

There are also forms of association formation that do not depend on NMDA receptors. Many of the experiments that showed that NMDA antagonists blocked some aspect of learning also showed that the same drug administration regimen left some other aspect of learning intact. For example, in the conditional freezing preparation, immediately after shock there is an associative short-term memory that survives the same AP5 treatment that blocks the longer term fear memory conditioned by the same shock. AP5-treated rats froze normally for about 90 s following shock, even though they showed a complete loss of the response when examined any more than 3 min after shock termination.¹⁰ These short-term associative memories may result from NMDA-independent synaptic changes or, perhaps, from biological processes that still wait to be uncovered.

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Notes

1. For reviews, see J.C. Watkins, The NMDA receptor concept: Origins and development, In *The NMDA Receptor*, J.C. Watkins and G.L. Collingridge, Eds. (Oxford University Press, Oxford, 1989); D.T. Monaghan, R.J. Bridges, and C.W. Cotman, The excitatory amino acid receptors: Their classes, pharmacology, and distinct properties in function of the nervous system, *Annual Review of Pharmacology and Toxicology*, 29, 365–402 (1989).
2. The role of NMDA receptors in these areas is discussed in the following chapters in *The NMDA Receptor*, J.C. Watkins and G.L. Collingridge, Eds. (Oxford University Press, Oxford, 1989): development—A. Artola and W. Singer, NMDA receptors and developmental plasticity in visual neocortex; motor patterns—N. Dale, The role of NMDA receptors in synaptic integration and organization of complex neural patterns; epilepsy—W.A. Wilson, S. Stasheff, S. Swartzwelder, S. Clark, W.W. Anderson, and D. Lewis, The NMDA receptor in epilepsy.
3. T.V.P. Bliss and T. Lomo, Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit following stimulation of the perforant path, *Journal of Physiology*, 334, 33–46 (1973).
4. For reviews, see T.H. Brown, P.F. Chapman, E.W. Kairiss, and C.L. Keenan, Long-term synaptic potentiation, *Science*, 242, 724–728 (1988); G.L. Collingridge, Long term potentiation in the hippocampus: Mechanisms of initiation and modulation by neurotransmitters, *Trends in Pharmacological Sciences*, 5, 407–411 (1985).
5. S.R. Kelso and T.H. Brown, Differential conditioning of associative synaptic enhancement in hippocampal brain slices, *Science*, 232, 85–87 (1986); W.B. Levy and O. Steward, Temporal contiguity requirements for long-term associative potentiation/depression in the hippocampus, *Neuroscience*, 8, 791–797 (1983).
6. G.L. Collingridge and J. Davies, NMDA receptors and long-term potentiation in the hippocampus, In *The NMDA Receptor*, J.C. Watkins and G.L. Collingridge, Eds. (Oxford University Press, Oxford, 1989).
7. D.V. Madison and E.R. Schuman, LTP, post or pre? A look at the evidence for the locus of long-term potentiation, *New Biologist*, 3, 549–557 (1991).
8. R.G.M. Morris, E. Anderson, G.S. Lynch, and M. Baudry, Selective impairment of learning and blockade of long-term potentiation by an *n*-methyl-D-aspartate receptor antagonist, AP5, *Nature*, 319, 774–776 (1986); S. Davis, S.P. Butcher, and R.G.M. Morris, The NMDA receptor antagonist D-2-amino-5-phosphonopentanoate (D-AP5) impairs spatial learning and LTP *in vivo* at intracerebral concentrations comparable to those that block LTP *in vitro*, *Journal of Neuroscience*, 12, 21–34 (1992).
9. J.R. Keith and J.W. Rudy, Why NMDA-receptor-dependent long-term potentiation may not be a mechanism of learning and memory: Reappraisal of the NMDA-receptor blockade strategy, *Psychobiology*, 18, 251–257 (1990); for a lively debate, see pages 258–272 of that issue of *Psychobiology*.
10. J.J. Kim, J.P. DeCola, J. Landeira-Fernandez, and M.S. Fanselow, *n*-methyl-D-aspartate receptor antagonist APV blocks acquisition but not expression of fear conditioning, *Behavioral Neuroscience*, 105, 160–167 (1991); J.J. Kim, M.S. Fanselow, J.P. DeCola, J. Landeira-Fernandez, Selective impairment of long-term but not short-term conditional fear by the NMDA antagonist APV, *Behavioral Neuroscience*, 106, 591–596 (1992); M.S. Fanselow, J.J. Kim, and J. Landeira-Fernandez, Anatomically selective blockade of Pavlovian fear conditioning by application of an NMDA antagonist to the amygdala and periaqueductal gray, *Society for Neuroscience Abstracts*, 17, 659 (1991); S.L. Young, M.S. Fanselow, and D.L. Bohnenk, The dorsal hippocampus and contextual fear conditioning, *Society for Neuroscience Abstracts*, 18, 1564 (1992).
11. P.F. Chapman, E.W. Kairiss, C.L. Keenan, and T.H. Brown, Long-term synaptic potentiation in the amygdala, *Synapse*, 6, 271–278 (1990).
12. M. Kim, S. Campeau, W.A. Falls, and M. Davis, Intra-amygdala infusion of the non-NMDA receptor antagonist CNQX blocks expression of fear-potentiated startle, *Behavioral and Neural Biology*, 59, 5–8 (1993); M.J.D. Miserendino, C.B. Sananes, K.R. Melia, and M. Davis, Blocking of acquisition but not expression of conditioned fear-potentiated startle by NMDA antagonists in the amygdala, *Nature*, 345, 716–718 (1990).
13. S.L. Young and M.S. Fanselow, Associative regulation of Pavlovian fear conditioning: US intensity, incentive shifts and latent inhibition, *Journal of Experimental Psychology: Animal Behavior Processes*, 18, 400–413 (1992).

Stimulus-Driven Attentional Capture

Steven Yantis

Vision provides an observer with information about surfaces in the local environment to enable navigation and object recognition. No successful visual system can perform this function without an attentional mechanism that intelligently selects relevant aspects of the image for

identification or other computational processes.

Human visual selection is controlled in at least two distinct ways, referred to here as *goal-directed selection* and *stimulus-driven capture*. When information is selected because it satisfies some goal-defined

criterion, selection is goal-directed; this is also sometimes called top-down or endogenous control over the locus of attention. Goal-directed selection depends on an observer's beliefs about the task at hand and about current environmental conditions, the observer's expectations about what he or she will see, and other knowledge-based factors. It entails a deliberate state of attentional readiness.

When information is selected because some attribute in the image captures attention independently of the observer's goals or beliefs, selec-

tion is stimulus-driven; this is sometimes called bottom-up or exogenous control over the locus of attention. Stimulus-driven attentional capture can be said to occur only when the attribute that elicits it is independent of the observer's state of attentional readiness. In particular, the feature or feature combination that an observer is "looking for" cannot be said to capture attention in a stimulus-driven way because it is specifically part of the observer's attentional set.

Some combination of these two selection mechanisms determines how attention is distributed within an image. However, when one is concerned with characterizing the attentional effect of some visual event or attribute, it is useful to consider each type of selection separately. Goal-directed selection has been investigated extensively for more than three decades.¹ In contrast, stimulus-driven selection has become a significant focus of investigation relatively recently. In this article, I review work that clarifies the role of stimulus-driven attentional capture in vision. First, I review evidence that limits the scope of the widely held belief that unique features in the visual field (e.g., a red object among green ones) capture attention in a purely bottom-up way. Second, I describe evidence that abrupt visual onsets capture attention. Finally, I argue that onsets capture attention not because they are accompanied by a luminance increment, but because they mark the appearance of a new perceptual object.

FEATURAL SINGLETONS AND ATTENTIONAL CAPTURE

Visual search experiments have provided crucial evidence about stimulus-driven and goal-directed attention allocation. In a typical experiment, observers are required to detect the presence of a prespecified target element in a display of multiple nontarget elements. For alphanumeric characters, search times usually increase with the number of elements in the display (a *display-size effect*). The presence of a display-size effect is often taken as evidence for a serial (or at least an attentionally demanding) scan of the elements in the display.

When the target differs from all the nontargets in some salient feature (e.g., the target is red, and the nontargets are all green), then that target (called a *featural singleton*) is easy to find: Search times often do not increase with display size. The absence of a display-size effect is taken as evidence that the singleton can be found without an attentionally demanding search. Evidence that a singleton target "pops out" of the display without effort on the part of the observer is one of the central facts that must be accounted for by any successful theory of visual attention.²

Recent findings suggest that when the target's *defining attribute* is a singleton (e.g., the task is to name or detect the red element in an array of one red and multiple green elements), not only is the singleton easy to find, but observers cannot ignore an irrelevant singleton even if it is in a different dimension than the relevant one. For example, consider the displays used by Theeuwes,³ shown in the top of Figure 1. Subjects were required to report the orientation of a line segment (horizontal or vertical) that always appeared inside a circle. Nontarget line segments appeared inside diamonds. On half the

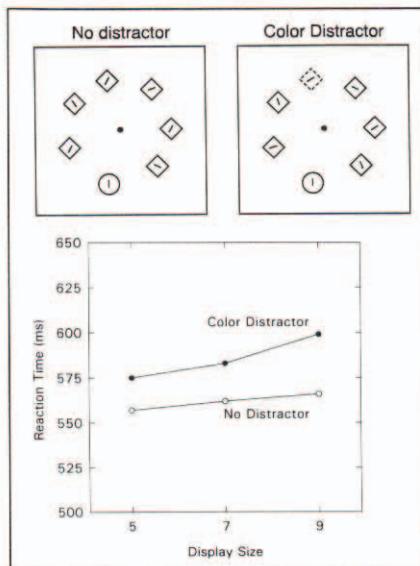


Fig. 1. Effect of irrelevant singletons when the target is a singleton. Top: Sample displays from the form condition of Theeuwes's³ visual search task, which requires the observer to report the orientation of the single nonoblique line segment. Green lines are shown as solid, red lines as dotted. The target line segment is always inside the green circle, which is a form singleton here. In the left panel, there is no distractor singleton. In the right panel, there is a red distractor singleton. Bottom: Reaction time as a function of display size for the distractor and no-distractor conditions. Reaction time is slower when there is a color distractor than when there is not, suggesting that the color singleton cannot be ignored. From Theeuwes.³

trials (the no-distractor condition), all the shapes in the array were green; on the remaining trials (the color-distractor condition), a known, irrelevant color singleton (a red diamond) was present. The task therefore required subjects to detect the form singleton and to ignore the color singleton when it was present. Theeuwes found that the presence of the known color singleton elevated reaction time (RT) significantly (Fig. 1, bottom). He claimed that when observers search for singletons, attention is drawn to regions of the display containing large local-feature contrast regardless of the dimension in which the feature contrast occurs. It is as if there is a global feature-

Steven Yantis is Associate Professor of Psychology at The Johns Hopkins University. Address correspondence to Steven Yantis, Department of Psychology, Johns Hopkins University, Baltimore, MD 21218; e-mail: yantis@jhuvms.hcf.jhu.edu.

differencing operator that guides attention, and the salience of the singleton, but not its identity, determines which feature (when more than one is present) captures attention.

In a related experiment, Pashler⁴ had subjects look for a form singleton (a circle target among slanted lines or vice versa). All the elements in the display were the same color (either red or green on any given trial) with the following exception: Within some blocks of trials, two elements in known, fixed positions were rendered in the other color. Thus, the target was defined as a form singleton, and on each trial in the critical blocks, there were two irrelevant color singletons. When the identity of the target was not known before the trial, the presence of an irrelevant color singleton reduced the accuracy with which subjects could report the location of the form singleton.⁵

These and other findings have led to the belief that singletons capture attention in a stimulus-driven fashion. However, as mentioned earlier, when a singleton is part of the observer's attentional set, its attentional effects are at least partly, and perhaps entirely, goal-directed. Do featural singletons capture attention when they are not part of the observer's attentional set?

Jonides and I⁶ examined this question by conducting a visual search study with arrays of letters. One element in each display differed saliently from the rest in color or brightness, but this experiment differed from those discussed earlier in that the singleton was no more likely to be the target than was any other element in the display; observers were fully informed that the singleton provided no information about the location of the target. The experiment yielded a significant display-size effect whether the target happened to be the singleton or not. This result rules out the possibility that highly salient color or brightness

singletons capture attention when they are irrelevant to the observer's perceptual goals. Surprisingly, not even a visual motion singleton captures attention when it is not part of the observer's attentional set;⁷ I return to this finding later.

Bacon and Egeth⁸ have shown directly that attentional capture by an irrelevant featural singleton critically depends on the observer's adopting a singleton-detection search strategy: An irrelevant singleton will not capture attention when the task requires the observer to adopt a different strategy. In one of their experiments, modeled after those of Theeuwes,³ several instances of the target were present in the display, rather than just one, so subjects could not rely on the detection of a singleton to find the target. In this case, an irrelevant singleton did not capture attention. In another experiment, the nontargets were heterogeneous shapes, so the target was again no longer a singleton; because singleton-detection mode could not be used, an irrelevant color singleton failed to capture attention.

Together, these studies suggest that when the target of search is a featural singleton, any salient singleton (even ones known to be irrelevant) captures attention, and when the target of search is not a singleton, irrelevant singletons do not capture attention.

ABRUPT VISUAL ONSETS AND ATTENTION

Although singletons as such do not capture attention, Jonides and I⁹ found that abrupt visual onsets do. Our experiments included displays in which one element (called the onset element) appeared in a location that was previously blank, and the remaining elements (called no-onset elements) appeared in locations that previously contained letters camou-

flaged with irrelevant line segments (see Fig. 2, top). In each display, exactly one element had an abrupt onset. The target was no more likely to be the onset element than any other element in the display, so there was no incentive for subjects to attend to the onset element. Nevertheless, when the target was the onset element, RT did not increase with display size; when the target was one of the no-onset elements, RT increased in the typical linear fashion (Fig. 2, bottom). This result provides evidence that in each trial, attention is directed to the onset location first and then to the remaining locations in an effortful, attentionally demanding search.

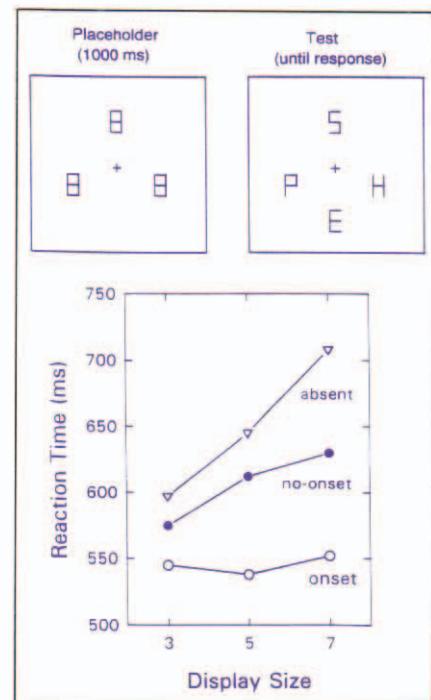


Fig. 2. Abrupt visual onsets. Top: The visual search task begins with a placeholder display, which is followed by a test display. One letter in the test display, in this case, the *E*, has an abrupt onset; the remaining letters are no-onset elements. Bottom: Results from a typical experiment. Reaction time is plotted as a function of display size and whether the target was the onset element, one of the no-onset elements, or absent from the display. The flat slope in the onset condition reflects attentional capture. Data are from Jonides and Yantis.⁶

Further studies have shown that capture by abrupt onset is not absolute. When observers focus their attention at a spatial location in anticipation of a target event there, an abrupt onset elsewhere does not capture attention. For example, if a spatial cue indicates the likely location of an upcoming target, subjects can direct attention to the indicated location in advance of the display. As long as the cue is sufficiently informative, and sufficient time is provided to focus attention, an abrupt onset in another location does not disrupt performance.¹⁰ Thus, capture by abrupt onset can be overridden by top-down control. This interaction between goal-directed control and stimulus-driven capture makes adaptive sense: If an organism is in a neutral attentional state, then the appearance of a new object in the visual field will often contain useful, even vital, information; however, if there is some reason to attend to a particular location, then onsets elsewhere should not distract from it needlessly.

Johnson, Jones, and I subsequently set out to determine the effects of multiple simultaneous onsets on attentional capture. We thought the presence of more than a single onset element might simply nullify the priority of all onsets; alternatively, all onset elements might be accorded absolute priority over all no-onset elements. Instead, we obtained an intermediate result suggesting that when a number of onset and no-onset elements appear in a visual search display, all the onset elements are immediately tagged as high priority (increasing the likelihood that they will be identified early in search), but the magnitudes of the priority tags decay with time.¹¹ Thus, in practice, only a few onset elements will have priority over no-onset elements; by the time search has proceeded for 100 ms or so, the priority tags have decayed, and the onset and no-onset elements are attentionally equivalent.

ATTENTIONAL CAPTURE BY NEW OBJECTS

What specific property of onset causes capture? One possibility is that the luminance change that accompanies an abrupt onset triggers low-level visual mechanisms that are sensitive to abrupt changes in illumination. This idea was what motivated our earliest studies of abrupt onsets. Another possibility, however, is that the appearance of a new perceptual object, even in the absence of a luminance increment, captures attention. These two possibilities are confounded in the experiments reviewed so far: All the abrupt onsets were new perceptual objects with luminance increments. To unconfound these factors, Hillstrom and I analyzed performance in a visual search task with elements defined by equiluminant discontinuities in depth, motion, and texture.¹² The results were clear: The appearance of a new object, even without a luminance increment, captured attention. Furthermore, a brief, highly salient luminance increment in a no-onset element failed to capture attention when the location of the luminance increment did not predict the target's location.

This result may seem surprising at first, particularly in light of the classic experiments of Posner and colleagues,¹³ which suggested that irrelevant luminance increments do summon attention. In Posner's paradigm, the target is a spot of light appearing in one of two boxes arranged to the left and right of fixation; subjects are required to press a single key as soon as the spot appears. At various moments before the target appears, one of the two boxes brightens briefly; this is called a cue. The cue may appear on the same side as the target (a valid cue) or on the opposite side (an invalid cue). Valid cues appearing within about 100 ms before the appearance of the target yield faster target-

detection times than invalid cues do, even if the subject is informed that the location of the cue does not predict the target's location. Posner reasonably interpreted this result as evidence that luminance increments capture attention, a conclusion that seems to contradict what Hillstrom and I found.

The apparent conflict disappears in light of my earlier conclusion about featural singletons: If (and only if) the target of search is a featural singleton, then matching singletons (or indeed any salient singleton) will capture attention. In Posner's task, the target is a luminance-increment singleton, and so is the cue; accordingly, the cue captures attention even though its location is uninformative. In the visual search experiment Hillstrom and I conducted, the target was a letter shape (not a singleton), so the irrelevant luminance singleton did not capture attention.

Hillstrom and I next examined the conditions under which visual motion will capture attention.⁷ This is a particularly interesting case because visual motion is perhaps the most natural way to draw attention. Furthermore, motion is in some sense a special case of visual onset. Although it does not involve the appearance of a new perceptual object, we fully expected it to yield evidence for attentional capture.

Contrary to our expectations, we found that when subjects search for a specific shape, and single-element motion provides no information about the position of the target, motion does not capture attention. In accounting for this unexpected result, we considered the possibility that motion (or any other attribute) captures attention only when it causes the appearance of a new perceptual object, or, in Kahneman and Treisman's terms, when it causes the creation of a new object file.¹⁴ Our conjecture was that when an object file is created to accommodate the appearance of a new perceptual ob-

ject, attention is directed there in a stimulus-driven fashion. In visual search experiments involving a single moving element, motion does not cause the creation of a new object file, and therefore does not capture attention. However, there are situations in which motion does meet the new-object requirement for attentional capture.

As an analogy, consider the Geometridae moth, which is found in northern Borneo and elsewhere. Its wings have an appearance similar to that of the lichen-covered bark on which it rests. As long as the moth remains motionless, it is nearly invisible, presumably because of similarity grouping of its wings with the background. As soon as it moves its wings even slightly, the grouping is disrupted and the moth stands out in sharp relief. In this case, it is not the motion of the wings per se that captures attention, but the appearance

of the previously camouflaged perceptual object. To test this idea, Hillstrom and I carried out the following experiment.

Subjects were required to identify the global letter in a display like the ones shown in Figure 3. The global letter was always an *H* or an *S*. The local letters were neutral (*E* or *U*), with this exception: There was always one unique local letter, which could be either compatible (i.e., the same as the global letter), incompatible (i.e., *H* or *S*, whichever was not the global letter), or neutral (i.e., neither *H* nor *S*) with respect to the global letter. Our measure of attentional capture was the extent to which the unique local letter influenced RT to the global letter.

There were three main conditions in the experiment (see Fig. 3). In the baseline condition, a global figure eight, made up of numerous densely packed local figure eights, was pre-

sented for 1 s. This display then turned into a global *H* or *S* made up of local neutral letters plus one unique letter. Many experiments have shown that when local letters are compatible with the global letter, RT may be speeded compared with RT when local letters are neutral, and when local letters are incompatible with the global letter, RT may be slowed. In the baseline condition, we expected minimal inhibition or facilitation because there was only one response-relevant local letter. Furthermore, in this condition, the unique local letter did not stand out from the other local letters because of the tightly packed configuration; in other words, these local letters formed a strong perceptual group, which might be expected to minimize the effects of the individual letters on performance.

In the second main condition, called the onset condition, the unique local letter appeared in a previously blank location. Based on our other results with abrupt visual onsets, we expected this local letter to capture attention, and therefore to have a significant inhibitory or facilitatory effect on RTs. According to our hypothesis, attention is captured here because the onset letter is a new perceptual object.

The third condition was the motion condition. Here, when the test display appeared, the unique local element started oscillating. We designed the display so that the unique local element would be grouped with the other elements during the preliminary figure-eight display; when the motion began, the unique letter was immediately segregated from the rest of its group (much as the motion of the moth's wings causes it to stand out). When this segregation occurs, we reasoned, an object file would have to be created for the new moving object, and this should capture attention and consequently should influence RTs to the global letter.

Cost and benefit difference scores

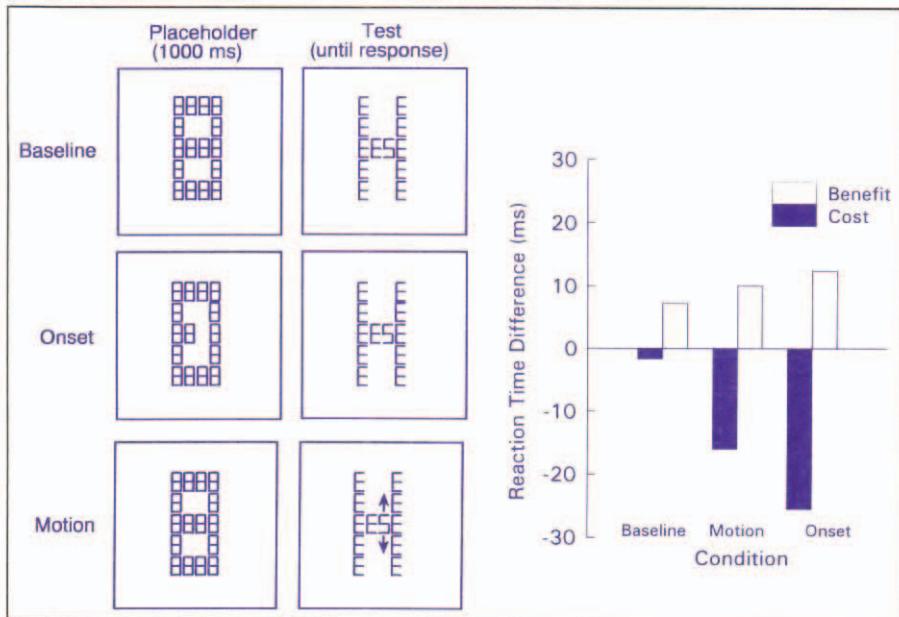


Fig. 3. New objects defined by motion or onset. Left: Subjects saw a placeholder display followed by a test display. They were to report whether the large (global) letter in the test display was an *S* or an *H*, ignoring the identity of the small (local) elements. Most of the local elements were response-neutral (in these examples, *E*). The unique local element was compatible, neutral, or incompatible with the response required by the global stimulus (in all three conditions illustrated here, it is incompatible with the target). The unique local element either was stationary (baseline condition), appeared in a previously blank location (onset condition), or began moving when the global letter was revealed (motion condition). Right: Reaction time (RT) differences for the three conditions. Benefit = neutral RT – compatible RT; cost = neutral RT – incompatible RT. From Hillstrom and Yantis.⁷

are plotted on the right side of Figure 3. The magnitude of the costs and benefits reflects the extent to which the unique local element captured attention. There were minimal costs and benefits in the baseline condition, but significant costs and benefits in both the onset and the motion conditions. This last observation provides corroboration for the new-object account. Motion will capture attention, but only when it causes the creation of a new object file by segregating an element from its background.

There is no reason to believe that motion is unique in this regard. Any change that causes an element to segregate from its perceptual group should force the creation of a new object file and thereby capture attention. For example, although in general a color singleton does not capture attention, a color change in one element can segregate that element from its perceptual group; in just these circumstances, color should mediate attentional capture.

CONCLUSIONS

Two generalizations about stimulus-driven attentional capture are supported by the evidence reviewed here. First, when the observer's task requires a deliberate attentional set for a featural singleton, then both relevant and irrelevant singletons of any kind may capture attention. Second, when the observer's task does

not require a deliberate attentional set for a singleton, then only the appearance of a new perceptual object will capture attention. New object files are created by abrupt visual onsets or by any perceptual event that segregates an element from its background. These conjectures, if corroborated, may help further constrain object-based theories of visual selective attention.

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Notes

1. A. Allport, Visual attention, in *Foundations of Cognitive Science*, M.I. Posner, Ed. (MIT Press, Cambridge, MA, 1989).
2. See, e.g., A. Treisman and G. Gelade, A feature integration theory of attention, *Cognitive Psychology*, 12, 97–136 (1980); J. Duncan and G.W. Humphreys, Visual search and stimulus similarity, *Psychological Review*, 96, 433–458 (1989); K.R. Cave and J.M. Wolfe, Modeling the role of parallel processing in visual search, *Cognitive Psychology*, 22, 225–271 (1990).
3. J. Theeuwes, Perceptual selectivity for color and form, *Perception & Psychophysics*, 51, 599–606 (1992).
4. H. Pashler, Cross-dimensional interaction and texture segregation, *Perception & Psychophysics*, 43, 307–318 (1988).
5. For additional evidence that singletons capture attention when the target is defined as a singleton, see J. Theeuwes, Cross-dimensional selectivity, *Perception & Psychophysics*, 50, 184–193 (1991); and Experiment 4 in C.L. Folk, R. Remington, and J.C. Johnston, Involuntary covert orienting is contingent on attentional control settings, *Journal of Experimental Psychology: Human Perception and Performance*, 18, 1030–1044 (1992).
6. J. Jonides and S. Yantis, Uniqueness of abrupt visual onset in capturing attention, *Perception & Psychophysics*, 43, 346–354 (1988); for a corroborating study, see J. Theeuwes, Perceptual selectivity is task dependent: Evidence from selective search, *Acta Psychologica*, 74, 81–99 (1990).
7. A.P. Hillstrom and S. Yantis, Visual motion and stimulus-driven attentional capture, *Perception & Psychophysics* (in press).
8. W.F. Bacon and H.E. Egeth, Overriding stimulus-driven attentional capture, *Perception & Psychophysics* (in press).
9. S. Yantis and J. Jonides, Abrupt visual onsets and selective attention: Evidence from visual search, *Journal of Experimental Psychology: Human Perception and Performance*, 10, 601–621 (1984).
10. S. Yantis and J. Jonides, Abrupt visual onsets and selective attention: Voluntary versus automatic allocation, *Journal of Experimental Psychology: Human Perception and Performance*, 16, 121–134 (1990); J. Theeuwes, Exogenous and endogenous control of attention: The effect of visual onsets and offsets, *Perception & Psychophysics*, 49, 83–90 (1991); H. Koshino, C.B. Warner, and J.F. Juola, Relative effectiveness of central, peripheral, and abrupt-onset cues in visual attention, *Quarterly Journal of Experimental Psychology*, 45A, 609–631 (1992).
11. S. Yantis and D.N. Johnson, Mechanisms of attentional priority, *Journal of Experimental Psychology: Human Perception and Performance*, 16, 812–825 (1990); S. Yantis and E. Jones, Mechanisms of attentional selection: Temporally-modulated priority tags, *Perception & Psychophysics*, 50, 166–178 (1991).
12. S. Yantis and A.P. Hillstrom, Stimulus-driven attentional capture: Evidence from equiluminant visual objects, *Journal of Experimental Psychology: Human Perception and Performance* (in press).
13. E.g., M.I. Posner, Y. Cohen, and R.D. Rafal, Neural systems control of spatial orienting, *Philosophical Transactions of the Royal Society of London*, 298B, 87–198 (1982). Their Figure 2 illustrates this finding nicely.
14. An object file is a visual representation of a perceptual object, containing specifications of the various attributes of the object, including its location, time of appearance, color, and shape. Kahneman and his colleagues have argued that the object file may form the basis of visual selection in many tasks; D. Kahneman, A. Treisman, and B. Gibbs, The reviewing of object files: Object-specific integration of information, *Cognitive Psychology*, 24, 175–219 (1992). For a review of related evidence, see N. Kanwisher and J. Driver, Objects, attributes, and visual attention: Which, what, and where, *Current Directions in Psychological Science*, 1, 26–31 (1992).

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