A new object captures attention—but only when you know it's new

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Two hypotheses have been advanced to explain why an object appearing suddenly in an empty location captures attention. According to the first hypothesis, the visual transients that accompany an abrupt onset automatically trigger attentional orienting toward the object. The second hypothesis claims that the visual system regards the onset as an advent of a new object, and the latter's novelty causes attention to be drawn toward it. To discriminate between these two accounts, Franconeri, Hollingworth, and Simons (2005) introduced a procedure in which an object was added to the display but, crucially, the object's onset transients were concealed. Their results showed that this additional object failed to capture attention, which they interpreted as evidence against the new-object hypothesis. But the Franconeri et al. procedure could somehow have impeded the visual system from identifying the additional object as new. In three experiments, Franconeri et al.'s results were first replicated and extended. Further, it was shown that when the conditions facilitated the encoding of the locations of the old items, the new object did succeed in capturing attention.

The continuous stream of stimulation that the visual system receives generally contains more information than it can manage effectively. The visual scene may change, sometimes quite rapidly and unpredictably. Unless the information crucial to the organism's current goals is processed promptly, its survival may be compromised. A question of considerable interest is how the visual system prioritizes the information in the scene and orients its attentional mechanisms accordingly. This is the issue of attentional control.

Two modes of attentional control have been identified (e.g., Egeth & Yantis, 1997; Pashler, Johnston, & Ruthruff, 2001; Yantis, 1993a, 1998). In endogenous attention, control is applied in a top-down, goal-directed fashion. Here, the attentional spotlight is under the observer's control, and attention is focused where the immediate goals are best served. In exogenous attentional control, however, particular features of the environment determine where the spotlight is trained. The intentions of the observer are inconsequential here, and we say that attention is "captured." The focus of this report is attentional capture.

To the extent that attention may be captured, an immediate issue would be identifying those aspects of the stimulus that endow it with the capacity to capture attention. One proposal has been that an object that possesses an aspect not shared by the other objects in the field (a "singleton") would attract attention because its uniqueness, presumably, bears additional information. Folk, Remington, and their colleagues (Folk & Remington, 1998, 1999; Folk, Remington, & Johnston, 1992) claimed that attention is a strictly top-down control process, with

the goals of the observer dictating which objects would be prioritized. In this view, a particular stimulus feature will gain the capacity to capture attention only if it has been programmed into the observer's attentional goal setting. Therefore, to demonstrate unambiguously that a particular stimulus feature is capable of exogenous control, the task must be configured in such a way that detecting this feature is excluded from the observer's current goals.

One such approach is Theeuwes's (1991) additional-singleton paradigm. Here, two singletons are presented: One specifies the target location, and the other, additional one is entirely irrelevant to the task. Attending (endogenously) to this irrelevant singleton would hinder rather than help task performance, which presumably should compel the observer to suppress orienting toward it. The critical question is whether the observer's attention would still be drawn inexorably to this additional singleton, thus providing a demonstration of attentional capture. Theeuwes (1991) pitted a color singleton (the additional, irrelevant singleton) against a shape singleton (which enveloped the target). He showed that latencies were indeed longer for trials in which the color singleton was present, suggesting that the singleton captured attention.

Bacon and Egeth (1994) allowed that in the Theeuwes experiment, the goal of the observer was to detect a shape singleton and not the irrelevant color singleton. Nevertheless, the task implicitly required the observer to engage in singleton monitoring. This, they contended, would compel the observer to enter into a "singleton-detection" mode, the consequence of which could well be the prioritization of all singletons, including the irrelevant color

singleton. Bacon and Egeth showed that when the task no longer allowed the target to be sought via singleton monitoring, the same color singleton failed to capture attention. This result implied that Theeuwes's demonstration did not qualify as evidence of attentional capture (cf. Theeuwes, 2004). There have been many attempts at evaluating different features of static stimuli for their capture capacity. Several recent reviews in the literature (e.g., Rauschenberger, 2003; Yantis, 1998) came to the conclusion that static-feature singletons do not capture attention. But, when an object appears suddenly in an unoccupied location (an "abrupt onset"), the object almost always succeeds in attracting attention to its site.¹

Two accounts have been proposed to explain why an object that onsets abruptly would lead to automatic prioritization. The first explanation emphasizes the local change in sensory stimulation that occurs when an object appears suddenly in an empty location. This sudden change in the luminance profile at the onset location may be critical in eliciting automatic attentional orienting to the onset's site; for example, the transient visual channels would be triggered in response to any abrupt luminance change (Breitmeyer & Ganz, 1976; Breitmeyer & Julesz, 1975; Nakayama & Mackeben, 1989), leading to reflexive orienting to the onset. It has been proposed that the magnocellular pathway, implicated in processing motion and other forms of dynamic visual information, may be involved here. The second explanation (Yantis, 2000; Yantis & Hillstrom, 1994) emphasizes the onset object's status as a *new* entity. When something is added to the visual scene, visual memory representation needs to be updated to reflect the changed circumstances. Whereas the existing objects are already represented in visual short-term memory (VSTM), there is no representation yet for the new object. The updating of VSTM has attentional consequences. For example, an object file (Kahneman & Treisman, 1984) has to be created for the additional object (Yantis, 1993b), which generates an attentional interrupt, prompting an automatic deployment of attention to the new object.

To distinguish between these two explanations, Yantis and Hillstrom (1994) eliminated the luminance change that normally accompanies an abrupt onset and tested whether capture could still be observed. If luminance change were critical, the equiluminant setup should thwart attentional capture. The Yantis and Hillstrom results confirmed that capture still obtained, despite the elimination of luminance-change cues. Gellatly, Cole, and Blurton (1999) improved on the Yantis and Hillstrom procedure, essentially controlling for local luminance change, and replicated the Yantis and Hillstrom results. These data, taken together, suggest that, per se, the luminance change as a result the abrupt onset of an object was not necessary for attentional prioritization of the object.

The equiluminant experiments required careful calibrations so that, in the critical conditions, all confounding luminance cues would be eliminated. Recently, Franconeri, Hollingworth, and Simons (2005) introduced an elegant way of testing the new object hypothesis: A new object was introduced but its onset transients were effectively ob-

scured, thus obviating the luminance control issue. In this paradigm, Franconeri et al. surrounded several stationary placeholders (Todd & Van Gelder, 1979) with an annulus that contracted as the trial progressed. At some stage, the contracting annulus passed in front of the placeholders and, being opaque, concealed them. When the placeholders were completely hidden from view, each shed several line segments and was transformed into a letter. At this juncture, an additional letter was introduced. But, as the letter's appearance occurred behind the opaque annulus, its onset transients were invisible. As the annulus contracted further, the objects (now letters) reappeared. The annulus blocked the objects for merely 10 msec, too briefly to disrupt the spatiotemporal continuity between the placeholders, before they were hidden from view, and the letters, when they emerged.

The task was to decide which of two target letters were among the display objects. Franconeri et al. (2005) asked whether a new object introduced in this manner would capture attention. They contrasted the condition in which the new object was a target with the condition in which it was a distractor—a letter. If the new object were automatically prioritized, it would be the first item toward which attention would be deployed. And if this were a target letter, search would terminate immediately, the net result of which should be an efficient search, with search latency independent of the number of letters in the display. The search slope, as a function of search set size, would correspondingly be more or less flat. But if the new object were a distractor, search would continue apace until the target was found. Search should therefore be inefficient and latencies should be a function of set size. Franconeri et al.'s results contradicted these predictions. They observed search slopes of comparable magnitudes, whether the additional object was a target or a distractor. Their results suggested that the additional new object was not prioritized; that is, it failed to capture attention.

In their Experiment 2, they presented the annulus *behind* the objects, so that even when its location was coincident with the placeholders, the latter would still be visible. Thus, when the additional object was introduced, its onset transients now became apparent. Franconeri et al.'s (2005) results showed that when the additional object was a target, the slope was flat, but not when the additional object was a distractor. Taken together, their results imply that the onset transients were crucial in determining whether a new object would be prioritized. When the onset transients were not visible, there was no evidence of capture. But when the transients were made apparent, capture was manifest.

It is instructive to unpack the implicit assumptions underlying the Franconeri et al. (2005) procedure. At the start of the trial in the experiment, the observer saw several identical placeholders, each occupying a unique location. An additional object was introduced when all the objects were hidden from view. When the objects reemerged, the placeholders and the additional object appeared as letters. Now, what distinguished the new from the old objects was that the former occupied a previously empty location. The objects were obscured for only 10 msec, so spatiotemporal

continuity was unlikely to be an issue. But for this continuity to be maintained in the first place, the locations of the placeholders would have to be encoded before they disappeared behind the annulus. Only then would the visual system have a record of where the existing ("old") objects were, thereby allowing it to flag the additional object—the only one for which spatiotemporal continuity could not be maintained—as new.

It is unclear, in the first place, whether the objects, specifically their locations, were encoded. Recall that the task of the observer was to search for one of two target letters. Encoding the object's location was not part of, nor would it help with, performing the task. There was no relationship between an object's location and the likelihood that it was the target. In Schneider and Shiffrin's (1977; Shiffrin & Schneider, 1977) terms, there was a variable mapping between an object's location and its status as a target. Thus, although one may argue that if the objects' locations had been encoded this information was unlikely to be lost when the objects were obscured from view for a mere 10 msec, it is not apparent that the objects' locations had been encoded in the first place.

This set of experiments used the same Franconeri et al. (2005) paradigm. The goal was to test the view that the Franconeri et al. results were due, in part, to encoding conditions that were not entirely conducive for the visual system to discriminate the additional object that appeared in the middle of the trial from the placeholders that existed from the start of the trial. Experiment 1 was aimed at replicating and extending the Franconeri et al. findings by incorporating changes to their design. Experiments 2 and 3 included manipulations meant to facilitate the encoding of the placeholders' locations. If these manipulations were successful, the new object ought to be highlighted. To the extent that a new object captures attention, capture success should be observed.

GENERAL METHOD

Stimuli

The displays were modeled closely on Franconeri et al. (2005). The display initially consisted of placeholders (Todd & Van Gelder, 1979) situated on the circumference of an imaginary circle (the diameter subtended a visual angle of 9.6° with observers viewing the display from a distance of 50 cm) centered on a fixation cross. Each placeholder was composed of straight-line segments forming a figure 8. Its width and height subtended visual angles of 0.75° and 1° , respectively. There were 12 possible equidistant locations for these placeholders, with their absolute positions changing across trials. For each trial, the locations of the placeholders were randomly determined, subject to the constraint that they not be clustered together. The placeholders (which later turned into letters) and the fixation cross remained stationary throughout the trial. At the start of the trial, an annulus (two circles, forming the inner and outer edges of the annulus, and centered on the fixation cross) surrounded the placeholders. The diameters of the outer and inner circles subtended 16.5° and 15° , respectively. The body of the annulus had the same luminance as the background (60 cd/m^2) and the edges had the same luminance as the placeholders (30 cd/m^2).

Figure 1 depicts the sequence of frames in a trial. The first frame (Figure 1A) was presented for 750 msec. As the trial progressed, the diameters of the inner and outer circular edges of the annulus decreased, creating the illusion that the annulus had shrunk (Figures 1B–1G). At some stage, the annulus swept past the placeholders. As it shrank further, the diameters of the inner and outer edges became smaller than the imaginary circle on which the objects were arrayed, which meant that the placeholders now surrounded the annulus (Figure 1F); finally, the shrinking halted (Figure 1G). At this point, the diameter of the outer and inner edges of the annulus subtended 2.5° and 1° , respectively. The entire animation sequence was 180 msec long (18 frames, each presented for 10 msec; the monitor refreshed at 100 Hz). The annulus crossed the placeholders at the halfway point of the animation sequence (i.e., Frame 9). When the annulus was "opaque," the placeholders were obscured from view when the annulus passed in front of the placeholders (Figure 1D). At this juncture, each placeholder shed several line segments and was transformed into a letter. As this transformation occurred behind the opaque annulus, the offset transients accompanying the disappearance of the line segments were not visible. As in Franconeri et al.

Figure 1. The frames presented during a baseline (no additional object) trial. (A) The annulus surrounded the placeholders at the start of the trial. (B), (C) The annulus started contracting, and at the midpoint of the trial (D), it obscured the placeholders, which shed line segments. (E) As the annulus shrank further, letters emerged from behind the annulus. (F) The annulus continued shrinking further and was surrounded by the letters. (G) The annulus finally stopped contracting.

(2005), the objects were hidden for only 10 msec. The placeholders remained on the screen for more than 800 msec before they were obscured. Object continuity was not expected to be compromised when the placeholders disappeared only momentarily from view.²

The annulus then shrank further, revealing the letters. The task was to determine whether the letter E or the letter H appeared in the search set by striking one of two prescribed keys. The distractor letters were drawn randomly from the set A, P, S, and U. To contrast the opaque annulus condition, a separate experiment was conducted by making the annulus "transparent." Here, the placeholders were visible when the shrinking annulus passed in front of them. Crucially, the offset transients, when they occurred, were apparent.

Design

There were three main variables. The first variable was whether an additional item was introduced when the annulus passed in front of the placeholders. On half of the trials, the number of objects on the screen remained unchanged throughout the trial (*baseline* trials) and on the other half of the trials, an additional object was introduced (*additional object* trials). The second variable was search set size. For the baseline trials, the search set consisted of the three, four, or five letters that had been placeholders when the trial first began. For the additional object trials, the trials began with three, four, or five placeholders. When the letters were revealed, there was one more object; that is, the search set consisted of four, five, or six letters, respectively.

The third variable pertained only to the additional object trials. The contrast was between trials in which the additional object was the target or a distractor. The 1/d design was implemented as follows. For each search set size, the additional object was the target on 1/d of the trials (where *d* represents the set size). For example, in the search set size 4 condition, for every three trials in which the additional object was a distractor letter, there was one trial in which it was a target letter. This was meant to ensure that the observer would have no incentive in attending to the additional object.

The trials were divided into 11 blocks, each containing 60 trials. The letter E and the letter H each appeared as targets on 30 trials each. For each of the 30 trials, 15 would be baseline trials (4, 5, and 6 trials, respectively, for set sizes of 3, 4, and 5 letters) and 15 would be additional object trials. The first block was a practice block and its data were not analyzed.

EXPERIMENT 1

The main aim of Experiment 1 was to replicate and extend Franconeri et al. (2005). In their experiments, an additional object appeared in all trials. One possible consequence is that observers might have anticipated the additional object, and this expectation could have diluted the power of the additional object in capturing attention. In Experiment 1, the additional object was introduced on only 50% of the trials.

Method

Observers. The observers were 29 students who participated for course credit. All had normal or corrected-to-normal vision.

Procedure. Two separate experiments were conducted. In Experiment 1A ($n = 15$), the annulus was opaque. For the additional object trials, a new object was introduced when all the objects were hidden behind the annulus. The onset transients of the new object were invisible, as were the offset transients that occurred when the placeholders lost line segments. In Experiment 1B, the annulus was transparent ($n = 14$), making the transients visible.

The procedure was as described above. The intertrial interval was 750 msec. The first five trials in each block were regarded as practice trials, and their data were not analyzed. Feedback was provided

in the form of a beep that sounded when the wrong key was struck. The error trial was rerun toward the end of the block. Observers were allowed unlimited rest time between blocks. They were briefed to search for the letters E and H. No mention was made of the additional object. An informal poll at the end of the experiment showed that some observers were aware that toward the end of the trial, an additional object sometimes appeared.

Results

Observers were very accurate. Preliminary analysis of the accuracy data yielded no interesting trends. There was no evidence of a speed-accuracy trade-off. Because the same pattern of results obtained for this and the other experiments, the accuracy data will not be considered further.

The mean RTs (top panel) and accuracy rates (bottom panel) as a function of search set size for Experiments 1A and 1B are presented in Figure 2 (left and center panels, respectively). The latency data for the observers were treated as follows. For each experimental condition, the average RT was first estimated. For the baseline condition, this average RT was calculated from 80, 100, and 120 trials for the set size 3, 4, and 5 conditions, respectively. For the additional object/distractor condition, the average RT was calculated from 60, 80, and 100 trials for the set size 4, 5, and 6 conditions, respectively. For the additional object/target condition, there were 20 trials for each set size, from which average RTs were calculated. Three linear regressions were computed for each observer, one each for the baseline, additional object distractor, and additional object/target conditions. The slopes, intercepts, and R^2 statistic of this and the other experiments are reported in Table 1. For the main analysis, the slopes for the baseline and the two additional object conditions were entered as the dependent variable.

To answer the question of whether search was equally efficient for the baseline and the additional object conditions in the two experiments, a 2 (Experiment 1A vs. 1B) $\times$ 3 (trial type: baseline, additional object/distractor, additional object/target) mixed ANOVA was conducted, with the experiment variable treated as a between-subjects variable. The results showed no overall experiment effect [$F(1,27) = 1.189, p > .2, \eta_p^2 = .04$]. There was a trial type effect [$F(2,54) = 5.101, p < .01, \eta_p^2 = .16$], and, crucially, an experiment $\times$ trial type interaction effect [$F(2,54) = 5.418, p < .01, \eta_p^2 = .17$]. Further analyses showed that, for Experiment 1A, a one-way ANOVA of the trial type variable revealed no effect ($F < 1$). An analogous ANOVA for Experiment 1B, however, showed a significant trial type effect [$F(2,26) = 7.451, p < .003, \eta_p^2 = .36$]. Additional analyses comparing the baseline and the additional object/distractor conditions, showed no difference between the experiments. A 2 (experiment) $\times$ 2 (trial type: baseline vs. additional object/distractor) revealed no significant effects [$F_s < 1$ for both main effects; $F(1,27) = 2.686, p > .1, \eta_p^2 = .09$, for the interaction]. However, for the additional object/target condition, a between-subjects ANOVA revealed a difference between the slopes of the two experiments [$F(1,27) = 5.603, p < .05, \eta_p^2 = .17$].³ The results of Franconeri et al. (2005) were replicated.

Figure 2. Mean RT and proportion correct as a function of search set size for the three trial conditions. Experiment 1A: opaque annulus; Experiment 1B: transparent annulus; Experiment 1C: annulus with a luminance edge (see note 4).

The intercept of the additional object/target condition for Experiment 1B was higher than for either the baseline or the additional object/distractor conditions. (To anticipate the results, this was also found for Experiments 3A and 3B.) This finding, which appears odd, especially in light of Franconeri et al. (2005), will be raised in the discussion section of Experiment 3.

Discussion

When an object appears abruptly in an unoccupied location, the object may be considered “new,” in the sense that it had not been in the display previously. The new object hypothesis claims that such an object would capture attention by virtue of its novelty. When an abrupt onset occurs, transients accompany its appearance. These low-level sensory changes could also attract attention reflexively to its site. The question posed in Experiment 1 was whether a new object had the capacity to capture attention when its onset transients were concealed. The purpose of contrasting Experiments 1A and 1B was to dissociate the effects of the onset transients from those of novelty per se. The two experiments were identical in all respects, except that whereas onset transients were invisible in Experiment 1A

(opaque annulus), they were apparent in Experiment 1B (transparent annulus).⁴

The observers’ task was to search for the target among several letters. If the additional, new object captures attention, its location ought to be visited first. If that object also happens to be the target, search ought to terminate immediately; that is, search would be efficient, and the average search time should be independent of set size. The results in Experiment 1A showed that the new object was treated in the same way as the other old objects were, implying that it failed to capture attention. In contrast, in Experiment 1B, the slope was flat for the additional object/target condition, suggesting that here search was efficient; this implied that the additional object was prioritized.

This set of results replicated Franconeri et al. (2005). The new, additional object appeared capable of capturing attention but only when its transients were apparent (transparent annulus, Experiment 1B). When the transients were obscured by the opaque annulus, the same new object now failed to capture attention. Since the objects were hidden from view for only 10 msec, it was unlikely that their very brief disappearance would dis-

Table 1
Slopes, Intercepts, and R^2 Statistics of the Experiments

	Slope	Intercept	R^2
Experiment 1A			
Baseline	33.4	530	.99
Additional object/distractor	40.9	506	.97
Additional object/target	36.3	533	.99
Experiment 1B			
Baseline	46.6	551	.99
Additional object/distractor	37.3	591	.97
Additional object/target	5.45	751	.64
Experiment 1C			
Baseline	47.6	505	.99
Additional object/distractor	46.1	506	.98
Additional object/target	37.5	530	.98
Experiment 2A			
Baseline	38.5	586	.98
Additional object/distractor	46.8	553	.99
Additional object/target	37.3	590	.87
Experiment 2B			
Baseline	35.5	558	.99
Additional object/distractor	37.7	552	.99
Additional object/target	37.2	565	.99
Experiment 3A			
Baseline	35.8	550	.99
Additional object/distractor	34.2	563	.99
Additional object/target	6.0	696	.19
Experiment 3B			
Baseline	23.7	561	.97
Additional object/target	5.8	614	.83

rupt the spatiotemporal continuity between the placeholders and the letters as they reemerged from behind the shrinking annulus. What these results suggest is that the object's status as a new entity played no important role in attentional capture; rather, the power resided in the transients that accompanied the object's sudden appearance in a previously empty location. But this conclusion is predicated on the assumption that the visual system had the requisite information to distinguish between the additional "new" object and the rest of the field; that is, despite having been flagged as a "new" entity, the additional object exerted no control over attentional prioritization. In other words, being new did not bestow on it the capacity to capture attention.

The only way to distinguish the new object from the old in this paradigm was to note which among the letters that emerged from behind the shrinking annulus occupied a previously empty location. If the locations of the placeholders had not been encoded in the first place, the new object could not be distinguished from the others. But as the search task did not require encoding location information, observers were unlikely to have explicitly encoded this information. The question is whether location information might have been encoded implicitly.

There was no collateral evidence that the placeholders' locations had been implicitly encoded. The experimental setup did not encourage implicit learning of the placeholder locations. The location of the objects varied

across trials. Thus, there was variable mapping (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977) between an object's location and its status as a target. But implicit encoding of the placeholders' locations will probably occur if their encoding was facilitated.

In Experiment 1, the locations of the placeholders were randomly determined, which could have made encoding their locations difficult (especially for the large set size conditions), even when the task had required explicit encoding. The goal of Experiment 2 was to facilitate implicit encoding of the placeholder locations. We exploited the idea that when objects are placed in such a way that they represent a "good" form, this form (and, correspondingly, the locations of the objects) may be more easily encoded (Attneave, 1955; Garner, 1970).

EXPERIMENT 2A

Experiments 2A and 2B were conducted, each facilitating location encoding in slightly different ways. The positions of the objects were constrained. In Experiment 2A, the placeholders formed the corners of a geometric shape (an equilateral triangle, a square, and a pentagon, respectively, for three-, four-, and five-placeholder conditions). According to Attneave (1955), good forms are encoded more readily. When an additional object was introduced on a trial, it appeared in a location that served to destroy the good form; an example is provided in Figure 3. The five placeholders formed the corners of a regular pentagon. A new item was introduced when the objects were behind the shrinking annulus. When the letters were later revealed, the original regular pentagon configuration was wrecked by the new object. If the locations of the placeholders had been encoded, this new object ought to have stood out.

Method

Observers. There were 14 new students for this experiment, recruited from the same pool, who participated under the same motivational conditions as those in the previous experiments.

Procedure. The setup followed the specifications of Experiment 1A. The annulus was opaque, concealing the onset transients when they occurred. As described above, the locations of the placeholders were constrained in such a way that they formed a geometric shape. For each set size, the positions of the placeholders relative to each other were fixed, but their absolute positions on the screen varied from trial to trial. For example, on some trials, the four placeholders formed a square; on other trials, they formed a diamond; and so forth. For the additional object condition, a new item was positioned in such a way that, when it appeared, the original regular geometric form was destroyed.

Results

The mean RT and accuracy rates of the trial conditions as a function of set size are presented in Figure 4 (left panel). The data were treated in the manner described earlier. The main question was whether the additional object would capture attention. The results were straightforward. A one-way ANOVA of the slopes computed from the 3 trial type conditions revealed no significant effect ($F < 1$).⁵ The additional object failed to capture attention.

Figure 3. The placeholders formed a regular geometric shape (pentagon) at the start of the trial. The annulus started shrinking as the trial progressed. For the additional object trial, a new object was introduced when the annulus obscured the placeholders. This new object (the letter E above) destroyed the geometric shape (last figure).

EXPERIMENT 2B

A further attempt was made at facilitating location encoding using the same logic. For the additional-object trials, the new item was placed in a position such that together with the objects in the placeholder locations, a regular geometric form emerged. Figure 5 provides an example. At the start of the trial, the placeholders occupied positions on the three corners of a square. When the additional object was introduced, it occupied the fourth unoccupied corner of the square, forming a square with the other objects. For trials in which the search set contained five and six objects, the additional object formed a pentagon and hexagon, respectively.

Method

Observers. Another 14 students were recruited from the same pool. They participated under the same motivational conditions as in the previous experiments.

Procedure. The procedure was identical to Experiment 2A. The locations of the objects for the baseline trials were determined in the same fashion as in the additional-object trials (except, of course, that the additional object was not introduced for these trials). For the additional-object trials, the final forms for the set size 4, 5, and 6 conditions were square, pentagon, and hexagon, respectively. As in Experiment 2A, the locations of the objects relative to one another for the different set size conditions were constrained, but their absolute positions on the screen varied across trials.

Results and Discussion

The mean RT and accuracy rates as a function of the different set sizes and display set size are plotted in Figure 4 (right panel). The data were analyzed in the same way as in Experiment 2A. A one-way ANOVA of the three slopes produced results that were no different from Experiment 2A. There was no effect of trial type ($F < 1$).⁶ Capture failed.

The manipulations in Experiment 2 were meant to facilitate encoding of the initial array of placeholders. Their positions were constrained in such a way that the additional object either destroyed a good form (Experiment 2A) or allowed a good form to emerge (Experiment 2B). The goal was to make the new object distinctive relative to the old objects. The results in both experiments showed that the additional object failed to capture attention.

But again, there was no collateral evidence that the manipulations succeeded. Although the objects were ar-

ranged so that they formed a regular geometric shape, their absolute locations varied across trials, and this variation could have undermined location encoding. In the next experiment, the locations of the placeholders were fixed to facilitate encoding of the placeholder locations.

EXPERIMENT 3A

The logic based on perceptual learning was used in this experiment to facilitate the implicit encoding of the locations of the placeholders. In Experiment 2, the relative positions of the placeholders were constrained, but their absolute positions varied across trials. This variable mapping could have discouraged implicit encoding of the locations. Yet the only way to distinguish the new object from the old objects was to encode the locations of the placeholders so that the spatiotemporal continuity between them and the letters that emerged later could be established. This would then allow the only letter for which no continuity could be established thereby to stand out as a new object.

In Experiment 3, the placeholders' absolute positions were fixed throughout the experiment. There was one unique configuration each for (the initial) set sizes 3, 4, and 5. As the placeholders appeared in the same locations across trials, the observers should, over time, learn the three different configurations (and thus the locations of the placeholders). For trials in which an additional object was presented, its location was randomly determined. Once the configurations were learned, it is reasoned that the additional object ought to stand out as a new entity.

Method

Observers. The observers were 14 new students recruited from the same pool who participated under motivational conditions identical to those in the previous experiments.

Procedure. As in the previous experiments, the two variables were 3 (baseline vs. additional object/distractor vs. additional object/target) $\times$ 3 (set size: 3, 4, 5 placeholders). The procedure was identical to the previous experiments, except that in the previous experiments, the configuration of the objects was randomly determined on each trial, whereas in this experiment a unique configuration for each of the three set sizes was determined at the outset, thereby fixing the absolute positions of the placeholders. Throughout the experiment, the observers would see, for each set size, objects arranged in exactly the same fashion. For trials in which an additional object was introduced, the location of this object was chosen from

Figure 4. Mean RT and proportion correct as a function of search set size for the three trial conditions. Experiment 2A: Additional object wrecked initial good form. Experiment 2B: Additional object completed form.

one of the unfilled locations (e.g., for set size 3, the new object occupied any one of the nine empty locations).

Results and Discussion

The mean RT and accuracy rates as a function of set size for the three trial conditions are presented in Figure 6 (left panel). The slope data were analyzed in the manner described earlier. A one-way ANOVA of the three trial-type conditions revealed an overall effect [$F(2,26) = 8.070, p < .005, \eta_p^2 = .62$]. Further analyses showed no

difference between the slopes of the baseline and the additional object/distractor conditions ($F < 1$). But the slopes between the additional object/distractor and additional object/target conditions were significantly different [$F(1,13) = 8.641, p < .01, \eta_p^2 = .40$]. Analyses of the mean RT data in a 2 (additional object/distractor vs. target) $\times$ 3 (set size) ANOVA revealed consistent results: There was no overall additional object effect ($F < 1$). But there was a set size effect [$F(2,26) = 9.473, p < .001, \eta_p^2 = .42$], and crucially, also a significant interaction ef-

Figure 5. The placeholders formed an incomplete geometric shape at the start of the trial (three vertices of a square). The annulus started shrinking as the trial progressed. For the additional-object trial, a new object was introduced when the annulus obscured the placeholders. This new object (the letter U above) completed the geometric shape (last figure).

Figure 6. Experiment 3A (left panel) and Experiment 3B (right panel). Mean RT and proportion correct as a function of search set size for the three trial conditions.

fect [$F(2,26) = 4.483, p < .05, \eta_p^2 = .26$]. This interaction effect was next investigated. For the additional object/target condition, no overall difference was found among the RTs for the three set sizes [$F(2,26) = 1.323, p > .2, \eta_p^2 = .09$], suggesting that search times were independent of set size. Indeed, there was no reliable difference between the two latencies that had the greatest disparity, set sizes 3 and 5 [$F(1,13) = 2.306, p > .1$]. The evidence points toward an efficient search when the additional object was the target.

Recall that, for the transparent annulus experiment (Experiment 1B) where the onset transients were apparent, efficient search was observed for the additional object/target condition. In Experiment 1B, the onset transients marked the additional object. The question is whether the additional object was marked in an analogous way when the encoding of the locations of the old objects was facilitated. To answer the question, the results of Experiments 1B and 3A were compared. A 2 (experiments) $\times$ 3 (trial type) ANOVA, using slopes as the dependent variable, with the experiment variable treated as a between-subjects variable, revealed only a trial type effect [$F(2,52) = 14.901, p < .001$]. There was no experiment effect ($F < 1$), nor an interaction effect ($F < 1$),⁷ suggesting that the additional object was prioritized similarly in the two experiments.

The locations of the placeholders were fixed for each set size, to facilitate implicit learning of the placeholders' locations. It was reasoned that once the observers learned where these "old" locations were, an object that occupied a previously unoccupied location would be designated "new." If a new object were indeed privileged by the attentional system, it ought to be processed first. If the object was the target, latency ought to be independent of the search set size. In contrast, if the new object was a distractor, search times ought to be a linear function of search set size. This pattern of results obtained was consistent with this account.

Fixing the configuration of the placeholders facilitated implicit learning of their position. The claim is that once subjects learned the filled locations, the visual system ought then to *know* which item was new. The argument so far has been that, in this paradigm, the additional object is flagged as new only when the visual system has been able to encode the locations of the preexisting objects. In Experiment 3A, the locations of the placeholders were fixed to facilitate implicit encoding of their location. When the additional object was the target, efficient search was observed, supporting the argument. This argument was next subjected to a more direct test. In Experiment 3B, observers were encouraged to learn the configuration of the placeholders, which varied from trial to trial. So long

as the placeholders' locations were learned, the new, additional object should stand out from the old objects.

EXPERIMENT 3B

Method

Observers. The observers were 13 new students recruited from the same pool and motivated under the same conditions as those in the previous experiments.

Design. The two variables were set size (3, 4, or 5 placeholders) and trial type (baseline vs. additional object/target). Half the trials were baseline trials. On the other half of the trials, an additional object was introduced when the placeholders were hidden behind the annulus. This additional object was always one of the two target letters.

Procedure. Observers were explicitly told that on half the trials, there would be a new object added to the display: one of two target letters. Observers were encouraged to memorize the configuration of the placeholders, so that if another object were added to the display, they could immediately locate it and identify it. The locations of the placeholders were randomly determined for each trial in the same manner as in Experiment 1.

The observers went through nine blocks, each containing 60 trials, with the first block treated as practice. The constitution of each block of trials was identical to the previous experiments, with the critical difference being that the new object was always one of the two target letters.

Results and Discussion

The mean RT and accuracy rates as a function of set size for the three trial conditions are presented in Figure 6 (right panel). The data were treated in the manner described previously.⁸ The hypothesis was that the additional object would be automatically flagged when observers explicitly coded the configuration of the placeholders. The data supported the hypothesis. A one-way ANOVA comparing the slopes of the baseline and additional object trials revealed that the slopes were significantly different [$F(1,12) = 55.64, p < .001, \eta_p^2 = .82$]. Further analysis of the mean RTs for the three set sizes of the additional object/target condition revealed no overall difference [$F(2,24) = 2.271, p > .1$].⁹ The strategy of encoding the placeholders' locations allowed observers to distinguish between the old placeholders and the new object.

The fact remains that the intercepts of the search function for the additional object/target condition were higher than in the other two conditions (Experiments 1B and 3A). Although the disparity in intercepts between the baseline and the additional object/target functions was less marked in Experiment 3B (48 msec compared with >100 msec), this difference was nevertheless significant. In contrast, Franconeri et al. (2005) found no large difference in the intercepts between the efficient and inefficient search functions.¹⁰ These differences are puzzling. Our tentative explanation is that the constitution of the trials contributed to the differences.

The disparity in the intercepts between the baseline and the additional object conditions in Experiment 3B has a more straightforward explanation. Observers were encouraged to encode the placeholders' configuration. When the search array emerged, the processing probably involved first the retrieval of the encoding of the configuration, then a comparison between the encoding and the search

array. If there was a mismatch (i.e., an additional object trial), there was some constant processing time added to the response latency, perhaps reflecting attention shifting to the location of the additional object.

In the case of Experiments 1B and 3A, we speculate that additional, postidentification checking caused by the relative rarity of the additional object/target trials added a constant to total RT. Franconeri et al. (2005) inserted, in all their trials, an additional object midway in the sequence. In our experiments, the additional object was inserted in only 50% of the trials. Moreover, the additional object/target condition formed only 10% of trials, which meant that when attention was captured by the additional object, search generally had to continue apace, since the additional object was more likely than not to be a distractor. On only a small proportion of trials (i.e., those where the additional object was the target), search halted immediately when the first object was engaged. Because the experience of finding the target immediately was rare, an additional checking stage may have been triggered, just to confirm that the object was indeed the target. This additional stage added a constant to the response latency. In contrast, the observers in Experiment 3B were told explicitly that the additional object would always be the target. Thus, the additional checking would be, more or less, obviated. The intercept for Experiment 3B was indeed lower. A comparison of the baseline and additional object/target conditions across the three experiments confirmed that the pattern observed in Experiment 3B was indeed different from the other two experiments.¹¹

GENERAL DISCUSSION

When an object appears abruptly as an onset, its success in capturing attention has been well documented (Egeth & Yantis, 1997; Yantis, 1998). There are two main accounts. Yantis and his colleagues (Yantis & Hillstrom, 1994; Yantis & Jonides, 1990) claimed that it was the object's novelty that endowed it with the capacity of capturing attention. The alternative hypothesis is that the onset's attention-capturing capacity derives from the transients produced when it appeared abruptly. There have been attempts made at dissociating the low-level luminance-change effects from the object-level explanation (Gellatly et al., 1999; Yantis & Hillstrom, 1994) by systematically controlling either the global or local luminance cues.

This same issue was taken up recently by Franconeri et al. (2005), whose procedure allowed a new object to be added to the display but without incurring the low-level onset transients. The question was whether this new object would still be prioritized when the transients were invisible. Their results showed that the onset transients were critical in determining whether attentional prioritization obtained. In Experiment 1, Franconeri et al.'s results were replicated and extended.

In this paradigm, the letters were initially camouflaged with additional line segments, making them physically identical. The only variable that distinguished them from each other was their location on the display. As the trial

progressed, these objects were concealed. They then reappeared as letters. On some trials, a new object was added to the display at the moment when all the objects disappeared from view. The only way that the visual system could flag this additional object as a new entity was by noting that it occupied a previously empty location. But for this to occur, the visual system first had to encode the locations of the placeholders; otherwise, it would not be able to discern which locations had been occupied and which were empty. The search task did not require explicit encoding of the objects' locations; the question was whether the observers would encode location information implicitly. Although the results of Franconeri et al. (2005) and Experiment 1 may be interpreted as evidence contradicting the new-object hypothesis, this argument depended on the assumption that the visual system had indeed flagged the additional object as new. But there was no collateral evidence in the experiment that the requisite encoding of the placeholders' locations had obtained. The objects' positions varied randomly from trial to trial (as in Experiment 1), which almost certainly would have discouraged implicit encoding of their locations.

The manipulations in Experiments 2 and 3 were meant to encourage implicit encoding of the placeholders' locations. In Experiment 2, the objects were constrained in such a way that, when considered as a group (at either the start or the end of the trial), they formed a regular geometric shape. It was reasoned that this manipulation ought to make the additional object stand out from the old objects, but the manipulation failed. Experiment 3A was another attempt at implicit encoding, this time facilitating perceptual learning of the placeholder (old objects) locations by allowing only one configuration of placeholders for each set size throughout the experiment; once the old objects had been encoded, it was thought that the visual system could swiftly pick out the additional object, since it was the only one for which there was yet no encoding. This last manipulation produced results that showed efficient search when the additional object was the target, suggesting that the additional object was prioritized. In Experiment 3B, observers were encouraged explicitly to encode the locations of the placeholders; efficient search for the additional object was also observed. Explicit knowledge of the placeholders' location allowed the new object to be discovered readily.

The displays in these experiments were austere. At the start of the trial, there were, at most, five identical objects. Encoding the display (including the objects' locations) should in no way strain the capacity of VSTM. It is perplexing, therefore, that the results seem to suggest that unless coaxed, the items' locations were not automatically encoded.

A recent report by Davoli, Suszko, and Abrams (2007) provides some clues to the puzzle. They demonstrated attentional capture by a new object even when the latter's onset transients were concealed. In their experiments, an array of placeholders was presented, then subsequently masked by a static pattern. A new object was added to the search array when it was revealed either 100 or 400 msec later by the removal of the pattern mask. They found that, even when the pattern mask remained on the screen for

400 msec, the new object captured attention, implying that there had been implicit encoding of the locations of the "old" placeholders, and the encoding survived pattern masking over a fairly long time. In a separate experiment, they showed that when the same pattern mask was not static but moved across the display, the additional object now failed to capture attention.

In the light of Davoli et al.'s (2007) data, the results of this set of experiments may be interpreted as follows. Observers may indeed have encoded the placeholders (including their locations) during the initial calm period (i.e., before the annulus started contracting). But these representations are volatile (Becker & Pashler, 2002; Rensink, 2000) and, unless actively maintained in VSTM, would be overwritten and thus irretrievably lost. What prevented active maintenance of the representations of the placeholders was the contracting annulus. The moving object probably caused attention to be shifted away from the placeholders and toward the annulus, once it started contracting.

The effect here is something akin to inattentional amnesia (Wolfe, 1999). When the annulus started contracting, its representation changed over time and had to be constantly updated. This updating competed with the encodings of the placeholders. Perhaps not all aspects of the placeholders' information were lost, but some information—probably that pertaining to the placeholders' locations—was sacrificed. There are several reasons for this. First, the location of an object was irrelevant to the identification task; it is not surprising that location information was not actively maintained. Second, the placeholders were static throughout, and the visual system might well regard coding their locations as superfluous. On the other hand, as the annulus was contracting, updating its location in VSTM might be considered more urgent.

Experiments 2 and 3 attempted to facilitate location encoding. Experiment 2 exploited the idea that good forms would be encoded better; the manipulation failed, probably because the positions of the objects changed from trial to trial, producing intertrial interference in their encoding. To rectify this, Experiment 3A used, essentially, a perceptual learning strategy. The fixed-configuration manipulation served to strengthen the representations of these configurations so that, over time, they become resistant to forgetting, even when attention was shifted away from them. In Experiment 3B, there was top-down biasing of the placeholders' locations as the observers were given an explicit reason to maintain the placeholders' location information in VSTM. Although the locations of the placeholders varied from trial to trial, their explicit encoding made them more resistant to disruption by the contracting annulus.

Consider a display that contains several stationary objects. An object appears abruptly in an empty location. The object's appearance would generally be marked by onset transients, which draw attention reflexively to its site. The question is whether the same object would still capture attention if the onset transients were somehow blocked from view. The results from this set of experiments suggest that if the conditions allowed the object to be flagged as "new," the object would be prioritized

and attentional capture would be observed. Essentially, this requires the visual system to encode the existing objects as "old." Once the system has this record, it would be able to recognize any addition as a new entity. This new object would be prioritized, even when the low-level changes that normally accompany its appearance had been masked.

AUTHOR NOTE

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NOTES

1. Yantis and Jonides (1990) argued that even in the case of onset capture, success would only be observed when attention was diffuse when the onset occurred. Recently, Neo and Chua (2006) showed that even when attention had been endogenously cued to the location in which the target was guaranteed to appear, an onset in a distractor location could still succeed in capturing attention, provided that the onset's occurrence was sufficiently rare.

2. Two versions of the experiment were run. In one version, the annulus contracted (described above). In the other version, the annulus expanded progressively. The annulus at the start of the trial was surrounded by placeholders (as depicted in Figure 1G, except that the letters were replaced by placeholders). As the trial progressed, the annulus expanded. Halfway through the trial (Frame 9), the annulus blocked the placeholders from view. As it expanded further, letters were revealed. The annulus now surrounded the letters. The end of the trial is depicted in Figure 1A (the placeholders replaced by letters). Observers ran the contracting and expanding annulus trials in separate blocks. Analysis of the data revealed no difference between the contracting and expanding annulus trials. In the interest of brevity, we described the experiments as if only the contracting annulus trials were run.

3. ANOVAs using mean RTs were also conducted, and the results were consistent with the slope analyses. A 2 (additional object/distractor vs. target) $\times$ 3 (set size) ANOVA for Experiment 1A revealed only a set size effect [$F(2,28) = 33.970, p < .001$]. All other effects were not reliable ($F_s < 1$). An analogous ANOVA for Experiment 1B showed a set size [$F(2,26) = 6.754, p < .05$], but, crucially, an additional object $\times$ set size effect [$F(2,26) = 3.851, p < .05$]. For the additional object/target data, a one-way ANOVA comparing the three set sizes yielded no significant effect ($F < 1$).

4. If the placeholders had been implicitly encoded, they were likely to be volatile and therefore susceptible to overwriting by subsequent representations. The hard edges of the annulus, which remained onscreen after the placeholders disappeared behind it, could well have destroyed

the representations of the placeholders. In a separate experiment, we examined whether new object capture would obtain if the edges of the annulus were less defined (Experiment 1C, $n = 14$). This was identical to Experiment 1A in all respects, except that the annulus had a luminance 1 cd/m² brighter than the background (Michelson contrast = 0.008). Its edges had the same luminance as the background, thus making them invisible. This was meant to prevent, or at least reduce, the disruption of working memory representations of the objects by the moving edges of the annulus, which ought to enhance spatiotemporal continuity when the objects later emerge from behind the shrinking annulus. The data, mean RT as a function of the different set sizes for the various trial conditions, are presented in Figure 2 (right panel). The results were, more or less, identical to those of Experiment 1A. A one-way ANOVA of the slopes for the three trial types revealed no difference among them ($F < 1$).

4. A 2 (additional object/distractor vs. target) $\times$ 3 (set size) ANOVA with mean RT as the dependent variable revealed results that were consistent with Experiment 1A. There was a set size effect [$F(2,26) = 17.544$, $p < .001$], but there was no additional object effect [$F(1,13) = 3.593$, $p < .09$], nor was there an interaction effect between the two variables ($F < 1$).

5. A 2 (additional object/distractor vs. target) $\times$ 3 (set size) ANOVA with mean RT as the dependent variable revealed results that were consistent with Experiments 1A and 1C. There was a set size effect [$F(2,26) = 28.007$, $p < .001$]. But there was no additional object effect ($F < 1$), nor was there an interaction effect between the two variables [$F(2,26) = 1.905$, $p > .1$].

6. A 2 (additional object/distractor vs. target) $\times$ 3 (set size) ANOVA with mean RT as the dependent variable revealed results consistent with Experiment 1A and 1C. There was a set size effect [$F(2,26) = 24.861$, $p < .001$]. But there was no additional object effect [$F(1,13) = 1.997$, $p > .1$], nor was there an interaction effect between the two variables ($F < 1$).

7. The same results obtained for the cross-experiment analysis using latencies as the dependent variable. A 2 (experiment) $\times$ 2 (additional object/distractor vs. target) $\times$ 3 set size ANOVA revealed significant

additional object and set size effects [$F(2,52) = 63.766$, $p < .001$, and $F(2,52) = 15.7$, $p < .001$, respectively], and also an additional object $\times$ set size interaction effect [$F(2,52) = 7.906$, $p < .001$]. But, crucially, the experiment variable did not interact with any of the other variables (all F s < 1).

8. The mean RT data for set sizes 3, 4, and 5 were computed from 64, 80, and 96 trials each for the baseline and the additional object/target trials.

9. The RT data, analyzed as a 2 (trial type) $\times$ 3 (set size) ANOVA, revealed results consistent with the slope analysis. The trial type variable was not significant [$F(1,12) = 3.249$, $p < .1$, $\eta_p^2 = .2$]. The set size effect was reliable [$F(2,24) = 3.249$, $p < .1$, $\eta_p^2 = .66$]. Crucially, the interaction effect was also significant [$F(2,24) = 10.216$, $p < .1$, $\eta_p^2 = .46$].

10. Although the difference in intercepts was less than half the difference observed in Experiments 1B and 3A, the 48-msec difference was reliable [$F(1,12) = 17.728$, $p < .001$]. The difference in Franconeri et al. (2005, estimated from their Figures 2 and 3) was about 20 msec.

11. The intercepts of the baseline and the additional object/target trials for Experiments 1B, 3A, and 3B were analyzed as a 3 (experiment) $\times$ 2 (condition: baseline vs. additional object condition) ANOVA. The experiment effect was not significant ($F < 1$). There was an overall condition effect [$F(1,38) = 33.988$, $p < .001$, $\eta_p^2 = .47$], and, more crucially, a significant interaction effect [$F(2,38) = 3.513$, $p < .05$, $\eta_p^2 = .16$]. To unpack the interaction effect, an analogous ANOVA was run, comparing Experiments 1B and 3A revealed only an overall intercept effect, but crucially no experiment or experiment $\times$ condition effect, suggesting that the pattern is more or less the same in these two experiments. However, a similar ANOVA comparing Experiments 1B and 3B (in both of which, the configurations varied randomly) showed a significant experiment $\times$ condition interaction effect [$F(1,25) = 5.993$, $p < .05$, $\eta_p^2 = .19$]. Recall that in Experiment 1B, the additional object/target trials constituted only 10% of all trials, whereas in Experiment 3B, they constituted 50% of trials.

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