



ISSN: 1350-6285 (Print) 1464-0716 (Online) Journal homepage: <http://www.tandfonline.com/loi/pvis20>

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**To cite this article:** Geoff G. Cole & Gustav Kuhn (2009) Appearance matters: Attentional orienting by new objects in the precueing paradigm, *Visual Cognition*, 17:5, 755-776, DOI: [10.1080/13506280802611582](https://doi.org/10.1080/13506280802611582)

**To link to this article:** <http://dx.doi.org/10.1080/13506280802611582>



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## Appearance matters: Attentional orienting by new objects in the precueing paradigm

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Five experiments examined whether the appearance of a new object is able to orient attention in the absence of an accompanying sensory transient. A variant of the precueing paradigm (Posner & Cohen, 1984) was employed in which the cue was the onset of a new object. Crucially, the new object's appearance was not associated with any unique sensory transient. This was achieved by using a variant of the "annulus" procedure recently developed by Franconeri, Hollingworth, and Simons (2005). Results showed that unless observers had an attentional set explicitly biased against onset, a validity effect was observed such that response times were shorter for targets occurring at the location of the new object relative to when targets occurred at the location of the "old" object. We conclude that new onsets do not need to be associated with a unique sensory transient in order to orient attention.

**Keywords:** Attention; Vision; Onsets; New objects.

The notion that visual attention is "object-based" has represented one of the most fundamental aspects of visual cognition during the past two decades. The theory proposes that attention is directed to objects and perceptual groups that are parsed preattentively on the basis of Gestalt principles of perceptual organization (e.g., Driver & Baylis, 1989; Duncan, 1984). In other words, object-based theories suggest that incoming stimulus information is preattentively processed to the level at which objects are constructed. A corollary to this notion is the idea that the *appearance* of a new object can also be represented at a relatively high level (Yantis & Jonides, 1996). According to this account, representations of a subset of visible objects are continuously updated via cognitive mechanisms (e.g., *object-files*; Kahneman, Treisman, & Gibbs, 1992) enabling each to retain coherence over space and time. Attention is then allocated to a new object because its constituent

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This work was supported by UK Economic and Social Research Council grant RES-000-22-1766.

features are also preattentively segmented into figure and ground and hence the additional item is added to the already represented “old” objects. The visual system will therefore prioritize new onsets because they could potentially be behaviourally important.

A basic experimental procedure to assess this so-called *new object hypothesis* has been to present observers with a variant of a target detection task in which, crucially, the target either accompanies a new item or accompanies an object that has already been present in the display for some time (e.g., 500 ms). It has been fairly well established that targets associated with new onset accrue attentional priority relative to targets associated with an old item (e.g., Cole, Kentridge, & Heywood, 2005; Gellatly & Cole, 2000; Gellatly, Cole, & Blurton, 1999; Yantis & Jonides, 1984). In order to assess whether the appearance of the new item can be represented at a high level the new onset must not be accompanied by any greater low-level sensory change, such as changes in luminance or chrominance, than that which occurs at the old objects. In the seminal study by Yantis and Jonides (1984), observers were presented with a letter identification task in which the target either appeared abruptly (i.e., a new object) or was created by the offsetting of segments at a number of “figures-of-eight” (i.e., old objects) that had been present in the display for some time. This transformation of old objects into letters simultaneous with the new onset ensured that luminance transients occurred at all item locations. Additionally, the target appeared at each display item with equal probability, thus ensuring that the new object was task irrelevant. If attention is automatically directed to the new object, reaction time (RT) to detect a target that coincides with the new item should be independent of the set size (i.e. the number of search items in a display). Yantis and Jonides found that RT was indeed relatively unaffected by the number of display items when the target was a new object. By contrast, when the target occurred at one of the old objects, RT increased as the number of display items increased. Because of the luminance control whereby transients occurred at all items in the display these data suggested that new objects capture attention above and beyond transient detection. However, subsequent work suggested that the luminance change accompanying the new object was greater than that which accompanies the old items. For instance, Miller (1989) showed that increasing the amount of luminance change that occurs at the location of the old objects when they transform into letters abolishes the new object effect. Miller’s findings thus support the alternative theory to the new object explanation of capture, namely the *transient hypothesis*. Accordingly, capture by new objects is said to occur as a result of mechanisms that process luminance change, irrespective of whether it coincides with a new object or not (Franconeri & Simons, 2003).

One method for ensuring control of any sensory artefacts is to briefly offset old objects (e.g., Cole, Kentridge, Gellatly, & Heywood, 2003; Cole,

Kentridge, & Heywood, 2004; Cole, Kuhn, & Liversedge, 2007; Cole & Liversedge, 2006; Davoli, Suszko, & Abrams, 2007). When they reappear an additional (new) object joins the display. Because all new onsets and old object reappearances occur in the same manner the sensory transients that accompany each are identical. Indeed, presenting such a display-wide luminance signal ensures that the relatively small luminance transients that accompany the new and old objects are masked. This method is in effect analogous to a “one-shot” “flicker” change detection trial in which the visual display is disrupted momentarily (e.g., Rensink, O'Regan, & Clark, 1997; Simons, 1996; Simons & Rensink, 2005). Using this procedure, Cole et al. (2004) examined the degree to which a colour change, occurring at one of a number of old objects, is subject to change blindness relative to object appearance. Results showed that object appearance attenuated change blindness relative to colour change. Since onset accrued priority when any accompanying sensory transient was controlled its newness must have been represented at a relatively high level, or at least beyond the level at which sensory transients are processed.

Along a similar line of research, Brockmole and Henderson (2005a, 2005b) have investigating the way that newly appearing objects, with and without transient, influence participants' eye movements. In their experiments new objects were added to a scene either during a fixation, so that the onset retained a transient, or during a saccade so that the saccadic suppression eliminated the transient signal. Capture was then measured by the probability with which these new objects were fixated. Their results showed that even in the absence of a transient signal, participants were more likely to fixate the new object than was expected by chance, thus suggesting that new objects are prioritized even in the absence of a transient signal.

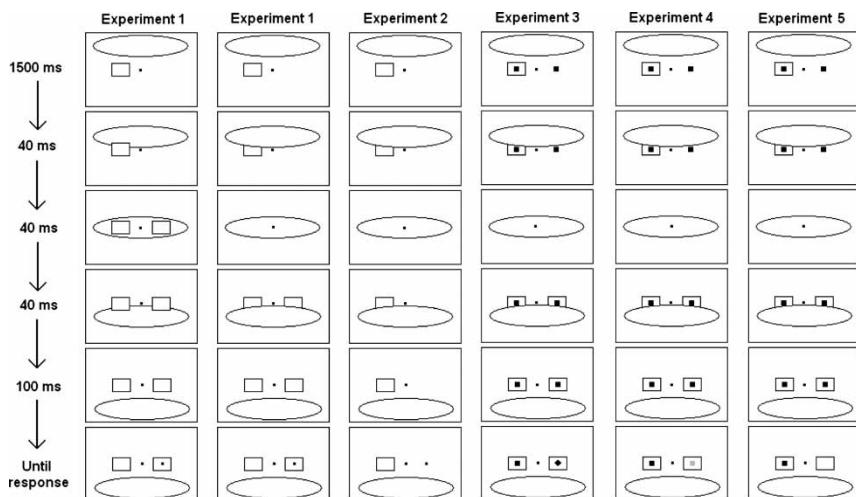
Employing a variant of the Yantis and Jonides (1984) procedure (already described), Franconeri, Hollingworth, and Simons (2005) provided a “definitive test” of whether object appearance can be represented at a high level. Their displays consisted of a placeholder array in which a number of figure-of-eights were surrounded by a large annulus. After 1000 ms, the annulus shrank, briefly occluding all the items before all reemerged. At the point of full occlusion the items changed into letters and a new letter appeared at a previously unoccupied location. Hence a single new object had appeared amongst an array of old objects. As with the experiments described earlier, this shrinking annulus procedure ensured that the new object appeared in an identical manner to that of the old objects reappearing, thus controlling for any unique sensory change. Results showed that RT to identify a target was not facilitated when it coincided with the new item relative to when it coincided with one of the old items. By contrast, in a control condition in which the annulus passed *behind* the display items, so that the transient accompanying the new onset was now visible, the

new object captured attention. Franconeri et al. concluded that new objects do not capture attention in the absence of an associated luminance transient. In other words, the visual system does not represent the appearance of a new object at a high level.

The principle aim of the present experiments was to reexamine whether new objects can indeed capture attention using one of the most robust and sensitive measurement of attentional orienting. We employed the annulus method of Franconeri et al. (2005) together with the precueing paradigm (Posner, 1980). The precueing procedure is one of the most widely used paradigms for examining issues of visual attention and has thus provided the basis for many developments within the field. For instance, the method has lead to the discovery of inhibition of return (Posner & Cohen, 1984) and the development of object-based attention (Egly, Driver, & Rafal, 1994). In the standard procedure, participants are presented with a peripheral "cue" that occurs approximately 100 ms before the onset of a simple target (e.g., a small dot). The cue is usually a luminance change presented at one of two outline boxes, one positioned either side of a centrally located fixation point. The critical analysis concerns the spatial relationship between the cue and target. When the target appears at the same location as the cue (i.e., "valid trials"), a reduction in RT is observed relative to when the target appears in the opposite location (i.e., "invalid" trials). The usual explanation is that the cue initiates a movement of attention towards itself thereby enhancing the processing of any stimuli that falls within the attended area. Stimuli occurring outside this region are not subject to the same degree of facilitation.

Given the sensitivity of the precueing paradigm to attentional orienting, we reasoned that if new objects can indeed capture attention in the absence of an accompanying luminance transient then capture should occur when the cue is the onset of a new object. Figure 1 illustrates our basic method for the five experiments reported. Each trial began with a placeholder display in which a single box was present on either the left or right side of fixation. Positioned above was an oval shaped disc analogous to Franconeri et al.'s (2005) annulus object. After 1500 ms, the disc moved down the display passing over the box before coming to rest at the bottom of the display. This movement occurred over the course of 120 ms. Simultaneous with the reappearance of the old object, a new object appeared at the opposite location. The target then occurred inside either the new item or old item.

Following the rationale of Franconeri et al. (2005), if new objects attract attention then we should observe a classic validity effect (i.e., faster RTs for valid than invalid trials). By contrast, if new objects rely on their accompanying luminance transient in order to capture attention then no validity effect should be observed because the luminance change associated with the new object is equal to that associated with the old object. In each



**Figure 1.** The trial sequence in all five experiments. The target is shown at the valid location in all the examples shown, with the exception of Experiment 2 in which the target is shown appearing at the “non-old object” location. Although the disc moved both in front and behind the display in all experiments, the behind condition is only shown for Experiment 1 (the extreme left-hand column). Additionally, the colour change target in Experiment 4 is represented here as a change in grey level.

experiment we also included a control condition in which the disc moved behind the old and new objects. Since the transient associated with the new onset was now visible we expected a validity effect to occur for this condition.

## EXPERIMENT 1

In Experiment 1 we carried out an initial experiment to examine whether we would observe a precueing type validity effect as described earlier. The procedure is shown in Figure 1. As with the basic precueing paradigm (Posner & Cohen, 1984), participants were required to respond as quickly as possible to the appearance of a small target dot.

### Method

*Participants.* Sixteen undergraduate psychology students took part in return for payment.

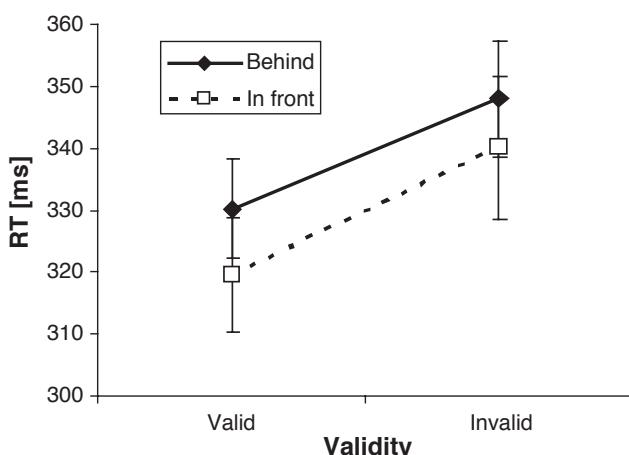
*Stimuli and apparatus.* The old and new objects were outline boxes measuring  $3.8^\circ$  in height and width. The thickness of the lines was  $0.5^\circ$ . The boxes were located  $4.2^\circ$  to the left and right of the fixation point measured to the nearest edge of the boxes and were black measuring  $0 \text{ cd}/\text{m}^2$ . The

occluding disc was also an outline figure measuring 7.6° in height and 21.8° in width. The thickness of its line was one pixel. The disc was initially located 3.1° above the fixation point measured to its nearest edge. Its final position was 3.1° below the fixation point. The occluding disc was the same level of grey as the background (28 cd/m<sup>2</sup> in luminance) with its outline being 7 cd/m<sup>2</sup>. The x, y coordinates of this outline, measured in CIE colour space (using a Cambridge Research Systems ColorCal chromameter), was 0.299 (x) and 0.318 (y). The CIE coordinates of the grey background was 0.289 (x) and 0.304 (y). The target was a small round disc measuring 0.23° in diameter and was 7 cd/m<sup>2</sup> in luminance (CIE coordinates, 0.299 [x] and 0.318 [y]). The experiment was carried out in a single dimly lit room and was driven by a Pentium PC running at 60 Hz linked to an Eizo CRT colour monitor.

*Design and procedure.* A within-participant, 2 × 2 factorial design was used. The first factor was the location of the target with respect to the new object; targets appeared either at the location of the new onset (i.e., valid) or at the old object (i.e., invalid). The second factor manipulated whether the large disc moved in front of the display items or behind. The trial sequence is shown in Figure 1. Each trial began with the presentation of a placeholder display, containing one box. After 1500 ms, the disc moved quickly down the display in four successive steps. The old object was fully occluded for 40 ms during which time the new object appeared. In the occlusion condition the disc passed in front of the old object; in the nonocclusion condition the disc passed behind. The target appeared 100 ms after the disc had stopped. The target display remained until the participant responded and the beginning of a trial was initiated by the participant's response on the previous trial. Observers were seated approximately 80 cm from the display and were explicitly told to ignore the figures and events occurring in the "background", just to simply respond as soon as they detected the small target. They were also instructed to maintain fixation for the entire duration of each trial and that although speed was paramount they should refrain from responding on "catch" trials. One hundred and ninety-two trials were presented equally divided between the four conditions. Targets and new objects occurred on the left or right with equal frequency. Additionally, a further 48 (20%) trials were presented in which no target appeared. These acted as catch trials and terminated automatically 2 s after the disc stopped. Hence, a total of 240 trials were presented in the experiment. Twenty-four practice trials were given following a demonstration trial. All trial types were presented in a random order.

## Results and discussion

All RTs lying outside 2 standard deviations for each participant's condition mean were omitted from analysis, resulting in the removal of 6.1% of responses. Participants responded on 5.7% of catch trials. Mean RTs for the four conditions are shown in Figure 2. A two-way ANOVA with disc passage (passing behind or in front of the objects) and validity (valid vs. invalid) as the two factors found no significant main effect of disc passage,  $F(1, 15) = 3.7, p < .08, \eta_p^2 = .2$ , but a significant main effect of validity,  $F(1, 15) = 16.1, p < .001, \eta_p^2 = .52$ . Thus, targets appearing at valid locations were detected significantly more quickly than those appearing at invalid locations. There was, however, no significant interaction,  $F(1, 15) < 1$ . Although the lack of an interaction demonstrates that the validity effect was as great in both passage conditions, we carried out two separate *t*-tests to examine whether the validity effects were both significant. There was indeed a significant effect when the disc passed behind the display,  $t(15) = 4.6, p < .001$ , as well as when it passed in front,  $t(15) = 3.3, p < .005$ . The critical aspect of these data is that a validity effect occurred in both passage conditions. In other words, the new object oriented attention regardless of whether luminance information was available or not. This demonstrates that the processing of such transients is not necessary for new objects to attract attention.



**Figure 2.** Results from Experiment 1 showing mean RTs for valid and invalid trials when the moving disc passes in front and behind the objects.

## EXPERIMENT 2

The results from Experiment 1 suggest that capture occurred as a consequence of new object appearance. This clearly implies that an *enhancement* of processing occurred at the location of the new object. However, these data could also have resulted from *inhibitory* processes, rather than facilitatory processes. It is now well established that a period of inhibition occurs at an object that initially attracted attention (Posner & Cohen, 1984). Recall that in our trial sequence an old object appears for over 1500 ms before the new object onsets. During this period, "inhibition of return" may well have been initiated at the old object location. Consequently any target appearing at the old object may have been subject to elevated RTs, thus giving rise to the new object advantage in the absence of capture. In Experiment 2 we examine whether inhibition of return can account for the new object effect observed in Experiment 1. We employed the same procedure with the sole exception that no new object appeared; only the single old object appears (at trial onset). The target then occurred either at the location of the old object or at the non-old object location (i.e., in empty space on the other side of fixation). If inhibition of return was indeed occurring at the old object then targets appearing at this location should be subject to longer RTs relative to targets located at the non-old object location.

### Method

All aspects of the method were identical to that described for Experiment 1 with the sole exception that no new object occurred. Thus, each trial began with the placeholder display in which a single box was present on either the left or right side of fixation. After 1500 ms, the large disc located above the box moved down the display passing either in front or behind the box before coming to rest at the bottom of the display. The target then occurred either inside the box (i.e., old object) or else on the other side of the fixation point. That is, at the location where the new object occurred in Experiment 1. The only other exception to the method of Experiment 1 was that 20 participants took part.

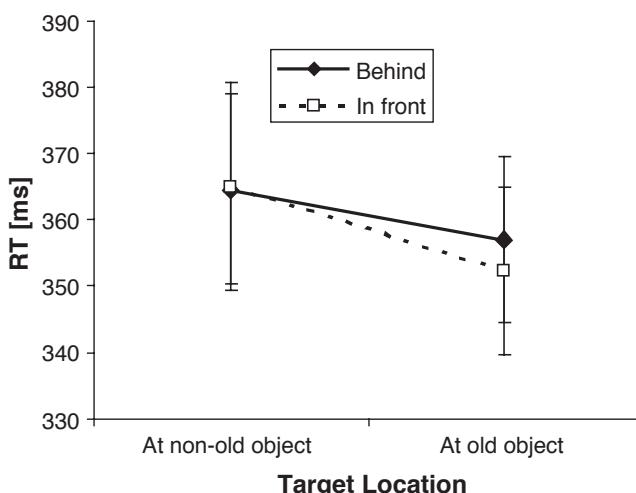
### Results and discussion

Due to a high number of responses on catch trials (35%) one participant's data was excluded. All other RTs lying outside 2 standard deviations for each participant's condition mean were also omitted from analysis. Outliers resulted in the removal of 5.9% of responses. Catch trials accounted for 4.6%

of responses. Mean RTs for the four conditions are shown in Figure 3. A two-way ANOVA, with disc passage (in front or behind the old object) and location of target with respect to the old object as factors, found no significant main effect of passage,  $F(1, 18) < 1$ , but a significant main effect of target location,  $F(1, 18) = 5.0, p < .05, \eta_p^2 = .22$ . There was no significant interaction,  $F(1, 18) < 1$ . These data and Figure 3 clearly show that inhibition of return did not occur at the location of the old object. Indeed, rather surprisingly, targets at this location were detected significantly *more quickly* than those appearing at the non-old object location. The results suggest that the initial appearance of the old object at the beginning of each trial attracted attention and this facilitation was still present when the target appeared 1720 ms later.

The length of time with which the old object attracts attention is one of the more puzzling aspects of the current findings. One possibility is that observers keep attending to the object in order to determine whether it changes in some way after the large disc passes. However, regardless of the reason for this facilitation the critical finding is that the new object advantage observed in Experiment 1 is due to the new object attracting attention rather than the old object suffering inhibition.

Additionally, we carried out a control experiment in order to examine whether it was visibly easier to detect the presence of a target occurring at the old object compared with targets occurring at the non-old object location (i.e., empty space). It is possible, for instance, that old object targets were easier to detect because they appeared at a well-defined location, i.e.,



**Figure 3.** Results from Experiment 2 showing mean RTs when the target appears at the old object location and when it appears at the non-old object location.

inside the old object. By contrast, targets appearing at the non-old object location did not occur at such a well-specified position. In the control experiment, observers were asked to make a speeded response to the appearance of a target that occurred either inside one of our objects or outside. In one block of 96 trials the object was located on the left side of fixation and in the other (counterbalanced) block the box was located on the right side. The object appeared at the beginning of a block and remained on-screen for the entire duration of the block. Hence, apart from the first trial, there were no new or old objects. Furthermore, the large disc was not present. Results showed no difference in the detectability of targets located inside ( $M = 316$ ,  $SD = 37$ ) or outside the object ( $M = 317$ ,  $SD = 36$ ),  $t(15) = 0.020$ . This control experiment thus demonstrates that the RT advantage for targets appearing at the old object in Experiment 2 was due to these objects attracting attention as a result of their appearance at trial onset.<sup>1</sup>

### EXPERIMENT 3

The results from Experiment 2 show that the new object capture effect observed in Experiment 1 was not due to inhibition of return occurring at the old object. However, in order to examine whether the appearance of a new object can truly capture attention in the absence of a unique transient we also need to assess whether the results from Experiment 1 occurred solely as a result of a particular attentional set commonly referred to as “contingent attentional capture”.

Attentional capture is modulated both by top-down observer contingencies and bottom-up features of the visual environment. Folk, Remington, and Johnston (1992) investigated the circumstances under which capture

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<sup>1</sup> We also repeated Experiment 1 whilst monitoring for saccades (using EyeLink II) in order to evaluate whether the onset advantage was due to strategic eye movements, rather than involuntary capture. Eye movements were detected for each individual trial using EyeLink II saccade detection algorithm (saccade velocity  $>30^\circ/\text{s}$ , acceleration  $>8000^\circ/\text{s}^2$ , amplitude  $>2^\circ$ ). A trial was defined from the onset of the first display to the manual response. Using this criterion, saccades were detected on 13.4% of trials ( $SD = 12.2\%$ ). All such trials were removed for the subsequent analysis. When the moving disc passed in front, participants RTs for valid trials ( $M = 307$ ,  $SD = 32.9$ ) were significantly shorter than for invalid trials ( $M = 334$ ,  $SD = 42.7$ ),  $t(11) = 4.15$ ,  $p = .002$ . When the moving disc passed behind, RTs for valid trials ( $M = 325$ ,  $SD = 37.4$ ) were again significantly shorter than for invalid trials ( $M = 340$ ,  $SD = 29.1$ ),  $t(11) = 3.03$ ,  $p = .01$ . We also ran an analysis testing whether our results were influenced by the eye movements by including eye movement as an extra variable. Data from four participants were excluded as they did not make any eye movements in one or more of the conditions. There was no significant Eye movement  $\times$  Validity interaction,  $F(1, 7) = 1.75$ ,  $p = .23$ , no significant Eye movement  $\times$  Occluder interaction,  $F(1, 7) < 1$ , and no significant Eye movement  $\times$  Occluder  $\times$  Validity interaction significant,  $F(1, 7) < 1$ . As the eye movements did not interact with any of the variables of interest, we are confident that the results are not influenced by eye movements.

occurs by modulating aspects of an observer's top-down goals. The authors showed that a particular visual cue has a greater chance of attracting attention if participants have an *attentional control setting* that includes features of the cue. For instance, a luminance cue is more likely to attract attention if the target is defined by luminance compared to when the target is defined by colour. Conversely, a colour cue is more likely to attract attention if the target is defined by colour compared to when the target is defined by luminance (Folk et al., 1992). Hence, what might at first appear to be bottom-up attentional capture by a particular visual feature may in fact be an example of top-down orienting. Additionally, contingent attentional capture has been shown to operate over various types of stimuli and cues, including onsets (Atchley, Kramer, & Hillstrom, 2000). In the present Experiment 1 participants were set to detect onset because the target was the appearance of a small dot. Indeed, an attentional set for onset is inherent in the basic precueing paradigm (Posner & Cohen, 1984). Given that the stimulus of interest (i.e., the new object) was also defined by onset, the results may only reflect a top-down bias towards anything that onsets. In Experiment 3 we therefore examined whether a new object would orient attention when participants were not set to look for onset. The precueing procedure used in Experiment 1 was replicated with the critical exception that participants were required to respond as quickly as possible to a change in the shape of one of two probe objects. These probes were located at the new and old objects and were present throughout each trial (see Figure 1).

## Method

*Participants.* Sixteen new undergraduate psychology students took part in return for payment.

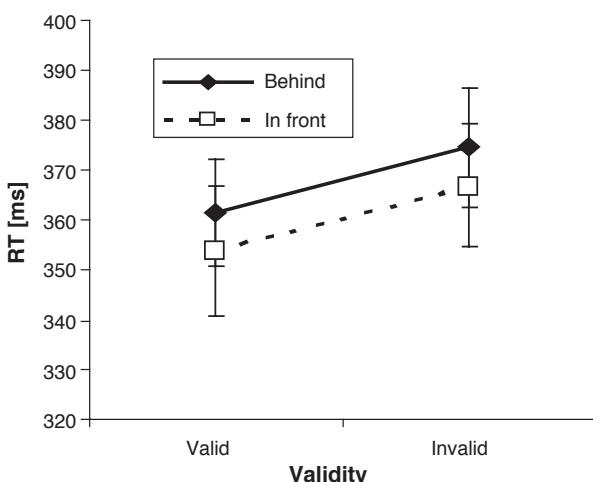
*Stimuli and apparatus.* All aspects of the stimuli, including size and location, were identical to those described for Experiment 1 with the exception that the target was a change in shape from a square to a diamond. Both the square and diamond measured 0.8° along each edge. The monitor used to present the stimuli was an Iiyama as opposed to the Eizo used in Experiments 1 and 2.

*Design and procedure.* All aspects of the design were as described for Experiment 1. Thus a within-participant, 2 × 2 factorial design was used with validity (valid vs. invalid) and passage of the large disc (in front vs. behind) as within-subject factors. The trial sequence is shown in Figure 1. Each trial began with the presentation of the placeholder display containing one box, located either on the right or left side of fixation, and two small probe squares. When the occluding disc completed its movement at the

bottom of the display one of the two probes changed into a diamond. Participants were asked to respond as quickly as possible to this shape change whilst avoiding responding on catch trials. All other aspects of the procedure were identical to that described in Experiment 1 including the total number of trials presented and the time course of the events in each trial display.

## Results and discussion

All RTs lying outside 2 standard deviations for each participant's condition mean were omitted from analysis, resulting in the removal of 5.8% of all responses. Participants responded on 5.9% of catch trials. Figure 4 presents mean RTs for all four conditions. A two-way ANOVA with validity and disc movement as within-subjects factors found a significant main effect of validity,  $F(1, 15) = 11.0, p < .05, \eta_p^2 = .42$ , and a significant main effect of disc passage,  $F(1, 15) = 5.2, p < .05, \eta_p^2 = .26$ . No significant interaction was observed,  $F(1, 15) < 1$ . As with Experiment 1, we carried out two separate *t*-tests to examine whether the validity effects were significant in both disc passage conditions. A significant effect occurred when the disc passed behind the display,  $t(15) = 2.3, p < .04$ , as well as when it passed in front,  $t(15) = 2.6, p < .02$ . An unexpected result of Experiment 3 was the significant main effect of disc passage whereby overall RTs were longer when the large disc passed



**Figure 4.** Results from Experiment 3, showing mean RTs for valid and invalid trials when the moving disc passes in front and behind the objects.

in front of the objects. We leave the discussion of this effect for the General Discussion.

In accordance with the results from Experiment 1, the central finding from Experiment 3 is that a validity effect has again been observed when the visibility of the cue (i.e., new object) was masked as a consequence of the disc moving in front of the display. Since this method eliminates any unique sensory transient accompanying the new object, these results again suggest that new objects do not rely on luminance change in order to attract attention. Importantly, we have observed this new object effect when observers were set to detect a change in the shape of an object rather than set to look for onset. These data therefore provide stronger evidence that new objects can orient attention via relatively high-level mechanisms.<sup>2</sup>

## EXPERIMENT 4

The principle aim of Experiment 4 was to examine whether the new object would still orient attention when we included an additional control designed to further reduce top-down influence. The experiment would also allow us to assess the robustness of the new onset effect. The task in Experiments 1 and 3 was to detect an onset or a shape change, both of which coincided with a change in luminance contrast. Observers therefore may have adopted the strategy of looking for any luminance difference that occurred between the large disc starting and finishing its movement. Because the onset itself was also defined by a change in luminance contrast, capture may have been influenced by a top-down attentional set for an overall luminance change. This is not unlikely given the finding that contingent attentional capture can operate in extremely subtle ways. For instance, following Gibson and Kelsey (1998), Atchley et al. (2000) showed that attention can be set by properties that signal the appearance of the whole search display and not solely by properties that may only define a target. Using a variant of a cueing paradigm, Atchley et al. found that an onset cue attracted attention when the search display occurred as a result of appearance. By contrast, the same onset no longer attracted

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<sup>2</sup> We again tested the inhibition of return hypothesis (see Experiment 2) using shape change (i.e., the target used in Experiment 3) as the target. In other words, we replicated Experiment 2 with the sole exception that observers were required to detect shape change rather than onset (14 participants were also used). It is possible that, for instance, inhibition of return was occurring at the old object in Experiment 1 but the effect was overridden because observers were adopting an attentional set for onset. Again, results showed an overall main effect such that targets located at the old object were subject to reduced RTs ( $M = 361$ ,  $SD = 46$ ) compared with targets located at the non-old object position ( $M = 379$ ,  $SD = 47$ ),  $F(1, 13) = 14.2$ ,  $p < .01$ . We also observed a main effect whereby RTs were shorter when the moving disc passed in front of the old object ( $M = 355$ ,  $SD = 53$ ) compared to when it passed behind ( $M = 386$ ,  $SD = 40$ ),  $F(1, 13) = 15.8$ ,  $p < .01$ .

attention when the search display occurred as a result of disappearance. That is, when figure-of-eight placeholders shedded segments to form letters, as in the procedure of Yantis and Jonides (1984; see introduction). The critical difference was that in the latter procedure the search display was no longer defined by onset, instead being defined by offset (of figure-of-eight segments). Given the subtlety of contingent attentional capture, Experiment 4 therefore presented targets that were defined as a change in colour rather than a change in luminance (see Figure 1).

## Method

*Participants.* Sixteen undergraduate psychology students took part in return for payment. None of the participants took part in any of the other experiments.

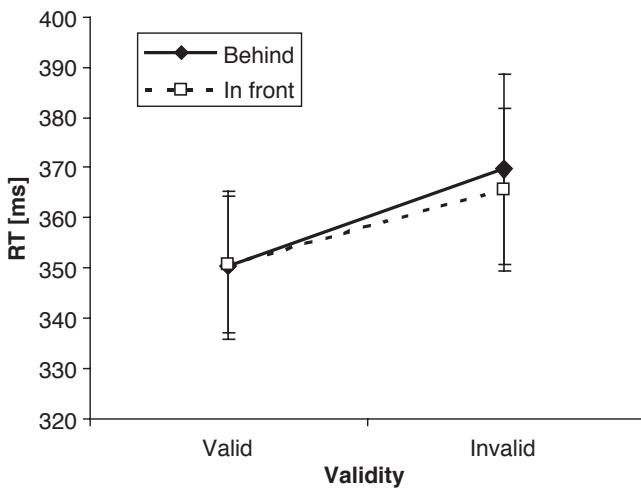
*Stimuli and apparatus.* All aspects of the stimuli were as reported for Experiment 1, with the exception that the target was a change in colour that occurred at one of two small squares that were present throughout each trial. The two squares were initially red ( $28 \text{ cd/m}^2$ , CIE coordinates, 0.382 [x] and 0.316 [y]) before one changed to purple ( $28 \text{ cd/m}^2$ , CIE coordinates, 0.287 [x] and 0.194 [y]).<sup>3</sup> They measured  $0.8^\circ$  along each side.

*Design and procedure.* All aspects of the design were as described previously. With respect to the procedure, each trial began with the placeholder display which contained the single box and two small squares; one located either side of fixation. When the disc completed its movement one of the two squares changed colour. Participants were asked to respond as quickly as possible to this colour change whilst avoiding responding on catch trials. All other aspects of the procedure were as described previously.

## Results and discussion

All RTs lying outside 2 standard deviations for each participant's condition mean were omitted from analysis, resulting in the removal of 6.0% of all responses. Participants responded on 8.2% of catch trials. Figure 5 presents mean RTs. A two-way ANOVA with validity and disc passage as within-subject variables found a significant main effect of validity,  $F(1,$

<sup>3</sup> One cannot of course guarantee that a change in colour will not also result in a change in luminance. Equiluminance can be defined as equivalence on-screen, equivalence at the retinal image, or equivalence at postretinal neural responses (see Cavanagh, Adelson, & Heard, 1992). The luminance of our targets therefore was equated physically rather than psychophysically.



**Figure 5.** Results from Experiment 4 showing mean RTs for valid and invalid trials when the moving disc passes in front and behind the objects.

$15) = 6.3$ ,  $p < .03$ ,  $\eta_p^2 = .3$ , but no significant main effect of passage,  $F(1, 15) < 1$ , nor a significant interaction between the two,  $F(1, 15) < 1$ . Separate  $t$ -tests were carried out to examine whether the validity effect was significant in both disc passage conditions. A significant effect occurred both when the disc passed behind the display as well as when it passed in front,  $t(15) = 2.4$ ,  $p < .05$ , and  $t(15) = 2.2$ ,  $p < .05$ , respectively. As with Experiments 1 and 3, we have again observed a validity effect both when the appearance of the new item was visible and when it was hidden by the moving disc. Importantly, this effect occurred in the absence of an attentional set relating to the new object.

## EXPERIMENT 5

In our final experiment, we examined the propensity with which the new object could orient attention when participants' attentional set was explicitly biased against the onset item. Participants were required to respond as quickly as possible to the *offset* of a probe dot. Each trial began with two small squares, one located inside the old object and the other positioned where the new object would appear (see Figure 1). When the large disc completed its movement at the bottom of the display one of the two small squares disappeared. Detecting offset may therefore be seen as the opposite response set to detecting onset. This will thus represent a relatively strict assessment of whether the onset item can attract attention.

## Method

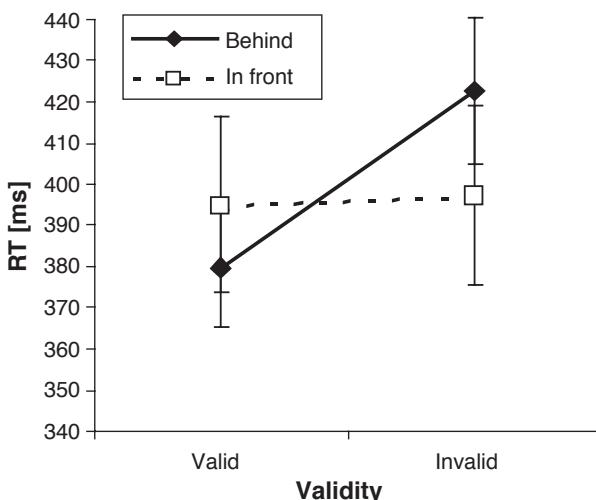
*Participants.* Ten undergraduate psychology students took part in return for payment. None had taken part in any of the previous experiments.

*Stimuli and apparatus.* All aspects of the stimuli and apparatus were as described previously. All properties of the two probe squares were as described for Experiment 3.

*Design and procedure.* All aspects of the design and procedure were as described previously. The only exception to this was that two squares were located either side of the fixation point at the beginning of each trial. One of these then disappeared, representing the target.

## Results and discussion

RTs lying outside 2 standard deviations for each participant's condition mean were omitted from analysis, resulting in the removal of 5.4% of all responses. Participants responded on 10.8% of catch trials. Figure 6 presents mean RTs for each condition. A two-way ANOVA found a significant effect of validity,  $F(1, 9) = 7.8$ ,  $p < .05$ ,  $\eta^2_p = .47$ , but no significant effect of disc passage,  $F(1, 9) < 1$ . However, there was a significant validity  $\times$  disc passage



**Figure 6.** Results from Experiment 5, showing mean RTs for valid and invalid trials when the moving disc passes in front and behind the objects.

interaction,  $F(1, 9) = 13.6$ ,  $p < .005$ ,  $\eta_p^2 = .6$ . Separate *t*-tests revealed a significant effect of validity when the large disc passed behind the objects,  $t(9) = 4.5$ ,  $p < .001$ , no such effect occurred when the disc passed in front,  $t(9) < 1$ . Overall, these data show that, given an attentional set biased against onset, the new object was only able to orient attention when its associated luminance transient was visible. When the transient was masked by the moving disc, no capture occurred. This suggests that an onsetting object is not able to attract attention at a relatively high level when observers are set to detect offset. These findings thus demonstrate that attentional orienting by the appearance of a new object is not inevitable. Aspects of an observer's attentional set will modulate whether capture occurs, as shown in the contingent attentional capture work (Folk et al., 1992). Interestingly though, the onset *was* able to attract attention when its associated transient was visible, despite the target being defined by offset. This suggests that an onset transient is able to override the affects of an observers attentional set.

The significant interaction observed in Experiment 5 is also important in demonstrating the validity of the occluder method. The fact that an orienting effect was observed in one condition and not the other shows that the disc procedure is sensitive enough to reveal differences when sensory transients are or are not available. This demonstrates that the absence of an interaction in Experiments 1, 3 and 4 was not due to our procedure being unable to find any differences in capture when the new item was or was not defined by a sensory transient.

## GENERAL DISCUSSION

In a series of five experiments we have assessed whether the appearance of a new object is able to capture attention in the absence of an accompanying sensory change. The precueing paradigm (Posner & Cohen, 1984) was employed together with a variant of the 'annulus' procedure of Franconeri et al. (2005). In Experiment 1, a new object induced a validity effect (i.e., attentional orienting) both when its luminance transient was visible and when it was occluded. Experiment 2 ruled out an account based on inhibition of return occurring at the old object. Given that the basic precueing procedure requires the detection of an onset, we carried out two further experiments eliminating the potential confound whereby observers are set to detect the same feature as the feature being examined for capture (i.e., onset). As Folk et al. (1992) showed, if an observer is looking for an onset, a different onset stimulus is likely to attract attention because of a top-down attentional set for object appearance. In Experiments 3 and 4 therefore, participants were required to detect shape change and colour change respectively. Again we observed attentional orienting by the new

item. In Experiment 5 we examined capture by the onset when participants were looking for *offset*. This represented a stricter assessment of whether new objects attract attention, because observers were set to detect disappearance as opposed to appearance. Unlike the results from Experiments 1, 3, and 4, the new object only oriented attention when its sensory transient was visible.

Taken together these data show that a low level sensory transient is not necessary for attentional orienting by object appearance; new objects can indeed attract attention. Importantly however, capture is not inevitable. The new object failed to attract attention if observers' attentional set was biased against onset. As Yantis and Jonides (1990) showed, capture by new objects can be overridden by a participant's goals and task demands; if the detection of new objects is detrimental to a task new objects may fail to attract attention. It is perhaps therefore not surprising that the new object failed to attract attention when observers were set to look for an offsetting object (i.e., the target probe). Our findings thus provide limited support for the new object hypothesis as well as revealing some limits of attentional capture by new objects. When attentional control settings were set at "neutral", that is, when observers were set to detect a property orthogonal to the cue (shape change and colour change), the new item attracted attention both when its sensory transient was and was not visible. It is interesting to note that although capture by the appearance of a new object was susceptible to attentional set, capture by the same event (i.e., object onset) when accompanied by luminance change was not susceptible to attentional set; even when observers were set to detect offset (Experiment 5) the new object captured attention when the large moving disc passed behind the objects. This suggests that luminance change is a more robust cue than a new object in attracting attention.

Although Franconeri et al. (2005), unlike the present results, failed to observe a new object effect, our results do not necessarily refute their findings. The debate concerning attentional capture by object appearance often conceives onset as either being represented by high level mechanisms (i.e., the new object hypothesis) or is the result of lower level luminance processing (i.e., the transient hypothesis). Experiments such as the current series, and Franconeri et al.'s, are clearly designed to examine which of these two opposing theories better explains capture. However, a more likely scenario is that neither wholly explains capture but each plays a role; the real issue is the degree to which each contributes. The new object hypothesis presumes that incoming signals are preattentively processed to the level at which objects are constructed and that new objects are also afforded this level of processing (e.g., Yantis & Jonides, 1996). However, the strong version of this theory cannot explain the existence of the change blindness phenomenon (e.g., Simons, 1996). The detection of change in this paradigm

requires relatively high-level representation of the to-be-compared images. These representations clearly fail, thus refuting the new object hypothesis.<sup>4</sup> By contrast, the strongest version of the transient hypothesis, which presumes that all capture occurs as a result of sensory (i.e., luminance) processing, is also unlikely to be true; results from the present experiments suggest this. Additionally, experimental work shows that most types of luminance change will not strongly capture attention (Enns, Austen, Di Lollo, Rauschenberger, & Yantis 2001), although some clearly do. Hence, the more pertinent issue is not whether the strong versions of the new object or transient hypotheses better explains capture but rather the limits of each. Within this context, we can conclude from the present results that although the strongest version of the new object hypothesis is unlikely to be true, as Franconeri et al. (2005) showed, a less stringent version can explain capture.

Indeed, results from research that address the new-object and transient hypothesis are not likely to support or refute either, rather they will provide evidence for the circumstances under which either provides a contribution to attentional orienting. For instance, Brockmole and Henderson (2005a) have observed that prioritization for new objects during a saccade (i.e., when the luminance transient is eliminated) is affected by participants' *memory* for the scene. Specifically, repeated viewing of a scene resulted in higher prioritization than when the scene was viewed only once. That is, new objects that are not accompanied by a transient signal are only prioritized if the observer can form a representation of the "new object". Considering this, Franconeri et al. and the present work clearly differ with respect to how the new and old objects are represented. In our experiments only one old object was present before the new item joined the display. Franconeri et al., by contrast, presented the new object amongst up to three old objects. Thus, the availability of memory is likely to result in the testing of a less stringent version of the new object hypothesis. In our more impoverished displays, it would have been hard for participants not to register the new object as being new. Indeed, the different findings of the present work and Franconeri et al.'s could be due to differences in methodology. For instance, although Franconeri et al.'s annulus procedure provides a definitive control for sensory change, evidence suggests that the manipulation of display size is not the most sensitive method for indexing attentional capture. Turatto, Galfano, Gardini, and Mascetti (2004), for example found that "colour

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<sup>4</sup> Undetected changes may lead to reductions in RT at the changed but unnoticed location. This implies that attention can be oriented to stimulus features that have not been detected. See Fernandez-Duque and Thornton (2000), Laloyaux, Destrebecqz, and Cleeremans (2006), and Mitroff, Simons, and Franconeri (2002) for discussion.

singletons" failed to attract attention when capture was measured by examining slope ratios based on display size manipulation. By contrast, when capture was indexed by assessing each display size independently and simply considering targets as being associated with valid and invalid cues, priority for singletons was found.

One final issue concerns the significant main effect of disc passage. In four of the seven moving disc experiments reported here we observed an effect whereby RTs were shorter when the disc passed in front of the display objects compared to when the disc moved behind.<sup>5</sup> One possible explanation concerns differences between the two conditions with respect to overall display-wide luminance change and a resulting alerting effect. When the occluder passes in front of the display items there is a luminance flicker at the old object (as a consequence of its disappearance/reappearance) as well as a luminance change at the new object location (as a consequence of object appearance). By contrast, when the occluder passes behind the display items there is no luminance flicker at the old object; the only luminance change occurs at the new object. Therefore, because there is less display-wide luminance change in the behind condition, the overall alerting effect is less, resulting in slower RTs.

We carried out a final experiment in which we examined whether this "in-front" effect occurs independently of new and old objects; we were concerned that the effect was somehow related to our new/old manipulation. The experiment employed the same procedure as Experiment 1 with the sole exception that two objects were present at the beginning of each trial (one on either side of fixation) rather than just one. That is, two old objects and no new objects. This enabled us to examine the in front/behind effect in isolation when no shift in spatial attention occurs. We again observed the effect such that RTs were shorter when the moving disc passed in front of the objects ( $M = 307$  ms,  $SD = 40$ , and  $M = 320$  ms,  $SD = 33$ , respectively),  $t(19) = 3.0$ ,  $p < .01$ . These data thus show that the effect is a general transient visible/occluded effect. Additionally, a similar effect occurs in other paradigms where an event's transient is visible in one condition but not in another (e.g., Welsh et al., 2005).

<sup>5</sup> The seven experiments include *all* our experiments we have made reference to. That is, all including control experiments (see discussion to Experiment 2 and Footnotes 1 and 2). Additionally, the in-front main effect narrowly failed to reach conventional statistical significance in Experiment 1.

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Manuscript received April 2007

Manuscript accepted May 2008

First published online February 2009