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The shape of a view: Are rectilinear views necessary to elicit boundary extension?

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Viewers tend to remember seeing beyond the boundaries of a view (*boundary extension* [BE]; Intraub & Richardson, 1989). However, only rectilinear views have been tested (e.g., photographs, or views through windows). Views more typical of natural settings (irregular or rounded) have not been considered. Is BE an artifact of rectilinear boundaries? In Experiment 1, participants memorized rectilinear, oval, or irregularly shaped views (outermost points were equated) of 15 natural scenes. Minutes later, memory for the expanse of each view was tested (5-point scale). In Experiments 2 and 3, memory for rectilinear and oval views was contrasted using a new boundary adjustment procedure. Not only did BE occur for all shapes (Experiments 1–3), but it did so to the same degree. Layout projection appears to be a general characteristic of memory for a view—providing anticipatory representation of upcoming layout by extending outward from the farthest visible point.

Research on memory for pictures is typically motivated by one of two different classes of questions. The first focuses on pictures as *pictures*, contrasting performance on a variety of cognitive tasks when the input modality is either pictorial or verbal (e.g., one-word labels or sentences; e.g., Nelson, Metzler, & Reed, 1974; Shepard, 1967; see Paivio, 1971, and Potter, 1999), or studying interactions of the two during text comprehension (Glenberg & Langston, 1992; Johnson-Glenberg, 2000). The second focuses on pictures as *surrogates* for views of the real world. As an example, early research on scene perception made use of line drawings, not to study pictorial representation, but to tap into general knowledge about object relations in real-world scenes and test their potential influence on object perception (see Biederman, 1981; also see Henderson & Hollingworth,

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1999). Another example is research on *change blindness* in which photographs were used to explore the nature of scene representation from one moment to the next (e.g., Rensink, O'Regan, & Clark, 1997; Simons & Rensink, 2005). In fact, research was conducted using cinematic sequences and staged events to demonstrate that change blindness was not simply a pictorial phenomenon (see Simons & Levin, 1997).

However, the most transparent example of the distinction between the two classes of questions is research on *boundary extension* (BE). Although, discovered in memory for photographs (Intraub & Richardson, 1989), the critical feature of boundary extension is that viewers tend to remember seeing the world beyond the edges of the picture. It has been proposed that the edge of a photograph (or line drawing of a scene) is treated by the visual system not as the terminus of a pictorial representation, but as the edge of an aperture through which the viewer is seeing the world (see Intraub, 2002). It is this claim that we address in the current paper. Is BE a fundamental component of scene perception caused by perceived occlusion of a view? Or is it an artifact caused by a pictorial convention—that of presenting rectilinear representations of space?

BOUNDARY EXTENSION AND OCCLUDED VIEWS

Memory for pictures of scenes tends to include a consistent error whereby viewers remember seeing more of the scene than was actually shown. Intraub and Richardson (1989) coined the term *boundary extension* to describe this projective error. It has been suggested that BE may play a functional role in scene comprehension by rapidly placing a truncated view of the world within its larger spatial context and perhaps by priming upcoming layout (e.g., Intraub, 1997, 2002). Intraub and Gottesman (Gottesman & Intraub, 2002, 2003; Intraub, Gottesman, & Bills, 1998) proposed that BE occurs in part because the visual system responds to the edges of a picture as if the viewer were looking at the world through a window—an aperture beyond which the scene is understood to continue. Anticipation of continuity beyond the edges of the view, perhaps supported by amodal continuation of objects and surfaces, results in a mental representation that overflows the boundaries of the original view. Thus viewers remember seeing a region of space that was not physically presented.

According to this view, BE is elicited by occlusion. There are several lines of research that support this hypothesis (see Intraub, 2002, for a review). For example, BE apparently does not occur in memory for all types of pictures, but instead appears to require cases in which the picture's edges are understood as limiting a view of a continuous scene (Gottesman & Intraub, 2002; Intraub et al., 1998; Legault & Standing, 1992). Intraub et al. (1998)

demonstrated that outline drawings of single common objects on simple backgrounds (e.g., stippling to indicate an asphalt road beneath the object) yielded BE, whereas the same outline objects on blank backgrounds yielded bidirectional normalization errors (larger items were remembered as smaller, and smaller items as larger). However, the same outline objects on blank backgrounds did yield BE if viewers heard a description of the background associated with the object in the scene (e.g., "an asphalt road") and imagined the background while studying the pictures. Another study demonstrated a similar distinction with photographic stimuli. Given the same single object, when viewers were biased to consider the blank background as unrelated to the picture, normalization errors occurred; but when it could be considered to be a surface (albeit a poorly defined one), BE occurred (Gottesman & Intraub, 2002). In other words, when the picture's edges were understood to be *view boundaries*, BE occurred.

This distinction between surrounding boundaries that are view boundaries and those that are not has been demonstrated *within* scenes as well. Gottesman and Intraub (2003) showed that within a scene, only surrounding boundaries that are view boundaries yielded BE. For example, a photograph of a desktop that included, among other items, a framed photo of a scene was remembered with extended boundaries, as was the picture within the picture. However, when surrounding edges *within* the view were not view boundaries (i.e., did not depict an aperture), but instead depicted the edges of an object (e.g., a sandal atop a towel that is on grass, with the towel's edges surrounding the sandal), viewers remembered having seen more grass at the edges of the view (BE), but did not remember seeing a greater expanse of towel around the sandal.

To determine if BE is simply a picture memory phenomenon or if it occurs as well in memory for views of real 3-D scenes, Intraub (2004) had observers use vision or haptics (without vision) to explore regions of the world through a window-like aperture directly in front of them. The experimenters then removed the windows. Minutes later, observers returned and reconstructed the windows to recreate the regions from memory. Boundary extension occurred: Both groups remembered having explored the space just beyond the window although this space had not been seen nor touched. Results of the haptic condition were replicated with a person who had been deaf and blind since early life, showing that a "haptic expert" is prone to the same anticipatory error. Thus, BE not only occurred in memory for 3-D space, but also occurred regardless of modality.

Thus, BE may be a fundamental aspect of scene representation caused by occlusion at the edges of a view. If true, then BE should occur for virtually all apertures that reveal a view of a scene. However, to date, all BE research has made use of rectilinear views. This includes studies of BE across the lifespan (e.g., ages 6–84; Candel, Merckelbach, Houben, & Vandyck, 2004;

Seamon, Schlegel, Hiester, Landau, & Blumenthal, 2002) and those exploring BE for neutral and emotionally charged pictures (e.g., Candel, Merckelbach, & Zandbergen, 2003; Mathews & Mackintosh, 2004; Safer, Christianson, Autry, & Österlund, 1998). This is because, by convention, pictures and drawings (which comprise the typical stimulus base in scene perception research) are rectangular. Is BE a fundamental component of scene representation, or might it be an artifact of rectilinear views?

NATURAL VS. ARTIFICIAL VIEW BOUNDARIES

Apertures in the natural world are anything but rectangular. We always view the world through the "window" created by ocular occlusion. The shape of the visual field is rounded, providing a tapering view that diminishes incrementally. As Gibson (1979) pointed out, the monocular visual field itself is an irregular oval that includes notches where the nose, upper lips, and centre of the brow occlude the view (see Figure 1). Consider also the following cases: sitting in a park looking through nearby foliage to see children play, watching ducks swim through an opening in high grass, looking out the entrance of a cave, or studying the desert through an opening in a rock formation. Would these conditions yield sizeable amounts of BE?

Apertures that contain irregularities (e.g., unique convex or concave regions) might be less likely to elicit BE than would manmade, rectangular apertures for a variety of reasons. Such irregularities may make the boundary more salient, drawing attention to the edges of the view and thus resulting in

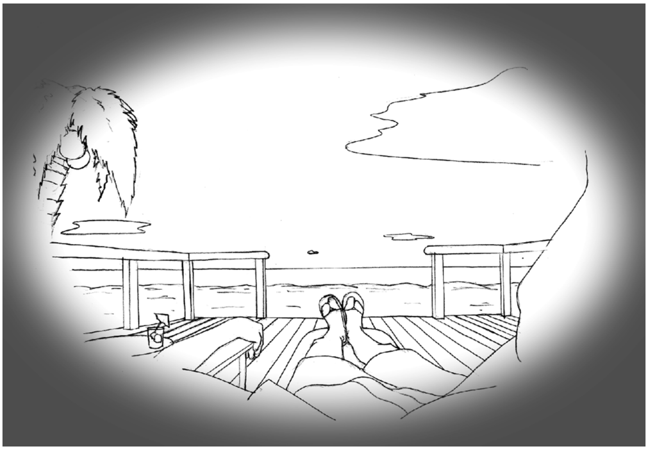

Figure 1. Illustration of the monocular field of view by Adam Rexrode based upon Gibson's (1950) interpretation of Ernst Mach's illustration.

more accurate memory of boundary placement. They may also provide identifiable landmarks that would aid memory for the spatial relation of the boundary to objects within the view. Finally, the overall shape of the aperture itself may serve to encourage or discourage extrapolation. A tapering, rounded aperture that provides an incremental diminishment of the view, slowly "closing it down", might dampen spatial extrapolation, whereas a rectilinear boundary, which provides an abrupt termination, may encourage processes that serve to "fill in" missing information in memory.

As an analogy for this idea, consider research on *perception* of occluded objects and textures. Occlusion of an object does not always lead to amodal *completion*, but instead interpolation of occluded contours and textures is graded (e.g., Kellman, Guttman, & Wickens, 2001; Singh & Hoffman, 1999). The strength of interpolation is affected by a variety of factors (see Kellman et al., 2001). For example, the angle formed by the visible edges of an occluded contour influences whether completion will occur (Kellman & Shipley, 1991). Particularly relevant to BE, construal of a region as a "dot" on an occluder or as a "hole" in the occluder will determine whether texture spreading occurs (Yin, Kellman, & Shipley, 1997, 2000). We suggest that mental representation of occluded regions in the case of BE is similarly sensitive to specific characteristics of the occluder and may be determined by a variety of factors, including the shape of the aperture.

Three experiments were conducted to determine if BE would occur in the case of more naturally occurring view boundaries. If BE is eliminated by tapering edges or landmarks, then it cannot be a fundamental aspect of the spatial representation of scenes. It may be that under more natural conditions, BE is unavailable to the viewer. On the other hand, if BE occurs for views with a variety of naturally shaped apertures, this would provide converging evidence that BE is a fundamental aspect of scene representation. Simply put, we sought to determine if prior BE research has overstated the availability and utility of BE in scene perception by testing it only in the context of rectilinear views.

EXPERIMENT 1

In Experiment 1, we presented the same 15 photographs with either a rectangular, oval, irregular and angular, or irregular and rounded view boundary. The rectangular view boundaries provided a replication of previous boundary extension findings and a comparison for the other border shapes. The three other shapes were chosen to represent the contours of more naturally occurring view boundaries: the oval view boundaries simulated the monocular visual field; and the irregular view boundaries (angular and rounded) simulated view boundaries for partial views such as

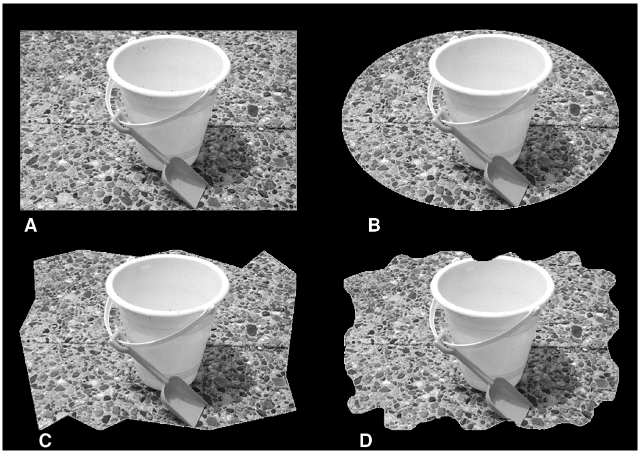

Figure 2. Sample stimulus ("pail") is shown within rectangular view (Panel A), oval view (Panel B), irregular linear view (Panel C), and irregular curved view (Panel D).

the opening to a cave or through foliage. One of the scenes shown within each aperture shape is presented in Figure 2. After studying the pictures, viewers were presented with the same views again and were asked to rate them as being the "same" as before, more close-up or more wide-angle on a 5-point scale (as in Intraub, Bender, & Mangels, 1992). To keep the scope of the view (spatial expanse) as similar as possible across views with different shapes, the outermost points of each view were equated as shown in Figure 3. Thus the views shared a similar scope, but had different contours.

Figure 3. Dotted line illustrates the perimeter of the rectangular view. The outermost points of the other shapes met, but did not exceed this perimeter. For example, stimulus ("panda") is shown in the irregular curved view.

With the exception of the rectangle, the other views contained tapering regions, where the view diminished incrementally. Is BE an artifact of rectilinear views? If not, will the shape of the view (putatively the shape of the viewing aperture) influence viewers' accuracy in remembering the original view?

Method

Participants. Participants were 124 University of Delaware undergraduates (64 female) who elected to take part in the departmental subject pool for a general psychology course.

Stimuli. Stimuli consisted of 15 close-up pictures of scenes with an object or object cluster on a natural background (e.g., a pail on a pebbled sidewalk; see Appendix). Depending on condition, the shape of the view was rectangular, oval, irregular linear, or irregular curved (one stimulus is shown with each type of view boundary in Figure 2). The rectangular view measured 460×700 pixels. The other three were created within this region such that the outermost points of the view were the same for all shapes (illustrated in Figure 3 with the irregular curved view).

Apparatus. Pictures were presented on a black background using Microsoft PowerPoint® on a 21-inch Dell monitor with the screen resolution set to $1024 \times 768 \times 32$ bits of colour. Participants were seated in three rows of four seats that ranged in distance between approximately 50–110 inches from the monitor, which was run by a Dell Dimension DIMXPS (P4/2.8 GHz). The visual angle subtended by the stimulus ranged from approximately $6^\circ \times 4^\circ$ for the front row to approximately $3^\circ \times 2^\circ$ for the back row.

Procedure. Participants were randomly assigned to one of the four view-boundary conditions ($N = 31$ in each condition). They viewed 15 pictures; each was presented for 10 s followed by a 2 s visual noise mask (multicoloured bars on a white background). Participants were instructed to focus their full attention on each picture and to try to remember it in as much detail as possible. They were instructed to pay attention to the objects, the background, and the layout. They were asked to try to remember everything in the pictures and retain an exact copy of each picture in memory. At test, the same 15 views were presented. Participants were instructed to rate each test picture on a 5-point scale as being "much closer-up" (-2), "slightly closer-up" (-1), "same" (0), "slightly more wide-angle" (1), or "much more wide-angle" (2), and then to indicate their confidence as "sure", "pretty sure", or "not sure". They were also given the option of

TABLE 1
Breakdown of confidence responses by shape in Experiment 1

Confidence rating	*Rectangular*	*Oval*	*Irregular linear*	*Irregular curved*
Sure	27%	37%	22%	32%
Pretty sure	57%	50%	63%	57%
Not sure	15%	13%	14%	12%

responding "do not remember picture". Test pictures remained visible until all participants had recorded their ratings on their response sheets.

Results and discussion

Table 1 shows the percentage of sure, pretty sure, and not sure responses for each condition; overall, participants were fairly confident about their responses. Viewers reported that they didn't remember seeing the picture on 1% or fewer trials in each condition. These trials were eliminated prior to analysis.

Viewers tended to rate the same view as being "more close-up" than before—indicating that they remembered the original views as having been more expansive (boundary extension). Mean boundary ratings for each of the four shapes are shown in Figure 4. As can be seen in the figure, confidence intervals revealed significant BE in each condition. A one-way ANOVA on viewers' mean boundary ratings across conditions revealed no difference as a function of the shape of the view, $F < 1$. To determine if BE occurred across participants irrespective of the magnitude of individual ratings, sign tests were conducted for each shape condition. Table 2 shows

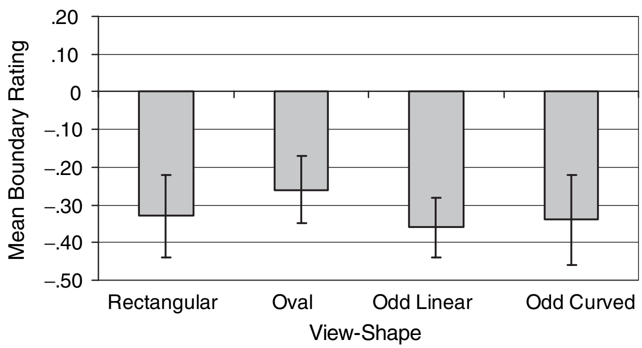

Figure 4. Mean boundary rating for each shape (Experiment 1). Error bars show the 95% confidence interval for each mean. Negative ratings indicate viewers remembered the pictures as having been closer-up, a distortion consistent with boundary extension.

TABLE 2
Number of participants reflecting a bias toward Extension, Restriction, or Neither (Tie) in Experiment 1

	Rectangular	*Oval*	*Irregular linear*	*Irregular curved*
Borders extended	25*	27*	30*	26*
Borders restricted	3	1	0	4
Tie	3	3	1	1

*Sign test for each shape was significant (p <.01).

the number of participants who made more boundary extension than boundary restriction responses in each condition. As shown in the table, sign tests revealed a significant bias, $p < .01$, to remember having seen beyond the edges of the stimulus view.

A picture analysis was conducted to determine if a small subset of pictures was causing BE or if as in prior studies, the effect was fairly widespread. This analysis also allowed us to determine if the shape of the view interacted with individual pictures. Mean boundary ratings for each picture were obtained in each shape condition and these means are presented in Figure 5. What is most important to note is that the differences among pictures appeared to be unaffected by the shape of the view. As can be seen in the figure, the majority of pictures were remembered with extended boundaries and the amount varied from scene to scene. This variability across scenes is similar to that observed in previous research (e.g., Intraub & Berkowits, 1996: Intraub & Bodamer, 1993). A 4 (shape) $\times$ 15 (picture) mixed measures ANOVA conducted on viewers' boundary ratings for each picture supported these observations; there was a main effect of picture, $F(10, 1887.20) = 26.64$, $p < .01$, no effect of shape, $F < 1$, and no interaction, $F(31.24, 1187.20) = 1.06$, $p = .38$. A Greenhouse-Geiser correction was applied to the within-subject variables to account for violation of the assumption of sphericity (the correction did not change the results).

EXPERIMENT 2

Although the contours of the viewing apertures differed greatly, they shared a similar "scope" in that the farthest points of view were always the same, suggesting that BE emanates from the view-boundary irrespective of its shape. However, the 5-point rating task may not have been sensitive enough to detect subtle differences in BE across the shapes. The purpose of Experiment 2 was to replicate these results using a quantitative test of spatial memory in which viewers could adjust the boundaries of the test view

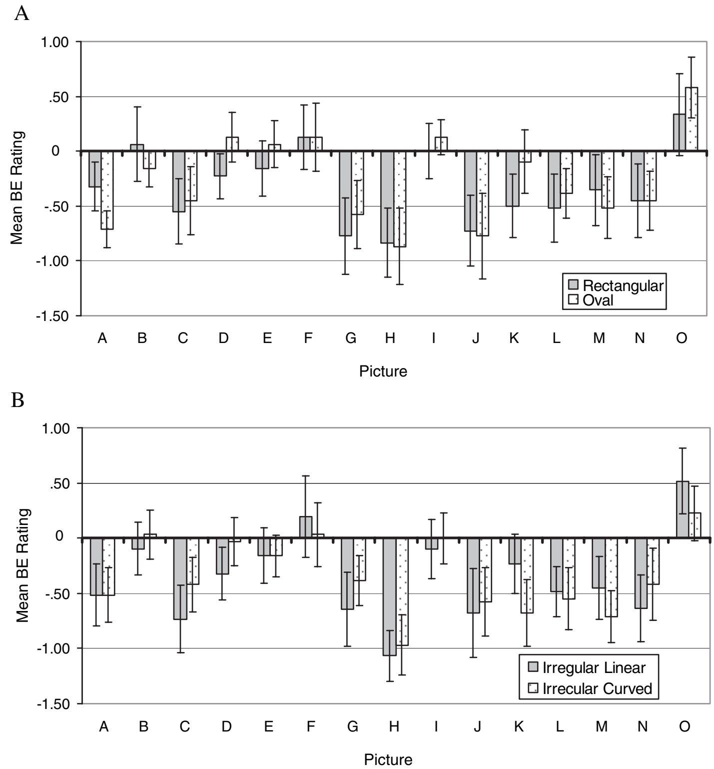

Figure 5. Mean boundary ratings for each picture (in presentation order: keys [A], wrench [B], bananas [C], chair [D], boy [E], shoe [F], tape [G], pail [H], hairdryer [I], dustpan [J], ball [K], cone [L], panda [M], pizza [N], lock [O]) in each condition (Experiment 1). Error bars show the 95% confidence interval for each mean. Negative ratings significantly different from 0 indicate pictures that were remembered as having been closer-up.

to match their remembered view. We used the rectangular and oval views from Experiment 1 because the contours were better suited to the flexible adjustments required by the quantitative test, allowing more sensitive measurement. Because height and width were equated, we were able to quantitatively compare memory for the same points in the picture even though in one case that point was the vertex of a tapering view and in the other case, it was the midpoint of a side in a rectilinear view.

Method

Participants. Participants were 84 University of Delaware undergraduates (31 female) who elected to take part in the departmental subject pool for a general psychology course.

Stimuli. Stimuli were the same as in Experiment 1 (rectangular and oval views). They were slightly larger than in the previous experiment. Outermost points were equated: For both shapes the view was 526 pixels high and 700 pixels wide.

Apparatus. Apparatus was the same, but a custom-written display program written in C++ using the Microsoft Windows® graphics user interface was used for stimulus presentation and boundary adjustment. Aperture shape was a transparent polygon (rectangular or oval) in an otherwise black field. During the test, pressing the "+" or "−" key on the keyboard changed the size of the polygon by a single pixel from the centre in all directions. Participants were individually tested. Viewing distance was approximately 18 inches; stimulus views subtended a visual angle of approximately $16^\circ \times 12^\circ$.

Procedure. Pictures were presented for 10 s each followed by the visual noise mask for 3 s. There were 42 participants in each condition (rectangular and oval). The same presentation instructions were read as in Experiment 1. Test instructions were given following stimulus presentation. Each test picture was actually identical to the stimulus view. Participants were instructed to use the "+" and "−" keys on the keyboard to increase or decrease the size of the aperture to reconstruct the view they had originally seen. The size of participants' reconstructed apertures was recorded in pixels. Confidence ratings were not reported.

Results and discussion

Overall, participants remembered having seen more of the scene than was shown. In the rectangular condition, they increased the visible area by 8% ($SD = 0.10$), $t(41) = 5.30$, $p < .01$; in the oval condition, they increased it by 7% ($SD = 0.11$), $t(41) = 4.21$, $p < .01$. Analyses were performed for change in width and height. Due to the fixed aspect ratio of the apertures, width and height were completely correlated and yielded the same results. For simplicity, the following analyses report only the change in width.

The analysis of change in width at the outermost points revealed the same pattern exhibited by viewers for overall area. Participants in the rectangular condition increased the width of the visible area by 3% ($SD = 4.54$), $t(41) = 4.94$, $p < .01$. Those in the oval condition also increased it by 3% ($SD = 5.03$), $t(41) = 4.01$, $p < .01$; and in fact, the increase in the width of the visible area was virtually identical across conditions, $t(82) = 0.34$, *ns*. To determine if the results truly show a unidirectional change, we conducted sign tests for each shape condition. There was enough space to allow viewers to move the

TABLE 3
Number of participants reflecting a bias toward Extension, Restriction, or Neither (Tie) in Experiments 2 and 3

	Rectangular	*Oval*
Experiment 2		
Borders extended	32*	32*
Borders restricted	7	9
Tie	3	1
Experiment 3		
Borders extended	20*	19*
Borders restricted	1	3
Tie	2	1

*Sign test was significant for both Experiment 2 and Experiment 3 ($p < .01$).

view boundaries in or out without cropping an object. However, it was possible to extend the boundaries a greater distance than to restrict them, thus potentially skewing the mean. Table 3 shows the breakdown of participants who extended the boundaries more often, those who restricted the boundaries more often, and those who extended and restricted equally often. As can be seen in the table, the majority of participants extended the boundaries more often than they restricted them in both the rectangular and oval shape conditions, $p < .01$.

To determine if BE occurred across a majority of the pictures and whether the shape of a view interacted with individual pictures, we did a picture analysis. The mean percentage change in width for each picture in each condition is presented in Figure 6. As in Experiment 1, inspection of the

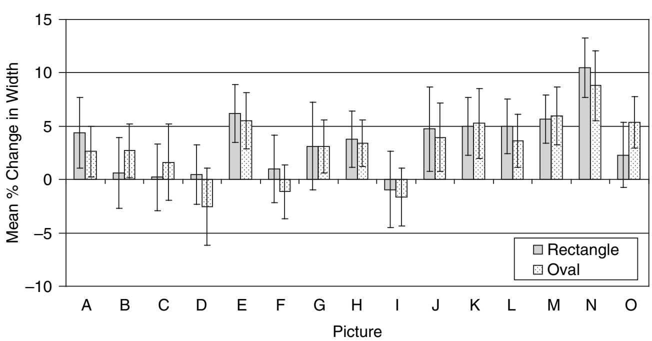

Figure 6. Mean percentage change in width for each picture (in presentation order: keys [A], wrench [B], bananas [C], chair [D], boy [E], shoe [F], tape [G], pail [H], hairdryer [I], dustpan [J], ball [K], cone [L], panda [M], pizza [N], lock [O]) in each condition (Experiment 2). Error bars show 95% confidence interval. Positive percentages significantly different from 0 indicate pictures that elicited boundary extension.

figure suggests variation among the pictures, but the same overall pattern regardless of shape. A 2 (shape) $\times$ 15 (picture) mixed measures ANOVA with a Greenhouse-Geiser correction conducted on viewers' mean percentage change in width for each picture supported these observations, revealing a main effect of picture, $F(6.80,\ 557.39) = 9.75$, $p < .01$, no effect of shape, $F < 1$, and no interaction, $F < 1$.

EXPERIMENT 3

In Experiment 2, viewers tended to move the boundaries outward during the test, and to expand the visible area by the same amount irrespective of whether the view was oval or rectangular. On the face of it, this suggests that BE occurred and that shape had no influence on BE. However, it is possible that the new procedure (in which viewers adjusted the size of the aperture) might have introduced an unexpected element into viewers' decisions. A change in the aperture, of course, also changes the size of the image with respect to the edges of the screen, resulting in a different picture-to-screen ratio. Certain ratios seem to be more aesthetically pleasing than others. For instance, a preference for the golden ratio is often found in art and this ratio is also embedded in nature, in the geometry of living things. Perhaps there is a certain picture-to-screen ratio that is particularly pleasing, or in some sense more "prototypic" than the picture-to-screen ratio of the stimulus views. When adjusting the boundaries, viewers in both conditions might have opened the aperture to create this expected size, rather than opening the aperture because of BE.

To test this hypothesis, in Experiment 3, we set the aperture size on the stimulus view to be equal to the mean reconstructed view provided by viewers in Experiment 2. If this aperture size represents a "pleasing" or "prototypic" ratio, then, no directional bias should be obtained at test. On the other hand, if the test reflects extended boundaries in memory, we would expect to replicate the results of Experiment 2 with the new aperture size.

Method

Participants. Participants were 46 University of Delaware undergraduates (34 female) who elected to take part in the departmental subject pool for a general psychology course.

Stimuli. Stimuli were the same as in Experiment 2 except that the width of the rectangular and oval apertures was 723 pixels and the height was 544 pixels. This represents the 3.3% increase in the width (and height) of the aperture set by viewers in Experiment 2.

Apparatus. Apparatus and program were the same used in Experiment 2.

Procedure. Procedure and instructions were the same as in Experiment 2 with 23 viewers in both the rectangular and oval shaped views. As in Experiment 2, the percentage of change in width (measured in pixels) was calculated and analysed.

Results and discussion

As in Experiment 2, viewers remembered seeing beyond the view boundaries: they increased the visible area by 13% ($SD = 20.75$), $t(22) = 3.01$, $p < .01$, in the rectangular condition and 10% ($SD = 10.90$) in the oval condition, $t(22) = 4.30$, $p < .01$. Again, focusing on the width of the reconstructed apertures, there was a 5.70% increase ($SD = 8.72$) in the rectangular condition, $t(22) = 3.14$, $p < .01$, and a 4.21% increase ($SD = 5.00$) in the oval condition, $t(22) = 4.04$, $p < .01$. Shape had no effect on the size of the increase, $t(44) = -0.71$, $p = .48$. As in Experiment 2, when we looked simply at the number of times viewers extended or restricted the aperture, sign tests revealed a strong significant bias for remembering more beyond the boundaries than was actually seen, $p < .01$ for both conditions. Table 3 shows the number of participants who extended the boundaries more frequently and those who restricted more often. As can be seen in the table, the pattern of responding was the same as in Experiment 2.

A picture analysis was conducted. Figure 7 shows the mean percentage change in width for each picture in each condition. Examination of the

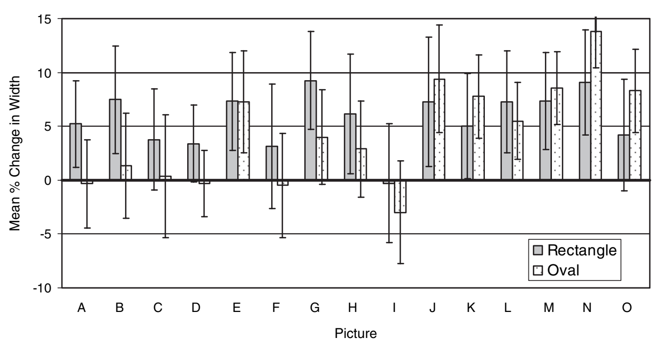

Figure 7. Mean percentage change in width for each picture (in presentation order: keys [A], wrench [B], bananas [C], chair [D], boy [E], shoe [F], tape [G], pail [H], hairdryer [I], dustpan [J], ball [K], cone [L], panda [M], pizza [N], lock [O]) in each condition (Experiment 3). Error bars show 95% confidence interval. Positive percentages significantly different from 0 indicate pictures that elicited boundary extension.

figure indicates that, as in Experiments 1 and 2, the majority of pictures yielded boundary extension and individual pictures varied in terms of the amount of extension that occurred. A 2 (shape) $\times$ 15 (picture) mixed measures ANOVA conducted on viewers' mean percentage change in width for each picture verified these observations: A main effect of picture, $F(7.43, 327.06) = 7.76$, $p < .01$, and no main effect of shape, $F < 1$. Unlike Experiments 1 and 2, a significant interaction was obtained, $F(7.43, 327.06) = 2.21$, $p = .03$. It is unclear if this interaction reflects a real difference or if it simply reflects noisy data due to fewer participants.

GENERAL DISCUSSION

Boundary extension is not limited to the conventional rectilinear views that typically characterize photographs. Viewers remembered beyond the edges of the view for a variety of view boundaries that are not typical for pictures, but that are common in the natural environment (rounded or free form). All views showed the same objects and shared the same outermost points; of particular interest is that they elicited the same amount of BE as well. In Experiment 1, spatial memory for rectangular, oval, and two irregularly shaped views of the same scenes were tested using the same 5-point boundary rating scale as in previous research (see Intraub, 2002). Viewers rated the *same* views as being more "close up" than before, indicating that memory for the views included boundary extension. The extent of extrapolation did not differ as a function of shape nor was there a shape by picture interaction.

In Experiment 2 we replicated these results using a new interactive test that provided a quantitative assessment of spatial memory. Viewers adjusted the size of oval or rectangular "apertures" to reveal the remembered portion of each scene. Boundary adjustments tended to be expansive; viewers included more of the background in their reconstructions than had been presented in the stimuli. More important, there was no difference between the rectangular and oval condition. In both cases viewers tended to open the apertures enough to increase the visible area by about 8%.

It is important to remember that in all three experiments the outermost points of each view boundary were the same, irrespective of shape, yet BE did not differ. In Experiments 2 and 3, the outermost points corresponded to the width (and height) of the aperture. Whether the aperture was rectangular or oval, viewers expanded the width (and height) by the same amount. Thus the results suggest that BE emanates outward from the contour of a view boundary, whatever shape that view boundary might take. In both Experiments 1 and 2, the amount of spatial extrapolation varied from one scene to the next in response to idiosyncratic characteristics of the view.

However, the magnitude of this extrapolation did not change as a function of the shape of the view, nor was there an interaction between scenes and shape.

Finally, although the boundary adjustment task (Experiment 2) yielded the same pattern of results as the boundary-rating task (Experiment 1), we were concerned about one aspect of the new test. In the rating task, the test item is unchanged, only the rating varies, whereas in the boundary adjustment task, the viewer must increase or decrease the physical size of the view to indicate boundary extension or boundary restriction. Was the mean increase in aperture size a true reflection of BE or were viewers simply adjusting the size of the image to create an aesthetically pleasing picture-to-screen ratio? To test this alternative, the mean boundary placement set by participants in Experiment 2 was used to create the stimulus views for Experiment 3. Thus, the new participants would memorize views at this "preferred" picture-to screen ratio. However, contrary to what would be expected if this alternative were true (i.e., no significant change in aperture size), viewers opened the apertures even farther, and did so to the same degree for the new oval and rectangular views.

Differences in BE across pictures

Pictures differed in how much BE they engendered. This is a typical observation in studies of BE (whether pictures or regions of real 3-D scenes serve as stimuli; see Intraub 2004). The factors that determine the amount of BE that will occur in memory are not yet fully known. However, evidence for influence at three different stages of processing has been demonstrated. The first stage is related specifically to BE. As described earlier, truncated views of otherwise continuous scenes yield background extrapolation; but idiosyncratic characteristics of each view determine how much. One such characteristic is the amount of visible background surrounding the main object. Given the same *centrally located* object or object cluster, views rated as "close-up" (little surrounding background) are remembered with the greatest amount of BE, followed by views rated as "prototypic" (more surrounding background), and views rated as "wide-angle" (i.e., a lot of surrounding background; e.g., Intraub et al., 1992; Intraub & Berkowits, 1996). In other research using computer-generated scenes, viewers' simulated distance from the main object in a view was maintained, but the size of the object was varied (Bertamini, Jones, Spooner, & Hecht, 2005); when the background view was diminished due to the larger centre object, more BE occurred. Other spatial and textural characteristics of the background may prove to be important (see Oliva & Torralba's, 2001, characterization of layout in terms of "spatial envelopes") as may be conceptual expectations about the scene, but these possibilities have yet to be tested.

The second stage of processing involves changes that occur in memory during retention (interitem influences, and various types of averaging). These changes can mitigate against the original extrapolation. Increases in set size and/or retention interval will increase the influence of these factors. For example, BE for the same 18 pictures was greater when tested immediately than when tested after a 48-hour retention interval (Intraub et al., 1992). Examination of picture cohort effects showed that over time, normalization (regression to the mean view) had shifted spatial memory. The original BE was robust enough to remain detectable, but was to some extent "washed out" (Intraub et al., 1992). Factors that decrease memory for the details of a view, are likely bring in errors that will lessen the detection of BE.

Finally, as is well known in the memory literature, the test itself can affect performance. If the test is long and involves sequential exposure to many different views, this too influences memory (see, for examples, Chapman, Ropar, Mitchell, & Ackroyd, 2005; Intraub, Hoffman, Wetherhold, & Stoehs, in press).

The differences in BE across stimuli in the present experiment are typical of those seen in other studies. What is important, given the purpose of these experiments, is that the BE was robust (even given a 15-item memory set), and that it did not differ as a function of large changes in the shape of the view boundary.

BE and occlusion

The results of the current experiments support the idea that BE is related to occlusion at the edges of the view. For example, consider the problem of "hole" perception. Bertamini and Croucher (2003) describe this problem as a question of how we perceive something that isn't there, but manage to perceive its size and shape. According to Palmer (1999), for an area to be perceived as a hole, there must be cues that indicate a surface that continues behind an occluding surface or ground. Nelson and Palmer (2001) showed viewers stimuli comprised of inner and outer regions that varied in depth factors such as shadowing, occlusion, and continuation cues and asked them to determine if the region was an object or a hole. They found that when depth cues indicated that a surface was occluded by a surrounding object, then that surface will be perceived as a hole. In their discussion of holes, Bertamini and Croucher propose that the boundaries of a hole belong to the surrounding (or occluding) object and that the area of the hole is perceived as background. It would then seem that because the borders or contours belong to the occluding object, the area of the hole (the contents within the hole or the background) can be perceived as continuous and unbound by those contours.

Nakayama, Shimojo and Silverman (1989) presented an excellent illustration of perception of bound versus unbound surfaces using a stereogram of a face that was occluded by horizontal strips. Viewers saw unoccluded faces and then were tested with faces occluded by black bars that made the visible strips of faces appear either in front of or behind the bars. They gave a yes/no response as to whether they had seen the face previously. Participants made fewer errors when the visible areas of the face were perceived as being behind the occluding bars. In this case, the contours belonged to the occluding strips and the visible portions of the face were continuous and unbound behind the occluders, allowing amodal perception. This illustration is particularly striking given that the visible portions of the face were identical in both cases. In the case of BE, there are occlusion cues at the boundaries, signalling that you are viewing the scene through an aperture and that the scene continues beyond that aperture. It naturally follows that the background, or in this case, the scene, continues behind the occluder and perhaps it is this perception of occlusion that encourages BE.

Evidence for continuation behind an occluder can also be seen in a memory task reported by Henderson and Hollingworth (2003) using a display that was similar to the one used by Nakayama et al. (1989). Henderson and Hollingworth conducted a clever study to determine if representations across saccades are point to point perfect or if they are more abstract. Viewers saw displays of scenes in which vertical gray bars occluded regions of the scene. Eye movements triggered a shift in the location of the gray bars such that previously visible regions of the scene were now occluded and previously occluded regions were now visible. This change was completed by the time the eyes landed. Participants were very poor at detecting these scene changes, indicating that the scene was remembered as continuing behind the occluders. As in the perception work, the contours or boundaries of the strips would be assigned to the gray occluding bars, cuing viewers to the continuation behind the occluders. Based on this evidence, Henderson and Hollingworth propose that transsaccadic representations are not pixel for pixel perfect. Evidence from boundary extension studies suggests the same conclusion. In fact, from our perspective, the occluding gray bars serve to provide multiple view boundaries that would encourage BE.

The outcome of these experiments can be explained in the following way. Perception of the world is always accomplished one view at a time. The goal is to grasp and retain a representation of the surrounding world, not the spurious boundaries of a single truncated view. In fact, view boundaries are "accidents of viewing conditions" and constantly change as we move our eyes, head, and bodies, making memory for the boundaries of each view unimportant. Perhaps the visual system has evolved to "ignore" the specific location of view boundaries and, instead, extrapolate beyond them, based upon the particular visual characteristics of a view (Intraub, 1997, 2002). The fundamental nature of these characteristics is illustrated by Intraub and Bodamer's (1993) research in which viewers were forewarned about BE and challenged to prevent it, yet were unsuccessful in doing so. Awareness allowed them to attenuate but not eliminate BE.

The present research further supports the fundamental nature of BE by showing that it generalizes to a variety of view-boundary shapes, occurring irrespective of the contours comprising the "aperture" through which the scene is viewed. Viewers remembered seeing beyond the boundaries of the view—just as if the view continued behind the occluding surface. BE is certainly not a special case of rectilinear borders. Regardless of shape, it seems to emanate from the contours of the view boundaries, supporting the idea that BE is a characteristic of our memory for a continuous world we can only perceive one view at a time.

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Appendix A

List of stimuli for all experiments

Key	*Stimulus description*
A	key with anchor keychain on a tile floor
B	wrench on a cloth on gravel
C	bananas on rocks
D	lawn chair on a deck
E	boy sitting on a towel on front lawn
F	pink shoe on grass
G	roll of tape on carpet
H	pail on pebbled sidewalk
I	hairdryer on a block sidewalk
J	dustpan on a brick floor
K	basketball on a wooden floor
L	traffic cone on gravel
M	stuffed panda bear on cement steps
N	slice of pizza on a cardboard box
O	lock on a washcloth on a tile floor