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Changes are not localized before they are explicitly detected

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Change detection is in many ways analogous to visual search. Yet, unlike search, successful detection depends not on the salience of features *within* a scene, but on the difference between the original and modified scene. If, as in search, preattentive mechanisms guide attention to the change location, the change itself must produce a preattentively detectable signal. Despite recent evidence for implicit representation of change in the absence of conscious detection, few studies have yet explored whether attention is guided to a change location *prior* to explicit detection. In four ‘‘change blindness’’ experiments using several variants of the ‘‘flicker’’ task, we tested the hypothesis that implicit or preattentive mechanisms guide change localization prior to explicit detection. None of the experiments revealed improved localization of changes prior to explicit reports of detection, suggesting that implicit detection of change does not contribute to the eventual explicit localization of a change. Instead, change localization is essentially arbitrary, driven by the salience of features within scenes.

When an original and a modified scene are separated by a brief disruption (e.g., a blank screen, an eye movement, etc.), observers are often unable to report the modification, a phenomenon known as ‘‘change blindness’’ (Rensink, O’Regan, & Clark, 1997; Simons, 2000; Simons & Levin, 1997). If the original and modified image alternate repeatedly, separated by a blank screen (the ‘‘flicker task’’), observers often require many cycles, or repetitions, to detect the change (Rensink et al., 1997). Without the blank screen, changes are noticed readily because the change produces a localizable tran-

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sient signal that draws attention and enables detection (Posner, 1980; Rensink et al., 1997).

Recently, a number of experiments have explored the role of attention in change detection performance. In the flicker task, changes to objects of central interest in a scene are detected more rapidly than changes to objects of marginal interest (Rensink et al., 1997). This finding is consistent with a model in which observers search serially through the changing scene, focusing on salient objects first (Rensink, 2000a). In fact, change detection performance is analogous to serial visual search performance (Rensink, 2000c). Observers often report effortfully searching through the display to find the change—they attend to one or two objects, encode them as fully as possible, and then check for changes after the disruption. As is true for visual search performance, when the target is embedded in a complex display, the average time to find a change increases linearly as the number of distractors increases (Rensink, 2000c). If changes can only be detected with focused attention, the more items there are, the more time it will take, on average, for attention to focus on the change location. Superior detection of changes to objects of central interest implies that those objects received either more or earlier attentional focus. Note that this finding says nothing about whether or not salient *changes* are more likely to be detected. Rather, it shows that salient *features* within a scene are more likely to be attended, and that if a change occurs to these features, detection is more likely.

Recently, another study demonstrated more directly that changes to attended objects are detected more readily (Scholl, 2000). Observers performed a flicker task with arrays of simple shapes. On each trial one object had a salient feature (either a unique colour or a late onset), but that feature was irrelevant to the change detection task; the distinctiveness was not predictive of the change location and observers were aware of this. In some models of attentional capture, abrupt onsets (Yantis, 1993; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984) and colour singletons (Theeuwes, 1992, 1994) are thought to exogenously draw attention. Thus changes to these distinctive objects should have been detected more readily than changes to other objects in the array, even though the distinctive feature was irrelevant to the change detection task. Consistent with this prediction, when the changing item happened to also be a colour singleton or a late onset item, it was found significantly faster than when it was a non-distinctive item (Scholl, 2000).

Taken together, these findings suggest that salience within a display can draw attention, and that once an object is attended, changes to that object will be detected more readily. According to several prominent models of visual search performance, preattentive mechanisms play a central role in guiding attention to the target feature by identifying particularly salient regions of the image as potential targets. Presumably, these preattentive mechanisms rely on bottom-up segmentation of the scene into salient regions (Wolfe & Bennett, 1997), perhaps constrained by the observer's attentional set to focus on particular feature dimensions (Folk, Remington, & Johnston, 1992). Attentional shifts may rely on such ‘‘saliency maps’’ in which target regions are defined by distinctiveness relative to other regions (Koch & Ullman, 1985). Essentially, preattentive mechanisms determine potential search targets based on within-scene salience and intentional, effortful processes lead to eventual awareness of the target.

Similar mechanisms may contribute to change detection performance. For most saliency map models, intensity, orientation, and colour are properties that define salient regions. Yet, in change detection, the critical region is defined temporally, by the difference between images—the relative salience within each image is not necessarily associated with the change magnitude. Can change signals also draw attention? If so, then models of salience-based attention shifts could incorporate ‘‘second-order’’ salience, in which static salience maps are compared over time, to account for successful change detection.

For preattentive mechanisms to guide attention to a change, the change must be registered by the visual system before it is consciously detected. Several recent studies provide evidence for implicit detection of change in the absence of evidence for explicit detection. For example, observers in one study reported no awareness of a change, yet they were able to guess its location above chance in a forced-choice decision task (Fernandez-Duque & Thornton, 2000). Other recent studies provide converging evidence that changes can implicitly affect behaviour in the absence of awareness. For example, when observers reported not seeing a change, their response times belied an implicit representation (Williams & Simons, 2000). Responses to missed changes were often slower than responses when there actually was no change in the display. That is, despite reporting no awareness, the observers’ response latencies appear to reveal some level of detection.

In a more direct measure of the effects of implicit detection on behaviour, eye movements were monitored while observers performed a block copying task (Ballard, Hayhoe, & Pelz, 1995; Hayhoe, Bensinger, & Ballard, 1998). On each trial, observers attempted to re-create a model pattern of blocks by moving blocks from a resource area to a work area, often making multiple eye movements in the process. For example, observers initially fixate the model, then fixate the resource area, and then re-fixate the model before saccading to the work area. If the colour of a block was changed during the re-fixation of the model area, observers often failed to detect the change. However, the change still influenced behavior (Hayhoe, 2000; Hayhoe et al., 1998): Observers showed longer fixation durations for changed objects in the re-fixated model than on unchanged objects even when they did not notice the change. Similarly, when observers miss a change in a task with changing scenes (Hollingworth, Williams, & Henderson, 2001b), and subsequently re-fixated the change location, they tend to look longer than if there were no change. Also, when observers view change and no-change trials, there is some evidence to suggest that they are relatively quicker to fixate the target location when a change is present (Hollingworth, Schrock, & Henderson, 2001a).

Together, these findings suggest that the visual system registers changes before observers can report them. However, these implicit mechanisms might or might not contribute to explicit change detection. In all of these cases, implicit measures were more sensitive than explicit measures, but none tested whether implicit detection necessarily preceded explicit detection—the studies simply compared trials with detection to trials without detection. One recent finding does imply that some form of detection precedes explicit detection (Rensink, 1998, 2000b). On each trial of a flicker task, observers first reported when they were *aware* of the change and then reported when they *visually experienced* the change. Awareness was defined as a sense or feeling of the change. Approximately 30% of the observers reported ''sensing'' the change before ''seeing'' it (Rensink, 1998, 2000b). This sensing response (named ''mindsight'') may correspond to implicit detection of the change prior to explicit awareness. Alternatively, mindsight may not imply implicit registration, but rather some level of explicit awareness that a change has been detected.

If implicit change detection and phenomena like mindsight precede explicit detection, they could, in principle, contribute to the eventual explicit detection of change. Alternatively, they could simply be an epiphenomenal byproduct of perception that either occurs simultaneously with explicit detection or does not contribute to awareness. Are these implicit effects in any way related to the conscious detection of a change? Do they guide attention to the change location, thereby facilitating conscious detection?

To date, only one finding suggests that changes can implicitly guide attention (Smilek, Eastwood, & Merikle, 2000). In a flicker task with simple arrays of letters, search slopes were shallower for larger changes; increases in the number of distractor items in the displays had less of an effect for the relatively bigger changes. These findings were taken to imply that changes implicitly attract attention, and that larger changes draw attention more forcefully. If this interpretation is correct, then at least for simple arrays, implicit detection does facilitate conscious detection. However, there exists a plausible alternative interpretation of this finding that does not require implicit detection. Given that larger changes are more readily detected than smaller changes, even when the changed item is within focused attention (Williams & Simons, 2000), smaller changes are more likely to be missed. If a change is missed, the observer will have to return to that item later to detect the change. With more items in the display, it will take longer, on average, for the changed item to be re-attended. Consequently, observers will show shallower search slopes when searching for larger changes because they will have to attend to or search through the same set of items fewer times on average. By this interpretation, the change need not implicitly draw attention in order to produce differences in search slopes (see footnote 1 for a more detailed illustration of this point).

Preattentive mechanisms might lead an observer to shift attention from one salient feature to the next within an image (hence centre of interest effects in change detection), but shifting attention to the change itself requires the detection of a difference between images. Can preattentive mechanisms help to guide attention to the change location in the same way they help guide attention to a salient feature in a static search task or to central objects within a scene? Although many studies have explored the role of attention in change detection, few, if any, have addressed the way in which changes are eventually detected.

One shortcoming of most change detection tasks is that the dependent measures used do not assess the mechanisms *leading* to change detection. Most tasks require a single response—either observers are asked to report if they detected a change or they are asked to view a display continuously until they eventually find the change. Thus, the only behavioural measures available to assess whether or not observers have detected a change are those that follow successful detection or that happen after the change is already completed. Such approaches are ill-suited to determine whether or not preattentive mechanisms guide eventual change detection.

[1] Differences in change detectability under conditions of focused attention can produce search slope differences when searching for a change. Search slope can be defined in terms of the number of cycles (i.e., repetitions of a change) needed to detect a change as a function of the probability (P) that a change will be detected on a given cycle when attention is focused on that item. Assuming a serial, self-terminating search, the number of cycles (C) needed to detect a change is:

$$C = (N+1)/2P \quad (1)$$

Here, N is the number of items in the display. P varies with the magnitude of the change size because larger changes are more likely than smaller changes to be detected with focused attention (Williams & Simons, 2000). By determining C for two different values of N, we can calculate the search slope as:

$$(C_i - C_j)/(N_i - N_j) \quad (2)$$

Note that this computation has no contribution from *implicit* accumulation of information across cycles. Yet, it can account for shallower search slopes for larger changes. As an example, compare two different values of P (.7 and .5) corresponding to a large and a small change, respectively. To determine the search slopes, we will use two different set sizes (5 items and 10 items). For the 5 item display with the large change, $C_5 = (5+1)/(2*.7) = 4.286$ cycles. For the 10-item display with the large change, $C_{10} = (10+1)/(2*.7) = 7.857$ cycles. Thus, the search slope for the large change is $(C_{10} - C_5)/(10 - 5) = (7.857 - 4.286)/5 = 0.714$ cycles/item. Similarly for the small change, $C_5 = (5+1)/(2*.5) = 6$ cycles and $C_{10} = (10+1)/(2*.5) = 11$ cycles, so the slope for the small change is $(C_{10} - C_5)/(10-5) = (11 - 6)/5 = 1$ cycles/item. Thus, the fact that larger changes are easier to detect with focused attention leads to a shallower search slope for larger changes than for smaller changes even without any contribution from implicit accumulation across cycles. The same principle holds for memory-less search (Horowitz & Wolfe, 1998), for which C = N/P. (For a more thorough evaluation of this issue, see Mitroff & Simons, 2000).

Modified behavioural measures may well help define the role of implicit detection in guiding attention to the change location and thereby producing awareness of the change. The current experiments test three explanations for successful change detection by assessing whether or not implicit detection guides localization. The first two models assume a functional role for implicit detection whereas the third views implicit detection as unnecessary for explicit detection. According to the ''homing'' model, the change signal acts as a beacon and attention is gradually drawn to it. As the focus of attention approaches the change, the perceived signal strength of the change increases, drawing attention even closer to the change location. Thus, as observers search for the change, shifting attention around the scene, the focus of their attention should progressively be drawn to the change location. This homing mechanism occurs implicitly. This model underlies some existing claims of implicit change localization (Smilek et al., 2000).

According to the ''temporal integration'' model, detection involves a process of implicit integration over time, with eventual explicit detection occurring when the accumulating change signal surpasses a threshold. Before the signal exceeds the threshold for awareness, it might exceed a lower threshold for implicit detection. If so, implicit change localization could precede explicit detection, but attention would not be drawn to the change location unless this lower, implicit threshold were surpassed. That is, the change signal gradually increases in strength over time, but has no effect on behavior until it surpasses a threshold.

According to the ''focused attention'' model, changes are not localized until they are explicitly detected—implicit change detection plays no role in localization. If implicit change detection does not guide attention to the change location, then explicit detection may occur by happenstance. Attention is guided from one salient region of a scene to the next, based on the same mechanisms driving search through static displays, and eventually observers happen to attend to the changing region. Once they do, they will most likely detect the change.

To explore whether or not attention arrives at the change location because it was drawn there by the change, this paper presents four experiments which employ variations of the flicker task. The first considers the influence of the amount of exposure to the change on localization accuracy, both with and without explicit detection. The second and third experiments explore change localization after each discrete exposure to the change, thereby providing a measure of the improvement in localization prior to explicit awareness. In Experiment 2, each trial ends when observers report seeing the change. In Experiment 3, each trial ends when observers correctly localize the change. This experiment allows a comparison of performance on trials in which the change is located with and without explicit awareness, thereby allowing an examination of the role of implicit and explicit processes in change detection. Finally, Experiment 4 compares localization performance for trials with and without changes and provides a measure of chance performance. This measure allows for an assessment of whether or not localization responses in the absence of awareness of the change are more accurate or faster than would be expected by chance.

EXPERIMENT 1

In a traditional flicker task (Rensink et al., 1997), observers view a continuously alternating original and modified image, separated by a blank screen. The total number of alternations, or cycles, of the original and the modified image is unlimited, and observers eventually do detect the change. Given that observers make only a single response after they explicitly detect the change, the task does not allow an assessment of change localization prior to detection. In Experiment 1, observers viewed a varying, but limited, number of cycles and then were asked to indicate the location of the change even if no explicit detection had occurred. If preattentive mechanisms guide attention to the change, additional exposure should improve localization, even when observers do not explicitly detect the change. In contrast, if the change does not implicitly draw attention, more exposure to the change should not improve localization prior to explicit detection.

Method

Participants. Nineteen undergraduate students were paid $7 for a single 45–60 minute testing session.

Apparatus. Images were presented using a PowerCenterPro180 Macintosh clone with a 17-inch monitor (set to 1024× 768 resolution with a refresh rate of 75 Hz). Observers were seated in front of the monitor without head restraint. Displays were presented and responses were recorded using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993).

Stimuli. The stimuli consisted of a set of 64 digitized photographs (each 19.05 × 12.70 cm) of natural scenes. From an approximate viewing distance of 50 cm, images subtended a visual angle of 20.86° horizontal by 14.25° vertical. However, the visual angle likely varied across observers given that head position was not fixed. A 3 mm wide black frame surrounded all of the images.

Changes were created by using Adobe Photoshop to either delete one item or region from the original image and replace it with the appropriate background in the scene or to insert a new item into the scene. Thus, each pair of images consisted of the original image and a modified version of that image in which a target object or region was added or deleted. Images were carefully constructed so that observers could not readily determine which image was the original (changes were internally consistent and no artefacts of the editing process were visible). Changed regions were relatively small, occupying an average of 3.35% (SD = 2.79%) of the total area of the image (changes ranged from 0.43% to 14.46% of the image). Images were divided into four equally sized imaginary quadrants, and across images, changes occurred equally often in each quadrant. (For more details of this image set, see Simons, Franconeri, & Reimer, 2000.)

Procedure. On each trial, a fixation point appeared against a gray background for 500 ms and then disappeared. After 250 ms, the first image of an image pair appeared and remained visible for 240 ms. A blank grey screen then replaced the image and remained visible for 100 ms. After this delay, the second image of the pair appeared for 240 ms, and then it too disappeared and was replaced by a blank grey screen for 100 ms. This sequence constitutes one complete cycle. On any given trial, the original and modified images were presented for one, two, four, or six cycles. When a trial included more than one cycle, the presentation was continuous such that each cycle immediately followed the preceding one, without the fixation point or the 250 ms initial blank.

On the final cycle of a trial, the second image of the image pair remained visible and was not replaced by a blank screen. Observers were required to use the mouse to click on the location of the change (i.e., the added object or the region where the object had been). If they did not detect the change, they were instructed to guess. (To ensure that observers made a new estimate of the change location for every trial, they were instructed to move the mouse cursor to the bottom of the screen prior to each trial.) After clicking on the change location, observers were prompted to indicate how certain they were of the change location. They responded whether they ''saw,'' ''felt'', or ''guessed'' the change location by pressing the ''s'', ''f'', or ''g'' key, respectively. ''Saw'' was defined as being certain of the change location. ''Guess'' was defined as being completely uncertain of the change location (the choice of a click location was arbitrary because the observer had no idea what had changed). If the observer had a sense or feeling about the change but could not localize it with certainty, the appropriate response was ''felt''. The purpose for including ''felt'' as an option was to eliminate any ambiguous responses in which observers might have some explicit awareness of the change location, but still not have complete awareness. By eliminating such ambiguous responses, we could be more certain that ''guess'' responses involved no explicit contamination. Consequently, any evidence for localization associated with ''guess'' responses must result from implicit detection. Essentially, the ''felt'' option was included to attempt to eliminate criterion issues that might contaminate implicit effects with explicit awareness of the change. Given that ''felt'' responses are inherently ambiguous, they are given somewhat less emphasis in the analyses later. However, a more detailed treatment is provided in Appendix B.

Before the test trials began, observers were given both written and oral instructions and were given the opportunity to ask questions. Once all questions were answered, observers viewed and received feedback on two practice trials that were constructed in the same way as the test images. They then viewed a total of 64 test trials, with 16 image pairs for each trial duration (one, two, four, or six cycles). The images assigned to each trial duration were counterbalanced across observers. Of the 16 trials with each duration, half involved an addition and half a deletion, with the specific images assigned to be an addition or deletion counterbalanced across observers. The order of presentation for the 64 trials was randomized for each observer.

The changing region was defined by the smallest rectangular region encompassing all of the changing pixels. Any click within this region was considered to be accurate. When a mouse click was not in the region defined by the rectangle, the localization error was defined as the Euclidean distance between the coordinates of the mouse click and the nearest point in the rectangular region.

Results

Change detection. As in previous studies, observers often missed changes despite their best efforts to locate them, even with repeated detection opportunities. On average, observers reported seeing only 40% (SD = 8.7%) of the changes (see Table 1). The proportion of trials for which observers responded ''saw'' increased substantially with the number of cycles, $F(3, 54) = 87.25$, $p < .001$. With one cycle, observers said that they saw the change only 12% of the time, whereas with six cycles, they reported ''seeing'' the change 61% of the time. Conversely, the proportion of trials in which observers reported ''guessing'' decreased with the number of cycles viewed (see Table 1).

TABLE 1
Change detection

Response	*1 cycle*	*2 cycles*	*4 cycles*	*6 cycles*	*Total across conditions*
Saw	12% (37/304)	30% (93/304)	55% (166/304)	61% (186/304)	39.6% (482/1216)
Guess	59% (180/304)	46% (139/304)	33% (101/304)	29% (88/304)	41.8% (508/1216)
Felt	29% (87/304)	24% (72/304)	12% (37/304)	10% (30/304)	18.6% (226/1216)

Change localization. Consistent with the explicit report data, observers correctly located the change on 44% of the trials (SD = 6.28%, with individual levels of accurate localization performance from 22% to 61% of the trials). When observers reported ''seeing'' the change, their mouse clicks generally were quite accurate (95% correct). However, the number of false alarms decreased substantially with additional exposure to the change (see Table 2). After only one cycle, although observers claimed to have seen changes, they clicked on the wrong location 30% of the time. In contrast, after four or six cycles, observers rarely made a false alarm. When reporting ''guessing'', they correctly localized the change on only 4% of trials.

Collapsed across the number of cycles and across all observers, the average localization response was 0.30 cm from the actual change location for ''saw'' responses and 6.36 cm for ''guess'' responses. (Localization measures are given in centimetres because head position was unrestricted and consequently, estimates of visual angle could vary somewhat across trials and observers.) Note that these error measures include all responses—even those in which the localization error was 0. Comparing across trial duration, the average error was unaffected for ''guess'', $F(3, 54) = 1.11$, $p = .352$, responses (see Figure 1). When reporting ''guess'', localization accuracy did not improve with additional exposure to the change. Although observers did notice more changes when given additional exposure, if they did not see the change, their localization accuracy did not improve.

''Felt'' responses. As previously noted, the reason for including the ''felt'' option was to eliminate those trials for which the relative contributions of implicit and explicit detection were unclear. The absolute number of ''felt'' responses in all conditions (one, two, four, or six cycles) was relatively small and, averaged across all conditions, a ''felt'' response was made on only 18.6%

TABLE 2
Localization accuracy

Response	*1 cycle*	*2 cycles*	*4 cycles*	*6 cycles*	*Total across conditions*
Saw	70% (26/37)	89% (83/93)	99% (164/166)	100% (186/186)	95% (459/482)
Guess	7% (13/180)	4% (5/139)	2% (2/101)	2% (2/88)	4% (22/508)
Felt	24% (21/87)	26% (19/72)	22% (8/37)	10% (3/30)	23% (51/226)
All responses	20%	35%	57%	63%	44%

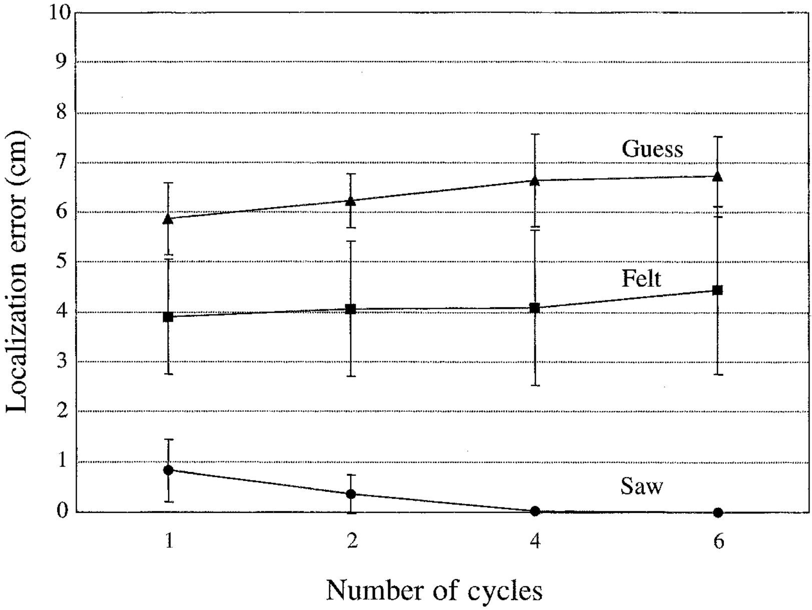

Figure 1. Mean localization errors (in cm) for ''saw'', ''felt'', and ''guess'' responses across number of cycles viewed (Experiment 1). Error bars represent a 95% confidence interval around the means.

of the trials. A more thorough treatment of the ''felt'' responses is available in Appendix B.

Discussion

Given evidence for implicit detection in the absence of explicit detection (Fernandez-Duque & Thornton, 2000), one might expect that implicit detection could lead to change localization prior to conscious experience of change. If so, then additional exposure to a changing scene should result in more accurate localization prior to conscious detection. However, localization accuracy of ''guess'' responses did not improve with additional exposure to the change (i.e., ''guesses'' after six cycles are no more accurate than ''guesses'' after one cycle), suggesting that implicit processes are not gradually guiding attention to the change location.

Although this finding provides preliminary evidence against implicit guidance of attention to the change location, this variant of the flicker paradigm may not provide an optimal test. On ''guess'' trials observers never saw the change. That is, their ''guess'' response did not precede the eventual explicit detection of change. Similarly, when observers ''saw'' the change, we had no measure of whether or not prior implicit detection led to conscious detection. Consequently, it is not possible to determine if localization improved *prior to* detection. For example, if observers reported ''seeing'' a change after the sixth cycle, it is possible that they implicitly detected the change after two or three cycles and that their localization would have shown improvement prior to their correct localization. Yet, like traditional flicker tasks, our modified task allowed only a single response at the end of the trial. In Experiments 2 and 3, the flicker task was further modified to allow an assessment of change localization leading up to the eventual conscious detection of a change.

EXPERIMENT 2a

Experiment 2 explores whether or not change localization improves prior to explicit detection when the change ultimately *is* detected. In Experiment 1, observers made a single localization response and confidence rating after viewing a fixed number of cycles. In Experiment 2, observers responded after each cycle viewed; first they clicked the mouse to indicate the location of the change and then they reported their confidence level (saw, felt, or guessed). This procedure allows an assessment of localization accuracy prior to explicit detection.

If implicit processes gradually guide attention to the change location, then localization accuracy should improve with successive ''guess'' responses. Alternatively, if implicit processes integrate change information until a threshold is surpassed, then only the ''guesses'' right before the change is explicitly detected should show some sign of localization improvement. As the change information accumulates below the threshold, localization accuracy should be unaffected, yet once the threshold is reached, attention will be guided to the change and localization accuracy will improve. Finally, if implicit processes are not involved in change localization, then accuracy should not improve prior to conscious detection—all ''guess'' responses should be equally inaccurate, regardless of the number of cycles viewed.

Methods

Participants. Nineteen undergraduate students were either paid $7 or received course credit for a single 45–60 minute testing session.

Apparatus and stimuli. Images were presented using a Macintosh iMac Computer with a 15-inch monitor (set to 1024× 768 resolution with a refresh rate of 75 Hz). Otherwise, the images and changes were identical to those of Experiment 1.

Procedure. Except as noted, the procedure was identical to that of Experiment 1. Each of the 64 trials proceeded as follows: (1) A message instructed the observer to move the cursor to the bottom of the screen and to press a key to begin; (2) A fixation point appeared for 500 ms followed by a blank grey screen for 250 ms; (3) The first image appeared for 350 ms, followed by a blank grey interval for 200 ms and then by the second image for 350 ms; (4) When the second image disappeared, an image-less 3 mm wide black frame remained against the uniform grey background. The frame exactly outlined the location previously occupied by the images; 5) Observers used the cursor to click on the location of the change within the frame. Since the image was no longer available, observers were instructed to click as close as possible to the actual change location; (6) Once the observers made a mouse click, they indicated their certainty with a keypress (saw, felt, or guess).

If the observers did not give a confidence rating of ''saw'', they repeated steps 1–6. The cycles continued in this fashion until either the observer responded ''saw'' or until 15 cycles had been viewed. If the change was not seen by the 15th cycle, observers were informed that a new trial was beginning. Given this procedure, for each of the 64 trials there were 1 to 15 possible localization responses and corresponding certainty judgements. Before these test trials, observers were given both written and oral instructions, and viewed two practice trials. Feedback was given on the practice trials but not on the test trials.

Results

As in Experiment 1, observers showed change blindness; on average, observers required 4.49 cycles (SD = 0.54) to notice the changes. Most changes ($M = 91\%$, SD = 3.45%) were detected within the 15 cycle limit, with individual detection rates ranging from 83% to 100%. Only those trials in which the change was detected are included in the following analyses.

Given that cycles repeated until observers reported ''seeing'' a change, this methodology allows an assessment of how likely observers were to localize the change on ''guesses'' that precede explicit detection. On 16.3% of trials, observers made at least one accurate ''guess''—they reported ''guessing'' but accurately clicked on the change location. Of these accurate ''guess'' responses, the majority (71%) were the final ''guess'' on the trial and preceded either a ''felt'' response (23% of the time) or a ''saw'' response (77% of the time). Although a number of trials had accurate ''guess'' responses, consistent with Experiment 1, only 5% of all ''guess'' responses corresponded to an accurate change localization. Change localization errors were calculated as described in Experiment 1. Across observers, the average localization response for all ''saw'' responses was 0.517 cm from the change and for ''guess'' responses it was 6.13 cm from the change. These measures include all localization responses in which the change was ultimately detected and thus include those responses where the error was 0. In general, observers were accurate when they reported ''seeing'' the change. On 88% of trials, when observers made a ''saw'' response they showed no localization error. The relatively higher false alarm rate in this experiment relative to that of Experiment 1 can most likely be attributed to the fact that, in this experiment, the image was no longer visible during the mouse click response.

The primary purpose of this experiment was to determine if change localization improves for consecutive ''guess'' responses prior to the eventual explicit detection of change. For each trial, the localization error was calculated for each ''guess'' response. On average, observers made 2.48 ''guess'' responses per trial prior to ''seeing'' the change. (This ratio includes trials on which there were no ''guesses''. When looking at only those trials with at least one ''guess'', observers made an average of 3.58 ''guesses'' per trial.) Given that the change could potentially be detected on any of the 15 cycles within a given trial, the ''guesses'' were organized in relation to the eventual detection of the change. That is, they were organized from the first ''guess'' to the last ''guess'' for that trial. If the last ''guess'' is ''n'', then the second-to-last ''guess'' is ''n–1'', the third-to-last is ''n–2'', and so on. All ''n–1'' errors were combined across trials and observers to return an average error for ''guess n–1''. This aggregation was done separately for all ''guess'' categories (n, n–1, n–2, etc.) and the results are depicted in Figure 2. In general, the accuracy of change localization did not improve across consecutive ''guesses'', except for the final ''guess'' response. The overall error, averaging across the mean errors in each ''guess'' category (but excluding the final ''guess'' category before detection), was 6.61 cm (mean SD = 3.88). The final ''guess'' category had a mean error of 3.96 cm (SD = 3.67). These results suggest observers' change localization is no more accurate for successive guesses until they make their final ''guess'', which typically (on 60% of trials with ''guesses'') occurred one cycle before a ''saw'' response.

The same pattern of no localization improvement prior to the final ''guess'' holds true for individual observers as well as for the averaged group data. For each trial, for each observer, the mean deviation between successive ''guess'' responses was calculated. That is, a ''guess'' response was subtracted from the prior ''guess'' response resulting in a deviation value. If this deviation was positive, it signified improvement in localization from one guess to the next. If, across a sequence of ''guesses'', localization performance improved, then the average of these deviations across all ''guesses'' on that trial should be positive. If an observer typically showed improvement across successive ''guesses'', then they should have more trials with a positive mean deviation than with a negative mean deviation. On the other hand, if an observer did not show improved localization across successive ''guesses'', then their mean deviation should be near 0, and they should have approximately the same number of positive and negative deviation trials. Across all observers the average difference between positive and negative trials was 13.16 (SD = 7.46), signifying that, on average, observers had more trials with improvement than without improvement. However, as with the across-observer data, when the final ''guess'' value was

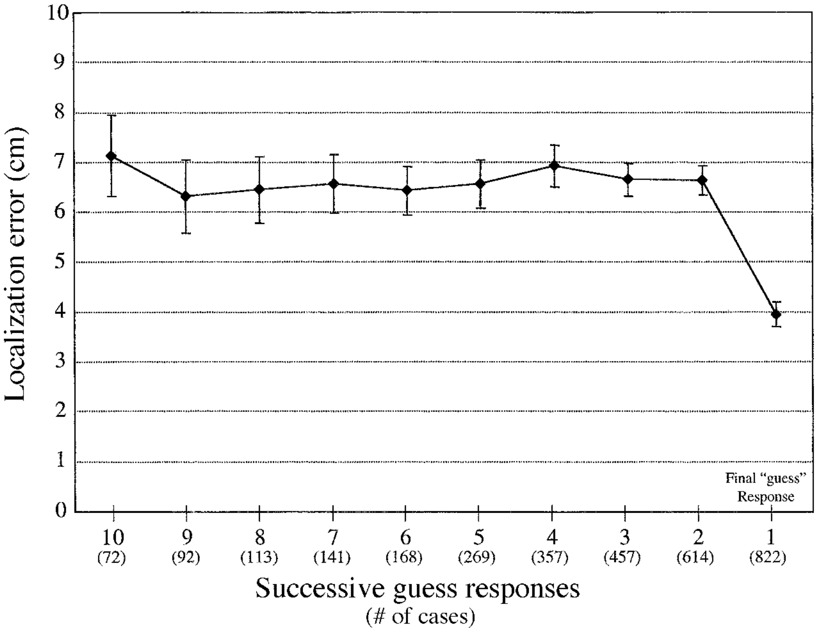

Figure 2. Mean localization error (in cm) for successive ''guess'' responses along with the corresponding number of cases combined across all observers (Experiment 2a). Error bars signify a 95% confidence interval around the means. ''Guess'' responses are ordered from first to last with 1 being the last ''guess''. The mean localization errors for ''guess'' responses 15–11 were not included due to the limited number of cases.

excluded from this analysis, there was no difference in the number of trials with and without improvement (average difference value = – 0.58, SD = 4.25). In other words, observers showed no localization improvement within trials until the final ''guess'' response.

'' Felt'' responses. The ''felt'' option was included to eliminate those trials that potentially were contaminated by incomplete explicit detection. However, observers might have used the ''felt'' option even when they had seen the change, but simply were not confident enough to say so. That is, they may have used the ''felt'' response to double check or verify their explicit detection. Given that a ''saw'' response would end the trial, observers might have been somewhat hesitant to respond ''saw'' without first verifying the change. To do so, they would need to use some other response. Given that guesses were defined to be entirely without awareness of the change, they would probably default to ''felt'' under those circumstances. Consistent with this interpretation, 50% of the final ''felt'' responses showed no localization error, suggesting that they were used to verify explicit detection

Observers might also have periodically used the ‘‘felt’’ option as a result of task demands. Perhaps after responding ‘‘guess’’ multiple times, observers would be inclined to respond ‘‘felt’’, even in the absence of a subjective shift in their detection of the change. If this explanation were correct, observers should be more likely to respond ‘‘felt’’ as the number of consecutive ‘‘guess’’ responses increased. However, the probability of a ‘‘felt’’ response was unrelated to the number of ‘‘guesses’’ on that trial.

‘‘Saw’’ responses. The number of ‘‘saw’’ responses may offer an additional measure of whether or not localization improves with additional exposure to the change. If attention is being drawn to the change location, then observers should be more likely to see the change with additional exposure. Likewise, if attention is not being implicitly drawn to the change, the number of ‘‘saw’’ responses should not increase with more exposure to the change. We calculated the mean proportion of ‘‘saw’’ responses for each number of cycles viewed (1–15). The proportion of ‘‘saw’’ responses was negatively correlated with the number of cycles seen ($r = -.726$), showing that as observers viewed more cycles, they became *less* likely to see the change. Effectively, the longer subjects viewed a change without finding it, the less likely they were to find it. This finding again suggests that attention was not implicitly guided to the change location.

Discussion

As in Experiment 1, change localization did not improve with more exposure, provided that observers reported being unaware of the change. Average localization error was effectively constant across all ‘‘guesses’’ prior to the final one. The findings of the current experiment reduce the plausibility of the ‘‘homing’’ model of attentional guidance because localization does not appear to gradually improve with additional exposure.[2] Note that just prior to explicit detection, change localization does improve for ‘‘guess’’ responses. However, this

[2]It is possible that the discrete presentation of each cycle in this experiment might somehow mask the existence of an implicit change signal that would otherwise draw attention. That is, the temporal gap or the required response between successive presentations of the cycles might eliminate any accumulation that otherwise would draw attention. We do not feel that this concern, although valid, can explain the lack of an implicit effect in our experiments. In other recent work with simpler displays, we have found comparable patterns of results both with and without a delay between cycles (Mitroff & Simons, 2000). Furthermore, the results of Experiment 1 are consistent in suggesting no implicit localization, and in that experiment, there were no delays between cycles. In theory, an experiment could demonstrate the soundness of our dependent measures by revealing the existence of accumulation for some stimuli but not others even in the presence of a gap between displays. However, in practice, such an experiment might be impossible. To demonstrate the existence of accumulation, an experiment would need to use stimuli that would not be detected immediately on the first cycle but that would still provide enough of a signal to accumulate over time. Given that we argue against the existence of implicit accumulation, our hypothesis is that such stimuli do not exist.

improvement is not gradual. The evidence from Experiment 2a is consistent with both the ‘‘temporal integration’’ model and the ‘‘focused attention’’ model—detection could result from surpassing an implicit threshold or from arbitrary guessing near the change location in the absence of implicit guidance of attention.

Although the results of Experiment 2a are consistent with both the temporal integration model and the focused attention model, we find the focused attention account more parsimonious. According to this model, as observers search for the change, they rule out possible changes on each cycle. After ruling out an attended location, they will likely guess that the change had occurred elsewhere in the image (because they assume it had not occurred where they had attended). They will then click a different location in the image, and on the subsequent cycle, they will likely attend to that guessed location. Consequently, if attention on cycle ‘‘n+1’’ is focused on the location of the ‘‘guess’’ response on cycle ‘‘n’’, and the ‘‘guess’’ was accurate, observers would likely explicitly detect the change on cycle ‘‘n’’. Consistent with this interpretation, observers responded ‘‘saw’’ 60% of the time on the cycle following their final ‘‘guess’’ (77% of the time when the final ‘‘guess’’ was accurate). Experiment 3 provides additional support for this explanation for the improvement in localization for the final ‘‘guess’’ response.

One concern about Experiment 2a (and Experiment 1) is that observers may have misused the confidence criteria. If the observer wanted to see the change one more time, or to ‘‘double check’’, they could not use the ‘‘saw’’ response because ‘‘saw’’ responses ended the trial. To see the display again, observers had to respond either ‘‘guess’’ or ‘‘felt’’. As discussed earlier, observers may have used the ‘‘felt’’ responses to allow themselves another trial to verify that they actually had seen the change. The same may be true for the final ‘‘guess’’ responses. To eliminate the possibility that the improvement in final responses resulted from trials in which confidence ratings were used to verify the change, Experiment 2b replicated Experiment 2a but allowed observers to report whether they ‘‘saw’’, ‘‘*verified*’’, ‘‘felt’’, or ‘‘guessed’’ the change location.

EXPERIMENT 2b

If the drop in localization error for the final ‘‘guess’’ response is due either to the surpassing of an implicit threshold via temporal integration or from observers happening to search near the change location, the same pattern of responses should be found as in Experiment 2a. However, if the final improvement instead results from misuse of the ‘‘felt’’ option, then the addition of a ‘‘verify’’ option should eliminate the improvement.

Methods

Participants. Twenty-one undergraduate students were paid $7 for a single 45–60 minute testing session. Data from one observer were not used because the observer did not complete all 64 trials.

Materials, apparatus, and procedure. The procedure was identical to that of Experiment 2a except observers were asked whether they ''[S]aw'', ''[V]erified'', ''[F]elt'', or ''[G]uessed'' the location of the change. ''Verified'' was defined as being in between ''saw'' and ''felt''. Observers were given the following written instructions: ''If you were just verifying or double checking the location, you should press V for Verified.'' All observers were orally instructed as well that the ''verify'' response was to be used when they were nearly certain about the change but wanted to ''just check one more time''.

Results

The results of Experiment 2b were consistent with those of Experiment 2a. On average, observers required 4.39 cycles (SD = 0.46) to notice changes, and most changes (M = 92%, SD = 2.33%) were detected within the 15 cycle limit, with individual detection rates ranging from 84% to 98%. As in Experiment 2a, trials for which the change was not detected were eliminated from further analyses. On 17.2% of trials, observers made at least one accurate ''guess''. Of these accurate ''guess'' responses, nearly three-quarters (72%) were the final ''guess'' on the trial and preceded either a ''felt,'' ''verify'', or, more frequently, a ''saw'' response (followed by ''saw'' 70% of the time, by ''felt'' 14%, and by ''verify'' 16%). In line with the two previous experiments, across all ''guesses'', only 5% were accurate.

The average localization error across all observers for ''saw'' responses was 0.005 cm and for ''guess'' responses was 6.21 cm. As in Experiments 1 and 2a, observers were accurate when they reported ''seeing'' the change, showing no localization error for 95% of their ''saw'' responses. Observers were 87% accurate for ''verify'' responses. In Experiment 2a, without the ''verify'' option, observers were slightly less accurate for ''saw'' responses (88%). It appears that observers used the ''verify'' option as expected: Waiting to respond ''saw'' until they were more confident. The primary purpose of this experiment was to determine if the addition of a ''verify'' option would eliminate the improvement in localization for the final ''guess'' response. As in Experiment 2a, successive ''guess'' responses were ordered by proximity to the last ''guess'' response ''n'' such that n–1 is the second to last ''guess'', n–2 is the third-to-last ''guess'', etc. As in Experiment 2a, localization error was essentially constant until the final ''guess'' response (see Figure 3). Averaging across the mean localization error for all ''guess'' categories other than the final ''guess'' category before detection, the overall mean error was 6.57 cm (mean SD = 3.59). The final ''guess'' category before detection had a mean error of 3.64 cm (SD = 3.61). Likewise, the within-observer analysis also showed that the only improvement was for the last ''guess'' category. Similar to Experiment 2a, observers' average difference value (the number of trials showing improvement minus the number of trials where localization gets worse) is a positive value when all ''guess'' values are examined, 17.05 (SD = 9.03). Yet, when the final ''guesses'' are

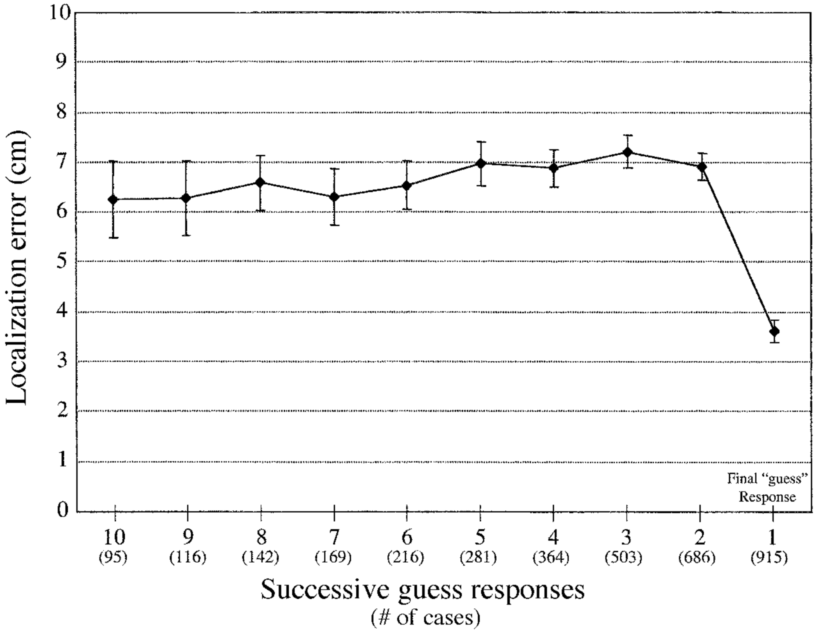

Figure 3. Mean localization error (in cm) for successive ''guess'' responses along with the corresponding number of cases combined across all observers (Experiment 2b). Error bars signify a 95% confidence interval around the means. ''Guess'' responses are ordered from first to last with 1 being the last ''guess''. The mean localization errors for ''guess'' responses 15–11 were not included due to the limited number of cases.

omitted, no improvement is found (mean difference = 0.15, SD = 5.40). Improvement only was found for the final ''guess'' category.

Interestingly, when given more options, observers were less likely to respond ''felt''. Although ''verify'' was used in only 5% of responses, its presence as an option reduced the number of ''felt'' responses from 20.2% in Experiment 2a to 12.7% in Experiment 2b (''saw'' and ''guess'' response rates were relatively unchanged). In fact, only 144 trials out of the 1280 (11%) possible trials included more than 1 ''felt'' response compared to the 25% in Experiment 2a. As in Experiment 2a, with additional exposure to the change, observers were less likely to respond ''saw'' ($r = -.617$), further demonstrating that attention was not guided to the change location.

Discussion

Despite the addition of the ''verify'' condition, the results of Experiment 2b are consistent with those of Experiment 2a. Observers were equally inaccurate for all ''guesses'' prior to the final one, and they showed the same increase in localization accuracy for the final ''guess''. If the observers from Experiment 2a were misusing the ‘‘guess’’ or ‘‘felt’’ response to verify the change location, it did not affect the pattern of results. Experiment 3 considers whether the improvement on the final ‘‘guess’’ response results from implicit guidance of attention or from observers happening to ‘‘guess’’ near the change without an implicit influence.

EXPERIMENT 3

The paradigm used in Experiment 2 was modified in two ways for this experiment. First, although observers continued to make localization responses after each cycle, they reported their confidence level only once, at the end of the trial. Second, trials ended when observers clicked on the change location rather than when they reported ‘‘seeing’’ the change. Therefore, in this task an accurate ‘‘guess’’ could end the trial; some correct localizations correspond to changes that were ‘‘seen’’ and others to ‘‘guesses’’. By comparing these two sets of trials we can determine how the pattern of localization accuracy differed when the change is explicitly detected and when it is not. This approach addresses two concerns with the previous tasks. First, it eliminates the potential misuse of ‘‘guess’’ and ‘‘felt’’ responses for verification. Second, it allows a direct comparison of responses preceding explicit detection and those preceding a correctly ‘‘guessed’’ localization.

Regardless of whether the drop in error for the final ‘‘guess’’ responses results from implicit processes guiding attention or from arbitrary guesses near the change, the trials in which observers report ‘‘seeing’’ the change should show the same results as in Experiment 2—localization error should decrease on the cycle prior to conscious detection of the change. The predictions of these two models differ for the case in which a trial ends due to an accurate ‘‘guess’’. If implicit processes guide localization through a process of temporal integration, these trials should show improvement for the cycle prior to correct localization. Regardless of whether or not the observer reports explicit detection, implicit processes should work the same way. On the other hand, if the improvement for the final ‘‘guess’’ before detection found in Experiment 2 results from arbitrary guesses, then no decline in accuracy should be found for the cycle just before an accurate ‘‘guess’’.

Methods

Participants. Twenty undergraduate students were paid $7 for a single 45–60 minute testing session.

Materials and apparatus. The materials and apparatus were the same as in Experiments 2a and 2b except that the trials were presented using code written with Vision Shell C libraries (http://www.visionshell.com) rather than via PsyScope (Cohen et al., 1993).

Procedure. The only significant changes to the procedure from Experiment 2a are that the trial ends when the observer happens to click on the changed location (or after 15 cycles without a correct click), and the confidence judgement is made only at the end of the trial, after correct localization. After clicking on the correct change location, observers reported whether they ''[S]aw'', ''[F]elt'', or ''[G]uessed'' the change location on their final mouse click.

Results

As in Experiments 2a and 2b, observers required an average of 4.17 cycles (SD = 0.63) to notice changes, and most changes (*M* = 92%, SD = 2.90%) were detected within the 15 cycle limit, with individual detection rates ranging from 81% to 98%. Consistent with the previous experiments, any trials that did not end in correct localization were eliminated from further analysis. In this experiment, a trial ended (unexpectedly) if observers correctly guessed the location of the change. On average, 15.5% of trials ended with a correct ''guess'' response, 19.4% ended with a correct ''felt'' response, and 57.3% ended with a correct ''saw'' response. This rate of accurate ''guessing'' is comparable to the proportion of accurate final ''guesses'' in Experiments 2a (16.3%) and 2b (17.2%).

The primary question in this experiment is whether or not localization improves prior to both accurate ''guess'' responses and accurate ''saw'' responses. As for Experiment 2 localization errors for each mouse click were ordered by proximity to the final, accurate click. By definition, the last mouse click has an error of 0 since the trial ended when the change was correctly located. For the trials in which observers reported ''saw'', localization improved only on the final mouse click before a correct localization (see Figure 4). The last mouse click prior to the accurate localization had a mean error of 3.17 cm (SD = 2.92). On average, the other mouse clicks had a mean error of 7.07 cm (mean SD = 3.82).

An analysis of the localization errors prior to an accurate ''guess'' response showed *no* improvement (see Figure 5). The final mouse click before localization had an average error of 7.01 cm (SD = 3.96) and, on average, all the other mouse clicks had an average error of 6.84 cm (average SD = 3.81). When localization occurs without the observer becoming aware of the change, there is no improvement for the final response before the actual localization. This lack of improvement prior to accurate ''guesses'' suggests that the observers were neither systematically moving closer nor further from the change but by chance clicked directly on or near the change. The within-observer analysis shows the same pattern of results. Prior to a ''saw'' response, observers typically had more trials with improvement in localization than trials without improvement (mean difference = 13.35, SD = 4.26). However, when the final response before localization was removed, observers showed no improvement across successive

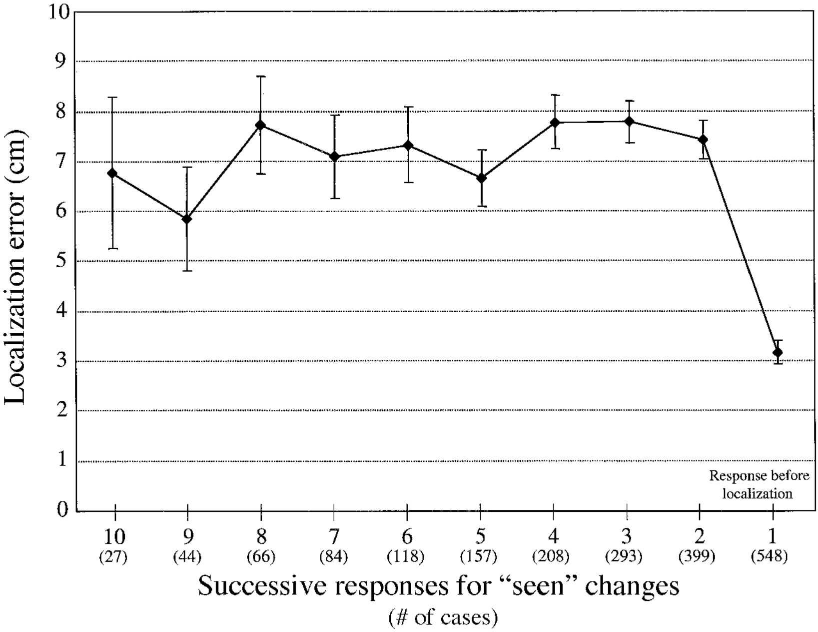

Figure 4. Mean localization error (in cm) of successive responses for which observers reported ''seeing'' the change and correctly located it along with the corresponding number of cases combined across all observers (Experiment 3). Error bars signify a 95% confidence interval around the means. Responses are ordered from first to last with 1 being the last. The mean localization errors for responses 15–11 were not included due to the limited number of cases.

responses (*M* = – 2.1, SD = 3.73). Prior to an accurate ''guess'' response, observers showed no improvement across successive ''guesses'' within a trial. On average, observers had no more trials with improvement than without (mean difference = – 3.4, SD = 2.71). Performance was comparable when considering all responses except the final response before localization (*M* = – 1.4, SD = 3.32). Thus, for the ''saw'' responses, observers improved, but only on the final response before localization. In contrast, for the ''guess'' responses, there was no improvement either with or without the final response before localization.

Discussion

As predicted, when observers reported ''seeing'' the change, the pattern of results replicated the findings from Experiment 2. No improvement in localization accuracy occurred until the final response before accurate localization. However, when the change was *not* explicitly detected, localization did not improve prior to the accurate ''guess'', suggesting that the observers were not implicitly guided to the change location.

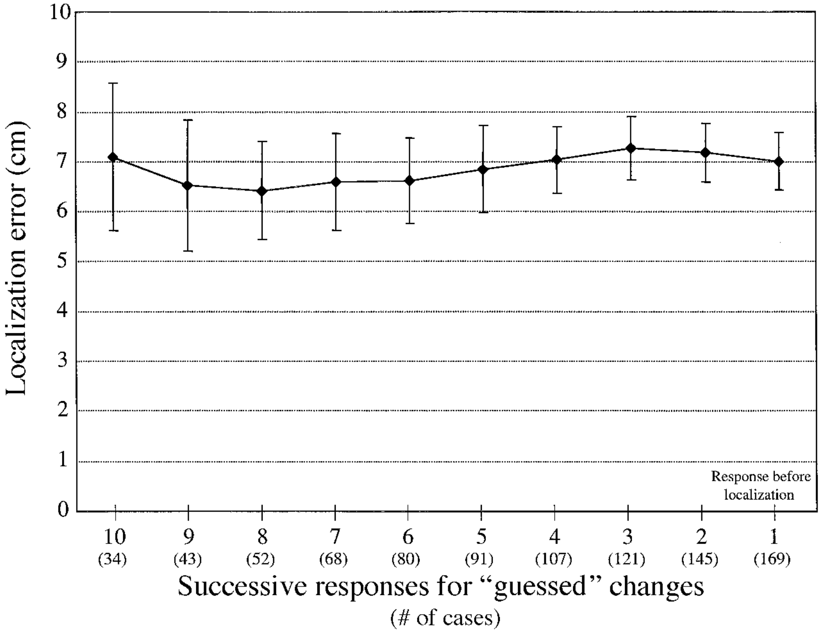

Figure 5. Mean localization error (in cm) of successive responses for which observers reported "guessing" and correctly located the change along with the corresponding number of cases combined across all observers (Experiment 3). Error bars signify a 95% confidence interval around the means. Responses are ordered from first to last with 1 being the last. The mean localization errors for responses 15–11 were not included due to the limited number of cases.

In this experiment, the only difference between responses on "saw" and "guess" trials is that one involves explicit detection and the other does not. Therefore, any difference between them is due to the role of explicit detection. Although trials with explicit change detection show localization improvement on the last cycle before detection, the trials without explicit detection show no improvement. For those trials without explicit detection, the only processes at work must be implicit and these implicit processes appear to have no role in localization. In conjunction with the results of Experiments 1 and 2, Experiment 3 further reduces the plausibility of the implicit temporal integration account. These experiments suggest that implicit detection does not gradually guide attention to the change nor does implicit detection accumulate with additional exposure.

EXPERIMENT 4

To further examine evidence for the "focused attention" model of detection, Experiment 4 adapted the paradigm used in Experiment 3 to address the primary theoretical question motivating Experiment 1. Experiment 1 varied the duration of the trials to see if guessing was better with more exposure to a change. In this experiment, we compare performance on those trials for which observers never detect the change to those in which there is no change present to determine whether or not the presence of a change improves localization. Experiment 3 showed that localization performance does not improve prior to a correctly guessed localization. Yet, performance overall might have been better than if no change had been present throughout the trial. That is, the change might not have implicitly *improved* localization over time, but it still might have *influenced* localization performance. If so, then performance when a change is present but undetected should be better than performance with no change present.

In this experiment, observers searched for a change on each trial, yet for one-quarter of the trials, no change occurred. As in Experiment 3, after each cycle, observers made a localization response. For the no-change trials, an ''accurate'' mouse click was on the item or location that would have ordinarily changed for that image.

Responses for no-change trials should show no localization improvement over time, and provide an estimate of chance localization for the image. By comparing performance on these trials with trials in which a change was present but never accurately located (missed-change trials), we can determine whether the presence of a change facilitates overall localization. Given that in both the no-change and missed-change trial, a change is never detected, any differences in localization must result from implicit detection of the presence of a change.

Methods

Participants. Eighteen paid observers participated in a single 45–60 minute testing session. Two observers' data were eliminated because they did not complete all 64 trials.

Materials and apparatus. The image set and apparatus were the same as in Experiment 3.

Procedure. A single modification was made to the procedure from Experiment 3. On one-quarter of the trials, there was no change: Rather than viewing an alternation of the original and changed image, they viewed an alternation of the original image with itself or the modified image with itself. Observers were told to look for a change and thus were expecting one on every trial, but were not told that one would occur on every trial. If they asked whether or not a change would occur on every trial, they were told to try to find a change on every trial. Each observer saw 16 no-change trials and 48 change trials, all randomly intermixed. The change trials had an equal number of additions and deletions. The images used for the no-change trials were varied across observers such that each image pair was seen as a no-change trial by four of the sixteen observers, with two of these observers viewing the original and two viewing the modified image. After the testing session, observers were informed of the no-change trials and questioned about any suspicions they had about the absence of changes.

Results

Similar to Experiments 2 and 3, observers required an average of 4.17 cycles (SD = 0.53) to notice the change, and the majority of changes (M = 90.5%, SD = 0.79%) were detected within the 15 cycle limit (individual detection rates ranged from 67% to 98%). On average, observers reported ''seeing'' 55.34% of the changes, ''feeling'' 19.01%, and ''guessing'' 16.15% (the remaining 9.5% of the trials did not end with an accurate localization); a level of performance comparable to that of Experiment 3. (For analysis of the consistency of change detection for particular images across all experiments, see Appendix A.)

Localization responses were ordered by proximity to the final, accurate mouse click. As for Experiment 3, when observers reported ''seeing'' the change, localization accuracy improved for the mouse click immediately before the correct localization (mean localization error = 3.66 cm, SD = 3.26) On average, the other mouse clicks had a mean error of 7.36 cm (mean SD = 4.04). For trials with accurate ''guesses,'' there was no improvement in localization prior to the final response. The last mouse click before an accurate ''guess'' had a mean error of 6.97 cm (SD = 3.56), and all other mouse clicks on average had a mean error of 7.26 cm (mean SD = 3.86). Thus, the results for the change trials in this experiment replicate those of Experiment 3. The within-observer analyses were also consistent with Experiment 3. For the ''saw'' trials, the only improvement came from the final response before localization; for all responses, observers typically had more trials with improvement than without (mean difference = 8.31, SD = 4.77) but when the final response before localization was omitted, this difference disappeared (M = 0.63, SD = 4.15). For the trials with an accurate ''guess'', with and without the final response before localization included, observers had no more trials showing improvement than trials showing no improvement (M = – 0.25, SD = 3.47; M = – 0.56, SD = 2.58, respectively).

Trials for which a change was present but undetected through 15 cycles (missed-change trials) comprised 9.5% of the change trials. Consistent with the findings for guesses in Experiment 1, there was no improvement in localization across the 15 cycles (see Figure 6). Mean localization error across all cycles was 6.98 cm (SD = 0.51). Further, the missed-change trials from Experiment 3 show the same lack of improvement. These trials account for 8% of the overall trials from Experiment 3 and had a mean localization error of 7.06 cm (SD = 0.44). When no change occurred, the trial always ended after 15 cycles. Localization accuracy was measured exactly as for the change trials, with the ''correct'' location being where the change would have been had the image changed.

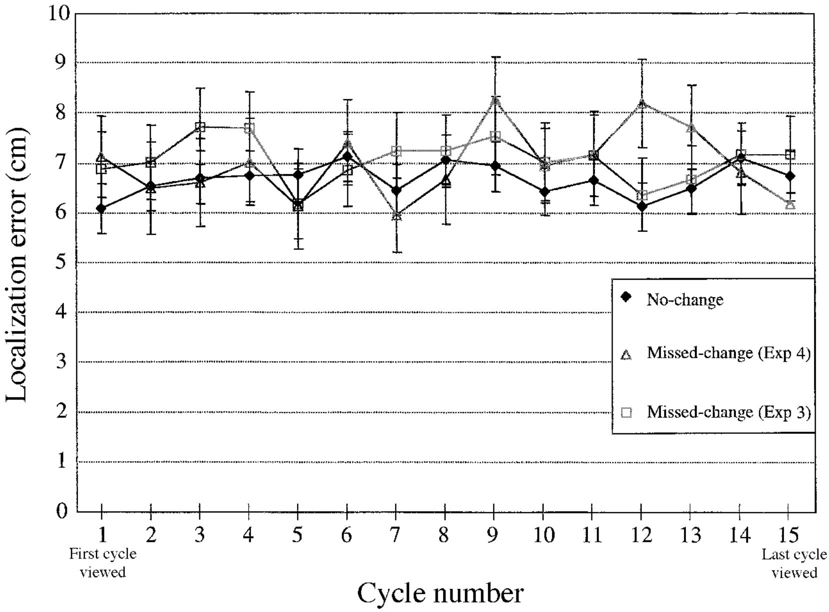

Figure 6. Mean localization error (in cm) across all cycles when a change was not present (Experiment 4) or when it was present, but not located (Experiments 3 and 4). Error bars represent a 95% confidence interval around each mean.

Across the 15 cycles, there was no improvement in localization accuracy (see Figure 6). From the first mouse click to the last, mean localization error averaged 6.66 cm (SD = 0.32).

As shown in Figure 6, localization performance was no better for trials with an undetected change than for trials with no change. For the no-change trials, observers periodically guessed a location that would have been part of the change if a change had been present. Interestingly, the proportion of such ''accurate'' guesses was nearly identical to the accurate guessing when changes were present. Across all mouse clicks on the no-change trials, 5% were on the location where the change would have occurred. In Experiment 2, when observers reported ''guessing'', they actually clicked on the change location 5% of the time. Thus, observers were no more likely to guess accurately when there was a change present than when there was no change at all. This finding suggests that such accurate guesses were not caused by implicit detection of the change. Consistent with this interpretation, the average number of cycles before an accurate guess was comparable for the no-change trials and the change trials. When observers accurately clicked the change location on the no-change trials, they did so after an average of 5.76 cycles. Averaging across all of the change trials in Experiments 3 and 4 for which observers reported ''guessing'', they clicked on the change location after an average of 5.59 cycles. Thus, the changes did not draw attention any faster than would be expected by chance.

When asked, the majority (68.75%) of observers reported no awareness of the presence of no-change trials. The remaining observers reported a suspicion of the no-change trials, but they tried to localize the changes on all trials. Note, of course, that change blindness itself might lead to the belief that some trials had no change (Levin, Momen, Drivdahl, & Simons, 2000).

Discussion

The observers in the current experiment performed comparably on the change trials to the observers of Experiments 2 and 3. Consistent with the earlier findings, the mere presence of the change did not influence overall localization accuracy. Furthermore, the findings on the no-change trials suggests that the level of localization accuracy for ''guesses'' in all of the experiments is consistent with chance. With and without a change present, observers ''guessed'' the location of the change 5% of the time and they did so, on average, after five and a half cycles. As long as observers did not explicitly detect the change, their localization performance was no better than chance.

GENERAL DISCUSSION

When actively searching for a change, implicit detection does not lead to improved localization of the change. In Experiment 1, ''guess'' responses were equally inaccurate, regardless of the number of times the change was repeated. That is, ''guesses'' made after six cycles were just as inaccurate as ''guesses'' made after just one cycle. In Experiment 2, localization of the change for consecutive ''guess'' responses showed no improvement except for the final ''guess''. Experiment 3 suggested that the improvement for the final localization probably results from observers happening to guess near the change location, which led to accurate detection on the subsequent cycle. Finally, localization for the no-change trials of Experiment 4 was comparable to that of the missed-change trials of Experiments 3 and 4. When the change was not explicitly detected nor accurately located, localization was as inaccurate as if there were no change present at all.

What role, then, does implicit detection play in the perception of change? When reporting no awareness of the change, observers still perform above 50% at selecting the changed item in a two-alternative forced-choice procedure (Fernandez-Duque & Thornton, 2000), their fixation performance changes (Hayhoe, 2000; Henderson & Hollingworth, 1999), and they sometimes respond more slowly (Williams & Simons, 2000). Much of visual processing occurs without awareness, and implicit change detection certainly could affect behaviour, but it does not appear to play a functional role in facilitating explicit change detection. Although our findings are not inconsistent with findings of implicit detection, they emphasize the need to explore further the mechanisms of implicit detection and to determine if implicit mechanisms play a functional role in visual processing. (See Mitroff & Simons (2000, 2001) for a critical examination of whether or not implicit change detection exists at all.)

Our findings suggest that prior to conscious detection, changes play no role in guiding localization performance. This finding seems difficult to reconcile with other claims for implicit mediation of localization (Smilek et al., 2000). The two sets of studies do vary in terms of the stimuli, paradigm, and dependent measures, so differences in the tasks may contribute to the different patterns of results. Yet, it is not clear why implicit mechanisms would improve localization for simple shapes in a search task and not for scenes in a flicker task. One possible alternative explanation for the earlier results might help to account for the discrepancy. Specifically, the difference in search slopes for different change magnitudes might result from greater discriminability of targets and distractors in focused attention, and not from implicit attraction to the change.

Given that we find no evidence for change localization prior to explicit awareness, how *are* changes eventually detected? Our data appear to eliminate the theory that search is guided by the salience of the change itself. If only one region of a scene is changing, then presumably it would be the most salient change signal in the display and would draw attention rapidly. Alternatively, if a preattentive ‘‘homing’’ mechanism guided attention gradually toward a change, we would expect improved localization with additional exposure to the change. However, neither of these results appear in any of our experiments.

One alternative explanation that is not absolutely eliminated by our experiments is that an implicit mechanism might temporally integrate a change signal across successive repetitions. After enough exposure, the change signal surpasses a threshold and is explicitly detected. This finding is consistent with the results of Experiment 2 in which performance only improves just prior to explicit detection. On the other hand, in Experiment 3, successful localization *without awareness* was not preceded by a sudden drop in accuracy. Yet, the strongest form of this argument is not disproved by the results of Experiment 3. The lack of improvement found for those trials in which the change was not explicitly detected may be due to the fact that the trial ended before explicit detection. The observer happened to click the change location before enough information was integrated, and the lack of improvement resulted from serendipitous guessing of the change location. This explanation is less parsimonious. Given that both patterns of results can be explained by arbitrary guessing of change locations (perhaps based on salience within an image rather than based on the salience of the change signal itself), why posit an additional mechanism that happened to have no effect in this experiment? Further, if temporal integration is in fact involved in ultimate detection of change, the findings of Experiment 4 suggest that, at least for some trials, it must be rather slow to develop. After 15 cycles with the change present (missed-change trials, Experiments 3 and 4), overall localization accuracy was no better than when no change was present (no-change trials, Experiment 4). The strength of the change signal either was too weak to be detectable or did not start accumulating before the end of the 15 cycles.

One final possibility is that the implicit detection mechanism does have access to the change location, but does not affect the accuracy of the localization response. That is, implicit detection might not play a role until the final attentional shift prior to explicit detection. This claim is consistent with the finding that observers perform somewhat above chance in localization of changes even if they did not explicitly detect the change (Fernandez-Duque & Thornton, 2000). However, it is difficult to see why localization performance would only improve on this final ''guess''. Although this alternative is not falsified by our results, it seems unlikely in light of the simpler explanation that observers ultimately locate the change through guessing based on image salience.

Multiple lines of research have recently begun to focus on implicit mechanisms. Many studies have found evidence for implicit processes, yet none has clearly shown that these processes actually lead to explicit detection. Since implicit processes are discussed in many models of attention and visual processing, it is important to know what purpose, if any, implicit representations serve. In the current set of experiments, we find that implicit processes are not involved in change localization prior to explicit detection. In addition to demonstrating the existence of implicit representations, future studies must take the further, important step of determining if and how these representations affect perception.

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APPENDIX A

Image analysis

The same 64 image pairs were used in all four experiments. Across all images for Experiments 2a, 2b, 3, and 4 (change trials only), the average number of cycles needed for detection was 4.31. The observers in Experiment 2a averaged 4.49 cycles and those in Experiment 2b, 3, and 4 averaged 4.39, 4.17, and 4.17 respectively. The average number of cycles required for each individual image in Experiments 2a, 2b, 3, and 4 ranged from 1.15 to 12.16 (observers in Experiment 1 were exposed to predetermined numbers of cycles for each trial).

The detection rates for the individual images were consistent across all four experiments (to standardize across experiments, we used the percentage of ''saw'' responses for each image, rather than number of cycles, for Experiment 1). Experiments 2a, 2b, 3, and 4 are positively intercorrelated and Experiment 1 is inversely correlated with the others (a high ''saw'' percentage is related to a low number of cycles needed for detection—see Table A1). Although the results of Experiment 4 were less strongly correlated with those of the other experiments, all of the correlations were reliable. (For more details about the specific changes and images, see Simons et al., 2000.)

TABLE A1

	Exp. 1	*Exp. 2a*	*Exp. 2b*	*Exp. 3*	*Exp. 4*
Exp. 1		– .789	– .800	– .739	– .580
Exp. 2a			.855	.794	.613
Exp. 2b				.690	.524
Exp. 3					.624
Exp. 4					

All values significant at the .01 level (2-tailed).

APPENDIX B

"Felt" responses

For those experiments in which participants only reported their certainty once (i.e., they made only one ''saw'', ''felt'', or ''guess'' response), that certainty response was ''felt'' on less than 20% of trials (18.6%, 19.4%, and 19% for Experiments 1, 3, and 4 respectively). For Experiments 1 and 2, accuracy when responding ''felt'' was intermediate to accuracy when responding ''guess'' and ''saw''. Similarly, the average localization error when responding ''felt'' was intermediate to the error when responding ''saw'' or ''guess'' (see Table A2).

In Experiment 1, when participants responded ''felt'', their localization error was unaffected by the amount of exposure to the change. That is, there were no differences in localization accuracy among the one, two, four, and six cycle trials, $F(3, 54) = .09$, $p = .963$. Thus, although participants were more accurate for felt responses than for guess responses overall, neither type of response showed an improvement with additional exposure. The absolute difference between ''felt'' and ''guess'' trials likely resulted from below-criterion explicit detection in the ''felt'' responses.

In Experiment 2, ''felt'' data were analysed by organizing responses relative to the final ''felt'' response (see text for similar analyses of ''guess'' trials). In general, observers rarely used the ''felt'' option multiple times during a trial. For example, of the 1216 possible trials in Experiment 2a, only 301 included more than 1 ''felt'' response, with an average of only 1.01 ''felt'' responses per trial (compared to an average of 2.48 ''guesses'' per trial). The frequency of using ''felt'' responses was diminished further in Experiment 2b with the addition of ''verify'' as an option (an average of only 0.60 ''felt'' responses per trial). With so few ''felt'' responses per trial, a thorough analysis of changes in localization accuracy across repeated responses is somewhat less informative. Despite these concerns, we considered improvement across the final four ''felt'' categories (n, n–1, n–2, and n–3) for Experiment 2a. Beyond these four categories, there were too few repeated ''felt'' responses for meaningful analysis. As for the ''guess'' responses, these four categories showed no localization improvement until the final ''felt'' response (mean localization error across categories n–1, n–2, and n–3 was 6.50 cm, mean SD = 3.9), whereas the mean localization error for the final ''felt'' response was 2.24 cm (SD = 3.75). As for the ''guess'' responses, this improvement on the final cycle likely resulted from detection after arbitrarily selecting a region near the change (see discussion in text). Unfortunately, given the paucity of ''felt'' responses in Experiment 2b, only the final ''felt'' response category and the n–1 category had more than 50 responses. Consequently, no analysis of localization improvement over repeated responses was feasible.

TABLE B2

	Correct localization given ''felt'' response	*Average localization error given ''felt'' response*
Experiment 1	23%	4.13 cm
Experiment 2a	27%	4.53 cm
Experiment 2b	32%	4.08 cm