Published in final edited form as:

Psychol Sci. 2008 October ; 19(10): 1007–1014. doi:10.1111/j.1467-9280.2008.02192.x.

False memory 1/20th of a second later: what the early onset of boundary extension reveals about perception

Helene Intraub and Christopher Dickinson

University of Delaware, Psychology

Abstract

Errors of commission are thought to be caused by heavy memory loads, confusing information, and/or lengthy retention intervals. We report false memory beyond the boundaries of a view, *boundary extension*, after less than 1/20th of a second. Photographs of scenes were interrupted by a 42-ms or 250-ms mask, 250-ms into viewing, before reappearing or being replaced with a different view (Experiment 1). Post-interruption photographs that were unchanged were rated as “closer-up”; when they changed, the same pair of closer-up and wider-angle views was rated as more similar when the closer view was first. Thus, observers remembered pre-interruption views with extended boundaries. Results replicated when the interruption included a saccade (Experiment 2). The brevity of these interruptions has implications for visual scanning; it also challenges the traditional perception/memory distinction. An alternative conceptualization is offered that shows how *source monitoring* can explain false memory after an interruption briefer than an eye blink.

Keywords

Perception; Memory; False Memory

When memory fails, the problem often involves errors of *omission*, but sometimes the problem involves errors of *commission*, in which one falsely remembers details, words, or events that weren’t actually experienced. Errors of commission are generally associated with the presentation of confusing information (e.g., the *misinformation effect*; Loftus, Miller, & Burns, 1978) or with heavy memory loads and the passage of time (Bartlett, 1932; Koriat, Goldsmith, & Pansky, 2000). It is generally accepted that as memory fades, representations become less veridical and increasingly prone to biases based on pre-existing knowledge. There are some examples, however, in which errors of commission have been found to occur very rapidly. One such example comes from research on *boundary extension* (Intraub, Gottesman, Willey, & Zuk, 1996).

Boundary extension is a constructive error in scene representation; observers remember having seen beyond the edges of a view. Figure 1 shows participants’ drawings from memory of a multi-object scene (right) and a simple, single-object scene (left). In both cases, the remembered representation “overflowed” the physical boundaries of the view, anticipating upcoming layout in the world. Boundary extension is specifically related to memory for views of scenes. It does not occur when an object is presented without a scenic structure (e.g., objects on blank backgrounds; Intraub, Gottesman, & Bills, 1998; Gottesman & Intraub, 2002). It is associated with selective neuronal responses in brain areas related to

scene representation: the parahippocampal place area, *PPA*, and retrosplenial cortex, *RSC* (Park, Intraub, Yi, Widders, & Chun, 2007). It has been observed across the lifespan; in children and adults (aged 6–87 years; Seamon, Schlegel, Hiester, Landau, & Blumenthal, 2002), and infants (aged 3–4 months; Quinn & Intraub, 2007).

Although most research on boundary extension has focused on relatively long-term memory (as in Figure 1), a few studies have tested very short-term retention. In a rapid serial visual presentation (RSVP) paradigm, boundary extension occurred when the retention interval was as brief as 1 s (Bertamini, Jones, Spooner, & Hecht, 2005; Intraub et al., 1996). In response to the error's rapidity, Roediger (1996) proposed that although boundary extension occurs after the picture is gone (memory), it may actually have taken place while it was being processed and understood (in some sense perceived), thus falling at a point not clearly defined as either perception or memory. This contention is an important one, but, although a 1-s retention interval is surprisingly brief when we think of a constructive memory error, it is a fairly long interval given the rapidity of scene comprehension, thought to occur within 150 ms or less (Potter, 1976; Thorpe, Fize, & Marlot, 1996).

What if instead of 1 s, memory for a scene were disrupted for the fleeting duration of an eye movement (saccade)—on the order of 30–50 ms (Rayner, 1998). Although it seems unlikely that computation of extrapolated layout beyond the boundaries could occur this quickly, if it did, it would raise important questions about the nature of scene representation during visual scanning, and the potentially adaptive role such errors might play. This brings us back to Roediger's (1996) point about the perception/memory “divide”, because it is important to recognize that visual scanning itself begs the question of where perception ends and memory begins.

This is because we can never see the surrounding world all at once and must sample it through movements of the head and eyes. In so doing, we are forced to toggle back and forth between the visuo-sensory input and memory because each eye fixation is followed by a saccade during which time vision is suppressed until onset of the next fixation (Volkman, 1986). For the fleeting duration of that saccade, the visual system must rely on memory; a short-lived transsaccadic memory (Irwin, 1991, 1993), and a long-term representation that accrues information across fixations (Hollingworth & Henderson, 2002). Might boundary extension (a constructive memory error) occur rapidly enough to be available in transsaccadic memory?

Current Experiments

We presented a single view of a new scene on each trial for 250 ms (a “fixation's worth”). This view was then briefly disrupted before reappearing at test. In Experiment 1, the disruption (caused by the onset of a mask) lasted for the duration of a saccade (42 ms) or for a longer duration that approximates the time from the onset of one fixation to the onset of the next (250 ms) to determine if memory in either case would be prone to boundary extension. In Experiment 2, the disruption included an actual saccade. Either the identical view or a slightly different view (more close-up or more wide-angle) appeared after the disruption. Observers rated it on a 5-point scale as being “the same,” “more close-up,” or “more wide-angle” than before. The four trial types (combinations of stimulus and test views) will be referred to as follows: close-up stimulus, close-up test picture (*CC*); wide-angle stimulus, wide-angle test picture (*WW*); close-up stimulus, wide-angle test picture (*CW*); and wide-angle stimulus, close-up test picture (*WC*).

Surely one would expect observers to recognize the same view in the briefest condition (42 ms mask), in which case the disruption lasts less than 1/20th of a second. In physiological terms, this amounts to an interruption lasting less than 1/8th of the time taken by a

spontaneous eye blink (VanderWerf, Brassinga, Reits, Aramideh, & de Visser, 2003). However, if boundary extension “intervenes”, a specific pattern of errors should emerge:

1. *Identical Close-ups (CC)*: when stimulus and test pictures are identical close-ups, the test picture should be rated as “too close-up”, thus indicating that the original view is remembered with extended boundaries.
2. *Identical Close-up vs. Identical Wider angle views (CC & WW)*: close-ups tend to yield more extension than wider views, which may yield little extension or no directional error (Intraub, Bender, & Mangels, 1992; also see Bertamini et al., 2005).
3. *Different Views (CW & WC)*: when stimulus and test views don’t match, a *rating asymmetry* should occur. The same pair of closer and wider views should be assessed as being more similar on CW than WC trials, because on CW trials if the first view is remembered with extended boundaries, it will more closely approximate the test picture.

Experiment 1

Method

Stimuli: Two versions of 36 digital photographs of people, animals, and landscapes were created. Background complexity ranged from fields of grass to audience-filled bleachers. Close-up versions were made by enlarging wider angle views 8% to 21% and cropping the picture to its original size (using Adobe Photoshop). Thus, each pair of views was the same size, but the wider view revealed more of the background and the objects covered less area (see Figure 2).

Apparatus: Stimuli were presented on a 21" flat-screen CRT monitor (32-bit color, 1024 × 768) run by a Pentium-based PC (XP, 128 Mb of video memory). Software written in C was based on an SR Research Inc., template program and used Simple DirectMedia Layer (SDL). Viewing distance was approximately 80 cm. Stimulus aspect ratio differed for each scene; on average, pictures subtended $9.2^\circ \times 10.2^\circ$ of visual angle (widths ranged from 5.9° to 13.7° ; heights ranged from 8.9° to 10.4°).

Participants and Procedure: Seventy-two University of Delaware undergraduates (42 female) participating in the General Psychology subject pool were randomly assigned to either the 42-ms or 250-ms mask condition. All four trial types (CC, WW, WC, and CW) were randomly intermixed in each condition, with the constraint that no more than three could appear in a row.

On each of the 36 trials, participants fixated a yellow cross followed by the stimulus (either the closer or wider angle version of one scene). The stimulus view was presented for 250 ms before being replaced by a mask (for 42 or 250 ms, depending on condition). The mask was dynamic (a black-and-white pattern mask with a $5.5^\circ \times 5.5^\circ$ circular “face”, similar to a “happy face”, in the center, that changed every 150 ms; see Dickinson & Intraub, in press). Thus, one central face appeared in the 42-ms condition and two appeared in the 250-ms condition. This was intended to enhance maintenance of central fixation, and to prevent initiation of verbal descriptions of boundary location. The test picture (identical or alternate view) immediately followed and remained on the screen until the participant rated it as: “much closer up (−2),” “a little closer up (−1),” “the same (0),” “a little farther away (1),” or “much farther away (2)” than before. They then entered a confidence rating (“sure [3],” “pretty sure [2],” or “not sure [1]”). On 2% of the 42-ms trials and 0% of the 250-ms trials, observers selected a “missed the picture” option (e.g., due to blinking); these were excluded from analysis. The experiment always began with two practice trials.

Results & Discussion—Boundary extension occurred in both the 250-ms and 42-ms masked-retention-interval conditions. All three rating patterns diagnostic of boundary extension were obtained, and boundary scores fell within the range observed in prior experiments using the rating scale (e.g., Dickinson & Intraub, in press). Figure 3 shows the mean rating for each trial type at each retention interval; CC trials yielded significant boundary extension and WW trials yielded little or none (depending on condition). As in prior research, boundary extension was not caused by a small subset of pictures; for 78% of the pictures in the CC conditions, mean scores reflected extension. An ANOVA (Retention Interval $\times$ Trial Type) for identical test trials (CC and WW) revealed greater boundary extension on CC trials than on WW trials, $F(1, 70) = 16.32$, $p < .001$, $\eta_p^2 = .19$, no effect of retention interval, $F(1, 70) = 2.10$, $p = .15$, and no interaction, $F < 1$.

Observers were clearly on task. As shown in Figure 3, they were able to recognize CW and WC trials, correctly rating the test items as being closer or wider. The mean ratings, however, revealed the critical asymmetry diagnostic of boundary extension. As the figure shows, the difference between the mean rating and 0 (“same”) was smaller on CW trials than on WC trials. A 2-way ANOVA (Retention Interval $\times$ Trial Type) for the distractor conditions (CW and WC) on the absolute value of the means showed that this difference was significant, $F(1, 70) = 65.17$, $p < .001$, $\eta_p^2 = .48$ (main effect of *trial type*); there was no effect of retention interval, $F(1, 70) = 1.84$, $p = .18$, and no interaction, $F < 1$.

Overall, responses to repeated views showed that a 42-ms interruption of sensory input not only resulted in boundary extension, but lead to mean boundary scores that were similar to those obtained after a much longer (250 ms) interruption. Mean confidence ratings for the two conditions both centered on “pretty sure (2)” and did not differ [1.98 vs. 2.08, 42-ms vs. 250-ms conditions: $t(70) = 1.22$, $p = .22$].

These results were surprising. Although observers knew precisely what would be tested on each trial, and were required to simply maintain fixation, a disruption lasting less than 1/20th of a second was sufficient for boundary extension to occur. Next we asked if the same outcome would hold if an actual saccade was made between the first and second presentations of the scene.

Experiment 2

In Experiment 1, although the 42-ms condition mimicked a saccade, the task demands were minimal compared to those required by an actual eye movement. In Experiment 2, stimulus and test locations were on different sides of the screen, requiring a saccade, and the test picture did not appear until the eyes moved into the test region. Thus the stimulus had to be maintained in memory while attention rapidly shifted to the new location (e.g., Hoffman & Subramaniam, 1995; Kowler, Anderson, Doshier, & Blaser, 1995) and an eye movement was planned and executed. If these greater demands compromise a presumably fragile transsaccadic memory, then, instead of boundary extension (as in Experiment 1) observers might make random errors. This would argue against the existence of boundary extension during visual scanning, suggesting instead that it is rapidly available only under extremely simplified laboratory conditions. In contrast, replication of Experiment 1 would indicate that the transsaccadic representation can include boundary extension, and thus this anticipatory spatial representation would be available to play a role in the integration of successive views.

Method

Participants: Thirty-two undergraduate volunteers (21 female) from the same population as Experiment 1 participated.

Stimuli and Procedure: Everything was the same as in Experiment 1 except that: a) stimuli appeared on one side of the screen and test pictures on the other, requiring a gaze shift (for ½ of the participants the stimulus was on the left, for the others it was on the right); b) the dynamic portion of the mask appeared in the center of the *test region* (serving as the saccade target); and c) the test picture appeared when the participant's eyes crossed into the test region. Thus the test picture was present when the eyes landed. The center-to-center distance between stimulus and test pictures ranged from 8.4° to 14.2° ($M = 11.8^\circ$). Test procedures were the same as in Experiment 1. Trials on which more than a single saccade was executed were excluded from analysis (39% of all trials).

Apparatus: The apparatus was unchanged except for the addition of an EyeLink II head-mounted video eye-tracking system that was used to monitor eye movements and control onset of the gaze-contingent test item. Eye position was sampled at 500 Hz, the system's spatial resolution was estimated to be less than 0.4°, and head position and viewing distance were fixed with a chinrest.

Results and Discussion—Boundary extension occurred; all three patterns were obtained. Figure 4 shows the mean ratings for each trial type. The CC condition yielded boundary extension and the WW condition yielded no directional error; mean ratings on CC trials were greater than on WW trials, $t(31) = 2.49$, $p = .018$, $d = .56$. Again, the mean CC rating was based on boundary extension ratings reflecting a majority of the pictures (64%). On WC and CW trials, participants correctly detected the distractors, but as before, their mean ratings revealed the critical asymmetry diagnostic of boundary extension; deviation from 0 ("same") was significantly smaller in the case of CW than WC trials, $t(31) = 2.87$, $p = .007$, $d = .80$.

Eye-movement data showed that observers followed instructions and rapidly shifted their gaze to the test area following stimulus offset. Mean saccade latency (from stimulus offset) was 258 ms and mean saccade duration was 54 ms; thus the retention interval was, on average, 312 ms. Although disruption by a mask and a saccade provided a more demanding situation than in Experiment 1, robust boundary extension occurred.

General Discussion

Boundary extension, an error of *commission*, occurs extraordinarily rapidly. Observers remembered having seen the continuation of the view beyond its physical boundaries when the sensory input was disrupted for less than 1/20th of a second! They remembered having seen *more* of the scene than was shown. The rapid onset of this false memory has implications for theories of scene perception. In addition, it challenges the traditionally held division between perception and memory. We discuss each in turn.

Scene Representation

These experiments show that scene representation is already extended by the time the observer compares one view with the next. Experiment 1 showed that when a single view of a scene was interrupted by a mask for the fleeting duration of a saccade (42-ms mask condition), although it had not changed, participants thought it showed less of the scene than before (i.e., a more close-up view). Distractor conditions (in which the closer version was followed by the wider angle version, or vice versa) yielded the critical response asymmetry diagnostic of boundary extension, thus supporting the same conclusion. Experiment 2 showed that the boundary-extended representation was robust enough to survive a shift in spatial attention and the implementation of a saccade.

Because memory had to be tested immediately following a single fixation, none of the conditions could include free viewing. Is it plausible to assume that boundary extension might occur on-line during visual scanning? One indication in support of this is that the experiments “bracket” the normal viewing situation. Experiment 1 was less demanding because observers simply had to maintain their gaze and attend to a single location on each trial; Experiment 2 was more demanding because observers had to consciously shift their gaze to a new location in response to a cue while holding the first view in memory. Yet, robust boundary extension occurred in both cases. Further support comes from other research in which comparable results were obtained when we embedded the stimulus in an RSVP sequence, thus capturing some of the dynamic changes inherent in visual scanning (Dickinson & Intraub, in press).

We argue that rather than being disruptive, boundary errors during visual scanning are more likely to have a positive impact on scene perception. This is because the “goal” of the system is to provide a coherent representation of the *world*; not a record of the spurious boundaries of each individual view. Anticipatory representation of the continuation of layout beyond view-boundaries may serve to “fill in” gaps during scanning, and perhaps prime soon-to-be-visible layout (Sanocki, 2003). Thus boundary extension could serve to facilitate integration of successive views into a coherent representation (Intraub, 1997). The surprising rapidity of the error, however, poses a challenge for the traditionally held division between perception and memory.

Perception vs. Memory

The traditional information-processing approach to perception begins with a representation of the *stimulus*. If there is no mask, a veridical sensory representation may be briefly maintained in a sensory register (Sperling, 1960); otherwise, aspects of the (previously veridical) representation will be directly processed in one or more very short-lived memory stores (e.g., transsaccadic memory, Irwin, 1991, 1993; conceptual short-term store, Potter, 1976; visual short-term memory, Phillips, 1974). Memory in these stores is not “picture perfect”. Indeed, considerable research has focused on the paucity of the representation during this time (e.g., *change blindness*; Simons & Rensink, 2005). If attention is maintained, however, ultimately these briefly stored aspects of the view will be consolidated in long-term memory.

At what point in this process would boundary extension take place? We would have to postulate that it would begin after the (veridical) sensory input is gone, but be completed rapidly enough to influence assessment of the next view. Considering that the briefest interruption in Experiment 1 was a mask lasting only 42 ms, the processes responsible for boundary extension would have to rapidly unfold in one of these early buffers. Perhaps this is what happens, but the timing seems prohibitively brief. Equally important, the *cause* of this extrapolation is left unspecified -- an ad-hoc “extrapolation process” must be invoked to explain it.

We offer an alternative conceptualization that we believe provides a more parsimonious account of rapid boundary extension. Again, beginning during the first fixation, this time, consider the possibility that the ensuing perceptual representation is derived not from one source (sensory input) but *simultaneously* draws on at least two other *sources* of input related to scene structure. Both are internally generated (i.e., “top-down”) processes. One, *amodal perception*, is instituted in response to occlusion of the world at the view-boundaries (Gottesman & Intraub, 2003).

Amodal processes (named as such because they draw on no sensory *modality*) “fill out” the occluded portions of objects (object completion: Kanizsa, 1979) and the continuity of

surface textures (Kellman, Yin, & Shipley, 1998; Nakayama, He, & Shimojo, 1995). This is a critical aspect of everyday perception. The amodally generated layout beyond the view-boundaries, in our example, would be a tightly constrained continuation of the visible content at the periphery of the view.

The other source of information is purely spatial, carrying no specific information about the scene. This spatial framework would provide the observer with a sense of the space beyond the left, right, top, and bottom boundaries of the view (Attneave, 1977; Franklin & Tversky, 1990). All views, after all, reveal only part of an otherwise continuous world. Thus scene perception has multiple sources: sensory, amodal, and spatial (and likely others, e.g., semantic knowledge). During the first fixation, while the stimulus is visible, mental representation would parallel the sensory input. Resolution would be highest at the point of fixation (foveal vision), decrease for information falling farther in the periphery, decrease again for the amodal region, and finally, at the point where only the general spatial framework is available, no further detail could be resolved without shifting one's gaze (or in a photograph, shifting the camera's viewpoint).

The boundary error doesn't occur while the stimulus is present, because the difference between currently active sensory information in the periphery and top-down amodal information is readily discernable. However, when the sensory input is interrupted, this changes. The mental representation is available, but no longer has the contribution of a sensory source. There are no "tags" to specify the exact point at which peripheral information was originally derived via low-acuity peripheral vision or highly constrained amodal perception; although both provide a level of detail unavailable in the spatial structure falling beyond them. Thus in deciding at test "exactly how much did I *actually* see," some of the information originally generated by amodal processing is misattributed to sensory perception, causing boundary extension.

In contrast to the traditional conceptualization, the extended region in this account is not constructed *after* the view is gone (i.e., when our experience shifts from "veridical perception" to "faulty memory"). Instead, the *extended* region was *already part of the representation* while the sensory input was available (albeit, an amodally generated part). We no longer need to propose activation of an "extrapolation process" following stimulus offset. Instead, boundary extension would be the result of a *source-monitoring* error (Johnson, Hashtroudi, & Lindsay, 1993)—specifically, a *reality-monitoring error* (Johnson & Raye, 1981) because it requires the system to distinguish between externally generated information (*visual* perception of the sensory input) and internally generated information (*amodal* perception just beyond the edges of the view).

A key insight expressed in the source-monitoring model is that the *source* of a memory is an *attribution* based upon the amount and quality of details (perceptual, contextual, semantic, or emotional) in the representation (Johnson, 2006; Johnson et al., 1993). It can explain highly detailed false memories (e.g., memory for events one did not experience, but heard others repeatedly describe; or that were dreamed) as well as more mundane everyday mental puzzles ("did I *actually* turn off the stove before we left, or did I just think about it?"). For example, if memory for a dream includes highly specific perceptual details (a hallmark of memories based on sensory experience), we may err in attributing its source to perception. We propose that the same ideas are applicable to memory tested following an interruption briefer than an eye blink, and can account for false memory beyond the boundaries of a view.

Conclusions

Boundary extension (an error of *commission*) occurs extremely rapidly; observers erred when sensory input was interrupted for less than 1/20th of a second. If we think of perception as incorporating information from multiple sources simultaneously (sensory, amodal, and spatial), instead of from the sensory input alone, we can then explain rapid boundary extension without appealing to an ad hoc “extrapolation process”. Instead, the same principles that underlie *source monitoring* in long-term memory can be applied to a situation in which we falsely remember having seen more of a scene than was shown. The rapidity of this error would be advantageous rather than harmful, because the goal of the visual system is not to represent the spurious boundaries of each fleeting view, but to incorporate those views into a coherent, continuous representation of a surrounding world.

Acknowledgments

This research was supported by NIH RO1MH54688. We greatly thank Kari Schweifel and Jason Rand for their assistance and Jay Reiss for manuscript comments.

References

- Attneave F, Farrar P. The visual world behind the head. *The American Journal of Psychology*. 1977; 90:549–563. [PubMed: 610446]
- Bartlett, F. *Remembering: a study of experimental and social psychology*. Cambridge University Press; Cambridge, England: 1932.
- Bertamini M, Jones LA, Spooner A, Hecht H. Boundary extension: The role of magnification, object size, context, and binocular information. *Journal of Experimental Psychology: Human Perception and Performance*. 2005; 31(6):1288–1307. [PubMed: 16366790]
- Dickinson CA, Intraub H. Transsaccadic representation of layout: What is the time course of boundary extension? *Journal of Experimental Psychology: Human Perception and Performance*. (in press).
- Franklin N, Tversky B. Searching imagined environments. *Journal of Experimental Psychology: General*. 1990; 119:63–76.
- Gottesman CV, Intraub H. Surface construal and the mental representation of scenes. *Journal of Experimental Psychology: Human Perception and Performance*. 2002; 28(3):589–599. [PubMed: 12075890]
- Gottesman CV, Intraub H. Constraints on spatial extrapolation in the mental representation of scenes: View-boundaries vs. object-boundaries. *Visual Cognition*. 2003; 10(7):875–893.
- Hoffman JE, Subramaniam B. The role of visual attention in saccadic eye movements. *Perception and Psychophysics*. 1995; 57(6):787–795. [PubMed: 7651803]
- Hollingworth A, Henderson JM. Accurate visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology: Human Perception and Performance*. 2002; 28(1):113–136.
- Intraub H. The representation of visual scenes. *Trends in Cognitive Sciences*. 1997; 1(6):217–221. [PubMed: 21223910]
- Intraub H, Bender RS, Mangels JA. Looking at pictures but remembering scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1992; 18(1):180–191.
- Intraub H, Gottesman CV, Bills AJ. Effects of perceiving and imagining scenes on memory for pictures. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1998; 24(1):186–201.
- Intraub H, Gottesman CV, Willey EV, Zuk IJ. Boundary extension for briefly glimpsed photographs: Do common perceptual processes result in unexpected memory distortions? *Journal of Memory and Language*. 1996; 35:118–134.
- Irwin DE. Information integration across saccadic eye movements. *Cognitive Psychology*. 1991; 23:420–456. [PubMed: 1884598]

- Irwin, DE. Perceiving an integrated visual world. In: Meyer, DE.; Kornblum, S., editors. *Attention and Performance 14: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience*. The MIT Press; Cambridge, MA: 1993. p. 121-142.
- Johnson M,K, Hashtroudi S, Lindsay DS. Source Monitoring. *Psychological Bulletin*. 1993; 114:3–28. [PubMed: 8346328]
- Johnson MK, Raye CL. Reality monitoring. *Psychological Review*. 1981; 88:67–85.
- Johnson MK. Memory and reality. *American Psychologist*. 2006; 61:760–771. [PubMed: 17115808]
- Kellman PJ, Yin C, Shipley TF. A common mechanism for illusory and occluded object completion. *Journal of Experimental Psychology: Human Perception and Performance*. 1998; 24(3):859–869. [PubMed: 9627421]
- Koriat A, Goldsmith M, Pansky A. Toward a psychology of memory accuracy. *Annual Review of Psychology*. 2000; 51:481–537.
- Kowler E, Anderson E, Doshier B, Blaser E. The role of attention in the programming of saccades. *Vision Research*. 1995; 35(13):1897–1916. [PubMed: 7660596]
- Loftus EF, Miller DG, Burns HJ. Semantic integration of verbal information into a visual memory. *Journal of Experimental Psychology: Human Learning and Memory*. 1978; 4:19–31. [PubMed: 621467]
- Nakayama, K.; He, ZJ.; Shimojo, S. Visual surface representation: A critical link between lower level and higher level vision. In: Kosslyn, SM.; Osherson, DN., editors. *Visual cognition*. Vol. Vol. 2. MIT Press; Cambridge, MA: 1995. p. 1-70.
- Park S, Intraub H, Yi D-J, Widders D, Chun MM. Beyond the Edges of a View: Boundary Extension in Human Scene-Selective Visual Cortex. *Neuron*. 2007; 54:335–342. [PubMed: 17442252]
- Phillips WA. On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics*. 1974; 16:283–290.
- Potter MC. Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*. 1976; 2(5):509–522. [PubMed: 1003124]
- Quinn PC, Intraub H. Perceiving “outside the box” occurs early in development: Evidence for boundary extension in 3- to 7-month-old infants. *Child Development*. 2007; 78:324–334. [PubMed: 17328708]
- Roediger HL. Memory illusions. *Journal of memory and Language*. 1996; 35:76–100.
- Rayner K. Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*. 1998; 124(3):372–422. [PubMed: 9849112]
- Simons DJ, Rensink RA. Change blindness: Past, present, and future. *Trends in Cognitive Sciences*. 2005; 9(1):16–20. [PubMed: 15639436]
- Sanocki T. Representation and perception of scenic layout. *Cognitive Psychology*. 2003; 47:43–86. [PubMed: 12852935]
- Seamon JG, Schlegel SE, Heister PM, Landau AM, Blumenthal BF. Misremembering pictured objects: People of all ages demonstrate the boundary extension illusion. *American Journal of Psychology*. 2002; 115:151–167. [PubMed: 12041005]
- Sperling G. The information available in brief visual presentations. *Psychological Monographs: General and Applied*. 1960; 74(11, Whole No. 498):1–29.
- Thorpe S, Fize D, Marlot C. Speed of processing in the human visual system. *Nature*. 1996; 381(6):520–522. [PubMed: 8632824]
- Volkman FC. Human visual suppression. *Vision Research*. 1986; 26(9):1401–1416. [PubMed: 3303665]
- VanderWerf F, Brassinga P, Reits D, Aramideh M, de Visser BO. Eyelid movements: behavioral studies of blinking in humans under different stimulus conditions. *Journal of Neurophysiology*. 2003; 89:2784–2796. [PubMed: 12612018]

Figure 1.

Close-up views (top row), participants' drawings of these views, drawn from memory (middle row), and wide-angle views of the same scenes (bottom row). Note that boundary extension (remembering beyond the given view) occurs for multi-object scenes when objects are cropped by view-boundaries, and for single-object scenes with no cropping; observers simply remember seeing more of the world than was shown. (Left panels are based on Intraub & Richardson, 1989, Figure 1; right panels are based on Intraub, Gottesman, Willey, & Zuk, 1996, Figure 1.)

Figure 2.

A sample pair of stimuli. When shown in succession in the same spatial location with no mask, the difference is salient; the wider angle view (right) reveals more of the scene, and the area of the main object decreases by 27.6%. (This image was taken from the Big Box of Art 615,000 Images database, Hemera Technologies. In the public domain.)

Figure 3.

Mean boundary ratings for each trial type in the 42-ms and 250-ms conditions (Experiment 1). Error bars show the 95% confidence for each mean. For identity trials (CC and WW), a negative mean score significantly below 0 (*same*) indicates boundary extension; effect size in the 42-ms and 250-ms CC conditions is $d = .96$ and $d = .78$, respectively. For different trials (CW and WC), an asymmetry [CW scores being closer to 0 (*same*)] indicates boundary extension.

Figure 4.

Mean boundary rating for each trial type following a single saccade between stimulus and test. Error bars show the 95% confidence interval of the mean. For identity trials (CC and WW), a negative mean score significantly below 0 (*same*) indicates boundary extension; effect size for the CC condition is $d = .85$. For different trials (CW and WC), an asymmetry [CW scores being closer to 0 (*same*)] indicates boundary extension.