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To determine if layout affects *boundary extension* (BE; false memory beyond view boundaries; Intraub & Richardson, 1989), 12 single-object scenes were photographed from three vantage points: central ($0°$), shifted rightward ($45°$), and shifted leftward ($45°$). Size and position of main objects were held constant. Pictures were presented for 15 s each and were repeated at test with their boundaries: (a) displaced inward or outward (Experiment 1: $N = 120$), or (b) identical to the stimulus views (Experiment 2: $N = 72$). When participants adjusted test boundaries to match memory, BE always occurred, but tended to be smaller for $45°$ views. We propose this reflects the fact that more of the 3-D scene is visible in the $45°$ views. This suggests that scene representation reflects the 3-D world conveyed by the global characteristics of layout, rather than the 2-D distance between the main object and the boundaries of a picture.

Keywords: Boundary extension; Scene perception; Spatial layout; Spatial orientation; Visual memory.

A number of basic operations appear to happen very rapidly when we perceive and remember scenes. With masked exposures lasting only tens of milliseconds, observers are able to extract global characteristics of spatial layout to categorize pictures (e.g., outdoor vs. indoor scene'', or "beach scene''; Greene & Oliva, 2009a, 2009b; Schyns & Oliva, 1994). Moreover, people frequently

remember having seen a continuation of the world just beyond the boundaries of a view (boundary extension—BE; Intraub & Richardson, 1989; see Michod & Intraub, 2009). Like scene categorization, boundary extension occurs rapidly. It has been observed following retention intervals as fleeting as 42 ms (Dickinson & Intraub, 2008; Intraub & Dickinson, 2008). The purpose of our research was to determine if the magnitude of the boundary extension error is determined by expectations about the scene's layout, or by the size and placement of the main object in the picture space.

Layout affects many aspects of scene perception (Sanocki, 2003; Sanocki & Epstein, 1997). In addition to supporting scene classification (Oliva & Torralba, 2001), layout can be quickly extrapolated beyond the current view (Castelhano & Pollatsek, in press; Hollingworth & Henderson, 2004), and also serves to guide the placement of eye fixations within scenes (Torralba, Oliva, Castelhano, & Henderson, 2006). Even in nonscene displays containing different arrangements of Ts and Ls, regularities in the spatial relations among the letters are rapidly learned, apparently without conscious awareness, leading to faster reaction times (*contextual cueing*; Chun, 2000; Chun & Jiang, 1998, 2003; Kunar, Flusberg, Horowitz, & Wolfe, 2007). Similar contextual cueing effects have been reported when observers search for letters embedded in photographs of scenes (Brockmole & Henderson, 2006). Neuroimaging research suggests that specific brain areas are sensitive to scene structure (most notably, the parahippocampal place area: Epstein, 2005; Epstein & Higgins, 2007; Epstein & Kanwisher, 1998; and the retrosplenial cortex: Epstein & Higgins, 2007; Park & Chun, 2009). Selective patterns of neural attenuation in those areas suggest that they respond to the boundary-extended scene representation, rather than the original physical image (Park, Intraub, Yi, Widders, & Chun, 2007).

Does the layout of a view affect boundary extension? The only feature of a view that is known to systematically affect boundary extension is the scope of the view (ranging from close-up to wide-angle). In several experiments with centralized main objects or object clusters on a natural background (e.g., a backpack on a leaf-covered field; a bowl of oranges on a table), views that were rated as being "close-up", "prototypic", or "wide-angle" were presented to new groups of observers and memory was tested. When tested within minutes, boundary extension was greatest for very tight close-ups and decreased as views widened, ultimately reaching a point where no directional distortion occurred (e.g., Intraub, Bender, & Mangles, 1992; Intraub & Berkowits, 1996). In other experiments without prior ratings, closer versus wider views yielded the same pattern of results (Bertamini, Jones, Spooner, & Hecht, 2005; Gottesman & Intraub, 2002; Intraub, Daniels, Horowitz, & Wolfe, 2008; Intraub & Dickinson, 2008; Intraub, Gottesman, & Bills, 1998; Intraub, Gottesman, Willey, & Zuk, 1996; Intraub & Richardson, 1989; Park et al., 2007).

Why do more wide-angle views yield less boundary extension? Intraub and colleagues have proposed that, in the case of these simple scenes, the scope of the view influences the observer's expectations about the background continuing without change (Gottesman & Intraub, 2002; Intraub et al., 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989). In a tight close-up of an object, where so little of the background is visible, there is a default expectation that the background will continue. However, as the space between the object and the view boundaries increases, the anticipated content beyond the boundary becomes less constrained by the visual information. For example, consider a coffee mug on a table. In a tight close-up, the likelihood of the tabletop continuing is high. Of course, in reality, the mug might be situated precariously close to the table's edge or there might be an unseen muffin almost touching the mug. For wider views, in which one can see much of the tabletop surrounding the mug, the likelihood of a change becomes greater; it is more likely that another object (e.g., a muffin) might be present or that the tabletop might end.

Intraub and Dickinson (2008; also see Intraub, 2010) have suggested that if we accept this notion of graded probabilities, then we can think of boundary extension as a *source monitoring* error (Johnson, Hashtroudi, & Lindsay, 1993; Lindsay, 2008). The strong expectations of continuity beyond the boundaries in a close-up are more likely to be misattributed to vision at the time of the test than are the weaker expectations in the case of the wider angle views. According to this account, scene representation is a mental representation of the world that the picture only partially reveals; how much of that representation will be attributed to vision when an observer remembers the scene is moderated by probabilistic expectations. Boundary extension will therefore be the greatest when expectations favour a low likelihood of a change.

In contrast, Bertamini et al. (2005) suggested that it is not the scope of the view, but the size of the main object in the picture space that determines how much boundary extension will occur. In the closer and wider views, the main object was always larger in a tight close-up than in a wide-angle view. Given that there is evidence for canonical object sizes in perception of and memory for pictures of objects without scene contexts (Konkle & Oliva, 2010) it is important to consider the possible influence of object size in boundary extension. To disentangle the size of the main object from the scope of the view, Bertamini et al. created computer-generated views in which the same "close-up" or "wide-angle" background was paired with a main object that was either large or small. Figure 1 shows examples of a "wide-angle background" (top row) and a "close-up background" (bottom row), each with a large and small version of the main object. Observers viewed sequences of three pictures in a self-paced design, followed by a 1 s mask. A test picture (which either matched, or was a closer or wider view than one of
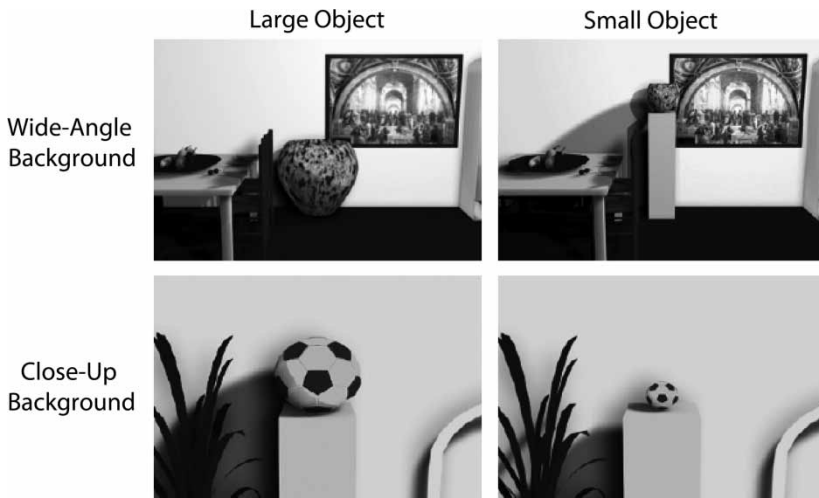
Figure 1. Pictures in the top row show the same "wide-angle" backgrounds with a large or small "main object" (the vase) and pictures in the bottom row show the same "close-up" backgrounds with a large or small main object (the soccer ball). *Source:* Figure 10 (p. 1299, adapted) and Figure 12 (p. 1301, adapted), from M. Bertamini, L. A. Jones, A. Spooner, & H. Hecht (2005). Boundary extension: The role of magnification, object size, context, and binocular information. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1288–1307.

the pictures) was presented and rated as being "the same", "more close-up", or "more wide-angle" than the stimulus on a 5-point scale (as in Intraub & Richardson, 1989). Regardless of the scope of the background, the size of the main object determined boundary extension; pictures with a large main object elicited boundary extension, whereas those with a very small main object did not.

Before accepting this interpretation of their results, however, it is important to recognize the difficulty of holding the scope of the background constant while manipulating object size, without changing other potentially important attributes of the views. For example, as shown in Figure 1, changing the size of the object sometimes changed the placement of the object in the picture space, required the addition of another object (e.g., a pedestal under the small vase), or changed the semantic interpretation of the object (e.g., normal soccer ball vs. miniature soccer ball). In addition, one might question whether the stylized images used in the study would evoke the same sense of place as do photographs or highly realistic computer-generated views.

Our challenge was to change the spatial expanse captured in our views without changing the meaning of the view ("gist"), or the size and placement of the main object in the picture space. To accomplish this, we decided to change the layout by varying the viewpoint with respect to the scene's

background surface. Scenes were photographed that shared the same basic structure: a large background surface (e.g., a fence, a stone wall, an indoor wall, and so forth) that extended well beyond the region framed by the camera, and a single salient foreground object. What varied was the vantage point with respect to the background surface. In the central vantage point condition, the line of sight was essentially perpendicular to the background surface, as shown in Figure 2 (top row). In the right- and left- vantage point conditions, to include more of the background surface, the same scene was photographed from a sharp angle: 45° to the left (shown in Figure 2, middle row), or 45° to the right (shown in Figure 2, bottom row). The reader can verify this difference by inspecting the pictures in the right column of Figure 2; one can see only five patio tiles and four wall stones from the central vantage point, whereas one can see six patio tiles and five wall stones from a vantage point of 45°. Main objects were always spherical or cylindrical so that they looked the same irrespective of viewpoint. Furthermore, size and placement of the main object (with respect to the picture's boundaries) was identical across views.

If boundary extension is determined by the size of the main object in the picture space as suggested by Bertamini et al. (2005), then we should observe the same amount of boundary extension in all three conditions because the size and placement of the main object is identical. On the other hand, if boundary extension is influenced by how much of the background surface is visible in the picture, then boundary extension should be greater in the central vantage point condition than in views taken from a 45° angle. This is because less of the surrounding background surface is visible in views taken from the central vantage point.

EXPERIMENT 1

In Experiment 1, after studying 13 views taken from a single vantage point (central, right, or left) participants adjusted the boundaries of each picture to recreate the original view (using the same procedure as Intraub, Hoffman, Wetherhold, & Stoehs, 2006). To avoid a bias towards moving borders either inward or outward, on half the trials the borders were set very close together (revealing much less of the scene than before: small-aperture test trials) and on half the trials they were set very far apart (revealing much more of the scene than before; large-aperture test trials). Figure 3 shows a stimulus view (central vantage point) in the top panel, and an example of the two potential test views for that picture: (a) small-aperture test view (middle picture), and (b) large-aperture test view (bottom picture).
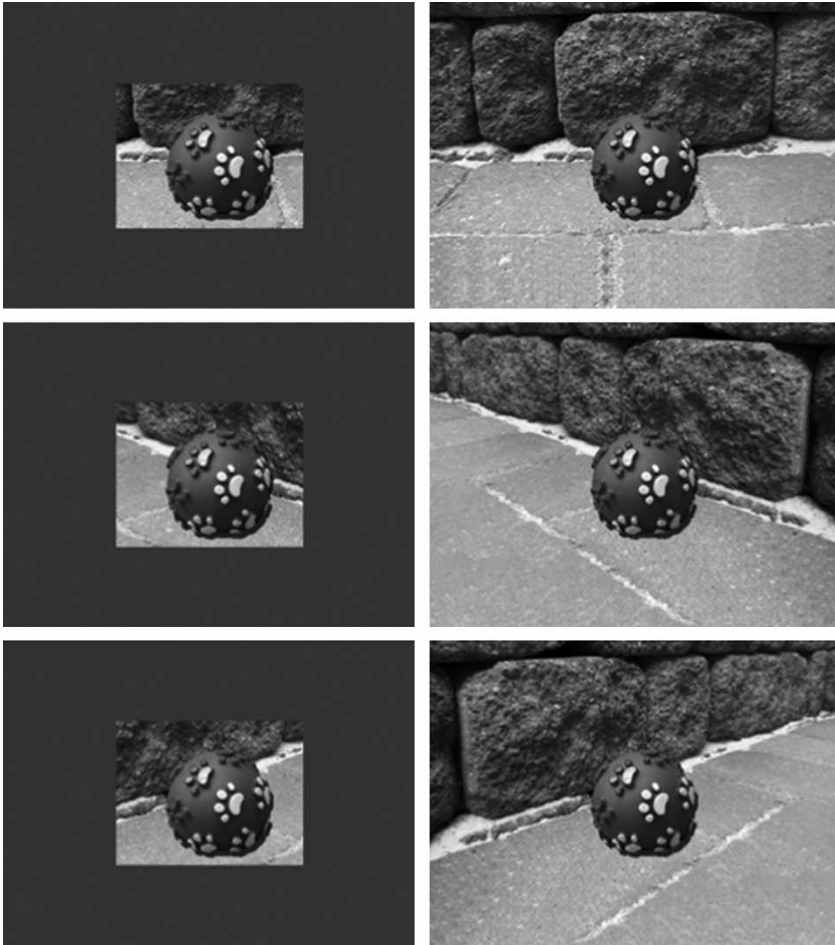
Figure 2.   Examples of the stimulus views (left column) and full-scene views (right column) of one scene in the central vantage point (top row), right vantage point (middle row), and left vantage point (bottom row) conditions. All pictures were presented in colour and were presented in a mirror-reversed orientation for half of the subjects in each condition.

Method

Participants

Participants were 120 (74 female) University of Delaware undergraduates, fulfilling a requirement for an introductory psychology course ($N = 40$ in each of the three vantage point conditions).
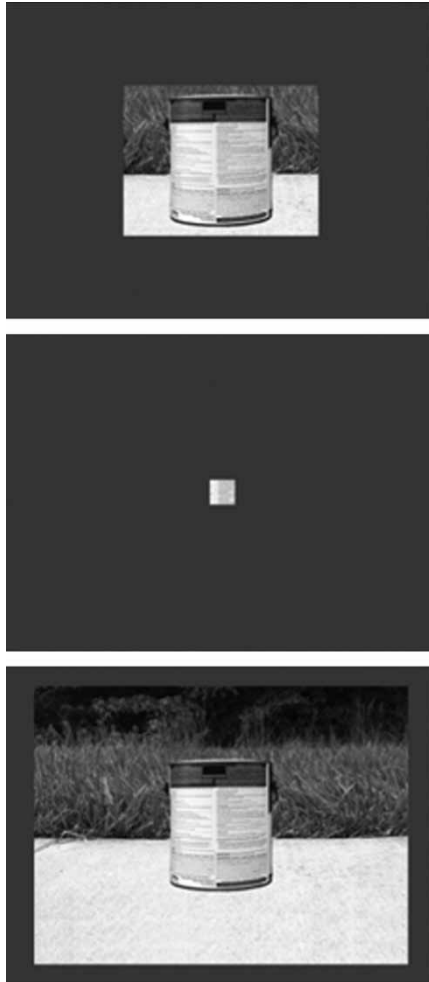
Figure 3. An example of a stimulus view (top row), a "small-aperture" test view (middle row), and a "large-aperture" test view (bottom row) for the "paint can" scene.

Stimuli

Stimuli were photographs of 12 scenes that included a salient background surface and a single main object in either an indoor or outdoor setting (an example is shown in Figure 2; see Appendix for descriptions of all scenes). The full view of each picture was 1024×768 pixels (as shown in the right column of Figure 2). A 464×361 portion of each picture (subtending approximately $14° \times 11°$ of visual angle) constituted the stimulus view. This

was presented in the centre of 1024×768 homogenous grey background (as shown in Figure 3).

Each scene was photographed from three vantage points with respect to the background surface (e.g., a fence). Figure 4 illustrates the camera's position and lateral viewing angle for the central, right and left vantage points. The camera's distance from the main object in the three versions of each scene was maintained by attaching a fixed length of string between the lens of the camera and the bottom of the main object. The central view was taken first, and then the camera was shifted 45° to the right and 45° to the left using the string and a protractor, as illustrated by the black dotted lines in the figure. The vertical viewing angle (i.e., the pitch of the camera) varied for each scene depending on object size and distance.

To obtain the final three versions of the scenes, four photographs of each scene were taken: (a) two central vantage point photographs, one with the
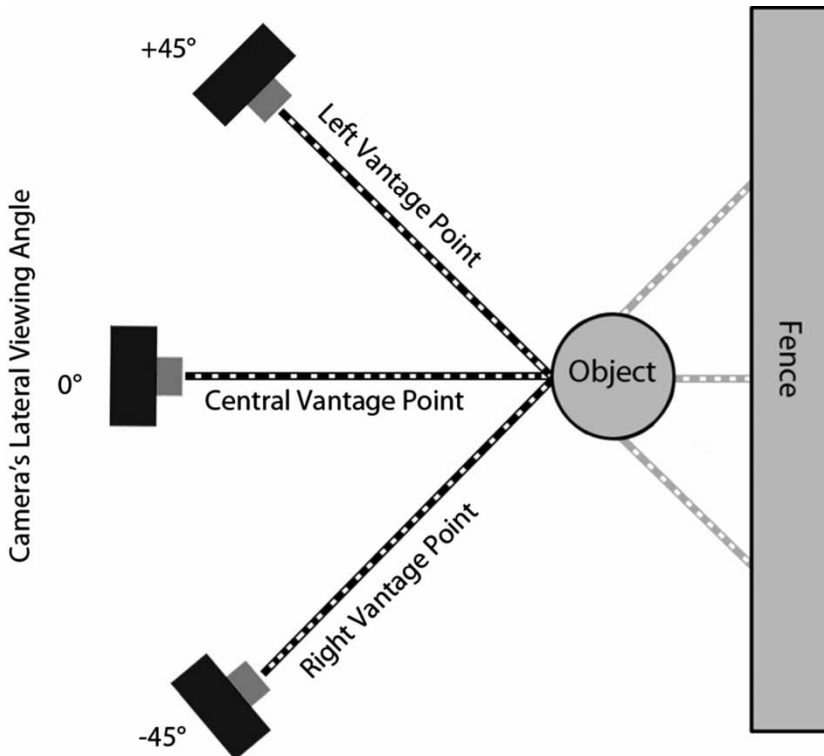
Figure 4. An illustration of the lateral viewing angle of the camera with respect to the background surface (in this case a fence) for each vantage point: central, right, and left. The darker portion of each sight-line indicates the string used to set the camera's position, as described in the Method (Experiment 1).

main object present and one with the main object absent, (b) a right vantage point photograph without the object, and (c) a left vantage point photograph without the object. The central vantage point photograph with the main object present served as a guide for object placement, and was the source of the object, which was "cut out" using Adobe Photoshop. This cut-out object was then placed on a transparent layer and was merged with the "empty" central vantage point photograph, and with the right and left vantage point photographs. This ensured that in all versions, the main object was identical and was always in the same position within the picture space. Although a right and left vantage point was photographed for each scene, we did not use both views. We selected whichever was the best (in terms of avoiding the presence of new objects in the distance) and used that view and its mirror reversal in the experiment.

Finally, because each object was not in the dead centre of the view, to prevent minor differences in composition from confounding comparisons between the left and right sides of the pictures, all pictures were mirror reversed for half of the participants in each condition. Two additional scenes were used in a practice sequence at the start of the experiment to familiarize the participant with the pace of the presentation, and one additional scene was presented at the beginning of the experimental sequence and served as practice for the border adjustment procedure at test.

Apparatus

Pictures were presented by a program written in the C programming language with Microsoft Visual C+ + 6.0 using Microsoft DirectX 9.0 and the EyeLink Windows API version 2.0, © 1997–2002 by SR Research Ltd. They were shown on a 21-inch Dell monitor with the screen resolution set to $1024 \times 768 \times 32$ bits of colour, which was run by a Dell Dimension DIMXPS (P4/2.8 GHz). The viewing distance was approximately 72 cm.

Design and procedure

Design.   Participants were randomly assigned to one of the three vantage point conditions: central, right, or left.

Instructions and presentation.   All participants were instructed to attend to each picture and to try to remember it in as much detail as possible, keeping in mind that the background was as important as the main object. Pictures were shown for 15 s each in a continuous sequence. All participants pressed the spacebar to initiate a short sample sequence (two pictures) to familiarize them with the presentation, and then initiated the experimental sequence when ready. There were 13 pictures presented; the first one, unbeknownst to the participants, would serve as a sample picture at test to

familiarize them with the border adjustment task; these data were not included in the analysis.

Test procedure.   Immediately following presentation, the first picture appeared and participants were instructed to use the mouse to adjust its borders so that it looked the same as before. This took approximately 2 min. Participants then adjusted the boundaries of the 12 stimulus pictures. On half the trials the pictures' borders were set very close together, revealing little of the scene (a 60 pixel × 60 pixel region in the centre of the picture; small-aperture trials), and on half they were set far apart, revealing more of the scene than before (a 890 pixel × 667 pixel region of the picture; large-aperture trials: see again, Figure 3). Trial types were randomly mixed with the constraint that no more than two of a kind could appear consecutively. Test stimuli were presented in the same order as during presentation.

On each trial, following border adjustment, participants indicated their confidence by using the mouse to click "sure" (3), "pretty sure" (2), or "not sure" (1). As in most boundary extension experiments, if they did not remember seeing the picture at all, they were asked to click on DRP ("don't remember picture").

Measurements.   To determine the percentage change in area, the number of pixels in the reconstructed view was divided by the number of pixels in the stimulus view and multiplied by 100. To assess changes in border position, the distance between the centre of the picture and each border was measured (in pixels) in the original and in each participant's reconstruction. On each side, the difference between the two was divided by the original distance and multiplied by 100 to obtain the percentage change at each border. Outliers were defined, a priori, as participants whose mean area remembered was 3 *SD*s or greater from the group mean; there were no outliers in Experiment 1.

Results and discussion

Participants reported that they didn't remember a picture (DRP) on 3.1%, 1.0%, and 2.1% of the trials in the central, right, and left vantage point conditions, respectively, and these trials were excluded from all analyses. On average, participants in each condition tended to report being "pretty sure" (2) of their responses; mean confidence ratings were 2.0 ($SD = 0.4$), 1.9 ($SD = 0.3$), and 1.9 ($SD = 0.4$) in the central, right, and left vantage point conditions, respectively.

Reconstructed areas.   To assess boundary extension we determined the mean remembered area in each condition. Participants tended to move the

boundaries outward and increase the scope of the views; mean percentage change in area for each vantage point condition is shown in the top panel of Figure 5. As shown in the figure, the mean reconstructed area was greater than the original area in all three conditions. Also evident in the figure is the tendency for boundary extension to be greatest in the central vantage point condition. Orthogonal planned comparisons between the central condition and each 45° condition revealed that this difference was significant in the
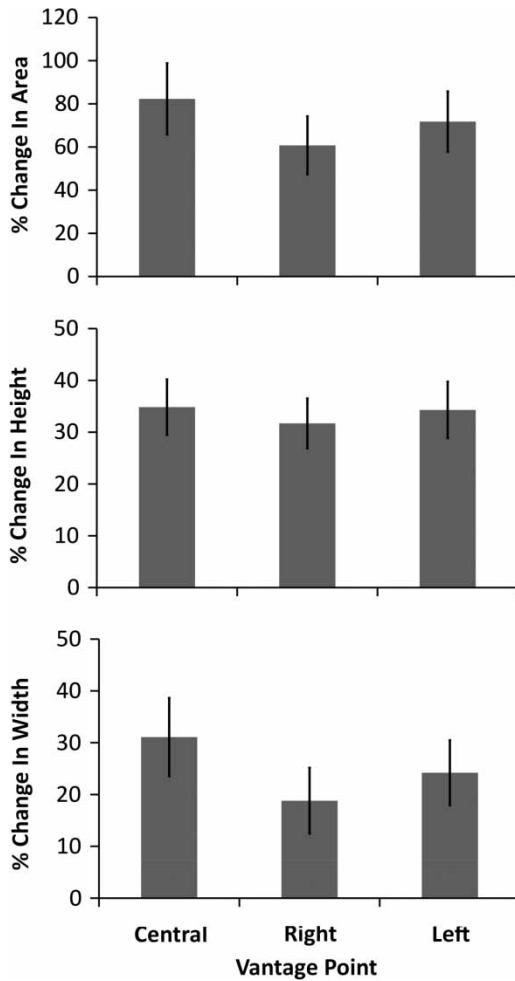
Figure 5. Mean percentage change in area (top row), height (middle row), and width (bottom row) for the central, right, and left vantage point conditions, respectively, in Experiment 1. Error bars indicate 95% confidence interval. Means significantly greater than zero indicate boundary extension.
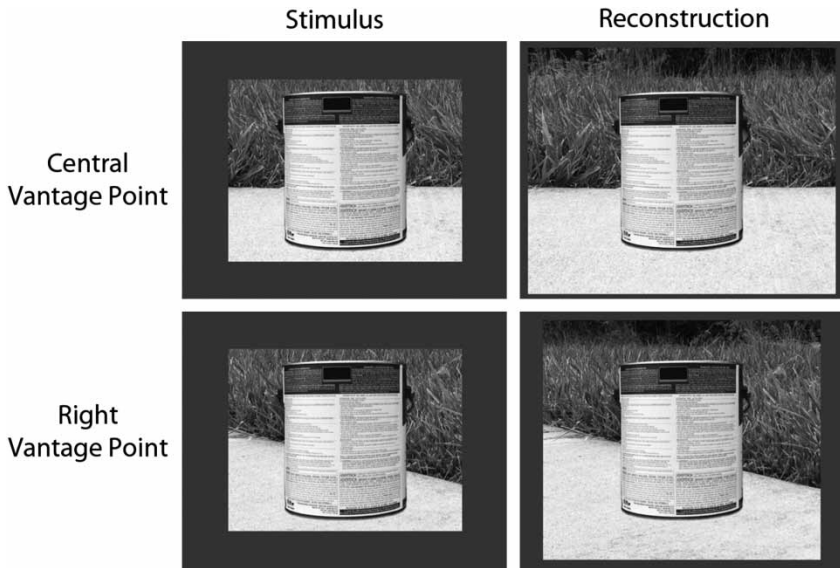
case of the right vantage point reconstructions, $t(117) = 2.11$, $p < .04$, but not the left vantage point reconstructions, $t(117) = 1.03$, $p = .30$.

One possible explanation of why the difference was not reliable when the central condition was compared with both $45°$ conditions is that test sensitivity was compromised by requiring participants to make extreme border adjustments that exposed them to a wide range of views of different sizes and aspect ratios as they adjusted the borders. This might have interfered with memory causing relatively noisy reconstructions. To test this possibility, in Experiment 2, we conducted the same experiment, but changed the test in a way that we hoped would enhance test sensitivity.

Additional border analyses.   Before turning to Experiment 2, because we used a border adjustment task, we had the opportunity to analyse the "shape" of the remembered space. First, we analysed the length and width of the reconstructed views to determine if similar to an experiment with real objects and surfaces (Intraub, 2004) participants had increased both the height and width of the views. As shown in Figure 5, this was the case in all three conditions both for height and width (middle and lower panels, respectively). To provide an illustration of the difference between the original views and the reconstructed views, Figure 6 shows the stimulus view for a single scene in the central and right vantage point conditions (left column) and the same scene with the "aperture" set to reflect the mean reconstructed height and width set by participants in each of those conditions (right column).[1]

Second, because the $45°$ views created a situation in which one side of the background surface was closer to the viewer than the other, we wondered if the closer side might yield more boundary extension than the side that was farther away, mirroring the difference between close-up and wide-angle views in the earlier boundary extension studies. There was no a priori reason to assume that boundary extension would differ in different regions of a scene; in fact, it might actually reflect a more global sense of remembered space, but we thought the question was worth pursuing.

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[1] Although the figure clearly shows boundary extension, it underestimates the actual mean *area* that was set by the participants by 4% in the central vantage point condition and by 5% in the right vantage point condition. This is because the formula, *mean area = mean width × mean height*, holds only under conditions in which the aspect ratio of all reconstructions are identical (here, however, aspect ratio was unconstrained and differed across reconstructions). The impact of aspect ratio can be seen in this illustration. Consider a group ($N = 2$) in which aspect ratio is maintained across reconstructions versus a group ($N = 2$) in which it differs. In Group 1 the reconstructions are 100 units × 100 units, and 10 units × 10 units, and Group 2 they are 10 units × 100 units, and 100 units × 10 units. In both groups the mean height and mean width would each be 55 units. However, the mean areas in the two conditions would be different: 1000 and 5050, respectively.

Figure 6. To illustrate the mean width and mean height set by participants in Experiment 1, the stimulus view (left column) and the mean reconstructed view (right column) is set for one scene in the central and right vantage point conditions. The mean increase in height and width was 35% and 31% respectively in the central vantage point condition, and 32% and 19% respectively in the right vantage point condition. Reconstructions underestimate the mean increase in area that participants reconstructed by 4% in the central vantage point condition and by 5% in the right vantage point condition as explained in Footnote 1.

The mean percentage change in boundary placement (from the centre of the scene) on the approaching (closer) and receding (more distant) sides of the right and left vantage point reconstructions is shown at the top panel of Figure 7. As can be seen in the figure, the approaching side elicited greater boundary extension than the receding side in both conditions. A mixed measures 2×2 ANOVA, Type-of-side (receding vs. approaching) $\times$ Vantage point direction (right vs. left) revealed a main effect of type-of-side, $F(1, 78) = 12.02$, $p < .01$, no effect of vantage point direction, $F(1, 78) = 1.53$, $p = .2$, and no interaction, $F(1, 78) = 2.65$, $p = .11$.

Smaller extension on the receding side could not account for the overall smaller area reported earlier between the central vantage point condition and right vantage point condition; when the approaching and receding sides were contrasted with the comparable left ($M = 32.3\%$) and right ($M = 29.8\%$) sides in the central condition, displacement was always greater in the central condition: for the left side, $t(117) = 3.0$, $p < .01$, and for the right side, $t(117) = 2.1$, $p < .05$.
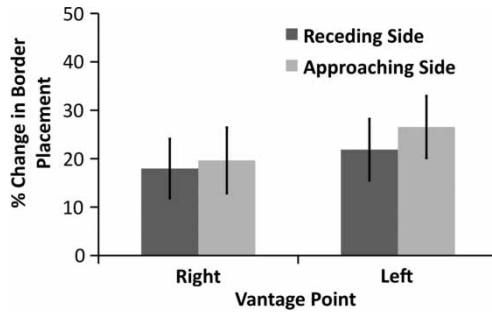
Figure 7.   The mean percentage change in border placement on the receding side and approaching side for the right and left vantage point conditions in Experiment 1.

Border adjustment and test views.   The border adjustment task is a relatively new procedure. We should note that, as reported in previous studies using this method (Dickinson & Intraub, 2009; Intraub et al., 2006), large-aperture trials resulted in significantly greater boundary extension than small-aperture trials. On large-aperture trials, the mean area increase for the central, right, and left vantage point views was 95.8% ($SD = 58.8$), 69.8% ($SD = 43.3$), 82.0% (48.6), respectively; with single mean t-tests revealing significant differences from 0% change in all cases, $t(39) = 10.3$, $p < .001$, $t(39) = 10.2$, $p < .001$, $t(39) = 10.7$, $p < .001$, respectively. On small-aperture trials, the mean area increase for the central, right, and left vantage point views was 68.5% ($SD = 50.0$), 51.8% ($SD = 45.2$), 61.7% ($SD = 44.9$), respectively; with single mean t-tests revealing significant differences from 0% change in all cases, $t(39) = 8.7$, $p < .001$, $t(39) = 7.3$, $p < .001$, $t(39) = 8.7$, $p < .001$, respectively.

A 2×3 mixed measures ANOVA, Aperture size (small-aperture vs. large-aperture) $\times$ Vantage point condition (central, right, left) verified a main effect of aperture size at test, $F(1, 117) = 46.5$, $p < .001$. As mentioned earlier, this pattern was reported in other border adjustment experiments, and Chapman, Ropar, Mitchell, and Ackroyd (2005) reported a similar effect when they used a zoom task to study boundary extension. We will return to possible reasons for the difference in the General Discussion. For present purposes, the implication is that these large differences might have added to the variance, helping to minimize test sensitivity. Thus, in Experiment 2, we used the same presentation sequence, but changed the test procedure to provide a more sensitive test of spatial memory.

EXPERIMENT 2

In Experiment 2 the initial views at test were always identical to the stimulus views. Participants could accept the view as presented, or adjust any of the

borders. We reasoned that this would provide a more sensitive test of boundary extension. Presenting the identical view would be expected to enhance memory performance, and require, if anything, relatively minor border adjustments that would spare participants exposure to numerous different views of the same scene. If central vantage point views elicit greater boundary extension than do right and left vantage point views, then the more sensitive test should show this irrespective of whether the 45° vantage point was taken from the left or the right. On the other hand, if the difference in remembered area between the right and central vantage point conditions in Experiment 1 was a spurious outcome, then we should observe no differences across the three vantage point conditions in Experiment 2.

Method

Participants

Participants were 72 (44 female) University of Delaware undergraduates, fulfilling a requirement for an introductory psychology course (originally $N = 24$ in each condition, but two outliers were eliminated; one in the left vantage point condition and one in the right vantage point condition).

Stimuli and apparatus

The stimuli and apparatus were the same as in Experiment 1.

Design and procedure

Presentation and test procedures duplicated those in Experiment 1 except for the position of the boundaries at test. When each test picture appeared, its boundaries were set to the same location as in the stimulus. Using the same a priori rule for outliers (3 *SD*s or greater), two participants were excluded from the analysis: one from the right vantage point condition and one from the left vantage point condition.

Results and discussion

Participants reported that they didn't remember a picture (DRP) on 0.6%, 0.7%, and 2.3% of the trials in the central, right, and left vantage point conditions, respectively; these trials were excluded from all analyses. On average, participants in each condition reported being "pretty sure" (2) of their responses; mean confidence ratings were 1.9 ($SD = 0.4$), 1.9 ($SD = 0.4$), and 1.8 ($SD = 0.3$) in the central, right, and left vantage point conditions, respectively.

Reconstructed areas. Although each test view was identical to the corresponding stimulus view, participants only recognized them as being the same on 19.2%, 19.3%, and 8.6% of the trials in the central, right, and left vantage point conditions, respectively. As Figure 8 (top panel) shows, participants tended to move the boundaries outwards; reconstructed mean areas were significantly greater than the original area in each case, signifying boundary extension. As in Experiment 1, inspection of Figure 8 (top panel) shows that boundary extension was greatest in the central vantage point condition. However, with the more sensitive test in Experiment 2, orthogonal planned comparisons revealed this difference to be significant both when the central condition was contrasted with the right vantage point condition, $t(67) = 2.18$, $p < .04$, and the left vantage point condition, $t(67) = 2.64$, $p < .02$.

In sum, a comparison with the size of the boundary extension effect in Experiment 1, showed that presenting the identical views at test resulted in a smaller amount of boundary extension overall. This is consistent with the rationale for the test; by eliminating the range of views participants saw while adjusting the test pictures in Experiment 1, memory was more veridical. It is true that some of the apparent improvement in performance could have been due to participants simply not bothering to change
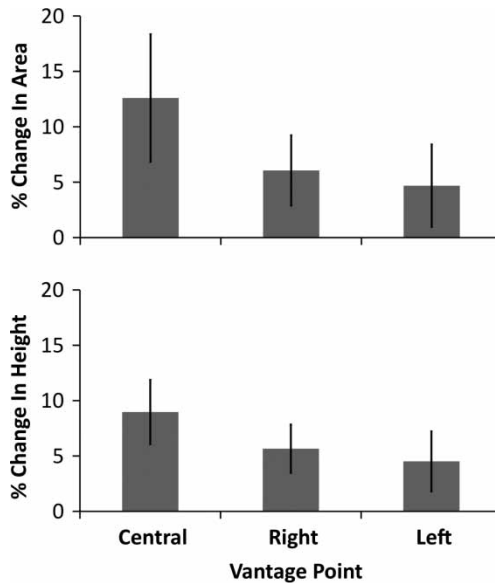
Figure 8.   Mean percentage change in area (top row) and height (bottom row) for the central, right, and left vantage point conditions, respectively, in Experiment 2. Error bars indicate 95% confidence interval. Means significantly greater than zero indicate boundary extension.

the borders because the design allowed then to accept the test pictures without making adjustments; however, as noted earlier, there were relatively few trials on which participants accepted the boundaries without moving them. Although smaller, boundary extension occurred in all conditions, clearly the central views yielded significantly greater area increases than did views that had been taken at an angle.

Additional border analyses. The smaller change in area (as compared with Experiment 1) is reflected in the changes in height and width of the reconstructed views. The mean percentage change in the height is shown in the lower panel of Figure 8; height of the reconstructed views was significantly greater than the height of the stimulus views in each condition. No significant difference was observed in the width of the views. The mean percentage change in width was, 2.7% ($SD = 6.8$), –0.1% ($SD = 2.7$), and -0.1% ($SD = 5.0$) for the central, right, and left vantage point conditions, respectively. Single mean *t*-tests revealed that none of these differed significantly from 0%; $t(23) = 1.9$, $p = .07$, $t(22) = 0.25$, $p = .8$, $t(22) = 0.07$, $p = .9$, respectively. Similarly, analysis of memory for the approaching and receding sides of the 45° views, revealed no boundary extension or restriction. Mean percentage changes were very small and did not approach significance: on the receding side the mean change was 0.4% ($SD = 3.7$) and -0.2% ($SD = 5.6$) in the right and left vantage point conditions, respectively; on the approaching the mean change was -0.7% ($SD = 3.2$) and 0.0% ($SD = 6.6$), respectively.

In sum, although the test views were always identical to the stimulus views, participants adjusted the boundaries to include additional background area (although the area increases were much smaller than those obtained with the test used in Experiment 1). These area increases were greater when the view was taken from the central vantage point than when it was taken from either the left or right vantage points. As was the case in Experiment 1, differences in boundary extension on the approaching and receding sides of the 45° views could not account for this overall difference in area; in fact, in Experiment 2 no significant changes in boundary placement were observed on these sides. All of the effect was due to a change in the positions of the upper and lower boundaries.

GENERAL DISCUSSION

Changes to the spatial layout of a view caused by a shift in vantage point systematically affected boundary extension. Boundary extension was greater when the vantage point was essentially perpendicular to the background surface (central vantage point) than when it formed a 45° angle. These

results do not support Bertamini et al.'s (2005) hypothesis that boundary extension is determined by the size of the main object in the picture space, because our object sizes were identical across vantage point conditions. Furthermore, the object's position in relation to the view-boundaries and the general meaning ("gist") of the views were held constant. All that changed was the vantage point onto the scene which affected how much of the background surface was visible in the photograph.

Across experiments, the mean area increase observed in the reconstructions was always greatest in the central vantage point condition, and the difference was reliable in all but one comparison (Experiment 1, central vs. left vantage point views). The weaker effect in Experiment 1 appears to be attributable to the way in which memory for the views was tested; the test view always differed dramatically from the stimulus view ("small aperture" or "large aperture"). The advantage of this method is that it forces the participant to reconstruct each view. The disadvantage is that the reconstructions were noisy, perhaps because exposure to multiple views during border adjustment interfered with memory. For this reason, in Experiment 2, we set each test picture's boundaries to be *identical* to those of the stimulus view. The advantage of this method is that it limits exposure to alterative views. The disadvantage is that participants, when unsure, might be more inclined to simply refrain from making subtle border adjustments, thus artificially decreasing boundary extension. Nevertheless, boundary extension again occurred in all vantage point conditions and central views yielded significantly greater area increases than did views taken from either the right or left vantage points.

Why did views taken from the central vantage point elicit greater boundary extension?

In answering this question, we need to evaluate what we mean by "scene representation". When part of a scene is presented in a photograph, does the ensuing representation reflect the pictured information (e.g., a visual representation) or does it reflect the likely characteristics of the scene that the picture only partially reveals (e.g., through multiple bottom-up and top-down sources of information)? The latter perspective allows us to explain the current results in the same way that we can explain the difference in boundary extension between close-up and wider-angle views described earlier (Gottesman & Intraub, 2002; Intraub, 2010; Intraub et al., 1992; Intraub & Bodamer, 1993). This is because, in views taken from the central vantage point, less of the background surface was visible than in views taken at a 45° angle (as can be seen by counting the stones in the background of each view in Figure 2). This is analogous to the change in scope that occurs

in close-up versus wider-angle views, while at the same time equating the amount of picture space dedicated to the background and keeping object size and position constant.

According to the multisource view (Intraub, 2010; Intraub & Dickinson, 2008), scene representation draws on (a) visual input during perception, (b) amodal continuation of objects and surfaces cropped by the edges of the view (Kanizsa, 1979; Kellman, Yin, & Shipley, 1998), (c) world knowledge based on scene classification (which occurs rapidly: E.g., Greene & Oliva, 2009a, 2009b; Schyns & Oliva, 1994), and (d) contextual associations activated by the specific objects in the view (Bar, 2004). At test, boundary extension occurs when participants attempt to remember which "part" of this *multisource* scene representation was originally derived from the *visual* source alone (i.e., source monitoring; Johnson et al., 1993; Lindsay, 2008).

We suggest that boundary extension was greater for central views because, compared to the 45° views, less of the background (e.g., less of the stone wall) had been visible, leading to a heightened expectation that the background surface would be likely to continue unchanged beyond the edges of the view. As a result, when deciding where the boundaries of the visible region had been, participants who studied the central views tended to accept more of the nonvisual continuation of the scene as having been seen before than did participants who had studied 45° views of the same scenes. Participants in all conditions misattributed information derived from top-down sources to vision, resulting in boundary extension, but those who had studied central views, based on these heightened expectations, accepted a bit more of the surrounding region as having been seen.

The notion that the representation is not simply a reflection of the visual information alone (the picture) is consistent with the results of Experiment 2. Here, even though the test view was always identical to the stimulus view observers had just studied, participants only infrequently recognized the views as being the same, and instead moved the borders outward to include a little more of the world. Again, the size of this source monitoring error was mediated by how much of the background surface (e.g., the stone wall) had been visible even though the amount of the picture space dedicated to showing the background surface was the same.

Another observation supports the idea that participants' representations were of *scenes*, rather than pictures. If observers were remembering the pictures as 2-D entities, one would expect that repetition of the same sized pictures in the same location on the screen, would allow them to remember the size and aspect ratios of the pictures. A good strategy for succeeding at the task would be to simply set the borders with respect to the screen. Indeed prior research with the border adjustment task included conditions in which the stimuli and test pictures differed in terms of size and placement on the screen (Intraub et al., 2006). However, whether or not size and placement

matched boundary extension occurred (see also Dickinson & Intraub, 2009). In the current experiments, participants appeared to adjust the borders according to the remembered *content of the view*, rather that the size or aspect ratio of the pictures (as 2-D objects) on the monitor. Furthermore the magnitude of boundary extension differed greatly depending on the test procedure—an effect that can be readily explained in terms of the *multisource* view.

Effects of test method on boundary extension

In Experiment 1, when boundary placement differed greatly between the stimuli and test pictures, large-aperture trials elicited larger reconstructed areas (70%–96%) than did the small-aperture trials (52%–69%). The same pattern was observed in previous border adjustment studies (Dickinson & Intraub, 2009; Intraub et al., 2006). Intraub et al. (2006) suggested that when participants viewed the more expansive large-aperture views at test, actually seeing the area beyond the boundary served to "ramp up" the existing representation of this area, adding detail. Thus, at test, this caused participants to accept more surrounding space as having been seen before. In contrast, small-aperture views showed much less of the scene than did the stimuli. Although participants could move the borders as far outwards as they wanted while setting the view, they were less likely to be exposed to a fully expanded view. Chapman et al. (2005) found a similar effect for wider and closer test views in a test requiring participants to expand or contract a picture behind an aperture to match memory for the stimulus.

In Experiment 2, when the 12 test items were *identical* to the stimulus views, again boundary extension occurred. However, the size of the error was considerably smaller than in Experiment 1, with mean area increases of between 4.8% and 12.6%. Why, in this case, more "extra" space was remembered beyond the top and bottom boundaries rather than on the sides is not clear (although this pattern has been observed before; Intraub et al., 2006). However, the fact that seeing the *identical* picture lead to a more "veridical" reconstruction (a smaller boundary extension error) is not surprising in itself. It has been well-established that recognition tests lead to better memory than recall (e.g., Johnson, 1983).

Other factors may also play a role in moderating the size of the boundary-extended region. One study suggests that visual attention is one such factor. Intraub et al. (2008) presented trials on which a briefly presented close-up or more wide-angle photograph of a scene was presented with superimposed numerals. When attention was divided by requiring participants to engage in a highly demanding visual search task (involving the numbers), boundary extension was greater than when they were instructed to ignore the numbers.

Intraub et al. proposed that dividing attention had decreased the difference in memory for the visual information and the amodal continuation of the scene, by lowering the quality of the remembered visual information. With the difference reduced, observers in the divided attention condition would be expected to accept more of the amodally derived information as having been originally obtained from a visual source.

Approaching vs. receding sides of a view

In views taken from a left or right vantage point, the background receded on one side and approached on the other. In Experiment 1, we found that the receding sides yielded less boundary extension than did the approaching sides. This is interesting in that it maps onto the difference between closer-up versus wider-angle views referred to earlier (Intraub et al., 1992; see Intraub, 2002, for a review) because the texture elements on the approaching side are "closer-up" and those on the receding side are more "wide-angled". This suggests that the structure of the layout can affect spatial memory for different regions within a scene (also see Dickinson & Intraub, 2009, for discussion of a laterality effect).

Although interesting, and worthy of further study, this effect seems to have occurred in addition to the more *global* impact of vantage point on memory for the view as a whole. Two observations suggest this. First, in Experiment 1, the difference between the central and right vantage point conditions was not attributable to one side on the right vantage point pictures; both the approaching and receding sides of the pictures exhibited significantly less boundary extension than the comparable (left and right) sides in the central vantage point pictures. Second, in Experiment 2, in which test pictures were identical to the stimuli, there was a significant effect of vantage point, even though no boundary extension was obtained on the right or left sides, and area increases were driven by changes at the top and bottom of the views. Thus, in addition to the global effect of layout, *under some conditions*, more local effects were also observed.

CONCLUSIONS

Our research suggests that the size of the boundary extension error elicited by a photograph of a scene is determined in part by expectations about the spatial layout of the world that the picture only partially reveals. Across conditions, the distance between the object and the picture's boundaries was identical if one measured it in terms of the picture space. However, changes in the vantage point altered the distance along the background surface (e.g., a stone wall) that was visible within that fixed space. This

suggests that the metric by which boundary extension is calculated is not the metric of the 2-D picture, but the metric of the 3-D world that the picture only partially reveals.

REFERENCES

Bar, M. (2004). Visual objects in context. *Nature Reviews: Neuroscience, 5*, 617–629.

Bertamini, M., Jones, L., Spooner, A., & Hecht, H. (2005). Boundary extension: The role of magnification, object size, context and binocular information. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1288–1307.

Brockmole, J. R., & Henderson, J. M. (2006). Using real-world scenes as contextual cues for search. *Visual Cognition, 13*, 99–108.

Castelhano, M. S., & Pollatsek, A. (in press). Extrapolating spatial layout in scene representations. *Memory and Cognition*.

Chapman, P., Ropar, D., Mitchell, P., & Ackroyd, K. (2005). Understanding boundary extension: Normalization and extension errors in picture memory among normal adults and boys with and without Asperger's syndrome. *Visual Cognition, 12*, 1265–1290.

Chun, M. M. (2000). Contextual cueing of visual attention. *Trends in Cognitive Sciences, 4*, 170–178.

Chun, M. M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36*, 28–71.

Chun, M. M., & Jiang, Y. (2003). Implicit, long-term spatial contextual memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 29*, 224–234.

Dickinson, C. A., & Intraub, H. (2008). Transsaccadic representation of layout: What is the time course of boundary extension? *Journal of Experimental Psychology: Human Perception and Performance, 34*, 543–555.

Dickinson, C. A., & Intraub, H. (2009). Spatial asymmetries in viewing and remembering scenes: Consequences of an attentional bias? *Attention Perception and Psychophysics, 71*, 1251–1262.

Epstein, R., & Kanwisher, N. (1998). A cortical representation of the local visual environment. *Nature, 392*, 598–601.

Epstein, R. A. (2005). The cortical basis of visual scene processing. *Visual Cognition, 12*, 954–978.

Epstein, R. A., & Higgins, J. S. (2007). Differential parahippocampal and retrosplenial involvement in three types of visual scene recognition. *Cerebral Cortex, 17*, 1680–1693.

Gottesman, C. V., & Intraub, H. (2002). Surface construal and the mental representation of scenes. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1–11.

Greene, M. R., & Oliva, A. (2009a). The briefest of glances: The time course of natural scene understanding. *Psychological Science, 20*, 464–472.

Greene, M. R., & Oliva, A. (2009b). Recognition of natural scenes from global properties: Seeing the forest without representing the trees. *Cognitive Psychology, 58*, 137–179.

Hollingworth, A., & Henderson, J. M. (2004). Sustained change blindness to incremental scene rotation: A dissociation between explicit change detection and visual memory. *Perception and Psychophysics, 66*, 800–807.

Intraub, H. (2002). Visual scene perception. In L. Nadel (Ed.), *Encyclopedia of cognitive science* (pp. 524–527). London, UK: Nature Publishing Group.

Intraub, H. (2004). Anticipatory spatial representation in a deaf and blind observer. *Cognition, 94*, 19–37.

Intraub, H. (2010). Rethinking scene perception: A multisource model. In B. Ross (Ed.), *Psychology of learning and motivation* (pp. 231–264). Burlington, VT: Academic Press.

Intraub, H., Bender, R. S., & Mangels, J. A. (1992). Looking at pictures but remembering scenes. *Journal of Experimental Psychology: Learning, Memory and Cognition, 18,* 180–191.

Intraub, H., & Berkowits, D. (1996). Beyond the edges of a picture. *American Journal of Psychology, 109,* 581–598.

Intraub, H., & Bodamer, J. L. (1993). Boundary extension: Fundamental aspect of pictorial representation or encoding artifact? *Journal of Experimental Psychology: Learning, Memory and Cognition, 19,* 1387–1397.

Intraub, H., Daniels, K. K., Horowitz, T. S., & Wolfe, J. M. (2008). Looking at scenes while searching for numbers: Dividing attention multiplies space. *Perception and Psychophysics, 70,* 1337–1349.

Intraub, H., & Dickinson, C. A. (2008). False memory 1/20th of a second later: What the early onset of boundary extension reveals about perception. *Psychological Science, 19,* 1007–1014.

Intraub, H., Gottesman, C. V., & Bills, A. J. (1998). Effects of perceiving and imagining scenes on memory for pictures. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 186–201.

Intraub, H., Gottesman, C. V., Willey, E. V., & Zuk, I. J. (1996). Boundary extension for briefly glimpsed pictures: Do common perceptual processes result in unexpected memory distortions? *Journal of Memory and Language, 35,* 118–134.

Intraub, H., Hoffman, J. E., Wetherhold, C. J., & Stoehs, S. (2006). More than meets the eye: The effect of planned fixations on scene representation. *Perception and Psychophysics, 5,* 759–769.

Intraub, H., & Richardson, M. (1989). Wide-angle memories of close-up scenes. *Journal of Experimental Psychology: Learning, Memory and Cognition, 15,* 179–187.

Johnson, M. K. (1983). A multiple-entry, modular memory system. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 17, pp. 81–123). New York, NY: Academic Press.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin, 114,* 3–28.

Kanizsa, G. (1979). *Organization in vision.* New York, NY: Praeger.

Kellman, P. J., Yin, C., & Shipley, T. F. (1998). A common mechanism for illusory and occluded object completion. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 859–869.

Konkle, T., & Oliva, A. (2010). Canonical visual size for real-world objects. *Journal of Experimental Psychology: Human Perception and Performance.* Advance online publication. doi:10.1037/a0020413

Kunar, M. A., Flusberg, S. J., Horowitz, T. S., & Wolfe, J. M. (2007). Does contextual cueing guide the deployment of attention? *Journal of Experimental Psychology: Human Perception and Performance, 33,* 816–828.

Lindsay, D. S. (2008). Source monitoring. In J. Byrne (Ed.), *Learning and memory: A comprehensive reference: Vol. 2. Cognitive psychology of memory* (pp. 325–348). Oxford, UK: Elsevier.

Michod, K. O., & Intraub, H. (2009). Boundary extension. *Scholarpedia, 4*(2), 3324.

Oliva, A., & Torralba, A. (2001). Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal in Computer Vision, 42,* 145–175.

Park, S., & Chun, M. M. (2009). Different roles of the parahippocampal place area (PPA) and retrosplenial cortex (RSC) in scene perception. *Neuroimage, 47,* 1747–1756.

Park, S., Intraub, H., Yi, D.-J., Widders, D., & Chun, M. M. (2007). Beyond the edges of a view: Boundary extension in human scene-selective visual cortex. *Neuron, 54,* 335–342.

Sanocki, T. (2003). Representation and perception of spatial layout. *Cognitive Psychology, 47,* 43–86.

Sanocki, T., & Epstein, W. (1997). Priming spatial layout of scenes. *Psychological Science, 8,* 374–378.

Schyns, P. G., & Oliva, A. (1994). From blobs to boundary edges: Evidence for time- and spatial-scale-dependent scene recognition. *Psychological Science, 5,* 195–200.

Torralba, A., Oliva, A., Castelhano, M., & Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: The role of global features in object search. *Psychological Review, 113,* 766–786.

APPENDIX
List of stimuli for all experiments

Picture name	Description
Ball	Dog ball on stone patio
Beach ball	Beach ball outside on concrete stairs
Bucket	Large bucket on grass against fence
Duct tape	Duct tape on tile floor against file cabinet
Frisbee	Frisbee on grass against fence
Hula hoop	Hula hoop on grass against brick wall
Mop bucket	Mop bucket on tile floor against white wall
Pail	Mini pail on asphalt against garage
Paint can	Can of paint on sidewalk
Trash can	Trash can on bathroom file floor
Vase	Vase outside on a wall
Wine bottle	Wine bottle on a gazebo bench