Title: When Something Old Becomes Something New: Spatiotemporal Object Continuity and Attentional Capture

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Two modes of attentional deployment are typically contrasted: one voluntary, the other involuntary. The latter is often referred to as exogenous orienting or attentional capture. Although folk psychology and personal experience suggest that most salient objects and events draw attention to themselves in a largely involuntary fashion, experiments have failed to support this assumption. The results of these experiments indicate that neither salient color differences (e. g., Gibson & Jiang, 1998; Jonides & Yantis, 1988; Theeuwes, 1990; S. Todd & Kramer, 1994; Yantis & Egeth, 1999) nor changes in luminance (e. g., Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Yantis & Hillstrom, 1994) capture attention independent of the observer's intentions to make strategic use of these highly distinguishable properties. The only event that appears to capture attention reliably in a stimulus-driven fashion is the appearance of a new perceptual object (see Jonides & Yantis, 1988; Yantis, 1993, 2000; Yantis & Egeth, 1999; Yantis & Hillstrom, 1994; but see also Folk, Remington, & Johnston, 1992; Gibson 1996a, 1996b; Gibson & Kelsey, 1998). This general finding has been formulated by Yantis (1993; Yantis & Hillstrom, 1994) as what has been referred to as the new object hypothesis of attentional capture (cf. Enns et al., 2001; Thomas & Luck, 2000).

Recently, reports have begun to emerge in the literature that events other than the
appearance of new objects capture attention in a stimulus-driven fashion. For example, Franconeri and Simons (2001) and Thomas and Luck (2000) found that abrupt color changes capture attention, and Theeuwes (1990) observed attentional capture by abrupt shape changes. According to predictions from a literal reading of the new object hypothesis (cf. Yantis & Hillstrom, 1994), only new objects should capture attention, but changes to existing objects should not (cf. Irwin, Colcombe, Kramer, & Hahn, 2000). From this perspective, the finding that abrupt color changes or abrupt shape changes capture attention may seem surprising. It lends credibility to the suggestion that new objects capture attention because of the attendant feature changes (cf. Enns et al., 2001; Thomas & Luck, 2000), in which case capture by new objects would represent only a special instance of capture by featural changes. This reading of Yantis and Hillstrom (1994), however, neglects to place the necessary emphasis on the perceptual novelty of the new object.

The experiments reported in the following were designed to address precisely this possibility. For this purpose, a modified version of Folk et al.'s (1992) contingent capture paradigm was used. In this paradigm, only a cue that matches the participant's attentional set will capture attention. If the participant is set for a red target, for example, a red cue will capture attention but an abrupt onset cue will not—and vice versa. Underlying the contingent capture paradigm, therefore, is a form of perceptual categorization by the visual system: Only stimuli assigned to the proper category will produce contingent capture. The goal of the present experiments was to determine whether featural changes will ever be classified by the visual system as equivalent to perceptually new objects and, if so, at which magnitude of change. To answer that question, participants were induced to adopt an attentional set for perceptual newness. Given this attentional set, only featural changes that are considered to constitute the emergence of a new (perceptual) object should produce contingent capture.

The question of whether feature changes are ever treated as functionally equivalent to new objects was examined for the luminance domain. There are several reasons for using luminance rather than other dimensions. First, luminance is more easily quantified than, say, color or shape. There is no sense in which an object possesses more "redness" or "squareness" than another object (cf. Stevens & Galanter, 1957; Yantis & Egeth, 1999). By contrast, not only can objects be arranged in order of their luminance, but their luminance can be expressed using a precise unit of measurement, such as cd/m². Second, predictions are more easily derived for changes in luminance than for either color or shape. On the one hand, objects in nature do not spontaneously undergo changes in color; on the other hand, their shape is rarely constant, owing to the perpetual change in shape caused by changes in perspective. It is not clear a priori, therefore, that the visual system should tolerate any change in color, or that it should not tolerate any change in shape. By contrast, objects in nature do undergo changes in luminance, owing to varying illumination conditions; at the same time, however, it is reasonable to assume that there are limits to the magnitude of luminance change that the visual system will still regard as ecologically plausible (cf. Enns et al., 2001). Finally, because attentional capture by new objects has occasionally been attributed to the stimulation of transient sensitive channels by the...
luminance transients that accompany the appearance of the new object in most paradigms (cf. Enns et al., 2001; Gellatly, Cole, & Blurt, 1999; Yantis & Hillstrom, 1994), changes in luminance were a natural choice for the present experiments.

To incorporate luminance changes into Folk et al.’s (1992) design, their design was modified to include cue placeholders, as illustrated in

![Figure 1 - Displays used in Experiment 1 (not drawn to scale).](image)

Figure 1. These cue placeholders were present from the beginning of each trial. The time from the onset of the trial to the onset of the cue display allowed these cue placeholders to age perceptually, so that the luminance change would occur to a perceptually well-established object. Such cue placeholders have been used previously by Atchley, Kramer, and Hillstrom (2000; see also Thomas & Luck, 2000, Experiment 1). In the following discussion, these cue placeholders are not to be confused with the letter placeholders used to premask the search items in the final display. The letter placeholders were used in all conditions of the experiment to create the contrast between new and old display items (cf. J. T. Todd & Van Gelder, 1979; Yantis & Jonides, 1984). The cue placeholders, however, were used only in the change cue condition. All manipulations in the first set of experiments were done only with respect to the cue, not the target (except in Experiment 2).

If cues undergoing a sufficiently large luminance change are capable of producing contingent capture when participants are set for new objects, this ability derives from a disruption of the spatiotemporal continuity of the cue: Following the luminance change, the modified cue is no longer considered the same object as its previous, dimmer version; rather, it is considered a new, brighter object. This new object, in turn, captures attention because it matches the participants’ set for new objects. In the final experiment (Experiment 5), other evidence that large luminance transients are capable of disrupting the spatiotemporal continuity of an object was examined. In this experiment, luminance changes were introduced into a particular type of apparent motion display: the Ternus display (Pante & Picciano, 1976; Pikler, 1917; Ternus, 1926; Wertheimer, 1912). This type of display is particularly sensitive to spatiotemporal object continuity.
**Experiment 1: Set for New Objects**

The first experiment establishes the basic methods for each subsequent experiment. As explained above, these experiments use a modified version of Folk et al.'s (1992) contingent capture experiments. Three different types of cue were used: a new object cue, a luminance change cue, and a luminance singleton cue (see Figure 1). The question of interest is whether a luminance change cue will produce contingent capture when participants are set for new objects. According to the logic of contingent capture, only a cue that matches the observer's attentional set will draw attention to itself. Attentional capture will manifest itself in responses that are faster to targets that appear in the cued location than to targets that appear elsewhere. Because it is possible that only sufficiently large luminance changes, which exceed the limits of what is ecologically plausible, precipitate the establishment of a new perceptual object, three different levels of luminance change were examined, ranging from relatively small to relatively large.

**Method**

**Participants.**

Eighteen participants (7 men and 11 women) were recruited from the Johns Hopkins University undergraduate subject pool to participate in one 50-min session each. The participants ranged in age from 18 to 22, with a mean of 19.6 years. All participants were naive to the purposes of the experiment and reported normal or corrected-to-normal vision. Participation was voluntary and occurred in return for partial course credit.

**Apparatus.**

The displays were generated on a 21-in. (53.34-cm) color monitor controlled by a graphics board in a 486-based computer. The display was viewed at a distance of 54 cm. A chin rest was used to fix participants' head position for the duration of the session. Responses were made on a custom-built button box, which was marked U on the left and H on the right in correspondence with the task described below. The experiment was conducted in a sound-attenuated room that was dimly lit with indirect incandescent lighting.

**Stimuli.**

The stimulus set consisted of six uppercase letters of the English alphabet (U, H, P, S, E, and A) of which two always served as target (U and H) and the remainder as nontargets. Each letter was constructed of a varying number of vertical and horizontal line segments that permitted each letter to be premasked by a figure-eight comprising seven such line segments (see Figure 1). The figure-eight premasks (letter placeholders) therefore "contained" the letter that they masked, and the transition from mask to letter was achieved simply by the removal of one or more line segments (cf. J. T. Todd & Van Gelder, 1979; Yantis & Jonides, 1984). For example, for a given letter placeholder to reveal an E, the two right line segments were removed. Each letter measured 0.50° × 0.75° of visual angle. The thickness of the individual line segments from which the letters were constructed was 0.10°.

Each display consisted of six boxes arranged on the perimeter of an invisible circle around a fixation cross (see Figure 1). The boxes measured 1.50° on each side, the diameter of the invisible circle was 5.00°, and the fixation cross measured 0.66° × 0.66°. Depending on the condition, each box could be surrounded by a set of four small disks. The diameter of each of the disks was 0.25°. When present, one disk was placed at each of the four corners of a given box, at a distance of 0.10° to the outline of the box.

The luminance of the screen background was 0.4 cd/m². The luminance of the target and nontarget letters, the letter placeholders, the boxes, and the fixation cross was 19.4 cd/m². The luminance of the cue disks depended on the cue luminance condition. Three different luminance values were used for the luminance change and luminance singleton cue conditions: 30.7, 32.8, and 70.7 cd/m². In both of these conditions, the cue distinguished itself from the other disks in the display by its greater luminance relative to the background. The luminance of these dimmer disks was 19.4 cd/m². The luminance of the cue disks in the luminance change condition prior to the luminance change was also 19.4 cd/m². For the new object condition, the three luminance
values used were 1. 3, 4. 7, and 14. 8 cd/m². The absolute magnitude of the luminance change in the luminance change condition was therefore far greater than in the new object condition.

**Design.**

Three different cue types (new object, luminance change, and luminance singleton) were combined factorially with three different levels of cue luminance (see above). The resulting nine conditions were presented in separate blocks. The order of these blocks was counterbalanced between participants by use of a Latin square design. Each of the nine blocks followed a 2 (target: H or U) × 6 (target position) × 6 (cue position) factorial design, resulting in 72 trials per block. The order of trials within each block was random. Each block was preceded by 16 practice trials.

**Procedure.**

The sequence of events for each trial was as follows. A fixation display was presented for 1,000 ms, followed by a cue display, which was presented for 150 ms. The fixation display was then presented again for 150 ms, followed by the target display, which remained until a response was made. Letter placeholders were presented during the three first displays (fixation, cue, fixation), and these placeholders were transformed into letters at the onset of the target display by removal of the masking line segments. In the target display, an onset target letter was presented in a previously empty location. Participants were informed that the onset letter was always the target, so that they would adopt a deliberate state of attentional readiness for onset.

In the new object cue condition, the cue consisted of a single set of four disks presented at the cued location during the cue display (see Figure 1, top row). In the luminance change cue condition, sets of four cue placeholder disks (cf. Atchley et al., 2000; Thomas & Luck, 2000, Experiment 1) were presented at all six display locations at the onset of the trial (see Figure 1, middle row). The rationale for using cue placeholders was that they allowed the cue disks to age perceptually, so that the subsequent luminance change would occur to a perceptually well-established object. The cue placeholders were presented for the duration of the initial fixation display (1,000 ms). During the cue display, the disks at the cued location increased in luminance for the duration of the cue display (150 ms) and then returned to their original luminance. In the luminance singleton condition, a set of four bright disks was presented at the cued location during the cue display, and the other display locations were surrounded by less luminous sets of disks (see Figure 1, bottom row). The cue display in the luminance singleton cue condition was identical to the cue display in the luminance change cue condition.

The difference between the two conditions was the absence of cue placeholders in the luminance singleton cue condition during the initial fixation display.

The luminance singleton cue condition is particularly relevant to the distinction between Experiments 1 and 2. On one interpretation, it is characterized by the luminance singleton's spatial uniqueness among the dimmer noncue disks in the cue display. That is, it can be characterized as a static discontinuity (cf. Folk et al., 1992). The Discussion section for Experiment 1 focuses primarily on this interpretation of the luminance singleton cue as a static discontinuity. However, there is a sense in which the luminance singleton cue can also be interpreted as a dynamic cue: Like the luminance change and new object cue displays, the luminance singleton display is characterized by luminance transients. These transients were greatest at the location of the luminance singleton cue.

If participants are set for luminance transients, it is reasonable to expect that the largest luminance transient might draw attention to itself. In Experiment 1, however, participants were set for new objects. Because all display locations equally contained new objects in the luminance singleton condition at the onset of the cue display, one would not predict the cue to capture attention in spite of being associated with the largest luminance transient. (However, see the caveat raised in the Discussion section.) The luminance singleton cue condition can therefore also serve as a control to verify that participants were indeed set for new objects in Experiment 1. A different prediction emerges for Experiment 2, in which participants were set for luminance transients: Here, it is quite reasonable to expect that the luminance singleton cue, in spite of being a static discontinuity, might capture attention because the cue location contains the largest luminance transient in the display. This prediction is recapitulated below, in the context of Experiment 2.

In all three cue conditions, the cue was spatially uninformative. That is, the position of the cue and the position of the target were completely uncorrelated. Participants were informed of this fact; they therefore had no
incentive to attend to the cue. Both the cue and the target appeared in each display position equally often, independently of each other. Hence, there were no implicit contingencies in the display that may have biased participants toward one particular display location.

Participants were instructed to respond following the presentation of the target display by pressing either the left or the right button on the button box in front of them, depending on which target (H or U) was present in the display. Speed was stressed over accuracy. Error feedback was provided by two successive 150-ms, 256-Hz tones. Participants received a "timeout" of 2 s following each error. Otherwise, the response started the next trial after an intertrial interval of 2 s. Error trials were reinserted at a later point in the same block. Block feedback was supplied by displaying the mean response time (RT) and the error rate (as a percentage) on the monitor, as well as the number of blocks remaining. If participants made more than 5% errors on a given block, they were additionally cautioned, "Please slow down and make fewer errors."

**Results**

The results for Experiment 1 are shown in Figure 2. Trials on which an error had occurred were excluded from analysis; furthermore, all RTs of more than two standard deviations from the mean were removed (for each participant separately). This procedure resulted in the removal of 4.3% of the data. As can be seen from Figure 2 (left and middle panels), when small changes in luminance were used, only the new object cue yielded clear evidence of capture, as indicated by the effect of cue validity on RT: That is, RTs to targets appearing in the cued location (valid cues) were faster than RTs to targets appearing in noncued locations (invalid cues). Both the luminance singleton and the luminance change cues failed to produce such a validity effect. By contrast, when large luminance changes were used, both new object and luminance change cues produced evidence of contingent capture (Figure 2, right panel). Although the contrast between the noncue disks and the cue disks was the same for the luminance change and luminance singleton cues, the singleton cue did not seem to capture attention even at the largest contrast level. What appears to be responsible for capture in the luminance change condition is the change in luminance rather than the final (static) luminance contrast.

The correct RT data were subjected to a repeated measures analysis of variance (ANOVA) with luminance (small, medium, or large), cue type (new object or luminance change), and validity (valid or invalid) as factors. Of the main effects, only the effect of validity, F(1,17) = 10.26, p < .01, reached significance. The main effect of validity is most likely driven entirely by the strong validity effect produced by the new object cue: RTs to invalidly cued targets were 35 ms slower in the new object condition, averaged across the three levels of luminance.

Further analysis revealed that only the new object cue consistently produced a validity effect across all three luminance values, t(17) = 3.26, p < .005; t(17) = 2.78, p < .02; and t(17) = 2.15, p < .05, respectively, for the small, medium, and large luminance contrast cues. The luminance change cue, by contrast, produced a significant cue effect only with the largest luminance increment, t(17) = 0.73, ns; t(17) = 0.11, ns; and t(17) = 2.68, p < .02, respectively. This pattern of results is reflected in the significant three-way interaction between luminance, cue type (new object or luminance change), and validity, F(2,34) = 3.38, p < .05. Finally, the
luminance singleton cue did not produce a validity effect even at the largest luminance contrast, \( t(17) = -1.39, ns; t(17) = -1.42, ns \); and \( t(17) = 0.25, ns \).

The error data are shown in Figure 2, alongside the RT data. There was no hint of a speed-accuracy trade-off. The error data were subjected to all of the same analyses as the RT data. The only effect that reached significance was the effect of validity for the new object cue in the medium luminance transient condition, \( t(17) = 3.56, p < .005 \). Overall, participants performed at near ceiling, which would explain the absence of significant effects in the error data. The same was true for all of the experiments discussed below. Therefore, in the following, the analyses of the error data will be explicitly reported only where significant effects were found. In each case, however, the error data are shown in the appropriate figure for every experiment.

**Discussion**

The data from the new object and luminance singleton conditions qualitatively replicate the findings of Folk et al. (1992): When participants are set for an abrupt onset, onset cues will capture attention, whereas feature cues will not. In the present experiment, rather than using color as the medium of contrast for the feature singleton, luminance was used. The results from the present experiment therefore also extend those of Folk et al. (1992); Both the luminance singleton cue and the luminance change cue in Experiment 1 can be characterized as discontinuities along the same dimension, luminance. Nevertheless, only the luminance change cue captured attention; the luminance singleton cue did not. The results of the luminance change condition at small luminance contrasts demonstrate that the presence of a dynamic discontinuity alone is not sufficient to produce capture when participants are looking for a new object target. The luminance change cue captured attention only when the luminance change was sufficiently large. On the basis of the premise that only cues matching the target-defining properties produce contingent capture and the assumption that participants were set for new objects but not luminance transients more generally, one can infer that a sufficiently large luminance change is treated as constituting the emergence of a new object.

If this conclusion is correct, it suggests that object files (cf. Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992) are not infinitely flexible. Although the identity of an object can persist through relatively large changes, following which the contents of the object file are merely updated, eventually the representation will be discarded in the face of sufficiently large changes. Once a certain point has been reached, object identity can no longer be maintained, and the visual system opts for the more plausible solution that it is dealing no longer with an altered old object but rather with a new object. This point of transition from altered old object to new object presumably occurs at an ecologically meaningful magnitude of change. In the present context, this level of transition appears to lie somewhere in the vicinity of 50 cd/m\(^2\). For other dimensions, the point of transition may be more difficult to quantify. A study by Thomas and Luck (2000, Experiment 1) suggests that similar points do exist in other dimensions as well. Thomas and Luck's design was similar to the one used in Experiment 1. Instead of changing the luminance of the cue placeholder, though, they changed its (equiluminant) color. This change in color produced contingent capture with a shape singleton target. It is not clear what attentional set Thomas and Luck's participants adopted, but given that the target was a singleton, it is possible that they engaged in singleton detection (cf. Bacon & Egeth, 1994). Although Thomas and Luck's results must therefore remain suggestive, they do raise the possibility that color changes as well can lead to a disruption of the spatiotemporal continuity of an object.

The fact that the luminance singleton cue failed to capture attention deserves additional commentary. After all, the luminance singleton cue display was accompanied by the onset of a new object: the cue display. Even though all display locations equally contained new objects, it remained a possibility that the singleton cue might have captured attention, for it represented a spatiofactual singularity in the singleton cue display: Recent work by Cole, Gellatly, and Blurton (2001), for instance, showed that attention is not distributed evenly across an attention-capturing new object at first but is concentrated at the vertices of that object (e.g., the corners of a square, rather than its whole outline). It was therefore conceivable that attention might have been drawn to the unique new object in the luminance singleton cue display, just as it is to distinct points on a freshly appeared new object (cf. Cole et al., 2001). The results of Experiment 1, however, argue against this hypothetical possibility, consistent with the results of Chastain and Cheal (1998, 1999; Cheal & Chastain, 1998), who used—in their terminology—multielement cue displays, which strongly resembled the cue singleton displays used in the present experiment. It appears that all new objects are treated as equal even when one of them represents a static discontinuity.

Just as the luminance singleton cue has similarities with the new object cue, it shares facets of the luminance
change cue as well. As in the latter condition, the target location was highlighted by a large luminance transient, because even though luminance transients occurred at all display locations, the largest transient occurred in the singleton cue location. It is conceivable, therefore, that under the proper conditions, the luminance singleton cue may capture attention. In Experiment 1, these conditions were not given, because participants were set for new objects—and only new objects—but not luminance transients more generally (unless these were interpreted as constituting the emergence of a new object). A different picture may emerge when participants are set for luminance transients more generally, as in Experiment 2. In this case, the large luminance transient associated with the onset of the luminance singleton may begin to capture attention.

Experiment 2: Set for Luminance Transients

As pointed out above, the conclusions drawn from Experiment 1 are predicated on the premise that participants were truly set for new objects and not luminance transients more generally, which would subsume nonequiluminant new objects like the ones used in Experiment 1. Experiment 2 was designed to evaluate the validity of this premise. In this experiment, the new object target of Experiment 1 was replaced with a pure luminance change target. Everything else was kept the same as in the previous experiment. 

If participants, however, were not implicitly set for luminance transients in Experiment 1, a different pattern of results should be observed in Experiment 2. The logic of contingent capture makes specific predictions for each of the three cue conditions of Experiment 2. First, the new object cue should continue to capture attention because the new object is created using local changes in luminance. Second, the luminance change cue should begin to capture attention at lower levels of luminance change than in Experiment 1 because no threshold needs to be reached at which luminance changes are interpreted as constituting the emergence of a new object. Finally, as argued above, the luminance singleton cue may begin to capture attention because it is associated with a large luminance transient.

Method

Participants.

Eighteen new participants (9 men and 9 women) either were recruited from the Johns Hopkins University undergraduate subject pool or were Johns Hopkins University graduate students. All of the graduate students, and some of the undergraduates, were compensated with $7 instead of credit for their participation. The participants ranged in age from 18 to 30 years, with a mean of 21.6 years.

Stimuli.

The same stimuli were used as in Experiment 1. The only difference between the two experiments was the procedure used to create the target. In the present experiment, five instead of four boxes contained letter placeholders at the onset of each trial. In the target display, these placeholders were replaced with letters by deleting the appropriate line segments for each letter. The item in the target position increased its luminance to 70.7 cd/m² at this point, creating a luminance transient that identified the target.

Design and procedure.

The same design and procedure were used as in Experiment 1.
Results

The results for Experiment 2 are shown in Figure 3 - Results from Experiment 2. Lum = luminance.

Figure 3 - Results from Experiment 2. Lum = luminance.

Figure 3. Error trials and outliers were removed as before, which resulted in a removal of 4.2% of the data. As can be seen from Figure 3, contrary to Experiment 1, where only the largest luminance contrasts produced contingent capture, all three levels of luminance change now yielded a sizable cue-target spatial compatibility effect. Across all three levels of luminance contrast, the luminance change cue produced a mean effect of 41 ms, $t(53) = 4.43, p << .001$, which is quite comparable to the effect produced by the new object cue in Experiment 1 (35 ms). Equally interesting is the fact that the luminance singleton cues appear to have been successful in influencing RTs as well. As before, the correct RT data were subjected to an ANOVA with luminance, cue type, and validity as factors. Only the main effect of validity, $F(1,17) = 17.75, p < .001$, and the interaction between cue and validity, $F(2,34) = 4.31, p < .05$, reached significance. The main effect of validity reflects the already mentioned difference between valid and invalid RTs for all three cue conditions across all three luminance contrasts. The interaction of cue and validity merits closer inspection, because it suggests that not all three types of cues were equally successful at producing contingent capture.

Planned contrasts were conducted to compare new object and luminance change cues (the major comparison of interest). As expected, these contrasts revealed no significant interaction between cue type and validity, $F(1,17) = 3.70, ns$, providing support for the qualitative equivalence of new object and luminance change cues in this experiment. By comparison, the interaction between cue type and validity was significant for the comparison of new object and luminance singleton cues, $F(1,17) = 6.31, p < .05$. An even closer inspection showed that for the luminance singleton cue, the difference between RTs to validly and invalidly cued targets was significant only for the largest luminance contrast, $t(17) = 1.66, ns$; $t(17) = 1.95, ns$; and $t(17) = 2.43, p < .05$, respectively. This relative ineffectiveness of the luminance singleton cue in comparison with the other two types of cues can probably account for the aforementioned significant two-way interaction between cue type and validity in the omnibus ANOVA.

Discussion

The pattern of results observed in Experiment 2 is quite different from that seen in Experiment 1, in which only the new object cue produced a significant effect at all three luminance contrasts, the luminance change cue produced a significant effect only at the largest level of luminance change, and the luminance singleton cue failed to produce any effect. The only difference between the two experiments was the type of target (but see Footnote 2).

This conclusion is further underscored by the contrast between the ineffectiveness of the luminance singleton cue in Experiment 1, on the one hand, and its ability to capture attention (at the largest level of luminance contrast) in Experiment 2, on the other: As argued earlier, new objects appeared in all display locations of the
luminance singleton display, whereas the largest luminance transient occurred in the cue location. Therefore, a set for new objects should not privilege any particular display location in the luminance singleton condition. By contrast, a set for luminance transients might have been expected to permit the luminance singleton cue to capture attention, as was the case in Experiment 2.

The finding that a set for new objects does not necessarily entail a set for luminance transients is consistent with prior evidence that luminance transients are neither necessary nor sufficient for the capture of attention (e.g., Gellatly et al., 1999; Yantis & Hillstrom, 1994). The results of Experiment 2 suggest that the converse is not true: Apparently, a set for luminance transients may subsume a set for new objects. This asymmetry in results is not surprising because the new object cues in both Experiments 1 and 2 were accompanied by luminance transients, whereas only the targets in Experiment 1 represented new perceptual objects, and the targets in Experiment 2, although produced by luminance changes, were not new perceptual objects. The widening of the attentional set in Experiment 2 was probably responsible for boosting the size of the effect for new object cues from 35 ms to 79 ms. Folk, Remington, and Wright (1994) have previously suggested that there exists a similar hierarchical relationship between apparent motion and abrupt onset stimuli, in that an attentional set for motion may entail a set for onsets, but a set for onsets need not imply a set for motion. In the present experiments, the only condition that violated the hierarchical relationship between new object and luminance transient cues was the large luminance change condition in Experiment 1. In this condition, large luminance transients satisfied the set for new objects. A similar exception occurred in the luminance singleton condition of Experiment 2 for the largest luminance contrast. This finding is not particularly surprising, given that even the luminance singleton cue was associated with the abrupt onset of the cue display and that the luminance transient was slightly larger in the cue location than in any of the other locations (see above).

In Experiment 2, the luminance change cues produced contingent capture at much smaller ratios of luminance change than those used in Atchley et al.’s (2000) study. Why this should be so is not clear. One possibility is that the decisive factor is not the ratio of luminance change but the absolute magnitude of the change, which was greater in Experiment 2 than in Atchley et al.’s experiments. The results of Experiment 3 make this unlikely, however. They suggest that the important factor in determining whether capture will be observed is the ratio, not the absolute magnitude of change. Apart from the luminance values used, another difference between the present experiment and those conducted by Atchley et al. is that in the latter, participants were set for both luminance increases and decreases, whereas in the former, they were set only for luminance increases. In Atchley et al.’s experiments, both types of targets were presented in mixed blocks, paired with both luminance increase and luminance decrease cues. Again, why this should have resulted in quantitatively different outcomes is not clear.

Experiment 3: Role of Contrast in Capture by Onsets

Taken together, Experiments 1 and 2 suggest that a luminance change of sufficient magnitude will act as a new object cue when participants are set for new object targets. The luminance transients necessary for producing the same effect with true new object cues were substantially smaller, by comparison. To produce the same effect as a new object cue of 1.3 cd/m² on a background of 0.4 cd/m² required a luminance change cue of 70.7 cd/m² with a cue placeholder of 19.4 cd/m². The magnitude of these transients was measured in terms of the absolute size of the luminance transients, however. A different picture emerges if one compares the ratios of luminance change in the two conditions. The ratio of the luminance of the new object cue to the screen background for the dimmest new object cue was a healthy 3.3, compared with a mere 1.6 and 1.7, respectively, for the two smallest luminance changes. Perhaps not coincidentally, for the change cue that did produce contingent capture in Experiment 1, the ratio of the cue to its cue placeholders was 3.6—comparable to the 3.3 ratio of the new object cue that captured attention. Experiment 3 addresses the question of whether a new object cue will continue to capture attention if ratios of less than 3.3 are used.

Method

Participants.

Eighteen new participants (4 men, 11 women, and 3 participants who elected not to have their gender recorded) took part in this experiment in return for course credit. The participants were between 18 and 21 years old (M = 19.6 years).
**Stimuli.**

The same stimuli were used as in Experiment 1. Only two changes were made from the earlier experiment. First, different luminance values were used for the cues in order to permit an exploration of a larger range of luminance ratios for all three cue types. Second, in the new object condition, a small solid square was placed at each of the four corners of each of the six squares (see Figure 4 - Displays used in Experiment 3 (not drawn to scale). Only the new object cue condition is shown.

Figure 4). The small rectangles were placed so that each of the cue disks would appear centered on top of one of the four little rectangles. These rectangles measured 0.45° on each side. The luminance of these rectangles varied with that of the new object cue disks placed on top of them. Three different square-disk luminance combinations were used: 4.7/56.7, 19.4/70.7, and 32.8/83.3 cd/m². These combinations corresponded to the values used for the cue placeholders and cue disks in the luminance change condition. The same values were also used for the bright and dim disks in the luminance singleton condition. The respective luminance ratios for each of the combinations of values were 12.1, 3.6, and 2.5. Note that as the ratio for each condition diminishes, the absolute magnitude of the luminance contrast remains the same and the absolute luminance of the stimuli increases.

**Design and procedure.**

The same design and procedure were used as in Experiment 1.

**Results and Discussion**

The results for Experiment 3 are shown in Figure 5 - Results from Experiment 3. Lum = luminance.
Figure 5. Error trials and outliers were removed using the same procedures as previously, which resulted in the removal of 4.1% of the data. As can be seen from Figure 5, even at the largest ratio of 12.1, the luminance singleton cue failed to produce an effect, $t(17) = 1.96$, ns, replicating the results from Experiment 1, where much smaller ratios had been used. By comparison, at this level of contrast, both the new object and the luminance change cues yielded contingent capture. The size of the effect was around 28 ms in both conditions, $t(17) = 2.78$ (for the new object cue), $t(17) = 2.81$ (for the luminance change cue), $p < .05$ (for both), which is comparable to the effects obtained in Experiment 1. At the next smallest luminance ratio (3.6), the luminance change cue still produced a 25-ms effect, $t(17) = 4.28$, $p < .001$, as could be predicted from the results of Experiment 1. Oddly, however, the new object cue not only failed to capture attention but also produced a validity effect in the wrong direction (i.e., $RT_{\text{valid}} > RT_{\text{invalid}}$). This result is inconsistent with Experiment 1 as well as a replication of Experiment 1 not reported here. In this replication, the new object cue produced a significant 37-ms effect with a luminance ratio of 3.3. At the smallest luminance ratio used in Experiment 3 (2.5), the new object cue still failed to produce an effect, $t(17) = 0.33$, ns. The luminance change cue, by comparison, continued to produce a 25-ms effect, $t(17) = 2.84$, $p < .05$.

The results from Experiment 1, the replication of Experiment 1, and Experiment 3 are summarized in Table 1.

<table>
<thead>
<tr>
<th>Luminance ratio</th>
<th>New object cue</th>
<th>Luminance change cue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>—</td>
<td>No/No</td>
</tr>
<tr>
<td>1.7</td>
<td>—</td>
<td>No</td>
</tr>
<tr>
<td>2.5</td>
<td>No</td>
<td>Yes (25 ms)</td>
</tr>
<tr>
<td>3.3</td>
<td>Yes/Yes (41/37 ms)</td>
<td>—</td>
</tr>
<tr>
<td>3.6</td>
<td>No (Yes?)</td>
<td>Yes (25 ms)</td>
</tr>
<tr>
<td>11.8</td>
<td>Yes (43 ms)</td>
<td>—</td>
</tr>
<tr>
<td>12.1</td>
<td>Yes (27 ms)</td>
<td>Yes (28 ms)</td>
</tr>
</tbody>
</table>

Note. Yes indicates conditions under which a given cue produced contingent capture, with the size of the observed effect in parentheses ($RT_{\text{valid}} - RT_{\text{invalid}}$). No indicates conditions under which no capture was observed. For cells with two yes or two no entries, the effect (or absence of effect) was replicated in another experiment. Dashes indicate that no data were collected for that cell. RT = response time.

1 in terms of the ratio of luminance change. From a comparison of the left and right columns, it is apparent that there is a fairly large consistency between new object and luminance change cues. Although they haven't been explicitly tested at such small ratios of luminance change, if one extrapolates from the negative results with a ratio of 2.5 and from the results with luminance change cues at smaller ratios, it is reasonable to assume that new object cues are ineffective at ratios smaller than 2.5. For both luminance change and new object cues, there appears to be a point of transition between ratios of 2.5 and 3.3. Above these values, both luminance change and new object cues unambiguously produce cue-target spatial validity effects\(^3\); below these values, neither cue presumably produces an effect; and within the range between 2.5 and 3.3, the evidence is somewhat ambivalent.

A sensible interpretation of the data from the first three experiments is that new object cues require a luminance change ratio of at least 3.3 for the emergent object to be registered as a new object, and that luminance changes to existing objects begin to be registered as new objects at the same ratio. This conclusion about the required ratio of luminance change holds only for new objects created by the onset of luminance borders; it does not extend to equiluminant new objects, which capture attention in the absence of a luminance change (e.g., Gellatly et al., 1999; Yantis & Hillstrom, 1994). It is very likely, however, that similar conclusions can be reached using, say, equiluminant chromatic changes (e.g., Thomas & Luck, 2000, Experiment 1), which may require a minimum color contrast before capture is observed. It is furthermore likely that a combination of changes in different dimensions will cause attentional capture more quickly (i.e., at smaller levels of change in each respective dimension) than a change in a single dimension by itself.

The results of Experiment 3, when taken in conjunction with the results of the other two experiments, suggest that contrast ratio, and not the absolute magnitude of change, matters. In Experiment 3, the absolute magnitude of change was held roughly constant at 51 cd/m\(^2\), and only the ratio was manipulated. The results clearly showed a dependence of contingent capture on the ratio of change. Furthermore, the results of Experiment 3 rule out that the final luminance value after the change plays any role in determining when capture will occur. In

Gellatly et al., 1999
Yantis & Hillstrom, 1994
Thomas & Luck, 2000
Experiment 3, as the ratio of change decreased from each luminance condition to the next, the corresponding final luminance value increased. Contingent capture was observed in the conditions with large ratios, even though the final luminance values were actually smallest in those conditions, but not in the condition with the small ratio, even though the final luminance value was largest in this condition. This outcome makes sense, given that the perception of brightness is strongly context dependent. Absolute luminance values mean very little if they are not placed within the context of other luminance values.

In spite of the relative equivalence of new object cues and luminance change cues, a glance at the effects summarized in Table 1 reveals that even when the ratios of luminance change were equated for the two types of cues, the effects observed with new object cues tended to be somewhat larger than those obtained with luminance change cues. For the conditions summarized in Table 1, the mean effect for luminance change cues was around 26 ms, whereas the mean for new object cues was around 37 ms. Although a luminance change may be treated as constituting the emergence of a new object, the resulting "new" object is treated as such merely by analogy. Simply because luminance change cues are functionally equivalent to new object cues under the proper conditions does not mean that they are ontologically equivalent as well. There appears to remain a qualitative distinction between the two types of cue even when the two are treated as equivalent.

**Experiments 4a and 4b: Minimum Time of Existence**

So far, it has been established that a luminance change to an existing object will be treated as constituting the emergence of a new perceptual object. Given this result, the question arises quite naturally, How long does an object need to have existed before a modification of the object will be considered the alteration of an already existing object? It is conceivable that at a very young "object age," these changes will be subsumed among the changes that accompany the emergence of the object: Whenever an object comes into existence, its birth as an object is precipitated by a number of featural changes. It is possible that the changes made to the object during its emergence are indistinguishable to the visual system from these featural changes. Only when the young object has been fully established as an ontologically autonomous "thing" will transformations of this object become distinct from the changes that led to its creation. Experiment 4 addressed the question of the minimum object age by manipulating the duration of the cue placeholders in the luminance change condition (see Figure 6 - Displays used in Experiment 4 (not drawn to scale). Two example cue placeholder durations are shown (66 ms and 100 ms). The new object and luminance singleton conditions were the same as in
Experiment 1.

Figure 6). In the limit, the luminance change cue will be indistinguishable from the luminance singleton cue, which represents a luminance change cue with a zero placeholder duration.

**Method**

**Participants.**

Thirty-six new participants (7 men and 29 women) were recruited from the same subject pool as before. These participants ranged in age from 18 to 22 years ($M = 19.6$ years).

**Stimuli and design.**

The same stimuli were used as in Experiment 1. However, only the largest luminance contrast from that experiment was used in Experiment 4, because this contrast was certain to yield robust contingent capture. It is important to remember that in Experiment 1, it did so only with the luminance change cue and not with the luminance singleton cue. In Experiment 4, if a sufficiently short placeholder duration effectively transforms the luminance change cue into the luminance singleton cue, it should no longer produce contingent capture even though the luminance contrast is high. A failure to have reached that critical placeholder duration, however, will result in continued capture by the luminance change cue even at short placeholder durations.

**Procedure.**

The basic sequence and time frame of events were the same in this experiment as in the previous three experiments. As before, a fixation display was presented for 1,000 ms, followed by a cue display of 150 ms. Nothing therefore changed for the new object and luminance singleton conditions. In the luminance change condition, however, the cue placeholders were no longer presented for the full duration of the initial fixation display. Instead, they were presented at a variable amount of time before the transition to the cue display depending on the cue placeholder condition: either 50, 100, or 500 ms (Experiment 4a) or 16, 33, or 66 ms (Experiment 4b) before the onset of the cue display. This sequence of events is illustrated in Figure 6.

**Results and Discussion**

The results for Experiments 4a and 4b are shown in
Figure 7 - Results from (A) Experiment 4a and (B) Experiment 4b. SOA = stimulus onset asynchrony; Lum = luminance.

Figure 7 (Panels A and B, respectively). Error trials and outliers were removed using the same procedures as previously, which resulted in the removal of 3.7% of the data for Experiment 4a and 4.5% for Experiment 4b. Because the placeholder duration manipulation did not involve the new object or luminance singleton conditions, the data for those conditions were collapsed across placeholder durations. Replicating the results of Experiment 1, the new object cue produced a cue-target spatial compatibility effect of 47 ms, \( t(53) = 5.34, p < .001 \), in Experiment 4a, and a 36-ms effect, \( t(53) = 4.19, p < .001 \), in Experiment 4b. Equally consistent with the results of Experiment 1, the singleton feature cue produced only small nonsignificant effects of 9 ms, \( t(53) = 1.32 \), in Experiment 4a, and 4 ms, \( t(53) = 1.19 \), in Experiment 4b (both \( t_s = 1.3, n_s \)). The luminance change cue showed a slightly different picture: In Experiment 4a, it produced significant effects at all three placeholder durations (50, 100, and 500 ms), \( t(17) = 4.73, p < .0005 \); \( t(17) = 3.47, p < .005 \); and \( t(17) = 2.26, p < .05 \), respectively. The mean effect across these three conditions was 35 ms. In Experiment 4b, the luminance change cue yielded contingent capture at the two longer durations (33 ms and 66 ms), \( t(17) = 4.31, p < .0005 \), and \( t(17) = 3.55, p < .005 \), respectively, but not at the shortest cue placeholder duration, \( t(17) = 1.53, n.s. \). For the two longer durations, the mean effect was 33 ms, a value that is quite consistent with the results of Experiment 4a. At the shortest duration, the effect diminished to 15 ms.

There were two sets of significant effects in the error data from Experiment 4b. First, across all three stimulus onset asynchronies (SOAs), new object cues produced a validity effect in the same direction as for the RT data, \( t(53) = 4.23, p < .0001 \). Second, the luminance change cue produced significant validity effects in the same direction as for the RT data at both the 33-ms SOA, \( t(17) = 4.27, p < .0005 \), and the 66-ms SOA, \( t(17) = 3.56, p < .005 \). As previously for the RT data, there was no significant effect at the shortest (16-ms) SOA, \( t(17) = 0.35, n.s. \). These results mirror those obtained in the RT data.

It appears, then, that an object requires on the order of 16 ms to establish a durable object file. Before that time, all featural changes to the object are used to update the object file of the emerging object, even if those changes would otherwise suffice to cause the creation of a new object file. At first glance, this result seems to have implications for attentional capture experiments using the paradigm popularized by Yantis and Jonides (1984), which is based on the premasking technique developed by J. T. Todd and Van Gelder (1979). In this paradigm, a contrast is created between perceptually old items and perceptually new items by using letter placeholders, just as in the present experiments. Typically, the letter placeholders are presented for a full 1,000 ms before the onset of the new object (see, e.g., Yantis & Jonides, 1984), on the basis of the intuition that this should be sufficient time to allow the premasked items to age perceptually. One implication of Experiment 4b could be that 16 ms or so would suffice to allow the placeholders to age perceptually. However, perceptual newness and ontological stability as an object are not the same thing. It is possible that an object may need 16 ms to establish itself and another 500 ms or so to age perceptually. An object that stabilizes after 16 ms is by definition perceptually new because it did not exist as an autonomous entity prior to that point.

As pointed out earlier, the luminance change condition collapses into the luminance singleton condition at a zero SOA. Because participants were set for new objects in this experiment, as in Experiment 1, the luminance singleton cue should have failed to capture attention whereas the luminance change cue should have captured attention, given that only the latter could be interpreted as constituting the emergence of a new object and hence matching the participants’ attentional set. At all SOAs but the shortest, this is the result that was obtained. Even at the shortest SOA, which failed to produce evidence of attentional capture, the luminance change cue was associated with a luminance change in the location of the cue. Like the luminance singleton cue, however, this luminance change was not associated with the appearance of a new object. The decisive difference between the luminance change and the luminance singleton cue conditions therefore appears to be the interpretation of the luminance transient in the luminance change condition as constituting the emergence of a new object. Only
when participants are set for luminance transients more generally should a cue associated with a luminance transient but not the emergence of a new object capture attention (cf. Experiment 2).

**Experiment 5: Spatiotemporal Object Continuity—Ternus Display**

The results of the experiments reported thus far have shown that a sufficiently large (luminance) change to an object that has had sufficient time to establish itself is perceptually equivalent to the appearance of a new object (at least insofar as attention is concerned). Presumably, the creation of a new object file is mediated by the disruption of the spatiotemporal continuity of the modified object caused by the large change: The visual system is reluctant to consider the two instances of the object as different tokens of the same object. If a disruption of the spatiotemporal continuity of the change cue is indeed responsible for allowing it to act as a new object cue, it should be possible to demonstrate that a change of magnitude similar to the one that produced capture in Experiment 1 will disrupt the spatiotemporal continuity of an object in a different context.

A particular type of apparent motion display, the Ternus display (Pantle & Picciano, 1976; Pikler, 1917; Ternus, 1926; Wertheimer, 1912), is demonstratively well suited for investigating spatiotemporal object continuity and has previously been used to great effect by Yantis and Gibson (1994). An example of a Ternus display is shown in Figure 8.

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**Figure 8 - Example of a Ternus display.**

Figure 8. In the Ternus display, two frames are presented in alternation, with an intervening blank interstimulus interval (ISI) presented between frames. Both frames typically contain a pair of horizontally aligned disks, with the disks in one frame shifted sideward by one position, so that the left disk in the second frame appears in the same spatial position as the right disk in the first frame (see Figure 8). When the two frames and blank ISIs are now cycled, a percept of motion emerges. This percept is ambiguous, with two possible interpretations: A peripheral disk is seen as jumping back and forth around a stationary center disk (element motion); alternatively, the two disks are seen as moving back and forth in tandem (group motion). At short ISIs, element motion tends to dominate, and at long ISIs group motion dominates (Pantle & Picciano, 1976). The two different percepts have been explained in terms of temporal grouping of the first instance of the "center" disk with its second occurrence (see He & Ooi, 1999; Kramer & Yantis, 1997; Yantis, 1995). At short temporal intervals, the "center" disk is seen as continuous across the temporal gap between frames; because it is perceived as stationary, the only remaining interpretation for the other disk is to be moving back and forth across this stationary disk. The persistence of the "center" disk across frames appears to be mediated not by visual persistence (see Kramer & Rudd, 1999) but by the spatiotemporal continuity of the object representation for the center disk (see Yantis, 1995; Yantis & Gibson, 1994).

Whereas generic apparent motion has proved quite insensitive to featural changes in the motion tokens (e. g., Bernbaum, Lenel, & Rosenbaum, 1981; Kolers & Pomerantz, 1971; Navon, 1976, 1983), Ternus apparent motion seems to be much more vulnerable to such changes. Kramer and Yantis (1997, Experiment 1), for example,
compared Ternus displays in which the motion tokens either had the same shape (homogeneous condition) or
different shapes (heterogeneous condition). They observed a rather large difference in the probability with which
participants reported group motion in the homogeneous and heterogeneous conditions. Similarly, Dawson,
Nevin-Meadows, and Wright (1994) observed a strong reduction in the report of element motion when they
changed the contrast polarity of the motion tokens from one frame to the next. The difference in sensitivity to
featural change between the Ternus display and more generic apparent motion displays may very well stem from
the fact that two types of grouping are at work in the former, whereas only one form of grouping is usually active
in the latter. In generic apparent motion displays, the motion tokens group across time between successive
frames (temporal grouping); in the Ternus display, they additionally group within each frame at a given moment in
time (spatial grouping; see He & Ooi, 1999; Kramer & Yantis, 1997). For example, when group motion is
perceived in the Ternus display, the two motion tokens that are seen as moving back and forth in tandem need
to cohere as a motion doublet. When element motion is perceived, the peripheral moving disk needs to group
across time with its displaced counterpart in the subsequent frame. The interplay of these two forces may render
the Ternus apparent motion more sensitive to changes in the features of the motion tokens.

The crucial test of the limits of spatiotemporal object continuity involves the “center” disk in Ternus displays at
short ISIs. All previous featural manipulations of the motion tokens in the Ternus display, however, have involved
either all of the tokens within a given frame (e.g., Dawson et al., 1994; Pantle & Picciano, 1976) or tokens
other than the “center” ones (Dawson et al., 1994; Kramer & Yantis, 1997). When all of the tokens in a given
frame differ from those in the other frame, spatial grouping of the tokens within each frame biases the perception
of the Ternus display toward group motion, because the within-display grouping reinforces the coherence of the
motion tokens moving in unison. Any disruption of the spatiotemporal continuity of the “center” disk may
therefore be masked by an effect in the same direction created by within-display grouping. When the featural
manipulation involves disks other than the “center” disk, the spatiotemporal continuity of the crucial motion
token is left unaffected. Contrary to previous investigations, only the “center” disk was manipulated in
Experiment 5. It was subjected to a luminance change of the same magnitude as that which produced
contingent capture in the other four experiments reported here. According to the logic expounded above, this
luminance change should increase the probability of observing group motion at short ISIs because it will
presumably disrupt the spatiotemporal continuity of the “center” disk, on which the perception of element motion
depends.

Method

Participants.

Fifteen new participants (4 men and 11 women) were recruited for Experiment 5. These participants ranged in
age from 18 to 29 years (M = 21.3 years). One participant was excluded from the study because he did not
complete the experiment.

Apparatus.

Apart from the computer used to run the experiment and the fact that participants viewed displays unconstrained
by a headrest, all conditions were the same as in the previous experiment. The displays were generated by a
Pentium-based PC and displayed on a 17-in. (43.18-cm) Trinitron monitor with an 85-Hz refresh rate.
Responses were made on a standard keyboard. Participants responded using the z and / keys, which were
labeled, respectively, Elem (for element motion) and Group (for group motion).

Stimuli.

Each frame of the Ternus display consisted of two disks 0.70° in diameter. The centers of the disks were
separated by 2.7°. The luminance of the displays was made to match that of the displays in the previous
experiments. Accordingly, the disks were 19.4 cd/m² on a background of 0.4 cd/m². The luminance of the
“center” disk in the second frame depended on the luminance condition. In one condition, the luminance of the
“center” disk in the second frame was the same as that of the “center” disk in the first frame (19.4 cd/m²). In
the other condition, the luminance of the “center” disk in the second frame was 70.7 cd/m², creating a
luminance contrast between the first and second frames equivalent to that which produced contingent capture in
Experiment 1.

**Design.**

There were 360 trials total, 180 trials in each block. The two different luminance contrasts for the "center" disk were presented in separate blocks. These blocks were counterbalanced between participants. Within every block, participants received 30 repetitions each of six different levels of ISI (0, 35, 70, 105, 140, and 175 ms). The trials within a block were presented in a pseudorandom order.

**Procedure.**

Each trial began with the presentation of a fixation cross for 175 ms, followed by the first frame of the Ternus display, which began the sequence of alternating displays. Each cycle consisted of Frame 1 of the Ternus display, a blank screen ISI, Frame 2, and a second bank ISI. The duration of a single frame of the Ternus display was 210 ms; the duration of the bank ISI depended on the ISI condition. The Ternus display was presented for eight full cycles. Participants then made a response to indicate whether they saw group motion or element motion in the preceding display by pressing one of two designated buttons on the keyboard in front of them. Responses were not speeded, and participants were told that there were no right or wrong answers.

**Results and Discussion**

Participants’ responses are summarized in

![Figure 9](image-url)

Figure 9 - Results from Experiment 5. Asterisks indicate significant differences at $p < .05$. Error bars represent one standard error of the mean. ISI = interstimulus interval.

Figure 9 as a function of luminance contrast and ISI. These responses are plotted as the probability of reporting group motion. Consistent with previous studies (e.g., Breitmeyer & Ritter, 1986; Dawson et al., 1994; Kramer & Yantis, 1997; Pantle & Picciano, 1976; Yantis, 1995; Yantis & Gibson, 1994), the probability of group motion increased monotonically with ISI, $F(5,55) = 53.75$, $p << .0001$. The condition in which there was no luminance difference can serve as baseline for the luminance contrast manipulation. This condition reflects the relationship between ISI and the probability of observing group motion for a Ternus display with the temporal and spatial parameters used in this experiment. The most important result that can be gleaned from Figure 9 is that participants were more likely to see group motion at the shortest ISI (0 ms) when the luminance of the "center" disk changed between successive frames of the Ternus display than if it remained constant. When the luminance of the "center" disk remained the same across frames, participants reported seeing group motion on an average of 0% of the trials at the 0-ms ISI. When the luminance increased by about 51 cd/m² from Frame 1 to Frame 2, the probability increased to 22%. The difference between the two conditions was statistically significant, $t(11) = 2.70$, $p < .05$.

Likewise statistically significant were the differences between the two conditions at the 70-, 105-, and 175-ms ISIs (all $t$s < -2.21, $p = .05$). However, at these ISIs, the effect went in the opposite direction: Participants were
less likely to report seeing group motion when the "center" disk changed in luminance. The resulting interaction between luminance condition and ISI was significant, $F(5,55) = 6.29$, $p < .0005$. The reduction in the probability of observing group motion at the longer ISIs is likely due to a disruption of spatial and temporal grouping by the heterogeneity of the two disks in the luminance change condition: As a consequence of the luminance change between frames, the first frame consists of two disks of equal luminance, whereas the second frame contains one disk at baseline luminance and one disk at greater-than-baseline luminance. The grouping by similarity of the disks in the second display, which reinforces the concurrent movement of both disks, is diminished by the dissimilarity of the two disks. Furthermore, the grouping of the two "left" disks across frames is disrupted by the dissimilarity of the two corresponding motion tokens. Both of these factors decrease the evidence to support a percept of group motion.

According to the premise that element motion is due to a persistence of the object representation of the "center" disk across frames, the increase in the probability of observing group motion at the shortest ISI can be interpreted as a release from element motion: Because the luminance change in the center disk disrupts the spatiotemporal continuity of that disk, the visual system is now free to match the center disk in the first frame with the "peripheral" disk in the second frame. The visual system may prefer this match because it minimizes the maximum distance that either of the disks needs to travel (cf. Dawson, 1991; Dawson et al., 1994; Ullman, 1979). The visual system is no longer bound by the assumption that the "center" disk is continuous in space and time and can determine new correspondences in apparent motion, on the basis of different assumptions. Because the release from element motion normally occurs at longer ISIs owing to temporal factors, it makes sense that the effect of luminance change should be most pronounced at the shortest ISI, where these temporal factors are less influential. By the same token, where these temporal factors dominate (i.e., at the longest ISIs), they should mask any effect due to luminance change. Accordingly, at the longer ISIs, where the probability of observing group motion eventually reaches nearly 100%, the luminance change no longer causes an increase in the probability of observing group motion (in fact, it causes a slight decrease, as mentioned earlier). Probably not coincidentally, the crossover between the two curves for the different luminance contrast conditions occurs at the point where the motion percept becomes ambiguous to observers; the probability of observing group motion is approximately 50% (in the baseline condition) at this point. In other words, the transition occurs at a point where the persistence of the "center" disk (favoring element motion) and the temporal separation of the frames (favoring group motion) exert an equal force on the observer's percept of the Ternus display.

In conclusion, it should be pointed out that the increase in the probability of observing group motion was obtained in a within-participant design. That is, the same participants judging the same displays at the same ISIs were more likely to report seeing group motion when the "center" disk underwent a change in luminance. Furthermore, this change in luminance was of the same magnitude as that which had produced contingent capture in Experiment 1—presumably by disrupting the spatiotemporal object continuity of the change cue. A reasonable interpretation of the results of both experiments, then, is that the luminance change caused the altered luminance change cue, as well as the "center" disk in the second frame of the Ternus display, to be seen as a new object. These two experiments therefore provide converging evidence that a luminance change of the magnitude used in these experiments may occasion the opening of a new object file.

**General Discussion**

The literature on attentional capture is currently being expanded by an increasing number of findings that suggest that certain types of featural changes to existing objects attract attention to themselves. Among the dynamic cues for which attentional capture has been reported are changes in color (Franconeri & Simons, 2001; Thomas & Luck, 2000), changes in form (Theeuwes, 1990), simultaneous changes in polarity and contrast (Enns et al., 2001), and abrupt onset of motion (Franconeri & Simons, 2001). These findings stand in contrast to the claim that only the abrupt onset of a new object captures attention in an involuntary fashion (cf. Yantis, 1993, 2000; Yantis & Hillstrom, 1994). The experiments reported here suggest that in those instances in which a change to an existing object captures attention, the change may have been interpreted by the visual system as constituting the emergence of a new perceptual object. In Experiment 1, a cue that underwent a luminance change produced contingent capture when participants were set for a new object target. Contingent capture, however, was observed only when the change was quite large. By contrast, in Experiment 2, even small luminance changes produced contingent capture when participants were set for luminance transient targets. This pattern of results suggests that a sufficiently large luminance change to an existing object disrupts the spatiotemporal continuity of the modified object and occasions the opening of a new object file. Experiment 3 established that the relative size of the luminance change determines whether capture will ensue, not the...
absolute size of the luminance change. The relative magnitude of the luminance transient necessary to produce contingent capture was comparable for new object and luminance change cues, which makes sense given that the luminance change cues were treated like new object cues. Finally, Experiment 5 showed that a luminance change of the magnitude that produced contingent capture in Experiment 1 is capable of disrupting the spatiotemporal continuity of an object in a paradigm other than contingent capture.

The functional equivalence of new object and luminance change cues in the experiments reported here has implications for studies investigating the ability of featural changes to capture attention. Although the displays used in these studies formally involve changes to an existing object, it may very well be that the visual system treats these changes as constituting the emergence of a new object. It is then the appearance of this new perceptual object that captures attention, rather than the featural change per se. Although the present experiments do not rule out the possibility that featural changes ever capture attention in the absence of the appearance of a new object, they do make it advisable to exercise caution in making such claims. The results of Hillstrom and Yantis (1994) made a similar case for attentional capture by motion. In their experiments, an item undergoing apparent motion was successful in capturing attention. On the surface of it, this finding suggests that motion is capable of capturing attention. However, Hillstrom and Yantis were able to demonstrate that capture occurred only when the motion precipitated the opening of a new object file—by segregating the item in motion from its background of stationary items. Similarly, it may be that featural changes capture attention, but only when they are accompanied by the appearance of a new perceptual object. This distinction may help to explain why some studies have reported capture by featural changes and other studies have failed to find such effects.

Apart from their relevance for attentional capture, the findings reported here shed some light onto the way in which the human visual system deals with the identity of objects in general. In philosophy, the question of whether an object retains its original identity after having been altered in some significant way is a source of continued debate. By contrast, because the human visual system evolved as part of an organism that was (and perhaps continues to be) subject to evolutionary pressures, it was forced to arrive at an eventual solution to the question of object identity. This solution apparently entails both flexibility and definite boundaries: Small featural changes are tolerated, whereas changes that exceed a certain magnitude lead to the disruption of object continuity. The present study offers a way to probe the conditions under which object continuity is no longer maintained and to assess the magnitude of change that the visual system has evolved to consider inconsistent with normal variability in the featural composition of objects in the natural world.

**Footnotes**

1

It should be noted at this point that the purpose of this article is not to settle the question of whether new objects attract attention without a top-down component. The experiments in this article were not designed to answer this question. Indeed, by their very nature, they entail a strong reliance on top-down attentional factors. At the same time, this heavy reliance on top-down factors does not imply that new objects require the proper attentional set to capture attention. The experiments reported here simply do not speak to this issue. Instead, their focus is on the possible interpretation of findings that certain dynamic cues capture attention in what appears to be an involuntary fashion.

2

As one reviewer pointed out, the luminance change associated with the target in Experiment 2 was smaller than that in Experiment 1 (see the Method section). Consequently, if participants were set for luminance changes in general (rather than for new objects in Experiment 1 and luminance changes in Experiment 2), they might have been set for smaller luminance changes in Experiment 2 than in Experiment 1. This difference in set for luminance change magnitude would predict that smaller luminance changes than in Experiment 1 should begin to show evidence of capture in Experiment 2. The new object account makes the same prediction. Where the two accounts diverge is in their predictions for the luminance singleton condition. Both the absolute magnitude (70.7 cd/m2) of the luminance transient associated with the onset of the cue in this condition and the ratio of change (1:177) already far exceed those for the luminance change condition. Only a change in the attentional set for the type of target (i.e., luminance change vs. new object) sensibly makes the prediction that the luminance singleton cue should begin to capture attention in Experiment 2. In anticipation of the results of Experiment 2, this is exactly what was observed. For more details about the predictions for the luminance
singleton condition in Experiments 1 and 2, and for the implications of the results obtained, refer to the main text. (See also Experiment 4.) The results of a control experiment based on Experiment 2 corroborate these contentions. In this experiment, the luminance change in the target was equated to the luminance change accompanying the onset of the target in Experiment 1. The ratio of change in the latter was 48:5. To produce the same ratio in the control experiment, the luminance of the placeholders was reduced to 1.46 cd/m², with the target remaining at roughly 70.7 cd/m². As before, the luminance change cue produced a significant validity effect even at the smallest level of luminance change: 49 ms, t(7) = 3.00, p < .05; 49 ms, t(7) = 1.84, p < .05; and 91 ms, t(7) = 1.89, p < .05, respectively, for each level of luminance change, from small to large. Also as before, the largest contrast in the luminance singleton condition produced evidence of capture: 88 ms, t(7) = 4.48, p < .005. (See Experiment 2.)

Atchley et al. (2000, Experiment 4), incidentally, observed contingent capture with a ratio of 4:0 but not with a ratio of 2:7.

In this case, center refers to the perceived position of the disk across frames. Within each respective display, the disk perceived to remain stationary in the center of the display is either the left or the right of two disks, with this spatial relationship switching from frame to frame. On the basis of this understanding, center and peripheral appear in quotation marks to indicate that these relative positions hold only for the perceived spatial relationships of the disks at short ISIs.

A modified version of Experiment 5 replicated this result (Rauschenberger & Yantis, 2001). In this experiment, three intermediate luminance values were presented in addition to those used in Experiment 5. Of these five luminance values, only the most extreme value (51 cd/m²) differed significantly from the no-change condition, t(11) = 2.54, p < .05. As in Experiment 5, this difference was significant in the predicted direction only at the shortest ISI. This result supports the interpretation that the effect observed in Experiment 5 was due to a disruption of the spatiotemporal continuity of the "center" disk of the Ternus display.

References:


Performance, 10, 601-621.


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