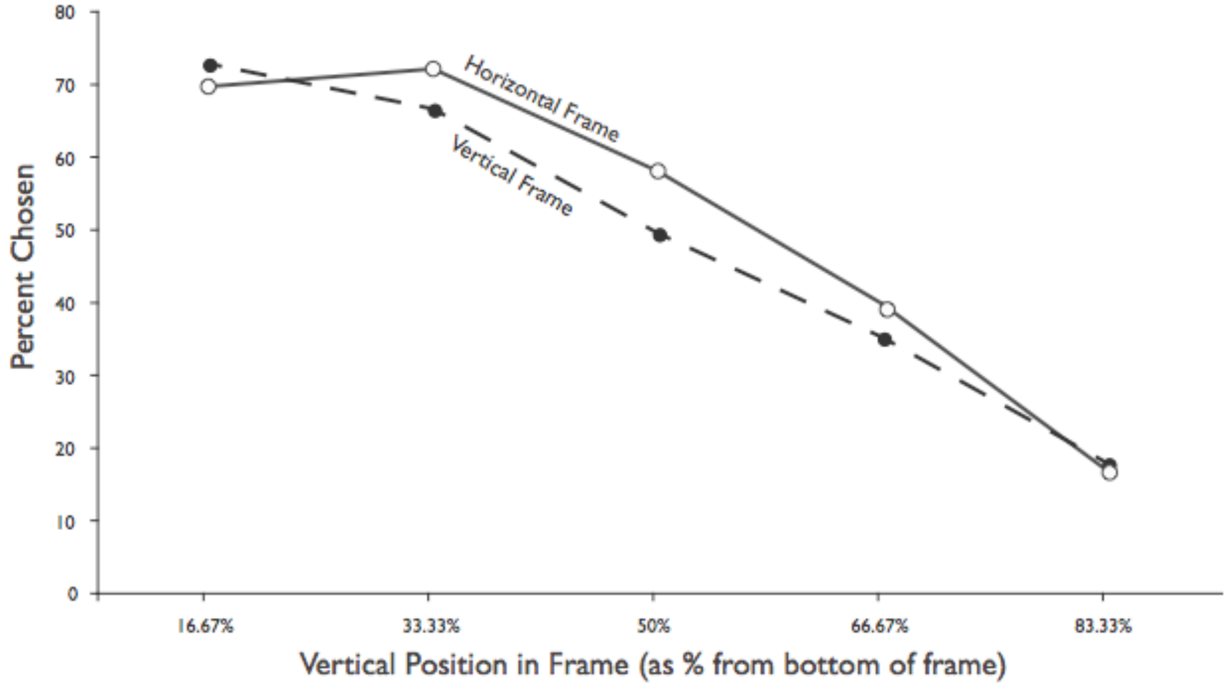

80
70
60
50
40
30
20
10
0
Percent Chosen
Horizontal Frame
Vertical Frame
16.67%
33.33%
50%
66.67%
83.33%
Vertical Position in Frame (as % from bottom of frame)

Figure 3

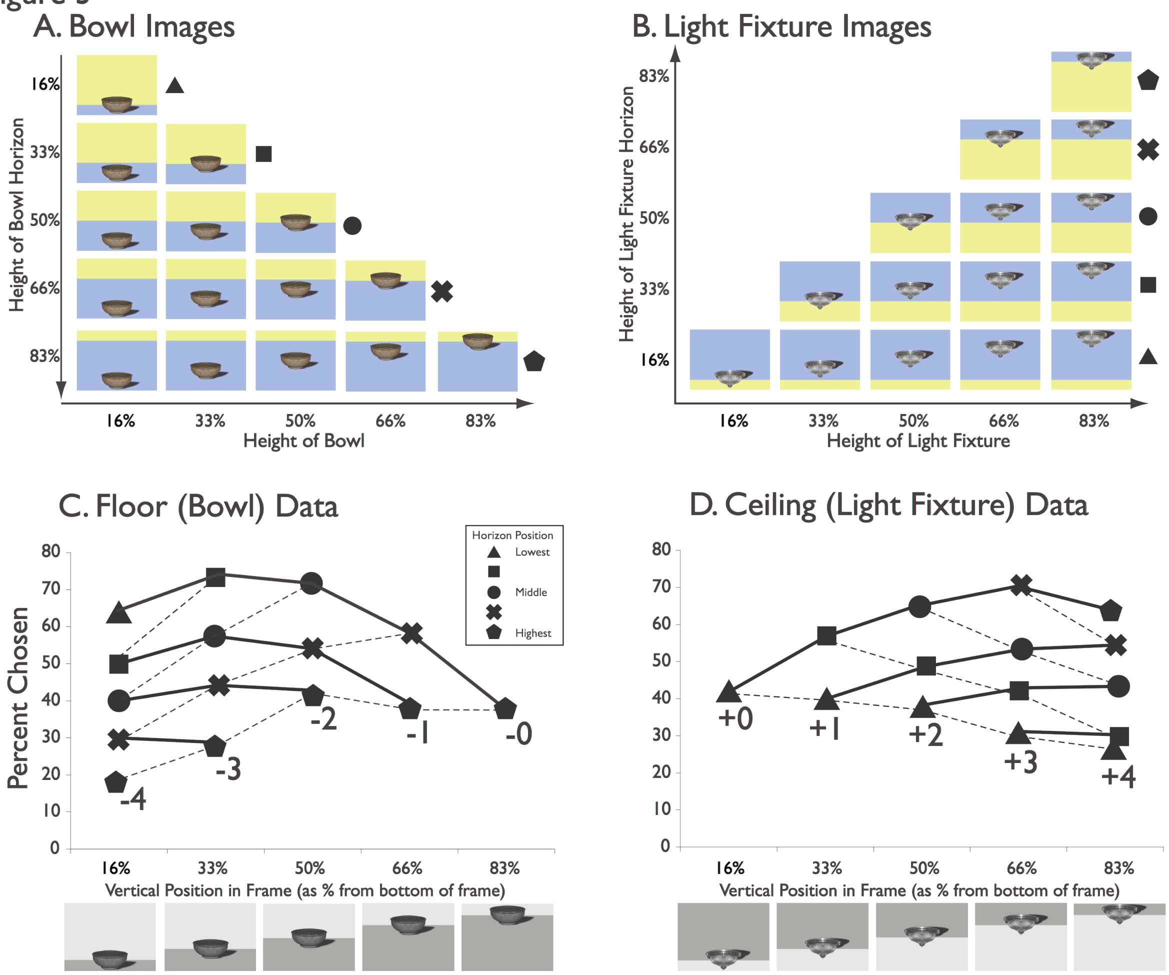
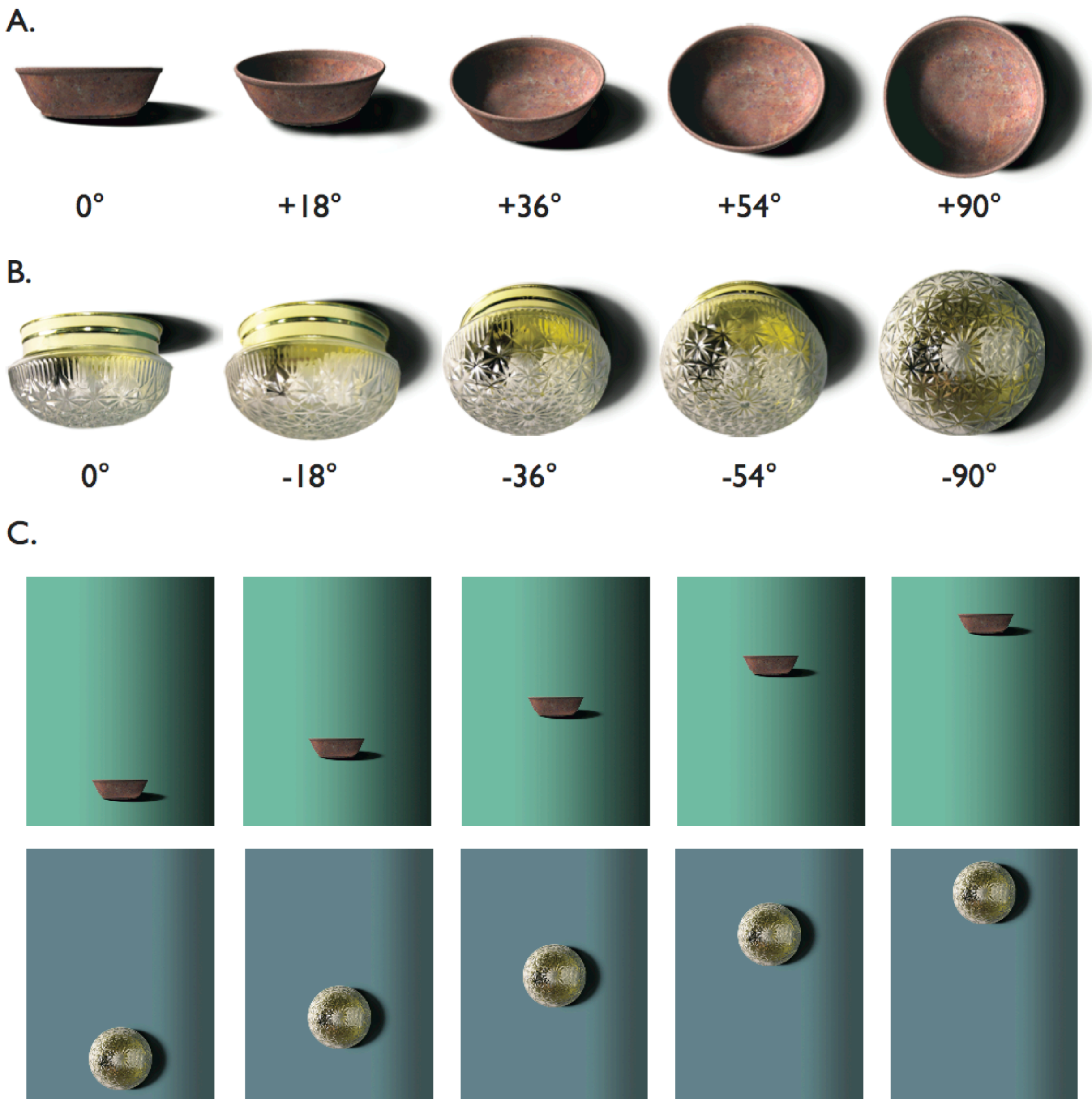
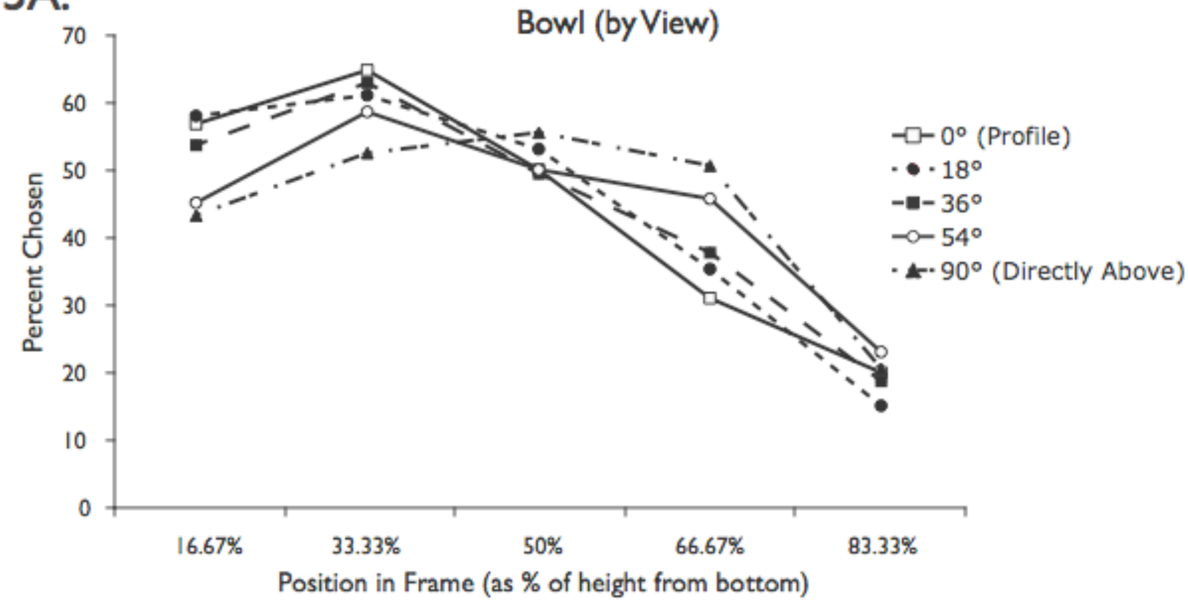

A. Bowl Images
Height of Bowl Horizon
16%
33%
50%
66%
83%
Height of Bowl
B. Light Fixture Images
Height of Light Fixture Horizon
Height of Light Fixture
C. Floor (Bowl) Data
Percent Chosen
Horizon Position
Lowest
Middle
Highest
-4
-3
-2
-1
-0
Vertical Position in Frame (as % from bottom of frame)
D. Ceiling (Light Fixture) Data
+0
+1
+2
+3
+4
Vertical Position in Frame (as % from bottom of frame)

Figure 4



5A.


Bowl (by View)
Percent Chosen
70
60
50
40
30
20
10
0
16.67%
33.33%
50%
66.67%
83.33%
Position in Frame (as % of height from bottom)
0° (Profile)
18°
36°
54°
90° (Directly Above)

5B.

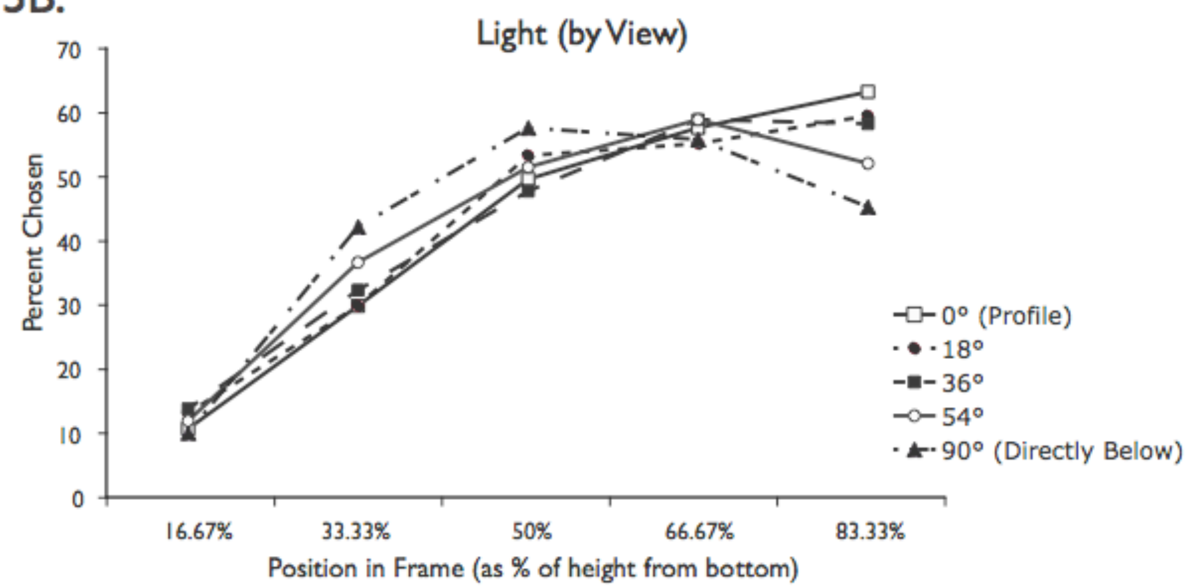
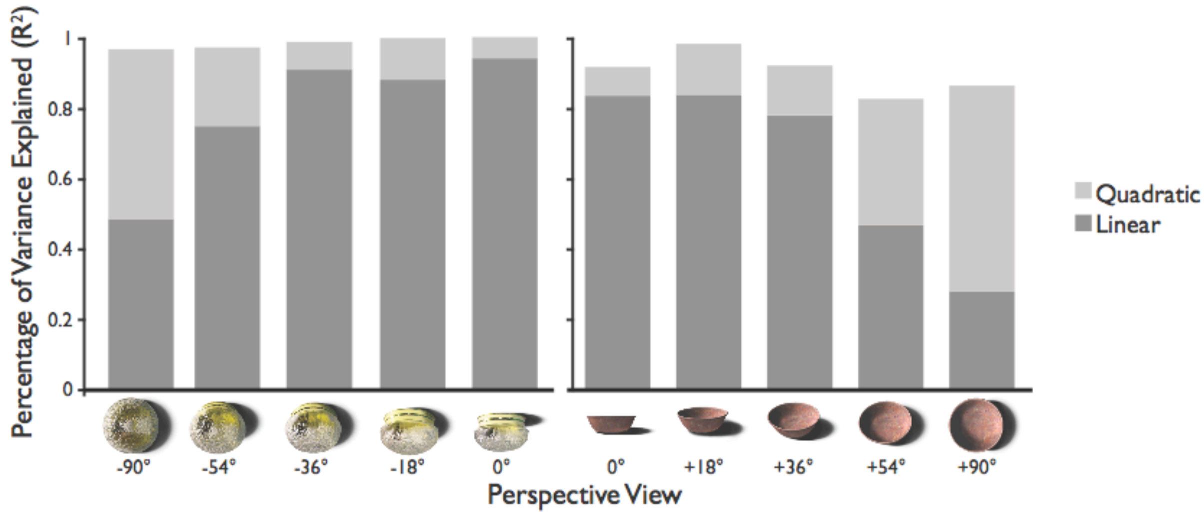

Light (by View)
Percent Chosen
70
60
50
40
30
20
10
0
16.67%
33.33%
50%
66.67%
83.33%
Position in Frame (as % of height from bottom)
0° (Profile)
18°
36°
54°
90° (Directly Below)

Figure 6


Percentage of Variance Explained (R^2)
1
0.8
0.6
0.4
0.2
0
Quadratic
Linear
-90°
-54°
-36°
-18°
0°
0°
+18°
+36°
+54°
+90°
Perspective View

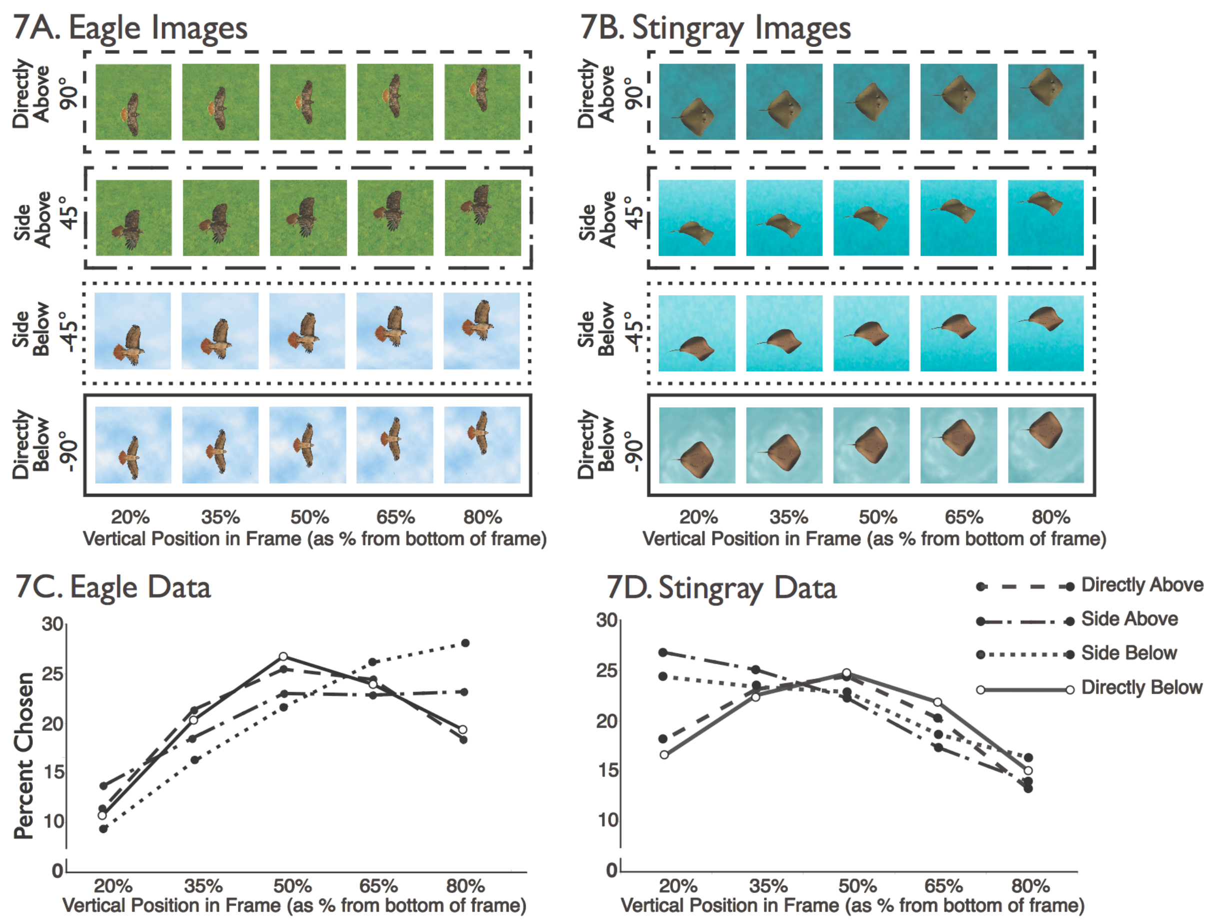
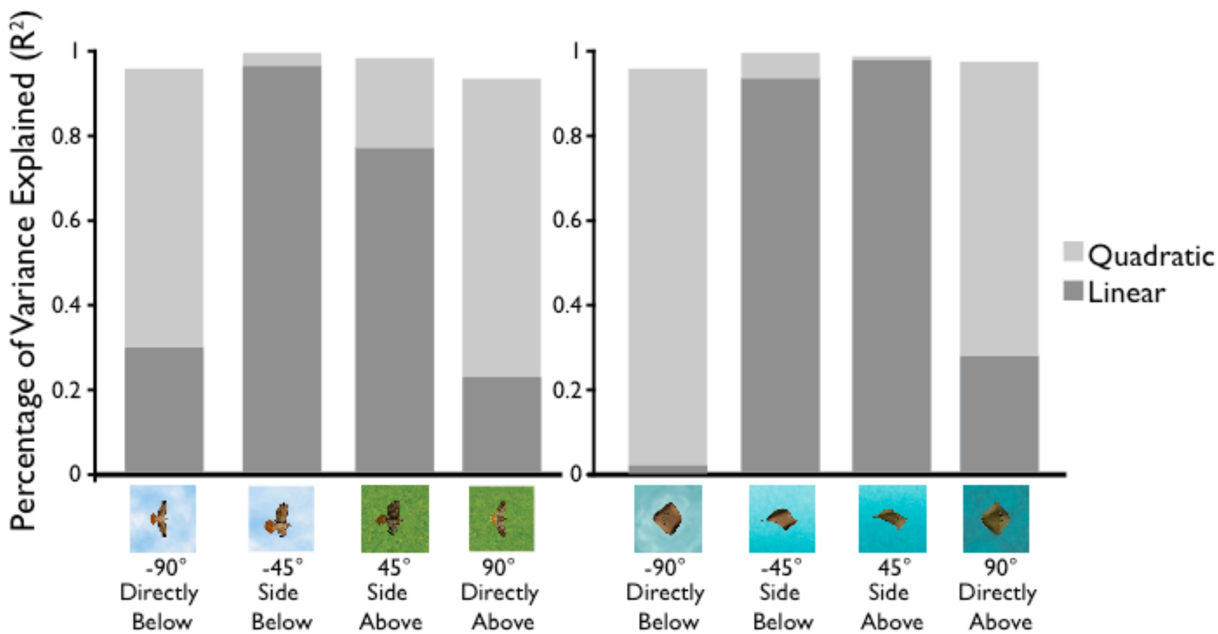

7A. Eagle Images
Directly Above 90°
Side Above 45°
Side Below -45°
Directly Below -90°
20%
35%
50%
65%
80%
Vertical Position in Frame (as % from bottom of frame)
7B. Stingray Images
Directly Above 90°
Side Above 45°
Side Below -45°
Directly Below -90°
20%
35%
50%
65%
80%
Vertical Position in Frame (as % from bottom of frame)
7C. Eagle Data
Percent Chosen
30
25
20
15
10
0
20%
35%
50%
65%
80%
Vertical Position in Frame (as % from bottom of frame)
7D. Stingray Data
30
25
20
15
10
0
20%
35%
50%
65%
80%
Vertical Position in Frame (as % from bottom of frame)
Directly Above
Side Above
Side Below
Directly Below

Figure 8


Percentage of Variance Explained (R^2)
1
0.8
0.6
0.4
0.2
0
Quadratic
Linear
-90°
Directly
Below
-45°
Side
Below
45°
Side
Above
90°
Directly
Above