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Constraints on spatial extrapolation in the mental representation of scenes: View-boundaries vs. object-boundaries

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Viewers remember seeing information from outside the boundaries of a scene (boundary extension; BE). To determine if view-boundaries have a special status in scene perception, we sought to determine if object-boundaries would yield the same effect. In Experiment 1 eight ''bird's-eye view'' photographs containing single object clusters (a smaller object on top of a larger one) were presented. After the presentation, participants reconstructed four scenes by selecting among five different-sized cutouts of each object. BE occurred between the view-boundaries and the object cluster, but not between the smaller object and the larger object's boundaries. There was no consistent effect of the larger object's boundaries. Experiment 2 replicated these results using a drawing task. BE does not occur whenever a border surrounds an object, it occurs when the border signifies the edge of the view. We propose the BE reflects anticipatory representation of scene structure that supports scene comprehension and view integration.

There are many examples of biases in memory for relative spatial location. Stimuli as simple as a dot in a circle (Huttenlocher, Hedges, & Duncan, 1991), as familiar as a map showing the relative position of well-known cities in adjacent states (Tversky, 1981), and as common as a photograph of a simple scene (Intraub & Richardson, 1989) yield predictable biases in spatial memory. In the latter case, viewers tend to remember having seen the unseen but likely information from just outside the boundaries of the view, thus causing the boundaries to be remembered as being farther from the centrally located objects—a phenomenon referred to as *boundary extension*. Intraub and her colleagues have proposed that this ''error'' reflects anticipatory processes

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during scene perception (e.g., Gottesman & Intraub, 1999, 2002; Intraub, Gottesman, & Bills, 1998; see Intraub, 2002 for a review). Anticipatory representation of the likely layout just outside a given view would support scene comprehension by providing context for interpreting a truncated view of a continuous world and by facilitating integration of successive views through priming (Gottesman, 2003; Intraub, 1997). If this proposal is correct, then the borders of a view possess a special status during scene perception. The purpose of the present research was to determine if this is the case, or if other surrounding borders within a scene would also yield the same type of spatial error.

The argument in support of the special status of view-boundaries is derived from the notion that boundary extension reflects anticipatory representation of layout. Other research has suggested that mental representation of layout can be useful in integrating information obtained from successive views of a scene and in guiding scene exploration (Hochberg, 1978, 1998). Experiments testing viewers' ability to detect changes in scenes have suggested that people retain very little detail from one glance at the scene to the next (e.g., Grimes, 1996; Rensink, O'Regan, & Clark, 1997, 2000; Simons & Levin, 1997). Our rich experience with the world and our ability to function in it appears therefore to be dependent on our ability to obtain information from our environment when that information becomes relevant to the task at hand. O'Regan (1992) has referred to this process as using the world as an ''outside memory''. Instead of storing detailed information in memory, one stores only references that allow the information to be obtained from the external world by making an eye movement. Rensink (2000) developed this idea further, suggesting a triadic model of scene representation. The model postulates three processing systems: A preattentive, parallel processing system that extracts features from the environment (similar to Treisman, 1998); an object representation system that requires attention; and a scene-representation system that does not require attention. The latter system includes representations of spatial layout that aid in obtaining information from the environment.

The potential importance of anticipating layout in view integration can be seen in research on priming. Sanocki and Epstein (1997) found that priming spatial layout can facilitate processing of object location. They presented participants with a photograph of a scene that showed two chairs located at different distances from the camera. Participants had to identify as quickly as possible which chair was closer. The picture with the chairs was preceded either by a photograph of the same scene without the chairs, a sketchy drawing of a scene or a control drawing of a geometric shape. Priming with the scene layout facilitated people's performance on the task even when the layout was a sketchy drawing. Sanocki (2003) showed that the Sanocki and Epstein results were not likely due to priming local detail but rather to priming layout because even when the local information was changed drastically by changing the illumination from prime to test the priming effect persisted. Furthermore, using the same distance judgement task, Gottesman (2003) demonstrated that layout priming occurs even when the region is primed by the unseen, extended layout beyond the priming scene's boundary.

We have proposed that when perceiving a view of a scene the layout is extrapolated beyond the current view, and that this extrapolation has implications for what is subsequently remembered. Boundary extension occurs when memory is tested through recall/drawing tasks as well as recognition tests (e.g., Intraub, Bender, & Mangels, 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989; Legault & Standing, 1992; Seamon, Schlegel, Hiester, Landau, & Blumenthal, 2002), even when viewers are forewarned about the error and try to prevent it (Intraub & Bodamer, 1993). When people are asked to draw pictures of scenes from memory they tend to include more of the background than was in the picture, predicting likely layout. They consequently draw objects as smaller in the picture space. Note that this ''compression'' of object size is a result of condensing more spatial layout into the same boundaries rather than indicating a distorted memory for the intrinsic (distal) size of the object. In recognition tests when viewers are presented with the same view they had seen previously they tend to rate it as being a closer view than before, indicating that they remember the picture as having shown a more expansive view.

The adaptive value of layout extrapolation can be thought of in a number of ways. First, the continuity of layout is an invariant characteristic of the environment (see Intraub, 2001)—as mundane as it may sound, wherever one looks there is always more. A single view reveals only part of a continuous world, as well as the promise of more to come. Perception and identification of each glimpse requires acknowledgment of continuation. In order for a tight close-up to be correctly understood, the viewer must place it into a context that doesn't exist within the view itself, but includes information from outside—as for example when we understand the truncated view through a window.

For spatial extrapolation to have adaptive value rather than maladaptive consequences, the degree to which the visual system extrapolates must be subject to constraints. One constraint can be seen in the typical pattern of boundary errors that has been observed in memory for views ranging from close up to very wide angle. The degree of extension decreases as the more wide-angle views are presented. (e.g., Intraub & Richardson, 1989; Intraub et al., 1992). The value of this can be seen in the following. Assuming that the most salient area of a picture with a single main object is the area around the object, in a close up much of this highly anticipated area is not shown in the picture. However, in a very wide-angle view of that object, much of the very highly expected information around the attended object is already in the picture—so little or no extension occurs.

Boundary extension is not a general visual error. A critical constraint is that the picture must depict a truncated view of a continuous world. For example, boundary extension occurs for line drawings depicting objects on background surfaces, but not for the same line drawings of objects alone on blank backgrounds (Intraub et al., 1998). A blank background, however, will yield boundary extension if a continuous surface is imagined (Intraub et al., 1998) or construed due to context (Gottesman & Intraub, 2002). The depiction of a truncated view is so fundamental, that the effect will even occur for more ''abstract'' scenes such as pictures of geometric forms, as long as they appear on a texture gradient indicating a 3D spatial layout (Gottesman, 2002). Boundary extension is not limited to pictures, it also occurs in memory for the rich, concrete environment of real 3D space—after viewing truncated regions of 3D scenes through an aperture (see Intraub, 2001, 2002).

The purpose of the present research was to determine if view-boundaries have a special status in scene perception, or if any surrounding border within a scene context will yield boundary extension—even if that border does not demark a truncated view of a continuous world. To determine if boundary extension would occur beyond the perimeter of a surrounding border that exists *within* a view, we photographed simple scenes in which an object cluster was centered on a natural background. For example, in Figure 1, in the first picture the background is a lawn, and the object cluster is a sandal on a towel. The edge of the larger object (in this case the towel) forms the perimeter of the object cluster and a smaller object is placed completely within its borders. If only view-boundaries yield anticipatory activation of expected layout, then, as is usual in boundary extension, there should be a ''compression'' of the object cluster, but the proportion of one object to the other should not be distorted. On the other hand, if any surrounding border causes boundary extension, then it should also occur at the cluster boundary, so that the smaller object will be remembered as having had a greater expanse of surrounding space between it and the larger object's boundary. The smaller object should be remembered as having covered a smaller proportion of space within the cluster (i.e., it should be compressed more than the external object).

EXPERIMENT 1

Two sets of four ''bird's-eye view'' scenes were created and photographed. Each scene contained an object cluster on a natural background. After viewing the four pictures, participants were provided with a card showing the background alone, and selected cutout objects from a test set to recreate the scene so that it looked exactly like the original. The test set for each object included five copies of the object that were identical except for size. One item in a test set was always identical to the object as presented in the stimulus. If, as expected, boundary extension were to occur, participants would select smaller sized objects than were in the original picture (because they would remember having seen more of the background). If this effect is limited to the view-boundaries

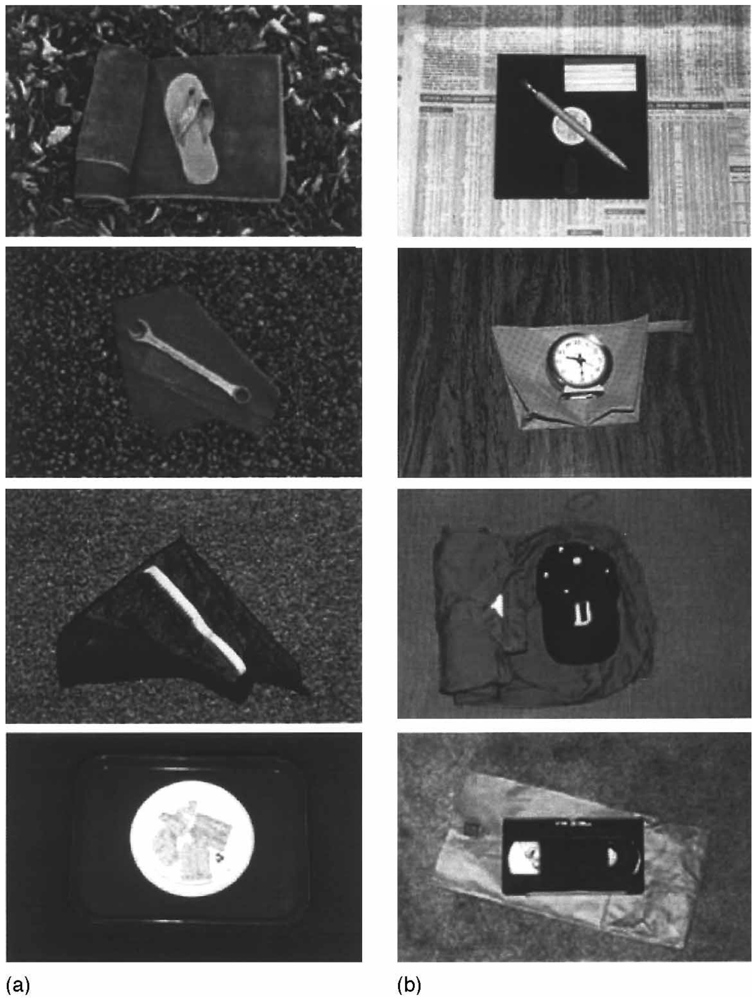

Figure 1. The stimuli used in Experiment 1. Panels A and B show the pictures that group 1 and group 2 were tested on, respectively. The photographs were in colour.

then the relative size of the two objects should be maintained, or vary due to error. On the other hand, if object-boundaries also evoke extrapolation then the internal object should be remembered as having been even smaller (proportionally) than the larger object, i.e., they should remember there being more space between the outer object's borders and the internal object.

Method

Participants. The participants were 81 undergraduates at the University of Delaware who volunteered to participate in the Departmental subject pool.

Stimuli. The stimuli used were eight photographs of scenes: These are shown in Figure 1. Each picture showed a ‘‘bird’s-eye view’’ of two common objects (e.g., a rag and a wrench, a hat and a shirt) on a naturalistic background (e.g., asphalt, blanket). In each picture the two objects differed in size and the smaller object (*the internal object*) was on top of the larger one (*the external object*). The internal object never occluded the boundaries of the external object. We specifically chose objects that did not have a fixed size-relation (such a dime on top of a quarter)—to use the example described earlier, sandals and folded towels can each vary widely in size. The only ‘‘fixed size’’ object presented was a 5.25-inch computer disk that served as the outer object, but the inner object was a pencil that could vary in length. The object cluster was always centrally located; the view-boundaries never cropped any of the objects. The eight pictures were presented in two groups so that each participant was tested only on four pictures. Group 1 ($N = 30$) was tested on the following pictures: A sandal on a towel on the grass, a wrench on a rag on asphalt, a brush on a scarf on carpeting, and a plate on a tray on a counter (see Figure 1A). Group 2 ($N = 51$) was tested on the following pictures: A pencil on a computer disk on a newspaper, a clock on a tote bag on a wooden surface, a baseball cap on a shirt on a blanket, and a videotape on a paperbag on carpeting (see Figure 1B). The pictures were printed in colour using a Canon BJC-610, with a resolution of 360 $\times$ 360 DPI, on glossy paper, which was then glued to thin cards. The cards were cut exactly to the edges of the photograph, making 12.9 $\times$ 8.5 cm cards that were laminated.

For the test, using Adobe PhotoShop, each object was copied and then four distractor items were made by reducing the object’s size by 8% and 16%, and increasing its size by 8% and 16% (percentages refer to the percentage change in width and height of the objects).[1] These percentages were chosen because distractors of this size appeared similar to errors we’ve observed previously. The original photographs used to make the presentation and test images were of a higher resolution, which allowed us to reduce the resolution such that all the test choices were of equal resolution irrespective of their size. The printout was laminated, and all the test objects were cut out (they looked like ‘‘puzzle pieces’’ and were similar to those used by Gottesman & Intraub, 2002). Examples of a set of test items for the ‘‘shirt/cap’’ scene are shown in Figure 2.

[1] The original photographs also included shots in which there were no objects on the background, and shots in which just the external objects were present. This allowed us to create unoccluded versions of the background and the larger objects for the test.

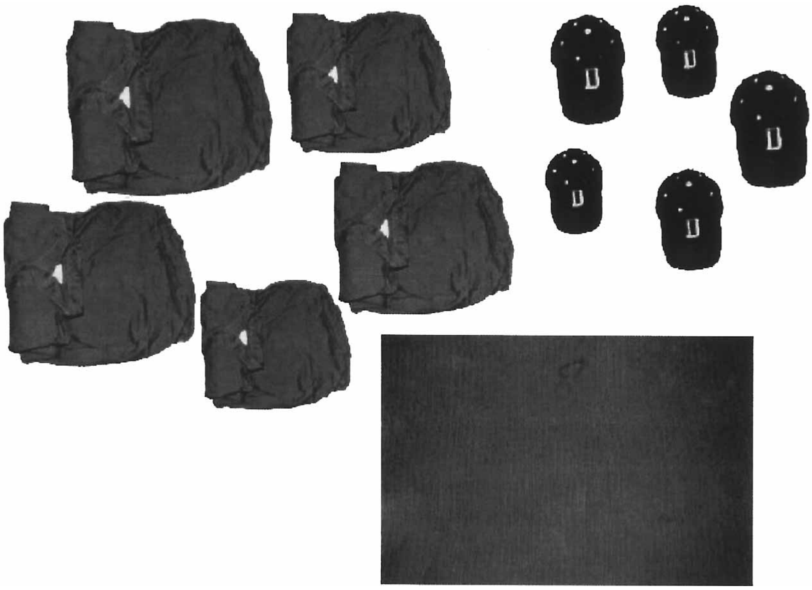

Figure 2. Example of a test set used in Experiment 1. The shirt was the external object and the cap was the internal object. All the pieces were cut out of colour photographs and laminated. Similar sets for each of the tested picture, were laid out on tables and covered with sheets of paper before the experiment started.

Photographs of the backgrounds (without the objects) were cut out to create the 12.9 × 8.5 cm background card (see Figure 2).[2]

Design and procedure. The experimental manipulation was within subjects. Participants were presented with the four scenes from one set only (two scenes from the other set served as buffer items at the beginning and end of the sequence, and memory for these was not tested). Choice of set was randomly determined. Between one and three participants were run in the same session. Participants were informed that a memory test would follow the presentation and they were instructed to try to remember the pictures in as much detail as

[2] There were five versions of each background card as well: Target and four distractors in which the size of the background's texture gradient was made either larger or smaller by 8% or 16%, corresponding to the different sizes of the distractor objects. However, early in the experiment, it became obvious that participants were unable to discriminate among the background versions for three of the pictures and they became frustrated at having to choose. Therefore, participants were given the target background card for these three pictures and were asked to select only the objects. They select the background cards for the other pictures, but these data (which were not germane to the question at hand), were excluded from analysis.

possible. The instructions stressed the importance of colours, details, and the layout of the picture including the size and location of objects in relation to one another and to the background. Prior to starting, they were shown a sample picture that illustrated the type of picture used in the experiment, i.e., a larger object on top of a smaller object on top of a homogenous natural background. Participants were seated at small tables, each with a stack of presentation cards facing down. The experimenter timed presentation by instructing the participants when to turn over a card and when to place it face down again. Study time per card was 15 s.

Immediately after presentation, the reconstruction test was explained using an example. Participants were instructed to reassemble the scene that they saw previously, being careful to replicate size and layout. Each participant was sent to a different large table that served as their test station. The background and multisized versions of each object in a given scene were laid out and covered by a single sheet of paper with a scene designation number printed on it. The experimenter referred to each scene by number, named it, and asked participants to visualize it in as much detail as possible. Once a participant felt he or she had a good image, the participant removed the sheet of paper and reconstructed the view from the parts provided. They were allowed to try as many combinations as needed until their reconstruction matched their memory. The task did not take long because there were only two objects: They were given a full 60 s in which to complete the task, and an additional 30 s was provided if requested. Once all members in the group completed the scene, they recorded their confidence in the reconstruction by circling ''sure'', ''pretty sure'', and ''not sure'' on a response sheet. The experimenter then named the next scene and the same procedure was repeated for all four stimuli.

Results and discussion

The results revealed boundary extension of view-boundaries but not of object-boundaries. Participants tended to be rather confident of their choices—reporting being ''sure'' or ''pretty sure'', 77% of time. However, they were correct only 24% of the time. The percentages of correct responses and the distribution of errors for the external and internal objects are shown in Table 1 (collapsed over all eight pictures). As can be seen in the table, the smaller distractors were selected more often than the larger distractors.

To calculate boundary scores similar to the ones used in previous boundary extension research (e.g., Intraub & Richardson, 1989; Intraub et al., 1992, 1998), the five possible test choices were coded as follows: Targets were coded as 0; 8% smaller objects and 16% smaller objects were coded as -1 and -2, respectively; 8% larger objects and 16% larger objects were coded as 1 and 2, respectively. Mean scores were computed for the internal and the external objects for each participant. Note that a score of 0 indicates no directional

TABLE 1
Distribution of times participants selected the correct object (0), or a distractor object that was 8% (−1) or 16% (−2) smaller, or 8% (1) or 16% (2) larger

Object	*Test alternatives*				
	−2	−1	*0*	*1*	*2*
External object	35.0	26.3	27.0	9.6	2.5
Internal object	29.1	26.3	22.0	13.0	8.0

One participant failed to respond to one picture, but that participant's scores on the other pictures were included in the analysis.

memory distortion, negative scores indicate boundary extension, and positive scores indicate boundary restriction. The mean scores for the set 1 pictures were −0.63 (SD = 0.59) for the external object and −0.69 (SD = 0.69) for the internal object. Both were significantly smaller than 0, as shown by 0.95 confidence intervals, indicating boundary extension. A t-test conducted on these scores showed no difference between the extension obtained for the internal object and the external object, $t(29) < 1$. In other words, the size relation between the objects was preserved. The mean scores for the group shown set 2 pictures were −0.78 (SD = 0.69) for the external object and −0.35 (SD = 0.83) for the internal object. Similar to the group who saw the set 1 pictures, both scores were significantly smaller than 0 as indicated by 0.95 confidence intervals, but a t-test revealed that overall in this group the external objects were compressed more than the internal objects, $t(50) = 4.54$, $p < .001$. These results show that whereas boundary extension occurred with respect to the view-borders, it did not occur with respect to the object-borders. Set 1 pictures yielded no difference in the relative amount of compression for the external and internal objects, and in set 2 the difference in compression between the two went in the opposite direction to extension of object-borders.

A picture analysis was conducted in order to see if this pattern was consistent across all the pictures. The mean scores for the two objects in each picture were calculated across participants and are shown in Figure 3. The error bars indicate 0.95 confidence intervals. As can be seen in the figure, the tendency to choose smaller objects was upheld for the external object in seven of the eight pictures, and for the internal object in five of the eight pictures (with the remaining three showing no consistent size change in memory).

The critical comparison, however, was between the relative sizes of the test objects chosen to reconstruct the cluster. As can be seen in Figure 3, overall, there was *no* greater compression for internal than for external objects. Although view-boundaries were always expanded with respect to the object cluster, object

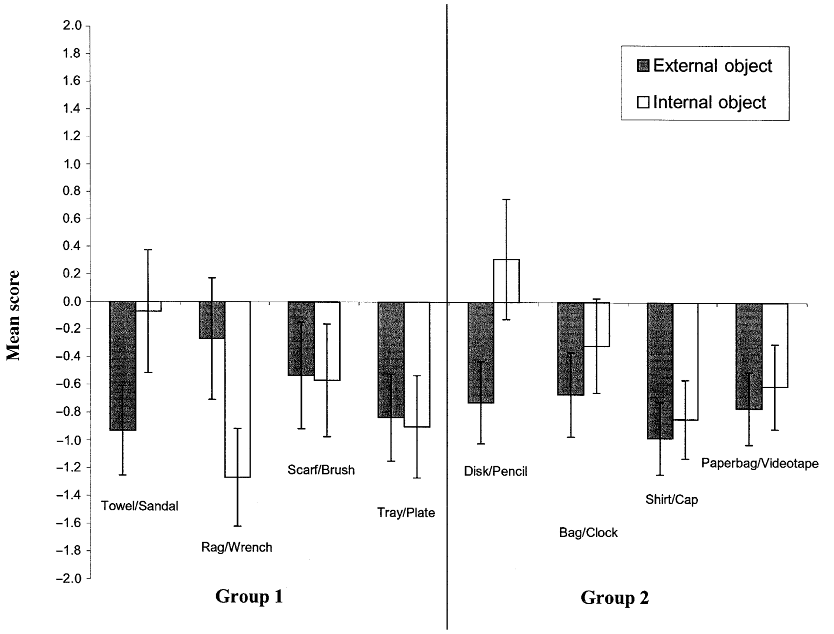

Figure 3. Mean scores for the external and internal objects in each picture, for the four pictures presented to group 1 and the four pictures presented to group 2. The scores were obtained by coding the five possible choices for each object as −2, −1, 0, 1, and 2, for the 16% smaller, 8% smaller, target, 8% bigger, and 16% bigger objects, respectively. The error bars show 0.95 confidence intervals. Negative scores indicate viewers remembered the object as having been smaller, consistent with boundary extension.

boundaries were not—the relationship between the internal and external objects did not follow a consistent pattern. For three of the pictures the mean score for the internal object was significantly greater than that for the external object, towel/sandal: $t(28) = 4.25$, $p < .001$; disk/pencil: $t(50) = 5.53$, $p < .001$; bag/clock: $t(50) = 2.23$, $p < .05$. For one picture the mean score for the internal object was significantly smaller than that obtained for the external object (wrench/rag, $t(29) = 4.55$, $p < .001$. For the remaining four pictures, there was no difference between the mean scores for the internal and external objects, scarf/brush and tray/plate: $t(29) < 1$; paperbag/videotape: $t(50) = 1.02$, n.s., shirt/cap: $t(50) = 1.07$, n.s. Overall, in seven of the eight scenes the internal object maintained its size relation to the larger object or was remembered as being relatively larger. In only one picture did a pattern consistent with spatial extrapolation occur.

An important issue that needed to be addressed, however, is that on trials in which participants selected the most extreme distractor (−2) for the external object, they had no opportunity to choose an even smaller distractor for the internal object (i.e., there was no -3). This could have served to minimize a real difference between scores that would indicate boundary extension at the object-boundaries. In order to see if this could account for the results, we reanalysed the data, excluding cases in which participants chose the smallest distractor for both the external and the internal object. The rational for excluding these trials was that these were the trials where participants did not have the option to choose a smaller version of an internal object than an external object. Using this procedure resulted in the removal of 13% of the picture scores in each group. After removing these potentially biasing cases, the pattern of results remained exactly the same for all pictures.

In sum, view-boundaries appear to have a special status, at least in the case of simple scenes with a single object cluster. Extrapolation of the background occurred at the view- boundaries, but did not occur at surrounding boundaries that demarked an object. That is, although the internal object was surrounded by another objects' boundaries, viewers did not consistently extrapolate more spatial expanse between those boundaries and the object located within. While the relation between the objects in the scene was not retained perfectly, there was no unidirectional distortion. In Experiment 2 we sought to replicate this experiment using a less constrained test that would provide another way to circumvent the problem caused by a small finite number of choices.

EXPERIMENT 2

The purpose of Experiment 2 was to replicate Experiment 1 using an open-ended test (drawing from memory) that would allow participants to freely express the size relations of the objects. The drawback of the drawing task is, of course, the limited artistic ability of the average participant. Bearing this caveat in mind, we again tested spatial memory at the view-boundaries and at the surrounding boundaries of the larger object.

Method

Participants. The participants were 75 undergraduates from the same population as in Experiment 1.

Stimuli. The stimuli used in the presentation were the same two sets of four photographs that were used in Experiment 1. Instead of being printed on cards, they were presented on a computer screen.

Apparatus. The stimuli were presented using Corel Presentations 7 on a 21 inch 445xi Nokia monitor using a 200 MHz Intel Pentium computer. The resolution was 365 $\times$ 240 pixels. The image size was 30 $\times$ 20 cm in the centre of the screen. The rest of the screen was black. Participants (8–10 at a time) sat in three rows with three or four seats in each, centred in front of the screen in a dimly lit room. The distance between the screen and the first, second, and third rows was approximately 2 m, 3 m, and 4 m, respectively. The approximate visual angles for participants sitting in the centre of the front and back rows were $8^\circ \times 5^\circ$ and $4^\circ \times 3^\circ$, respectively.

Design and procedure. As in Experiment 1 participants viewed pictures from either set 1 ($N = 41$) or set 2 ($N = 34$) for 15 s each (with a buffer picture at the beginning and end). Following presentation, response booklets with four rectangles (each 10×15 cm; the same aspect ratio as the stimuli) were distributed. A label describing each of the stimuli was printed above each rectangle. The experimenter pointed to the rectangle on the answer sheet and to the edges of a sample picture presented on the computer screen. Participants were asked to consider the edges of the rectangle to be the same as the edges of the picture on the screen and to draw the pictures accordingly, with special attention to the size and position of the objects within the picture space.

Analysing the drawings. To measure object sizes in the stimuli and in the individual subject's drawings, the histogram feature of Adobe PhotoShop 4.0 was used to obtain the number of pixels in each object in the stimuli. In the case of the subjects' drawings, the outline of the objects was traced onto a separate piece of paper with dark ink (done on a light board that provided rear-projected lighting). The tracings were digitized using a Hewlett Packard Scanjet 4c scanner with 150 pixel/inch resolution, and the number of pixels was determined in the same way. Note that the image size of the stimuli and the drawings was the same to assure that direct comparisons could be made.

The proportion drawn was calculated for each object drawn by dividing the area of the object in the drawing by the area of the object in the stimulus. Therefore, a proportion equal to 1 would indicate an accurate drawing. A proportion significantly less than 1 would signify boundary extension (whereas greater than 1 would signify boundary restriction).

Drawings were excluded from the analysis if they revealed extreme errors.[3] One participant from each group was not included in the analysis because all four drawings included such errors. For the remaining participants, 5 drawings (out of 160) from group 1 and 18 drawings (out of 130) from group 2 were excluded from the analysis.

[3] The type of errors observed were as follows: (1) only one of the two objects were drawn (three drawings—group 1), (2) an object was clearly not the object presented in the stimulus (eleven drawings—group 2), (3) participants drew the objects in a completely different orientation than it was in the original picture (nine drawings—group 2), or (4) participants drew double borders for a specific object (to change the size of their object) but did not indicate which was their final intended object border (six drawings—group 1). On two pictures in group 2 participants failed to draw any object.

Results and discussion

The results replicated Experiment 1: Boundary extension was obtained at the view-boundaries but not at the object-boundaries. The mean proportion drawn for the external objects and the mean proportion drawn for the internal objects were obtained for each participant. The mean proportion drawn in group 1 was 0.87 (SD = 0.27) for the external object and 0.88 (SD = 0.39) for the internal object. In both cases, the objects were drawn as covering less space than in the original, and the proportions were both significantly smaller than 1, as shown by 0.95 confidence intervals. A t-test conducted on the proportions showed no difference between the extension obtained for the internal object and the external object, $t(39) < 1$. The mean proportion drawn in group 2 (set 2 pictures), was 0.81 (SD = 0.30) for the external object and 1.00 (SD = 0.46) for the internal object. Only the proportion drawn for the external objects was significantly smaller than 1 as indicated by 0.95 confidence intervals. The overall trend was similar to that of group 1 as can be seen in the picture analysis below. However, the mean for the internal object was strongly influenced by memory for one of the objects, the pencil, which, unlike any of the other objects, was remembered as much larger than in the original. This finding could be due to an artefact. The pencil was on top of an old 5.25-inch diskette—something with which current students are not familiar. If they tended to remember it as a 3.5-inch disk this could have distorted memory for the size of the pencil relative to the disk. A free recall task would be more sensitive to such an error than the reconstruction task in Experiment 1, in which the original objects are again presented.

A picture analysis was conducted in order to see if this pattern was consistent across all the pictures. The mean proportion drawn for the two objects in each picture are shown in Figure 4. The error bars indicate 0.95 confidence intervals. As can be seen in the figure, both external and internal objects tended to be remembered as having been smaller, the objects in four pictures were remembered significantly smaller. Only one object (the pencil, described earlier) was remembered as having been significantly larger.

As in Experiment 1, the relative size of the two objects in each scene was compared. If the size relation is maintained, then there should be no difference between the mean proportions. In three pictures, the size relation was maintained ($t < 1$ on towel/sandal, scarf/brush, and bag/clock). For three of the pictures the internal object was compressed more than the external object, tray/plate: $t(37) = 3.35$, $p < .01$; shirt/cap: $t(24) = 5.25$, $p < .001$; paperbag/videotape: $t(27) = 2.44$, $p < .05$. For two pictures the internal object was compressed significantly less than the external object, rag/wrench: $t(39) = 3.07$, $p < .01$; disk/pencil: $t(31) = 5.42$, $p < .001$.

In sum, as in the previous experiment, the drawings showed that participants tended to extrapolate spatial expanse at the view-boundaries, but not at the surrounding object-boundaries. Instead of a unidirectional error at the object

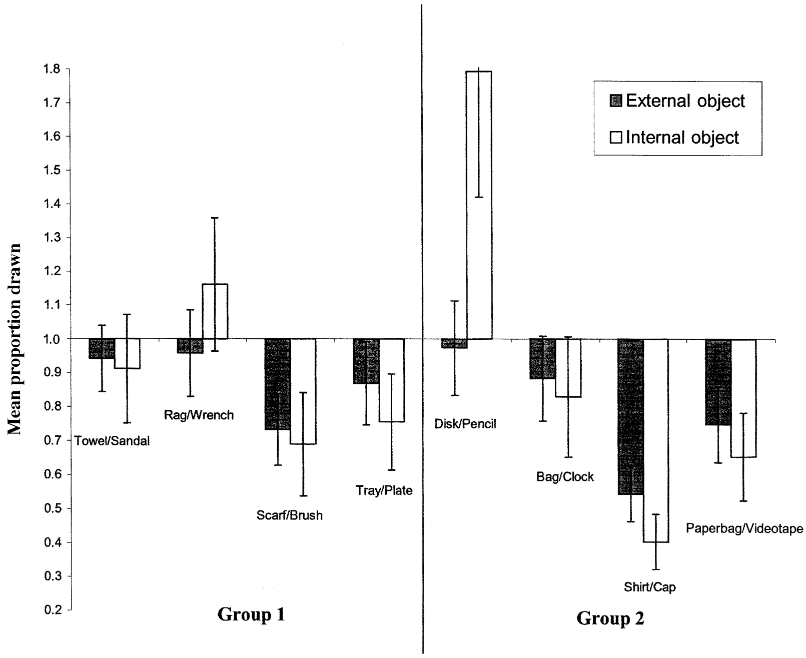

Figure 4. Proportion of area drawn for the external and internal objects in each picture, for the four pictures presented to group 1 and the four pictures presented to group 2 (Experiment 2). Proportion drawn was calculated by dividing the area covered by the object in the participant's drawing by the area covered by the object in the photograph. Error bars show the 0.95 confidence intervals. Scores smaller than 1 indicate viewers drew the object smaller than it was, a distortion consistent with boundary extension.

boundaries, the relative sizes of the objects varied from picture to picture. Despite concerns about the problems inherent in drawing tasks, the results clearly replicated those obtained using the reconstruction procedure in Experiment 1.

GENERAL DISCUSSION

A surrounding border is not sufficient to elicit boundary extension. Whereas view-boundaries tended to be misplaced outward, revealing more of the expected background—this was not the case for the surrounding object-boundaries. Spatial representation of the objects in our bird's-eye view scenes did not reveal a tendency to displace the larger object's borders outward. Sometimes the correct spatial relation was maintained, but in other cases the changes in relative size resulted in less space between the object's borders, and, occasionally, in more space. Surrounding object-boundaries clearly did not result in a unidirectional distortion of spatial expanse akin to boundary extension. This outcome was obtained when memory was tested in two different ways. In Experiment 1, a reconstruction task allowed participants to compare different sized versions of the objects in relation to one another, selecting the combination that best matched memory. In Experiment 2, a free recall drawing task provided participants with greater freedom in representing the placement of the objects. In both experiments, the boundaries of the view yielded boundary extension, but the boundaries of an object did not—even though those object boundaries surrounded another object.

Our prediction regarding a difference between these two types of boundaries was based on the proposition that boundary extension is an error with adaptive value (e.g., Gottesman & Intraub, 2002; Intraub, 2002). At the heart of our thesis is the fact that the world is continuous, but sensory input is not. We scan the visual world three or four times per second—an activity that yields a succession of discrete views. How are these views integrated to form a coherent representation of a continuous scene? Part of the answer may lie in the anticipatory representation of upcoming layout. This anticipation of the scene's continuity would serve to aid scene comprehension, by assuring that a truncated view is understood within a continuous context (e.g., the asphalt shown in a close-up photograph of a traffic cone on the street is understood not to be a rectangular patch of asphalt, but a partial view of a continuous road). Anticipatory representation beyond the boundaries of the view would also serve to facilitate view integration by priming scene layout (Gottesman, 2003; Sanocki, 2003; Sanocki & Epstein, 1997). This anticipatory spatial projection would also serve to draw attention to unexpected discontinuities that might appear in the upcoming view (see Intraub, 1997, 2002).

An object-boundary is different than a view-boundary, in that it does not constitute a truncation of space. The view-boundary is extrinsic to the scene—it is an ''accidental'' border. Such borders exist as we move through a scene—they are fleeting and momentary. However, the object relations in our study are intrinsic to the scene—a comparable reason to expand the space inside the border does not exist. If truncation is the critical factor that causes boundary extension at a border, then might there be conditions in which a border that is *inside* a scene would yield boundary extension? If our theory is correct, this should happen when the boundary *inside* the picture is itself a view-boundary. We have some evidence to suggest that this indeed is the case. As part of an experiment conducted by the second author to address a different question, a special stimulus was included. It was a photograph of a desktop containing three common objects—one of which was a framed photograph of a simple scene containing a single object (Figure 5A). The desktop scene was one of five scenes participants had viewed for 15 s each followed by a brief recognition test. At the end of the experiment, all 28 participants were asked to draw the photograph that was inside the picture frame on the desktop. Unlike the results obtained with

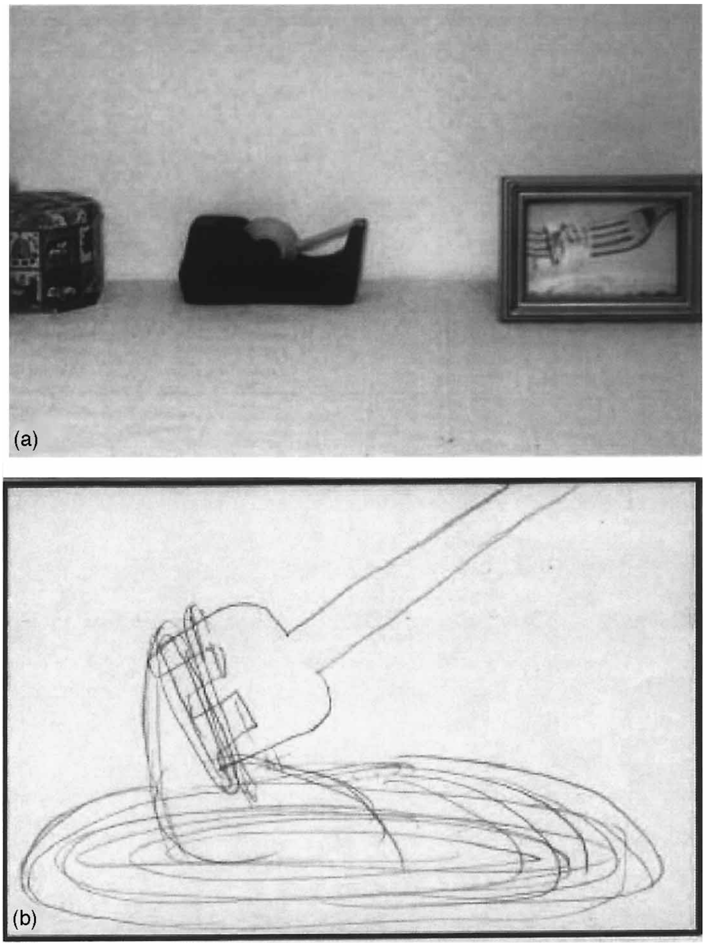

Figure 5. Desktop scene used in a pilot study (panel A) and example of a participant's drawing of the picture within the frame (pane B). The head of the fork was drawn approximately 19% of its size in the frames photograph.

object boundaries in the current experiment, boundary extension unequivocally occurred. Viewers reduced the size of the head of the fork dramatically. The mean proportion drawn was 0.19 (*SD* = 0.20), that is, participants drew the fork about 19% of its original size. Figure 5B shows a typical drawing. This suggests that indeed, boundary extension can be obtained for boundaries within a picture as long as those boundaries mark the boundaries of a truncated view of a continuous space.

One of the perceptual processes that contribute to boundary extension may be a type of *amodal* perception. The term ''amodal'' refers to the experience of ''perceiving'' occluded portions of objects and surfaces without any sensory input (Kanizsa, 1979; Michotte, Thines, & Crabbe, 1964). Nakayama, He, and Shimojo (1995) proposed that amodal perception is a fundamental aspect of surface representation. Most research on amodal completion and amodal continuation has focused on the conditions under which objects are perceived as completing behind an occluder (e.g., He & Nakayama, 1992; Kellman & Shipley, 1991; Yantis, 1995). The relation to the current work is that the boundaries of the picture are also a kind of occluder—the visual system may treat a picture as if it were looking at the world through a window (see Intraub, 2001, 2002). Kellman, Yin, and Shipley (1998) distinguished between two kinds of amodal perception: Completion and continuation. Amodal ''completion'' refers to completing the edge of an object across a gap, and requires visible object edges on both sides of the gap. Amodal ''continuation'' refers to continuing a surface behind an occluder to an indefinite endpoint. Two complementary processes have been proposed: A process of uniting edges of objects across gaps caused by occlusion, and a process of ''spreading'' surface features within the objects' edges (Grossberg & Mingolla, 1985; Kellman & Shipley, 1991). Yin, Kellman, and Shipley (1997, 2000), have shown that while edge completion interacts with surface spreading, surface spreading can lead to amodal continuation in situations where amodal completion may not occur. The anticipatory processes that result in boundary extension would likely draw upon amodal spreading rather than amodal completion because boundary extension occurs even when there are no incomplete objects at the view-boundaries.

Although object boundaries in themselves do not result in boundary extension, we don't mean to say that object placement is always correctly remembered. There are clearly cases in which object placement within a scene is systematically distorted for other reasons. A good example comes from research on memory for still photographs of ''frozen action'' (e.g., a frame of movie film), in which viewers tend to remember the frozen-motion object as having been farther along its expected path of motion (Freyd, 1983: Futterweit & Beilin, 1994). Other object placement errors have been reported when implied forces are present in the context (e.g., an unsupported object is remembered as having been lower in the scene—as if gravity had an effect; Freyd, Pantzer, & Cheng, 1988). Boundary extension, however, appears to be related to the view as a whole.

In conclusion, the visual system does not treat all surrounding boundaries in the same way. View-boundaries appear to have a special status. These fleeting, ''accidental'' boundaries are not only inaccurately registered in memory, but yield the same unidirectional error—an extrapolation outward toward anticipated, previously unseen space. Surrounding object- boundaries within a view, such as those of the larger objects in the bird's-eye view object clusters reported here do not yield this anticipatory error. However, internal boundaries in a scene will elicit boundary extension, but only if they too are view-boundaries (as in the case of the picture within a picture; see Figure 5). This research points to the importance of further defining and characterizing what is meant by a ''view''. A view, in the current research is readily defined as the edges of the photograph; however, in real space, it is clearly the case that objects can form the boundaries of view—as when we look at a distant landscape through a pair a trees. Future research will address the role of spatial attention and grouping in defining a view. The present research shows constraints on occurrence of boundary extension that make it a valuable tool in assessing ''views'' under more ambiguous circumstances. Scene representation seems to capture the dynamic nature of visual exploration, anticipating upcoming information as well as maintaining critical features of a scene's content and layout.

REFERENCES

Freyd, J. J. (1983). The mental representation of movement when static stimuli are viewed. *Perception and Psychophysics*, *33*, 575–581.

Freyd, J. J., Pantzer, T. M., & Cheng, J. L. (1988). Representing statics as forces in equilibrium. *Journal of Experimental Psychology: General*, *117*, 395–407.

Futterweit, L. R., & Beilin, H. (1994). Recognition memory for movement in photographs: A developmental study. *Journal of Experimental Child Psychology*, *57*, 163–179.

Gottesman, C. V. (2002). Boundary extension for abstract scenes. *Manuscript submitted for publication*.

Gottesman, C.V. (2003). Layout extrapolations as primes for spatial processing. *Manuscript submitted for publication*.

Gottesman, C. V., & Intraub, H. (1999). Wide-angle memories of close-up scenes: A demonstration of boundary extension. *Behavior Research Methods, Instruments and Computers*, *31*, 86–93.

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.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Vancouver Studies in Cognitive Science: Vol. 5. Perception* (pp. 89–110). New York: Oxford University Press.

Grossberg, S., & Mingolla, E. (1985). Neural dynamics of form perception: Boundary completion, illusory figures, and neon color spreading. *Psychological Review*, *92*, 173–211.

He, Z. J., & Nakayama, K. (1992). Surfaces versus features in visual search. *Nature*, *359*, 231–233.

Hochberg, J. (1978). *Perception* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Hochberg, J. (1998). *Perception and cognition at century's end.* San Diego, CA: Academic Press.

Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review*, *98*, 352–376.

Intraub, H. (1997). The representation of visual scenes. *Trends in Cognitive Science*, *1*, 217–222.

Intraub, H. (2001). Internalized constraints in the representation of spatial layout. *Behavioral and Brain Sciences*, *24*(4), 677–678.

Intraub, H. (2002). Anticipatory spatial representation of natural scenes: Momentum without movement? *Visual Cognition*, *9*, 93–119.

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

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

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

Kellman, P. J., & Shipley, T. F. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology*, *23*, 141–221.

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.

Legault, E., & Standing, L. (1992). Memory for size of drawings and of photographs. *Perceptual and Motor Skills*, *75*, 121.

Michotte, A., Thines, G., & Crabbe, G. (1964). Amodal Completion. In A. Michotte, G. Thines, A. Costall, & G. Butterworth (Eds.), *Michotte's experimental phenomenology of perception*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Nakayama, K., He, Z. J., & Shimojo, S. (1995). Visual surface representation: A critical link between lower level and higher level vision. In S. M. Kosslyn & D. N. Osherson (Eds.), *Visual cognition* (Vol. 2, pp. 1–70). Cambridge, MA: MIT Press.

O'Regan, J. K. (1992). Solving the ''real'' mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, *46*, 461–488.

Rensink, R. A. (2000). The dynamic representation of scenes. *Visual Cognition*, *7*, 17–42.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, *8*, 368–373.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (2000). On the failure to detect changes in scenes across brief interruptions. *Visual Cognition*, *7*, 127–145.

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.

Seamon, J. G., Schlegel, S. E., Hiester, P. M., Landau, S. M., & Blumenthal, B. F. (2002). Misremembering pictured objects: People of all ages demonstrate the boundary extension illusion. *American Journal of Psychology*, *115*, 151–167.

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Science*, *1*, 261–267.

Treisman, A. (1998). The perception of features and objects. In R. D. Wright (Ed.), *Visual attention* (pp. 26–54), New York: Oxford University Press.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology*, *13*, 407–433.

Yantis, S. (1995). Perceived continuity of occluded visual objects. *Psychological Science*, *6*, 182–186.

Yin, C., Kellman, P. J., & Shipley, T. F. (1997). Surface completion complements boundary interpolation in the visual integration of partly occluded objects. *Perception*, *26*, 1459–1479.

Yin, C., Kellman, P. J., & Shipley, T. F. (2000). Surface integration influences depth discrimination. *Vision Research*, *40*, 1969–1978.

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