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Boundary Extension for Briefly Glimpsed Photographs: Do Common Perceptual Processes Result in Unexpected Memory Distortions?

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"Boundary extension" is a memory illusion in which observers remember seeing more of a scene than was shown. Two experiments tested the possibility that this spatial distortion occurs soon after picture perception. In Experiment 1, undergraduates viewed close-up or wide-angle photographs for 250 ms or 4 s. Recall and recognition tests followed. Brief presentations yielded as much boundary extension as long presentations. In Experiment 2, picture triads were presented at a rate of 333 ms per picture with no interstimulus interval. After 1 s, one picture repeated and remained in view while subjects indicated whether it was the same or showed more or less of the scene. Even when conditions mimicked a series of rapid eye fixations, boundary extension occurred. The presentation of a picture appears to activate a perceptual schema that allows observers to understand it in a larger context and this process distorts memory for its actual boundaries.

Illusions are dramatic reminders of the limited knowledge we have about our mental processes. The surprise that they engender reflects the fact that they violate an implicitly held assumption about what "should have happened" under a given set of circumstances. Traditionally, perceptual illusions have served a valuable purpose in causing the researcher to reconsider basic assumptions about perception, and to ask questions that would not otherwise have been considered. "Memory illusions," which can be characterized as unexpected distortions in the recollection of events, can play the same important role. Our research focuses on one such memory illusion, called "boundary extension" (Intraub & Richardson, 1989). Its discovery has led us to ask questions about picture memory that we otherwise would never have considered asking. These experiments have led to the development of a working model of pictorial representation that focuses as much on "what isn't in the picture" as what actually is.

BOUNDARY EXTENSION

When remembering a photograph, viewers tend to remember having seen a greater expanse of the scene than had been shown (Intraub & Richardson, 1989). For example, a picture depicting a close-up of a basketball on a lawn is likely to be remembered as having been a more wide-angle view. This results in the observer remembering having seen more of the lawn, and remembering the ball and the individual blades of grass as having taken up a smaller area within the picture space. Intraub and Richardson (1989) coined the term "boundary extension" to describe this distortion of the pictorial representation.

Boundary extension is clearly not a perceptual illusion. When actually looking at the photograph, the viewer has no difficulty in describing exactly where the boundaries are. It occurs when the observer remembers the photograph. It is somewhat puzzling why a unidirectional error in memory for the boundaries should occur at all. Generally, we think of memory distortions as requiring many confusing stimuli, or long periods of time, or a lack of attention, or the presentation of misleading information. Yet boundary extension occurs under conditions in which no attempt is made to confuse or mislead the viewer.

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Boundary extension has been obtained when there are as few as three pictures in the memory set (Intraub & Bodamer, 1993: demonstration trial) and has been detected using a variety of memory tests. Extended boundaries were observed: (a) when subjects drew pictures from memory (Intraub, 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989; Legault & Standing, 1992; Nyström, 1992), (b) when they viewed the same pictures again in a recognition test (Intraub, 1992; Intraub, Bender, & Mangels, 1992; Intraub & Bodamer, 1993; Intraub & Richardson, 1989; Legault & Standing, 1992; Nyström, 1992), and (c) when they physically moved the test picture's boundaries to match their recollection (Nyström, 1992). It is a very robust phenomenon that is particularly striking when the depicted views are "close-ups." For example, in one experiment, after studying a sequence of 7 close-up views of simple real-world scenes for 15 s each, subjects drew them. Of 343 drawings made by 49 subjects, only 4 drawings did not exhibit boundary extension. The degree of extension was so great that, on average, main objects were drawn such that they covered one-third of the area that they had covered in the original stimulus photograph (Intraub, 1992).

In other research, Intraub and Bodamer (1993) gave subjects a demonstration of boundary extension and then instructed them to try to prevent it from occurring in the experiment that followed. Subjects were unsuccessful in doing so. After viewing only 12 pictures for 15 s each, they were able to reduce the degree of the distortion (as compared with a control group), but could not eliminate it. Both their drawings and their recognition test results indicated that they remembered having seen a greater expanse of the scene than had been shown.

In terms of the time course of the distortion, the original research focused on long-term retention of the pictures, with retention intervals of either 35 min or 2 days (Intraub & Richardson, 1989). Initially, it was thought that this distortion would take time to develop in memory. It seemed unlikely that subjects would be prone to such large errors in spatial memory soon after presentation—particularly because viewers were given so much time to study each picture (15 s). To determine if any boundary extension could be detected within minutes, Intraub et al. (1992) compared recognition performance for a sequence of 18 scenes (15 s each) when the interval between sequence offset and test was either 3 min or 2 days. Not only did boundary extension occur in the 3-min retention condition, but surprisingly, the degree of the distortion was greater than after the 2-day delay.

Intraub et al. (1992) explained this unexpected reduction in the distortion over time by proposing that boundary memory is affected by at least two different types of processes in memory. The interaction of these two effects makes it appear that memory for boundaries improves over time, when in actuality one type of memory distortion simply counteracts the other. To capture the two different processes that were proposed, we will refer to their model as the Extension–Normalization Model.

The first process involves the activation of a mental schema, referred to as the "perceptual schema." The perceptual schema is activated when the viewer sees a partial view of a scene (as in a photograph). The schema is a mental representation of the likely structure of the scene that is understood to "exist" just beyond the edges of the picture. It allows the viewer to understand the partial view within a larger context. Following offset, memory for the depicted scene reflects not only the actual bottom-up information that had been presented, but highly probable top-down information from the schema. This highly probable information becomes incorporated in the episodic representation of the picture, thus causing boundary extension.

The second process is "normalization" (cf. Bartlett, 1932; Gibson, 1969). Over time, the pictorial representations begin a regression toward the average view in the memory set. This will yield boundary extension for the relatively close-up views in the set, but will yield boundary restriction for the relatively wide-angle views. According to our hypothesis, activation of the perceptual schema (in response to a partial view) causes an immediate extension of remembered boundaries. This overall pattern of extension is then tempered over time as normalization takes place. This accounts for the somewhat surprising observation that boundary extension is greater minutes following presentation than days following presentation. The present research focuses on the first of the two proposed processes: activation of the perceptual schema.

It is reasonable to question why the visual/cognitive system would involve activation of a perceptual schema during picture perception. One possible explanation requires us to focus not only on picture processing, but on more general activities of the system. Consider the fact that input to the visual system is always in the form of a partial view. Wherever the eye fixates, there is always more of the scene just outside the scope of that fixation. Visual scanning is made up of discrete eye fixations and saccades, with each fixation providing a limited view of a continuous scene. In addition to this, due to the structure of the retina, very little of the visual field falls on the fovea and enjoys full visual acuity at any given moment in time. One of the classic questions in the field of perception has been how to account for our experience of a continuous visual world, given this seemingly piecemeal form of input. Hochberg (1978, 1986) has been a major proponent of the view that an abstract spatial representation he refers to as a ''mental schema'' underlies our ability to interpret and integrate successive glimpses of the visual world.

The basic premise is that the mental schema maintains important spatial and form-related information, without being a sensory representation. For example, according to Hochberg (1986), from glimpse to glimpse, we do not retain a detailed sensory record of what went before and, in fact, many visual details may not even be noticed. He supports this latter point by reporting how poor viewers are at detecting ''continuity errors'' when watching movies. For example, he points out that in the movie, *Nights of Cabiria,* there is a two-shot series of close-ups in which a truck that was visible over the shoulder of an actor disappears from one cut to the next: a continuity error that viewers of the film do not tend to detect. If observers maintained a sensory memory from glimpse to glimpse, one would expect the disappearing truck to be an obvious change in the visual field. O'Regan (1992) reviews other examples that support the idea that the knowledge drawn from each glimpse is far less detailed than one might expect. Indeed there is growing evidence that an abstract, nonsensory spatial representation (a memory structure) plays a role in the integration of eye fixations (e.g., Irwin, Brown, & Sun, 1988; O'Regan, 1992; Rayner & Pollatsek, 1992). Just as an abstract representation may play a role in comprehending and understanding successive views, we have postulated that it may also serve our ability to understand the partial view of the visual world that is shown in a photograph. In other words, a picture is simply a special case of a partial view.

If we assume that the visual/cognitive system is designed to ignore boundaries and integrate partial views, then the observation of boundary extension in memory for pictures becomes understandable. The partial view activates the schema. The observer understands the picture within this visual/spatial context and then remembers not only what was physically present, but what was understood to have existed just outside the picture's boundaries. Two lines of evidence have thus far provided support for the perceptual schema hypothesis. These include research on: (a) memory for different views of real-world scenes and (b) memory for scene versus nonscene displays.

REMEMBERING DIFFERENT VIEWS

Imagine several views of a centrally located object, ranging from a close-up view to a wide-angle view. In the case of a tight close-up, highly probable visual information about the scene will not be captured in the photograph. It will, however, be represented in the perceptual schema and is critical to the observer's comprehension of the close-up. As more wide-angle views of the same object are presented, more of the probable visual information from the surrounding scene will be contained within the picture itself. As a result, boundary extension (memory for surrounding information that was not physically present) would be expected to be greatest for close-ups and would be expected to decrease for increasingly wide-angle views. At some point, a view may be wide enough for the amount of extension to asymptote, so that no directional error will be obtained. However, activation of the perceptual schema predicts only one type of overall distortion and that is boundary extension. It should never lead to overall boundary restriction for close-ups, prototypes, or wide-angle views.

This predicted pattern runs against the predictions of memory models in which prototypicality plays an important role. For example, one alternate explanation that attributes boundary extension solely to normalization processes within memory (described previously as the ''memory schema hypothesis'': Intraub, 1992; Intraub et al., 1992) is that boundary extension reflects a transformation in memory toward a canonical viewing distance (see Palmer, Rosch, & Chase, 1981, for the related topic of canonical viewing angles in pictures). This hypothesis leads to the prediction that close-ups should yield boundary extension, prototypic views should yield no directional distortion, and wide-angle views should yield boundary restriction, as the picture views transform toward the prototypic view.

Consistent with the perceptual schema hypothesis, and contrary to the memory schema hypothesis, when memory is tested within minutes, the pattern that has been obtained in recognition performance (Intraub et al., 1992), and in recall (Intraub, 1992; Intraub & Berkowits, in press), is consistent with the perceptual schema hypothesis. Boundary extension is greatest for close-ups and smallest for wide-angle views (sometimes yielding no directional distortion in the case of the wide-angle views). In immediate tests, no overall boundary restriction has been obtained.

Scenes versus Nonscenes

According to the perceptual schema hypothesis, partial views of scenes activate expectancies about the continuation of those scenes beyond a picture's boundaries. If this is true, then pictures that do not depict partial views should not activate the perceptual schema. Legault and Standing (1992) tested this hypothesis by examining memory for objects when they were in scenes and when they were not. To accomplish this, observers viewed photographs of objects in scenes, or outline drawings of the same objects on a blank field. When they drew the pictures from memory, the observers' drawings revealed boundary extension for the scenes and no directional distortion for the pictures of objects on blank backgrounds.

We have replicated this finding using photographs of a main object in a natural context, outline drawings made by tracing the photograph, and outline drawings made by tracing only the main object without any scene information included (Gottesman & Intraub, 1993, November; Intraub, Gottesman, & Bills, 1995, November). Whereas photographs and outline scenes yielded boundary extension, the outline objects with no background yielded no directional distortion. This suggests that the unidirectional phenomenon of boundary extension only occurs when a picture depicts a partial view. Consistent with the Extension–Normalization Model, we found that in the nonscene condition, where we expected to eliminate the influence of the perceptual schema, not only was there no directional distortion overall, but analysis of the individual pictures revealed a small but significant normalization pattern. Larger objects in the set yielded boundary extension, and smaller objects in the set yielded an equivalent degree of boundary restriction.

These experiments, in conjunction with the picture view experiments described in the last section, provide support for the perceptual schema hypothesis; that is, the possibility that the schema is activated during perception and that highly probable surrounding information becomes incorporated in the observer's mental representation of the picture in memory. Subjects, according to this conceptualization, remember what they understood about the continuous nature of the scene rather than remembering the specific view that was actually presented.

If this is true, and boundary extension is a memory distortion that reflects a perceptual process, then it should become evident very quickly. It should not require multisecond viewing times to develop, and it should be observed long before the multiminute retention intervals that were tested in prior research (e.g., Intraub et al., 1992; Intraub & Berkowits, in press). The following experiments sought to determine if the time course of boundary extension is consistent with this conceptualization of its cause.

EXPERIMENT 1

Previous research on boundary extension has used multisecond stimulus durations: most frequently, 15 s per picture. The purpose of Experiment 1 was to determine if multisecond durations are necessary for boundary extension to develop or if boundary extension would occur for pictures presented for a duration that would mimic a single brief eye fixation (250 ms).

If boundary extension is a memory illusion that reflects top-down processes occurring during perception, then a brief glimpse should be sufficient to cause schema activation and result in an overinclusive memory. This would certainly be expected if these processes are involved in understanding and integrating eye fixations. An alternative view is that a single glimpse may not be sufficient to elicit expectations about the area outside the picture's boundaries because such expectations build up over time when viewing the stimulus. Limited viewing time might result in an inaccurate memory of the picture's boundaries because observers may only capture the ''gist'' of the picture (Biederman, 1981). In this case, however, contrary to the perceptual schema hypothesis, no directional distortion would be expected for briefly presented pictures, because subjects' guesses should result in both extension and restriction.

To test these hypotheses, two durations (4 s and 250 ms) and two views of the same scenes (close-up and wide-angle) were presented at a constant stimulus onset asynchrony (SOA) in a 2 × 2 between-subjects design. As in prior research a multiminute retention interval followed sequence offset. In this way, we manipulated stimulus duration independent of retention interval.

Following presentation of the sequence, subjects drew each picture and then took part in a boundary recognition test. The benefits of the drawing task are that it allows the subjects to express freely what they remember and also provides a quantitative measure of the degree of the distortion. The benefits of the recognition test are that it allows the subject to see the stimulus again while assessing boundary placement, and is not subject to differences in the subjects' artistic abilities. We decided to use both tests, with recognition following recall, because Intraub and Richardson (1989) had found that an interpolated drawing task did not affect recognition memory for boundaries. To replicate Intraub and Richardson (1989) as well as to provide a more immediate test of memory, in a fifth condition, the 250-ms close-ups were presented, followed immediately by the recognition test, with no intervening drawing task.

Method

Subjects

Subjects were 151 University of Delaware undergraduates (82 female) taking a course in introductory psychology, who had elected to take part in the departmental subject pool.

Apparatus

Subjects were seated facing a 15″ × 23″ (approximately 28 × 38 cm) rear projection screen. There were three rows with three seats in each. The slides were projected using two channels of a three-channel projection tachistoscope that consisted of three Kodak Carousel projectors equipped with UniBlitz shutters

(Model 225-L) and Uniblitz shutter drives (Model SD-122B), controlled by an Apple II computer. The distances from the screen to the center of the front, middle, and back rows were 74″, 118″, and 157″, respectively. The visual angles ranged from approximately 17° × 12° (center, front row) to 8° × 5° (center, back row).

To measure the area of the main object in the subjects' drawings, an area estimation program was run on a computer graphics system. The system was composed of an IBM compatible computer (386/25 mHz), equipped with a Truevision AtVista 4 megabyte graphics board, a 13″ Mitsubishi color monitor (Model FA3415ATK), and a Japan Victor Corporation (JVC) CCD color video camera.

Stimuli

The stimuli were seven scenes depicting single objects against simple natural backgrounds that contained no cropped objects. Backgrounds were chosen to be distinctive and nonconfusing within the picture set. The seven scenes included: (a) a bunch of bananas resting on a surface of rocks, (b) a basketball on a gym floor, against a wall, (c) a can of soda against a stone wall, (d) a hair dryer on a tile floor, (e) a tea kettle on a white tablecloth, (f) a Swiss Army knife with several blades open lying on a concrete sidewalk, and (g) a stuffed panda bear sitting on a flight of stone steps (see Fig. 1). An additional picture (of a yellow pail and a shovel on a pebbled sidewalk) served as a buffer picture at the beginning of the sequence. Two versions of each scene were photographed on 35-mm slides: a close-up view and a wide-angle view. Scenes were selected such that the wide-angle view showed more of the background, but did not bring any new objects into view. On average the main object in the close-ups covered approximately 33% of the picture space, whereas the main object in the wide-angle views covered approximately 2% of the picture space (see Fig. 1 for an example).

Design and Procedure

There were five conditions with 30–31 subjects in each. In all conditions pictures were presented at an SOA of 5 s, with a black and white patterned visual noise mask presented in the interstimulus interval (ISI). A computer tone was sounded 500 ms prior to the onset of each picture. In four of the conditions, subjects viewed either close-up or wide-angle pictures for either 250 ms or 4 s each. This was followed by a drawing test and a boundary recognition test. In the fifth condition, subjects viewed the same sequence as those in the close-up–250-ms condition, but instead of the drawing test, took part in the recognition test immediately following presentation.

Subjects were instructed to focus their attention on each slide as it was presented and to try and remember it in as much detail as possible. They were told that the background information was just as important to remember as was the main object.

Recall. Immediately following presentation the subjects were issued response booklets. Each page contained two rectangles which measured 4″ × 6″ (10 × 15 cm), so that they had the same aspect ratio (1:1.5) as the stimuli (35-mm slides). An unambiguous one-word title next to each rectangle indicated which picture the subject should draw in that space. Pictures were listed in the same order as they had been initially presented. Subjects were asked to draw each of the pictures in as much detail as possible. They were told, "Don't worry if you're not great artist; just do your best to represent the object and its background. Consider the edges of the rectangle to be the edges of the photograph you saw and draw the picture accordingly, filling in the space on your page as it had been filled in the photograph on the screen. After you draw each picture, make any changes that your think are necessary. If you want to clarify any part of your drawings, feel free to add words." Drawings took about 20 min to complete. Booklets were collected, and subjects were provided with response sheets for the recognition test.

Recognition. The subjects were told they would be seeing the same scenes again, but that this time their task was to rate each slide on a 5-point scale as to whether each picture was exactly the same or slightly different than

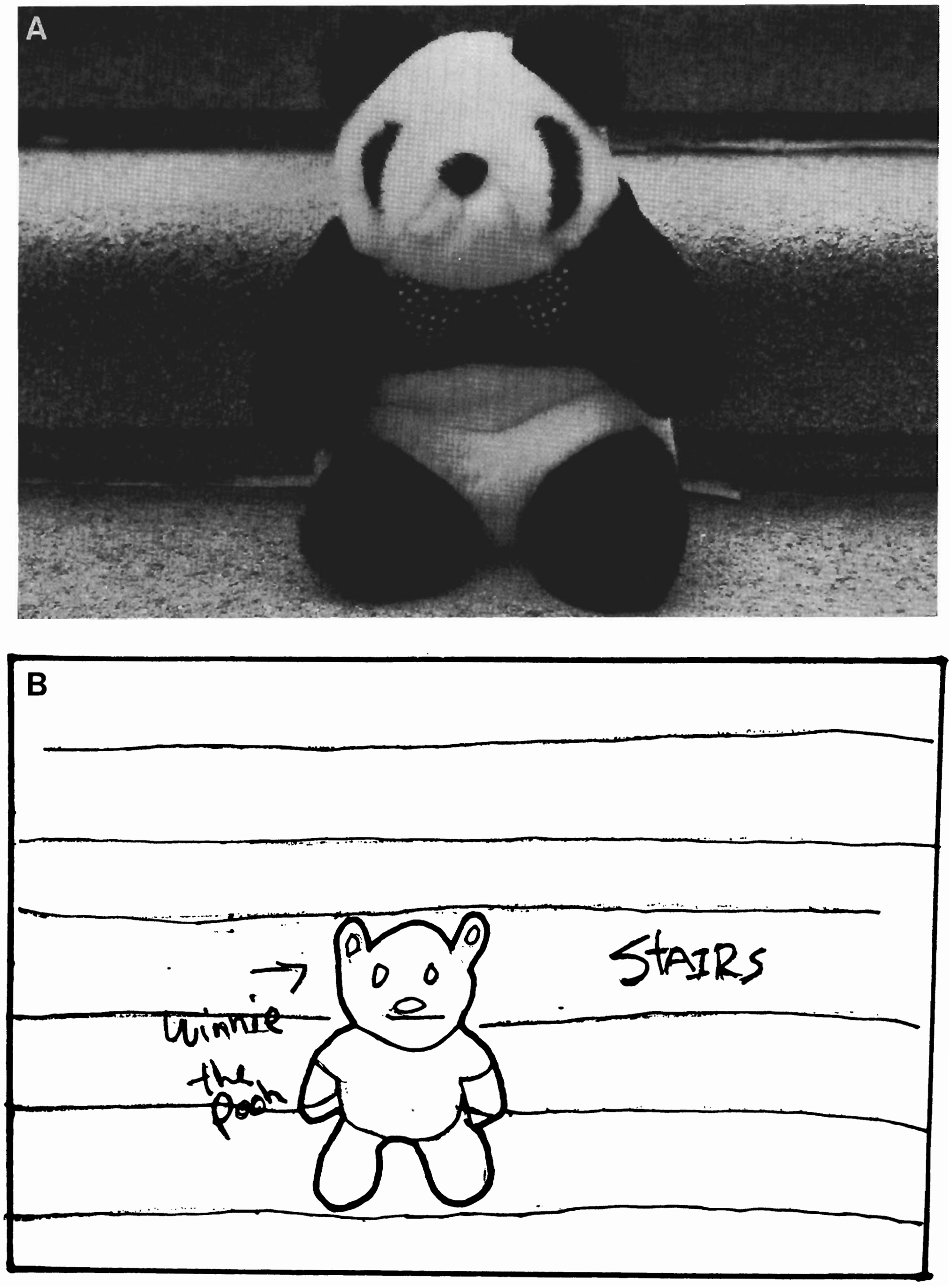

FIG. 1. (A and C) Close-up and wide-angle versions of "bear on the steps", panels (B and D) representative drawing of each by subjects in the 250-ms duration condition (within .04 of the mean proportion drawn for that picture). (Actual stimuli are color photographs and original pencil drawings were traced in black ink.)

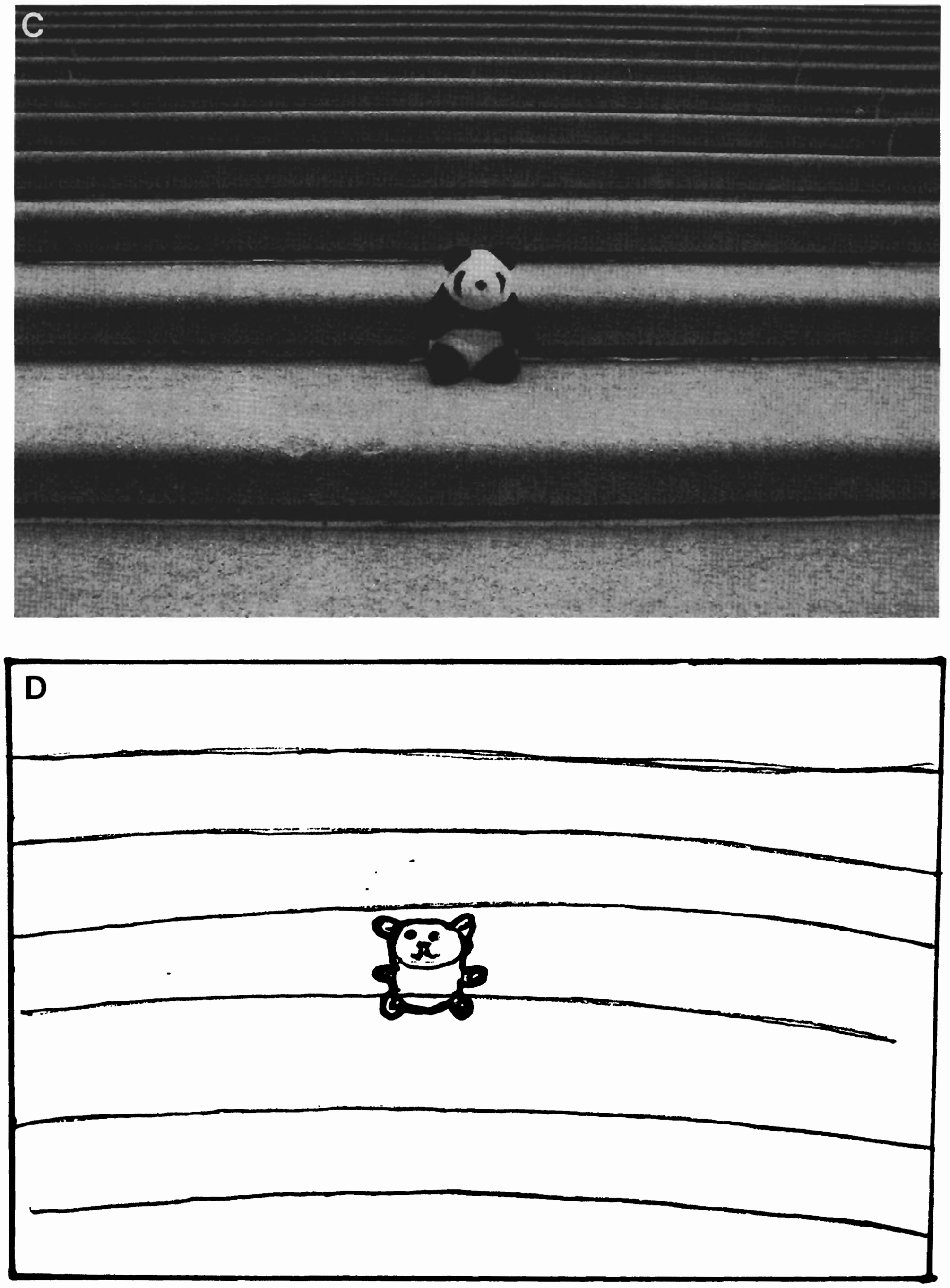

FIG. 1—*Continued*

the one they had seen during presentation. We explained that test pictures might differ from the presentation pictures by showing either more or less of the scene. To demonstrate this possibility, as in previous research, we showed them four views of the same scene (a bicycle against a fence), that ranged from close-up to wide-angle. It was pointed out that when the camera is closer (creating a ''close-up''), less of the scene is visible than when it is farther away. They were instructed to decide if the test picture was the ''same'' (0), ''slightly too close'' (−1), ''much too close'' (−2), ''slightly too far'' (1), or ''much too far'' (2). If they could not remember a picture at all they were instructed to circle ''Don't remember picture'' (DRP). Subjects circled a confidence rating of sure, pretty sure, or not sure for each response.

The test slides were presented for 15 s each, in the same order as they had been originally presented.

Analyzing subjects' drawings. To measure the area of the main object in each slide, the slide was projected into the same 4″ × 6″ rectangle used in the drawing response sheets, and the outline of the main object was traced using black ink. To measure the main object's area in each of the subjects' drawings, its outline was similarly darkened with black ink (to enhance readability during digitization). These outline drawings were digitized using the video camera and were displayed on the monitor. The experimenter delineated the outlined area to be calculated, and an area estimation program was run. The area was described in terms of square tenths of inches (which corresponds to the grid sheets used in other experiments from this lab, in which area was manually estimated).

Results and Discussion

Recall

The proportion drawn was calculated by dividing the area of the main object in the subject's drawing by the area of the same object in the actual drawing. Proportions more than 3 standard deviations from the picture's mean (1.7% of all responses) were treated as missing data. Nine subjects were eliminated from the drawing analysis because they had more than one missing data point: either through a failure to draw or drawing at greater than 3 standard deviations from the mean.

TABLE 1

MEAN PROPORTION DRAWN FOR PICTURES AS A FUNCTION OF STIMULUS DURATION AND PICTURE TYPE

	Picture type	
Duration	Close	Wide
250 ms		
M	.30	.90
SD	.15	.42
4 S		
M	.32	1.16
SD	.15	.51

Note. The number of subjects ranged from 27 to 29 in each group. The limits of the .95 confidence interval in the 250-ms-close, 250-ms-wide, 4-s-close, and 4-s-wide conditions were *M* =.05, .16, .06, and .19, respectively.

The mean proportion drawn and the .95 confidence interval for each condition is shown in Table 1. Both the 250-ms presentations and the 4-s presentations replicated previous research. As may be seen in the table, close-ups yielded boundary extension (i.e., proportion significantly less than 1) and the wide-angle pictures yielded no directional distortion (i.e., proportion does not differ from 1). Consistent with this, a 2 × 2 ANOVA (Stimulus duration × Picture type) showed that the proportion drawn was smaller for the close-ups than for the wide-angle pictures ($F(1,107) = 123.08$, $MSE = .12$, $p < .001$). Contrary to the hypothesis that briefly presented pictures would be less likely to exhibit a unidirectional pattern of errors, overall, 250-ms exposures resulted in a slightly greater degree of boundary extension than did the 4-s exposures ($F(1,107) = 4.45$, $MSE = .12$, $p < .05$). This difference is most apparent for the wide-angle pictures, but the interaction did not reach significance ($F(1,107) = 3.49$, MSE = .12, $p = .06$). Inspection of the table shows that boundary extension for 250-ms presentations was at least as great as for 4-s presentations.

Because there were only seven stimuli, we were concerned that allowing one missing data point for some subjects could add unnecessary error in the analysis, because the sizes of the main objects differed greatly within the close-up set and within the wide-angle set. We therefore reanalyzed the data including only those subjects who had drawn every picture. The mean proportion drawn in the close-up–250-ms, wide-angle–250-ms, close-up–4-s, and wide-angle–4-s conditions was .29 (SD = .12), .86 (SD = .37), .32 (SD = .16), and .98 (SD = .44), respectively. As before, close-ups yielded more extension than did wide-angle pictures ($F(1,85) = 103.66$, $MSE = .08$, $p < .001$). In this case, the brief durations yielded the same degree of extension as did the longer durations ($F(1,85) = 1.32$, $MSE = .08$).

The large degree of boundary extension obtained in the close-up conditions was reflected in the mean proportion drawn for the individual pictures, which ranged from .22 to .39. The wide-angle pictures, on the other hand, yielded a large range of responses, exhibiting both extension and restriction, that together yielded no overall directional distortion.

Recognition

Following the same exclusion rule we used for drawings, three subjects who had more than one missing data point were excluded from the recognition memory analysis. Overall, subjects were confident of their responses. They rated 28% of their responses as ''sure,'' 60% as ''pretty-sure,'' and only 11% as ''not sure.'' They failed to respond on 1% of the trials.

Overall, subjects correctly identified the test picture as ''same'' 41% of the time. The mean percentage correct for each condition is shown in Table 2. A 2 × 2 ANOVA on the percentage correct in each condition revealed that wide-angle pictures were correctly recognized more often than were close-ups ($F(1,113) = 5.40$, $MSE = 368.89$, $p < .05$). It also showed that the 4-s duration led to slightly better recognition accuracy than the 250-ms duration ($F(1,113) = 9.23$, $MSE = 368.89$, $p < .01$). There was no interaction ($F(1,113) = 2.29$, $MSE = 368.89$).

To minimize possible effects of guessing, we eliminated all responses rated as ''not sure'' and conducted the same analysis on the percentage correct (see Table 2). In this case, there was no significant difference in the percentage correct for close-up and wide-angle pictures ($F(1,113) = 3.10$, $MSE = 551.15$, $p = .08$). Once again, subjects correctly identified more pictures as ''same'' in the 4-s condition than in the 250-ms condition ($F(1,113) = 7.74$, $MSE = 551.15$, $p < .01$.), and there was no interaction ($F < 1$).

TABLE 2

PERCENTAGE OF ''SAME'' RESPONSES FOR PICTURES PRESENTED IN EACH CONDITION FOR ALL RESPONSES AND FOR HIGH CONFIDENCE RESPONSES (''SURE'' AND ''PRETTY-SURE'')

	Picture type	
Duration	Close	Wide
All responses		
250 ms		
M	34	37
SD	14	23
4 s		
M	39	53
SD	17	22
High confidence responses		
250 ms		
M	32	37
SD	17	26
4 s		
M	42	52
SD	21	28

Note. The number of subjects ranged from 28 to 30 in each group.

Boundary memory. When subjects did not correctly identify the test picture they tended to rate it as being ''closer-up'' than before, thus indicating that they remembered the picture as having provided a more wide-angle view. The percentage of errors indicating this for close-ups was 89% (250-ms condition) and 87% (4-s condition) and for wide-angles was 71% (250-ms condition) and 61% (4-s condition). Wilcoxon tests showed that this pattern was upheld across subjects in all conditions

TABLE 3

Mean Boundary Score (Range −2 to + 2) for Pictures in Each Condition for All Responses and for High Confidence Responses (''Sure'' and ''Pretty-Sure'')

Duration	Picture type Close	 Wide
All responses		
250 ms		
M	−.74	−.37
SD	.45	.42
4 s		
M	−.61	−.15
SD	.35	.32
High confidence responses		
250 ms		
M	−.78	−.41
SD	.47	.43
4 s		
M	−.64	−.23
SD	.40	.42

Note. For all responses, the limits of the .95 confidence intervals for the 250-ms-close, 250-ms-wide, 4-s-close, and 4-s-wide conditions were M = .17, .15, .13, and .12, respectively. For the highly confident responses, the limits were M = .18, .16, .14, and .16, respectively.

($p \leqslant .05$, two-tailed).[1] The mean boundary score and .95 confidence interval for each condition are shown in Table 3. All conditions yielded significant degrees of boundary extension. A 2 × 2 ANOVA (Stimulus Duration × Picture Type) on the subjects' mean boundary scores showed that as expected, close-ups yielded a greater degree of extension than did wide-angle pictures ($F(1, 113) = 32.21$, $MSE = .15$, $p < .001$). As was the case in recall, the 250-ms duration yielded a greater degree of distortion than did the 4-s duration ($F(1,113) = 5.84$, $MSE = .15$, $p < .05$). There was no interaction of stimulus duration and picture type ($F < 1$).

To minimize a possible effect of guessing, we conducted the same analyses after eliminating responses rated as ''not sure.'' The mean boundary score and .95 confidence interval are shown for each condition in Table 3. If anything, the degree of distortion was slightly greater when the ''not sure'' responses were removed. The ANOVA yielded the same results as before. There was a greater degree of boundary extension for close-ups than for wide-angle pictures ($F(1,113) = 23.75$, $MSE = .18$, $p < .001$) and a greater degree of boundary extension in the 250-ms condition than in the 4-s condition ($F(1,113) = 4.11$, $MSE = .18$, $p < .05$). There were no interactions ($F < 1$).

In terms of the individual pictures, for close-ups regardless of duration, all but one picture yielded boundary scores between −.40 and −1.21, indicating boundary extension. For the wide-angle pictures, scores ranged from .14 to −.90, with the majority of pictures in both duration conditions yielding negative boundary scores.

Close-ups presented for 250 ms with no interpolated recall task. Recognition memory was compared for 250-ms presentations of close-ups with and without the interpolated recall task. As in Intraub and Richardson (1989), the recognition results were unaffected by the interpolated task. The mean percentage correctly recognized as ''same'' in the no recall condition was 42% ($SD = 22$). This did not differ from the condition with the interpolated task (see close-up–250-ms condition in Table 2), $t(57) = 1.77$. The same outcome was obtained when ''not sure'' responses were eliminated, $t(57) = 1.74$.

When they were in error, subjects rated the same picture as being ''closer-up'' than before 93% of the time. A Wilcoxon test showed this to be a significant directional bias ($z = -4.73$, $p < .05$). The mean boundary score for the no-recall condition was −.64 ($SD = .35$), which was significantly different from 0, indicating boundary extension (.95 confidence interval: UL = −.51, LL = −.76). The degree of the distortion did not differ from that obtained in the recall/recognition condition,

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[1] For the 250-ms–close-up, 250-ms–wide-angle, 4-s–close-up, and the 4-s–wide-angle conditions, $z = -4.49$, -3.78, -4.50, and -1.96, respectively.

$t(57) = .96$. This outcome was also unaffected when ''not sure'' responses were eliminated, $t(57) = 1.23$.

EXPERIMENT 2

Experiment 1 demonstrated that boundary extension is clearly not limited to long stimulus durations and can be seen within minutes of having viewed seven photographs for 250 ms each. Rather than resulting in less boundary extension, if anything there was a tendency toward a greater degree of directionality for the 250-ms durations than the 4-s durations. The purpose of Experiment 2 was to delve into the early time course of the phenomenon further, by determining if the same distortion would occur when the SOA is brief enough to mimic the rapid successive nature of eye fixations. Yarbus (1967) reported a fixation frequency as fast as three fixations per second in viewing photographs. The present experiment tested whether boundary extension would occur under conditions of rapid serial visual presentation (RSVP), at a rate of three pictures per second, a small memory load of only three pictures, and a retention interval as brief as 1 s.

Method

Subjects

Subjects were 60 undergraduates from the same subject pool described in Experiment 1.

Stimuli

Because 126 pictures were required to conduct this experiment, we used scenes from numerous sets in our picture library (35-mm slides), including those from previous boundary extension experiments. As a result, this set was much more representative of the types of scenes (simple to complex) that one sees in books, magazines, and personal photograph collections. They contained a wide range of picture views, subject matter, backgrounds, and numbers of objects.

Apparatus

The photographs were projected using a 35-mm carousel projector and were digitized using the computer graphics system described in Experiment 1. Image resolution was 378 × 243 pixels × 16 bits of color. This allows 65,536 different colors, making up for the relatively low spatial resolution and producing a high quality image. Subjectively, the images appeared to be televised photographs.

To create a display that was similar to the rear projection screen used in Experiment 1, a rectangle (6.5″ × 9″) was cut out of the center of a black poster board. This was attached to a wooden frame that allowed it to be placed directly in front of the monitor, touching the screen. In this way, as in the previous experiment, the boundary of each picture was bordered in black, and a view of the lab, surrounding each picture was therefore similarly blocked from view. The visual angle was approximately 11° × 15°.

Design and Procedure

Subjects were individually tested. They were seated directly in front of the color monitor and were asked to select a comfortable position (e.g., some prefer to lean forward, others to lean back). The chair was then positioned such that the distance from the subject's head to the center of the monitor was about 35″. The subject was asked to remain in this position for the duration of the experiment. If they were uncomfortable, they were asked to tell the experimenter so he could move the chair to maintain the 35″ distance.

Subjects were presented with 42 sequences each of which contained three new color photographs of unrelated scenes. The pictures were displayed for 333 ms (20 video frames) each, with no ISI. The third picture was followed by a visual noise mask for 60 video frames (1 s), which in turn was succeeded by a target picture, (i.e., one of the three stimuli just viewed) for 600 video frames (10 s). The visual noise mask was a white field with black patterns and overlapping lines. The purpose of the visual mask was to minimize any iconic persistence for the last picture in the sequence.

Target picture and serial position were counterbalanced across subjects, so that each target picture was presented in the serial positions 1, 2, and 3 equally often. To accomplish this, we used three different presentation orders with 20 randomly assigned subjects viewing each one. For each presentation order, the same three pictures were presented in each trial, and the same picture was tested, but the serial position of the target picture differed. For example, the first picture triad shown was always the same, and the item tested was always the picture of "keys." However, in each of the three presentation orders the keys appeared in a different serial position within its triad.

Subjects were told to pay attention to each picture as it appeared and to try to remember it in as much detail as possible. They were told that the background was as important to remember as were the main objects and with this in mind were asked to try to retain "an exact copy" of each picture in memory. The experimenter then explained the recognition memory task using the same instruction and the same sample pictures described in Experiment 1. This meant that unlike Experiment 1, these subjects were aware of the type of test prior to viewing the sequences. All questions were answered and the experiment was begun.

During the experiment, the only illumination came from the monitor, which contained a centrally located fixation point. Before each sequence, the experimenter said, "ready," and two rows of Xs flashed on the screen, followed 500 ms later by the sequence. The entire session was completed in approximately 20 min.

Results and Discussion

Although the presentation rate was very rapid and the duration brief, subjects were rather confident of their responses; 22% of the responses were rated as "sure," 54% as "pretty sure," and 23% of the responses were rated as "not sure." Subjects did not respond on 1% of the trials.

Percentage of Pictures Correctly Recognized

Subjects correctly identified the test picture as the same picture they saw before on 43% of the trials. Table 4 shows the percentage correctly recognized as a function of serial position. Orthogonal planned comparisons revealed that there was no effect of serial position on the subject's ability to recognize that the test picture was the same as the presentation picture. For the comparison of serial position 3 with the first two positions, $F(1,59) = 2.53$, $MSE = 198.19$, n.s., and for the comparison of positions 1 and 2, $F < 1$. An increase in the retention interval from 1000 to 1667 ms did not affect accuracy.

TABLE 4

PERCENTAGE OF "SAME" RESPONSES FOR PICTURES IN EACH SERIAL POSITION FOR ALL RESPONSES AND FOR HIGH CONFIDENCE RESPONSES ("SURE" AND "PRETTY-SURE")

	Percentage of "same" responses	
Position	*M*	*SD*
All responses		
1	43	20
2	41	18
3	46	21
High confidence responses		
1	39	23
2	40	23
3	46	24

To minimize "noise" in the data due to guessing, we analyzed the percentage correctly recognized after deleting those trials on which subjects reported being "not sure." This did not affect accuracy; subjects were correct 43% of the time. As may be seen in Table 4, however, under these conditions a recency effect for the last picture was obtained. Subjects correctly recognized the picture more often in serial position 3 than in serial positions 1 and 2 ($F(1,59) = 6.36$, $MSE = 256.80$, $p < .05$). There was no significant difference between pictures presented in the first and second positions ($F < 1$). This small recency effect is consistent with other research showing that memory for briefly glimpsed pic-

TABLE 5

MEAN BOUNDARY SCORE (RANGE −2 TO +2) AND THE UPPER LIMIT (UL) AND LOWER LIMIT (LL) OF THE .95 CONFIDENCE INTERVAL IN EACH SERIAL POSITION: ALL RESPONSES AND HIGH CONFIDENCE RESPONSES (''SURE'' AND ''PRETTY-SURE'')

	Boundary score		Confidence interval	
Position	*M*	*SD*	UL	LL
		All responses		
1	−.37	.21	−.32	−.42
2	−.41	.26	−.34	−.47
3	−.38	.21	−.32	−.43
		High confidence responses		
1	−.44	.24	−.38	−.50
2	−.50	.29	−.43	−.57
3	−.43	.27	−.36	−.50

tures is worse when the picture is followed by another picture than when it is followed by a meaningless visual noise mask (Intraub, 1984; Loftus & Ginn, 1984).

Boundary Memory

The error data clearly showed boundary extension after retention intervals as brief as 1 s. On trials in which subjects reported that the test picture was not the same as the presentation picture, they rated it as ''closer-up than before,'' 82% of the time. A Wilcoxon test showed that this directional bias was significant ($z = -6.74$, $p < .001$). Boundary extension occurred not only across subjects, but as can be seen in the Appendix, the mean boundary scores for all but 6 of the 42 pictures tested was negative, indicating boundary extension.

Table 5 shows the mean boundary scores for pictures in each of the three serial positions. All means yielded significant degrees of boundary extension (i.e., all were negative and differed significantly from 0 (''same''); see Table 5 for .95 confidence intervals). The same planned comparisons described earlier, were conducted on the mean boundary scores to determine if there were any serial position effects. As before, no effect was obtained ($F < 1$, for both comparisons).

Once again, to minimize possible effects of guessing, responses rated as ''not sure'' were eliminated and the results reanalyzed. When subjects did not recognize the item as ''same,'' they reported it as closer-up than before 86% of the time, and this tendency was upheld across subjects (Wilcoxon, $z = -6.74$, $p < .001$). Table 5 shows the mean boundary scores and the .95 confidence intervals for the data when the ''not sure'' responses were excluded. Unlike the correct recognition responses, mean boundary scores did not yield a recency effect in the reanalysis. There was no difference in boundary scores for pictures presented in the third position as compared with those in the first two positions, $F(1,59) = 1.20$, $MSE = .05$, and there was no difference in scores between pictures presented in the first and the second serial positions ($F(1,59) = 1.76$, $MSE = .06$). It is clearly the case that the unidirectional bias of boundary extension is not limited to cases in which the subject is unsure. If anything, when subjects were more confident, the degree of boundary extension appeared to be greater (see Table 5).

GENERAL DISCUSSION

Boundary extension is a memory illusion in which viewers remember having seen a greater expanse of a scene than was shown in a picture. The present research shows that this systematic distortion of memory occurs when pictures are presented for as little as 250 ms each (1 picture/5s: Experiment 1), and that it can be detected as quickly as 1 s following picture offset (Experiment 2). These results have implications for a developing model of pictorial representation that we have referred to as the Extension–Normalization Model.

We have postulated that boundary extension is a direct reflection of the type of processes that take place during scene perception. The visual/cognitive system is designed to manage comprehension of successively presented partial views during visual scanning. It has been proposed that an abstract representation of the expected layout of a scene aids in comprehension and integration of these partial views, thus giving rise to the viewer's experience of a continuous visual world (e.g., Hochberg, 1978, 1986; O'Regan, 1992). We have speculated that the visual system uses these same processes when interpreting the partial views in photographs. Expected information from just outside the picture's boundaries is so fundamental to picture comprehension, that it becomes incorporated in the pictorial representation—thus ''pushing'' boundaries outward. The present research sought to determine if, as this conceptualization suggests, boundary extension could be detected following stimulus durations and presentation rates that are as brief and rapid as those that characterize visual scanning.

Experiment 1 showed that a 250-ms glimpse of a scene was sufficient to activate expectations about the scene structure just outside the picture's boundaries. Following exposure to eight of these ''simulated'' eye fixations (with 5-s SOAs), boundary extension was observed in subjects' drawings and recognition memory responses. These briefly glimpsed pictures yielded the same pattern of errors that has been observed for stimuli presented for much longer durations in previous research: close-ups yielded boundary extension and wide-angle pictures yielded either a smaller degree of extension or no overall directional distortion (Intraub et al., 1992; Intraub & Berkowits, in press). Contrary to the notion that expectations about scene structure outside the picture's boundaries would not be elicited by a brief glimpse, the degree of boundary extension following 250-ms presentations was at least as large as that observed following 4-s presentations.

In Experiment 2, when three ''simulated'' eye fixations were presented in rapid succession (3 pictures/s) to mimic the temporal aspects of rapid visual scanning, boundary extension was obtained after only a 1-s retention interval. The effect was strong and occurred over subjects and over pictures. Boundary extension clearly does not require a long viewing time, a long retention interval, or a large number of stimuli to become manifest. As was also the case in Experiment 1, the distortion was not limited to those trials in which subjects reported being unsure of their memory. If anything, the degree of the distortion tended to be larger when low confidence trials were removed.

Given the magnitude and apparent pervasiveness of the distortion, the reader may question why this phenomenon is not readily apparent in daily life. An observation made during group demonstrations suggests an answer. At first, when comparing their greatly distorted drawings to the original picture, viewers often fail to notice that there is anything wrong. They point out that the main object is correctly located and various details have been correctly recalled. However, when they are instructed to, ''Look at the boundaries,'' they tend to respond with the surprise and laughter typically elicited by perceptual illusions. In terms of our theoretical outlook, this makes sense. The visual system is designed to integrate partial views, ignoring their boundaries in order to provide the experience of a continuous visual world. Not only does this aid in perception, but it has implications for what is later remembered. Although it results in a nonveridical representation of the photograph, it is likely to result in a veridical representation of the scene that the photograph only partially revealed.

In conclusion, the Extension–Normalization Model provides one account of memory for scene boundaries. Thus far it has provided a worthwhile framework for exploring the representation of scenes in memory. It raises the possibility that pictures are a special case of the perception of partial views. This formulation, while strengthened by the current findings, is still speculative. Regardless of whether this theoretical approach continues to be supported, it is clear that any account of pictorial representation will have to provide an explanation of this memory illusion. That is, an explanation of why subjects are so likely to mistakenly remember having seen more of a scene than had actually been shown.

APPENDIX

Mean Boundary Scores for Each Picture by Picture Set

Picture set 1	*M*	Picture 2	*M*	Picture 3	*M*
Key	−.94	Candle	−.57	Dust pan	−.25
Bear	−.33	Beer	−.47	Detergent	−.07
Soda can	−.93	Fan	−.27	Bucket	−.55
Refrigerator	−.27	Desk	−.44	Discs	.12
Blender	.20	Horn	−.73	Drum	−.06
Books	−.87	Hanger	.03	Clock	−.07
Telephone pole	−.45	Music stand	−.38	Dessert	−.82
Egg	−.88	Dresser	.07	Cereal	−.42
Thread	−.78	Boat	−.23	Food	−.78
Birds	−.78	Steak sauce	.07	Fruit	.22
Door	−.03	Bar	−.31	Nest	−.45
Teapot	−.72	Wheel barrow	−.17	Breakfast	−.58
Oranges	−.23	Corn	−.55	Chair	−.22
Motorcycle	−.35	Paper cutter	−.34	Cups	−.60

Note. Pictures in each set were always in the same serial positon in a given presentation order.

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