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Attention capture is modulated in dual-task situations

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Because some features affect the efficiency of visual search even when they are irrelevant to the task, they are thought to *capture* attention in a stimulus-driven manner. If such attention shifts are stimulus driven, they should be unaffected by reduced resources. We added a concurrent auditory task to a traditional attention capture paradigm and found that capture by an irrelevant, abruptly appearing stimulus (i.e., an onset) was eliminated. In contrast, prioritization of an irrelevant color singleton—a stimulus that at most receives only mild prioritization in this paradigm—was increased under dual-task conditions. These results challenge the hypothesis that attention capture by irrelevant features is stimulus driven. Instead, prioritization depends on and is modulated by the availability of resources.

When viewing a scene, observers volitionally deploy attention to regions of interest. However, unique, distinctive, or transient aspects of a scene sometimes grab attention even when they are irrelevant to our goals. A functional attention system must balance the need to focus selectively on goal-directed action against the need for immediate interruption by other important events. If attention were perpetually captured by salient events or objects, purposeful, goal-directed processing would be unmanageable. However, if goal-directed selection were uninterruptible, important events requiring immediate action might go unnoticed. Attention capture research has catalogued the sorts of features that affect search performance irrespective of the observer's goals and intentions—features that presumably invoke stimulus-driven shifts of attention. This article uses a new method to investigate whether these attention shifts are truly automatic and stimulus driven: exploring how they are affected by the availability of attention resources.

Automatic processes are thought to be immune to variations in top-down attention set or expectation (e.g., Shiffrin & Schneider, 1977), and most studies of attention capture try to demonstrate that capture occurs even when observers have no incentive to attend to a feature; a stimulus-driven shift of attention to a feature should occur even when observers know the feature is irrelevant. In fact, this premise is often treated as an operational definition of attention capture—if a stimulus is irrelevant and it still influences performance, it must have captured attention in a stimulus-driven fashion (e.g., Theeuwes, 1994; Yantis, 1993; Yantis & Hillstrom, 1994).

In one standard attention capture task, the *irrelevant feature search task,* observers view a search display containing one item with a unique feature (e.g., it appears suddenly or has a unique color), but this feature is irrelevant to the search because it is just as likely to be a property of a distractor as it is to be a property of the target (e.g., Jonides & Yantis, 1988). In this task, the abrupt onset of a new object captures attention, but other salient features such as unique colors do not (e.g., Gibson & Jiang, 1998; Jonides & Yantis, 1988). However, other events such as motion, looming, and certain contrast changes also capture attention in this task (Abrams & Christ, 2003; Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Franconeri & Simons, 2003).

The primary critique of claims that attention shifts are stimulus driven is that they are modulated by task-induced strategies, goals, or incentives. Attention capture by onsets in the irrelevant feature search task might result from a default attention set for onsets (Folk, Remington, & Johnston, 1992) or from the fact that the search array appears suddenly (Gibson & Kelsey, 1998). However, the nature of attention shifts in attention capture tasks,

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whether they are stimulus driven or goal directed, is an area of active debate. Task expectations and attention sets certainly influence shifts of attention, but even in the absence of task-induced sets, abrupt onsets capture attention (Franconeri, Simons, & Junge, 2004).

Interestingly, all previous challenges to the idea that attention shifts in the irrelevant feature search task are stimulus driven have focused on the nature and demands of the search task itself. Here we adopt a new approach to assess whether this task measures stimulus-driven shifts of attention. Rather than examining how strategies or expectations affect attention shifts, we relied on the premise that automatic processes should be impervious to manipulations of attention load (e.g., Shiffrin & Schneider, 1977). We introduced a concurrent, attention-demanding auditory task that had nothing whatsoever to do with the search task itself. If attention shifts are stimulus driven, then visual attention capture should be unaffected by the presence of this concurrent task. Alternatively, if attention shifts depend on top-down influences or strategic factors, an attention-demanding concurrent task should affect the extent of capture. Our experiments kept the visual search task constant and examined the effect of a concurrent auditory task on attention capture by irrelevant, abrupt onset objects (Experiment 1), a stimulus that typically captures attention in this task, and by color singletons (Experiment 2), a stimulus that typically does not capture attention in this task.

EXPERIMENT 1

Experiment 1 used the irrelevant feature search paradigm (e.g., Jonides & Yantis, 1988; Yantis & Jonides, 1984) to test whether attention capture by an abrupt onset would be modulated by a concurrent auditory task. All participants experienced the same perceptual information but differential availability of attention.

Method

Twenty-four University of Illinois undergraduates with normal vision were paid $8 each for participating. The participants visually searched for a target letter while performing a concurrent auditory 1-back task (see Figure 1A). At the start of each trial, a white, circular fixation point (.4º in diameter) appeared in the center of the display, and a digitized voice began reading a string of 10 numbers at a rate of two per second for 5 sec. In the dual-task condition, participants counted the number of sequential repetitions in the string (e.g., the string 1, 9, 4, 4, 5, 8, 3, 3, 6, 1 has two sequential repetitions). Digit strings were randomly generated for each trial and were constrained to either two or three sequential repetitions. The participants were told that up to four repetitions could occur to elicit continued attention to the auditory stream even after they counted three repetitions. Two seconds after the start of the auditory stream, either two or six figure-eight premasks (1.9º horizontally and vertically) appeared. The premask positions were randomly selected from 10 equally spaced locations around an imaginary circle (9.0º diameter) centered on fixation. One second later, line segments were removed from the premasks, revealing block letters selected from the set A, C, E, F, H, L, P, S, and U, and simultaneously, an additional letter appeared in a location not previously occupied by a

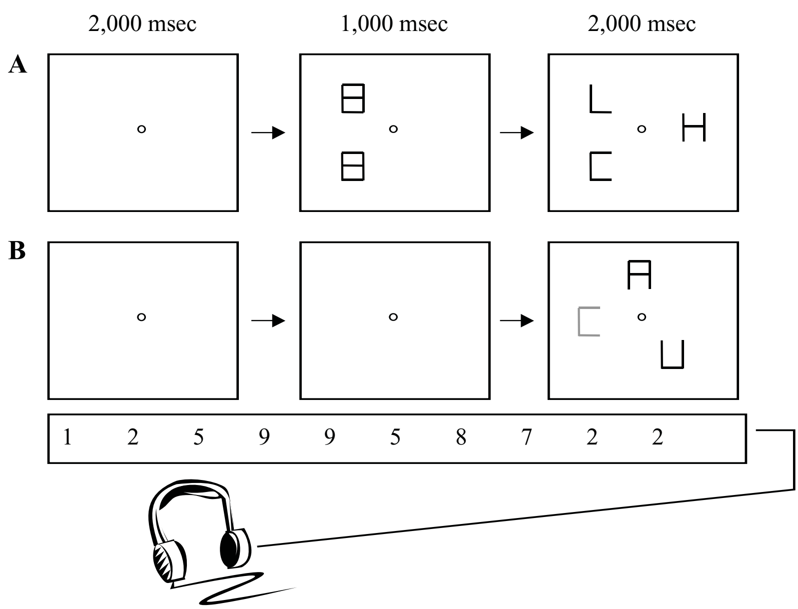

Figure 1. (A) The sequence of events for Experiment 1. After the participant hit the space bar, the fixation point appeared and the auditory stream began. After 2,000 msec, figure-eight premasks were presented, which became letters 1,000 msec later. The target in this case happened to be an onset. (B) The sequence of events for Experiment 2. After the participant hit the space bar, the fixation point appeared and the auditory stream began. After 3,000 msec, the search display was revealed. White letters are depicted in the figure as black, and the red color singleton is depicted as gray. The color singleton in this case happened to be a distractor.

premask, yielding a search set of either three or seven letters. This onset item was no more likely to be the target than any other letter in the display, so there was no statistical incentive to prioritize the onset item during search. The participants were instructed to indicate whether an H or a U was present in the letter array as quickly and as accurately as possible by pressing keys on a keyboard. The search array remained visible for 2,000 msec, and participants could respond at any time during this window. The auditory number string concluded when the letter array was removed.

Half of the participants were assigned to the single-task condition and were told that the auditory stream was completely irrelevant. The other half were assigned to the dual-task condition and counted the number of sequential repetitions in the auditory stream. The participants in the dual-task condition were prompted for the number of repetitions in the auditory stream at the conclusion of each trial. Each participant completed 300 randomly ordered trials, 90 with three search items and 210 with seven search items. In both cases, the search target was the irrelevant onset item on 30 trials, and on the remaining trials, the onset item was a distractor.

Results and Discussion

Trials with errors in the letter judgment were excluded from further analysis (3% of trials in the single-task condition; 7% of trials in the dual-task condition).[1] Table 1 summarizes error rates for each condition, with no evidence of speed–accuracy tradeoffs. By determining the search slope (response latency as a function of the number of items in the display), we calculated search efficiency separately for trials in which the irrelevant onset item was the search target and for trials in which the onset was a distractor. Traditionally, capture in this task is inferred if response times are relatively unaffected by the number of distractor items (a flat slope) when the target happens to be the onset item (Jonides & Yantis, 1988; Yantis & Jonides, 1984). Any decrease in slope when the onset happens to be the search target relative to trials when it is a distractor reflects some degree of attentional prioritization of onsets (Todd & Kramer, 1994). Figure 2 depicts response latencies for each condition and set size.

An mixed-model analysis of variance (ANOVA) was performed on search slopes with singleton type (target-singleton vs. distractor-singleton) as a within-subjects factor and task condition (single vs. dual) as a between-subjects factor. Not surprisingly, target-singletons' slopes were shallower (18 msec/item) than distractor-singleton slopes (38 msec/item) [$F(1,22) = 27.46$, $p < .01$]. Overall, search slopes in the single-task condition (M = 26 msec/item) did not differ from those in the dual-task condition (29 msec/item) [$F(1,22) = 0.26$, $p = .62$]. Critically, however, these two factors interacted [$F(1,22) = 8.79$, $p < .01$]. Consistent with the standard findings in the literature, onsets captured attention in the single-task condition. Planned comparisons demonstrated that search slopes were significantly shallower when the onset item was the search target (11 msec/item) than when it was a distractor (42 msec/item) [$t(11) = 6.38$, $p < .01$].[2] However, in the presence of a concurrent auditory task, this capture was effectively eliminated. Search efficiency did not differ reliably when the onset was a target (25 msec/item) and when it was a distractor (33 msec/item) [$t(11) = 1.49$, $p = .17$]. Thus, onsets fail to capture attention when participants are performing an attention-demanding secondary task even though they do capture if participants simply ignore the auditory information.

In a second analysis, target- and distractor-singleton slopes were also compared across task conditions in a between-subjects analysis. Onset target slopes tended to be shallower in the single-task condition than in the dual-task condition [$t(22) = 1.85$, $p = .08$], whereas distractor-singleton slopes tended to be steeper in the single-task condition than the dual-task [$t(22) = 1.63$, $p = .12$].[3] The direction of these slope differences is consistent with the onset having less of an effect in the dual-task condition. Search slopes reflected less efficient search in the dual-task condition when the target was the onset (less prioritization of the onset when it is the target), but more efficient search when it was a distractor (less prioritization of the onset when it is a distractor item). This result is consistent with compromised attention capture by onsets under dual-task conditions.

EXPERIMENT 2

Experiment 2 examined capture by a color singleton, a feature that typically does not capture attention in this paradigm. Perhaps under dual-task conditions, a salient but irrelevant color singleton will be harder to ignore. That is, a dual-task might *create* capture in a task thought to reflect purely stimulus-driven attention shifts.

Method

Twenty-six University of Illinois undergraduates with normal color vision (tested with the Ishihara Colorblindness Test) were paid $8 each for participating. Two participants were excluded from the analyses, one because of a high error rate on the letter judgment

Table 1
Error Rates (in Percentages) for Each Condition in Experiments 1 and 2

	Singleton Target		Singleton Distractor	
	Set 3	Set 7	Set 3	Set 7
Experiment 1: Onset				
Single task	1.94	1.67	3.61	3.19
Dual task	6.94	7.78	6.25	6.57
Experiment 2: Color				
Single task	3.33	3.06	3.75	3.80
Dual task	3.06	4.44	6.53	5.69

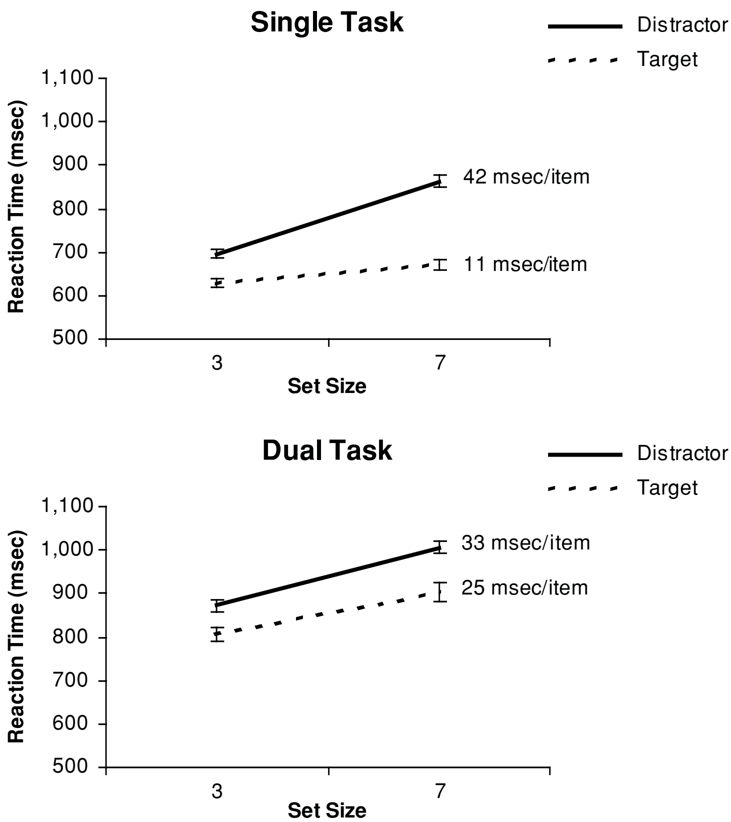

Figure 2. Mean reaction times when the onset was the target and when it was a distractor for each set size in Experiment 1. Error bars represent one standard error of the mean.

task and one because of colorblindness. Except as noted, the displays, design, and procedure were identical to those of Experiment 1. In Experiment 2, the displays contained no premasks—the letters appeared all at once 3,000 msec after the start of the auditory stream (see Figure 1B). On each trial, one letter was red and all other letters were white. The red item was no more likely to be the target of the search than it was to be any of the distractor items.

Results and Discussion

Trials with errors (see Table 1) in the letter judgment task were excluded from further analysis (4% of trials in the single-task condition; 5% of trials in the dual-task condition).[4] As in Experiment 1, no evidence of speed–accuracy tradeoffs were observed. Search slopes were calculated separately for trials in which the color singleton was a target and for trials in which it was a distractor (see Figure 3).

In this experiment, the ANOVA revealed a main effect of singleton type [$F(1,22) = 58.00$, $p < .01$], a main effect of task condition [$F(1,22) = 7.67$, $p < .05$], and an interaction of these two factors [$F(1,22) = 4.54$, $p < .05$]. Overall, search slopes when the color singleton was the target (21 msec/item) were shallower than when it was a distractor (42 msec/item); slopes were also shallower in the dual-task condition (26 msec/item) than in the single-task condition (38 msec/item). Planned comparisons demonstrated that in the single-task condition, search slopes were somewhat shallower when the color singleton happened to be the target (M = 30 msec/item) than when it happened to be a distractor (M = 45 msec/item) [$t(11) = 4.26$, $p < .01$]. This finding suggests some degree of prioritization of color singletons, but by traditional standards, the slope was too steep to reflect attention capture (Todd & Kramer, 1994).[5] Strikingly, in the dual-task condition, search slopes were significantly shallower when the color singleton was a target (12 msec/item) than when it was a distractor (40 msec/item) [$t(11) = 6.37$, $p < .01$]. Thus, performing a concurrent dual task *increased* prioritization of an irrelevant color singleton.[6]

Between-subjects comparisons across task conditions also confirmed the effect of the auditory task on search efficiency. When the target of search was a singleton, search was more efficient in the dual-task than in the single-task condition [$t(22) = 3.67$, $p < .01$]. Search slopes did not differ significantly between the two distractor singleton conditions [$t(22) = 0.99$, $p = .33$].

GENERAL DISCUSSION

Unique or transient aspects of the visual world tend to attract our attention. At times, this prioritization seems involuntary, as it often occurs unintentionally and cannot be overridden by explicit knowledge that it is irrelevant

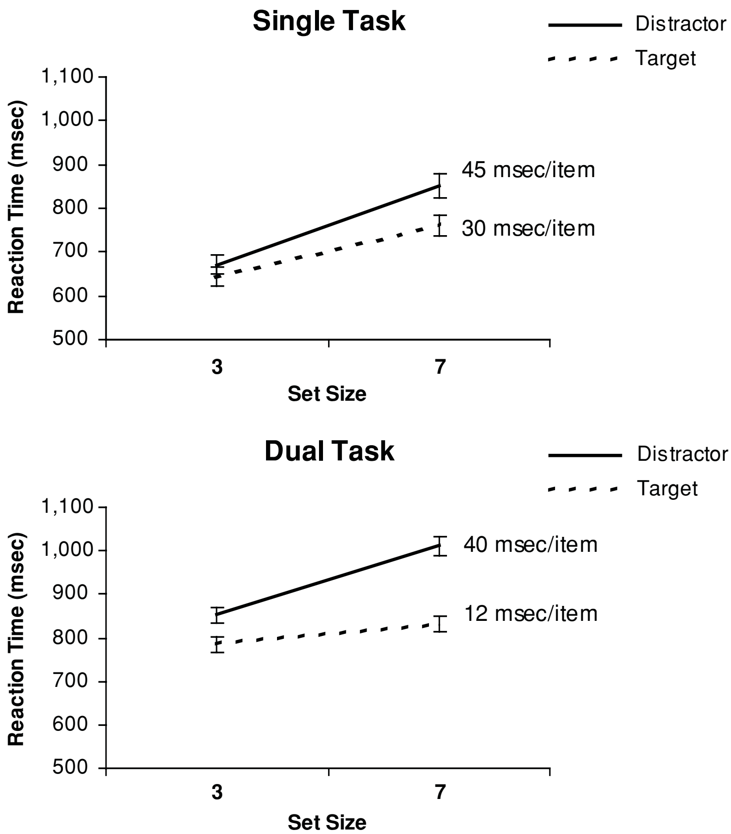

Figure 3. Mean reaction times when the color singleton was the target and when it was a distractor for each set size in Experiment 2. Error bars represent one standard error of the mean.

to our goals. This has led some researchers to argue that attention is captured in these situations in an automatic and stimulus-driven manner (see, e.g., Jonides & Yantis, 1988; Theeuwes, 1994; Yantis, 1993; Yantis & Hillstrom, 1994). Challenges to claims of stimulus-driven capture attribute evidence for prioritization to search strategies, target–distractor similarity, default biases, or task-induced biases (e.g., Folk et al., 1992; Gibson & Kelsey, 1998). That is, top-down expectations and biases rather than stimulus features lead to prioritization. Our experiments investigated the nature of attention capture without changing the primary search task. Consequently, the nature of the search itself cannot explain variations in performance. We manipulated the resources available for visual search by engaging observers in a concurrent auditory task.

In two experiments, attention capture was modulated by the concurrent secondary task. Onsets lost their attention-capturing properties in Experiment 1. Strikingly, in Experiment 2, the secondary task produced results remarkably similar to stimulus-driven capture by a feature that typically does not capture attention. These results undermine the claim that the irrelevant feature search paradigm measures purely stimulus-driven capture. The stimuli were identical, and performance depended on whether or not participants devoted attention to the auditory task.

If attention shifts to a unique item are stimulus driven, they should be immune to modulation by a secondary task. Thus, factors other than the stimulus properties must explain at least some of the variation in performance in this task. The fact that attentional prioritization in visual search was modulated by attending to an auditory stimulus suggests that both tasks tapped into resources that also contribute to what has been described as attention capture. Evidence that a nonvisual task can modulate attention capture is consistent with recent evidence that the difficulty of a visual search task interacts with the processing of auditory distractors (Tellinghuisen & Nowak, 2003). When perceptual load was manipulated by varying the similarity of the distractors and target and the heterogeneity of the distractor items, auditory distractors had a larger effect on performance under conditions of high perceptual load; the difficult visual search task interfered with cross-modal inhibition of irrelevant stimuli. In other words, when attention is occupied with search, participants are less able to ignore auditory distractors.

The finding that prioritization of onsets was effectively eliminated by a dual task, whereas prioritization of color singletons was enhanced, suggests that onset and color singletons are differentially affected by the availability of attention resources. Many explanations can account for an increase or decrease in capture, but devising a single explanation that is consistent with both effects is more challenging. For example, capture may decrease if a dual task causes observers to become more cautious about responding to the visual stimuli, such that, despite initial capture, observers subsequently "research" the display to verify their percepts. Alternatively, capture might increase if a dual task induced a more diffuse attentional state, which may enhance the capturing power of a stimulus. Neither explanation, however, accounts for both the increase in capture for color and the decrease in capture for onsets; to explain this pattern, we must take the stimulus type into account.

One possible explanation for the observed difference in capture by onsets and color singletons involves the distinction between transient and sustained distractors. An abrupt onset is a transient event—after the onset occurs, the onset item is no longer unique. If resources are needed to detect the occurrence of the onset, then the dual task might reduce the probability of detection, leading the attention system to treat the onset item just like the nononset items. Intercept differences between single- and dual-task conditions greater than 130 msec were observed, suggesting that the initiation of search may have been delayed as a result of the secondary task. This is consistent with the notion that search was delayed beyond the interval when onsets capture most effectively; that is, the transient produced by the onset (if it was detected at all) had dissipated by the time search began. In contrast, a uniquely colored item is a sustained event—the color singleton remains distinct from the other items in the display throughout the search. Todd and Kramer (1994) suggested that with increasing search difficulty (i.e., larger set sizes), participants shift attention to distinctive stimuli first as a strategy for organizing their search. In a similar manner, our dual task might have lead participants to prioritize an irrelevant color singleton but not an abrupt onset item.

A second possible explanation is based on evidence that increased working memory load places demands on the central executive, impairing the efficient allocation of attention (de Fockert, Rees, Frith, & Lavie, 2004; Lavie & de Fockert, 2005). In a single-task condition, observers might successfully keep a set of targets or search parameters in working memory, enhancing their ability to guide search. A dual-task situation would disrupt this attention set, making it less likely to influence search. Observers in our experiments might have had an attention set for onsets because each target is revealed by the onset of information (be it a single item or the entire display). If the dual task impairs the central executive, disrupting that attention set, then onsets could become less effective at capturing attention, and color singletons could become more effective because they no longer would conflict with an attention set.[7]

In summary, attention capture by a unique item during visual search is modulated by dual-task situations that vary the attention resources available for the search task without changing the search itself. Capture depends on the availability of attention resources, undermining claims that prioritization in the irrelevant feature task reflects purely stimulus-driven and reflexive orientation of attention. The effect of the dual task varies across stimulus types, however, with capture by onsets decreasing and capture by color singletons increasing. The mechanism or mechanisms raised as possible explanations for this pattern are currently speculative, and further empirical work may help to determine the extent to which attention capture depends on available resources and unimpaired executive functioning.

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NOTES

1. A 2 (set size: 3 vs. 7) × 2 (onset type: onset target vs. onset distractor) × 2 (condition: single- vs. dual-task) mixed model ANOVA revealed that error rates did not differ depending on set size [$F(1,22) = 0.02$, $p = .88$] or onset type [$F(1,22) = 0.15$, $p = .71$]. However, participants were less accurate at identifying the target letter under the dual-task condition compared to the single-task condition [$F(1,22) = 23.17$, $p < .01$]. No interactions were close to reaching significance (all *p*s > .14). This overall effect of a dual task was comparable across set size and onset type (onset target or distractor) so it does not affect the interpretation of the results.

2. The onset-target search slope was significantly greater than 0 msec/item [$t(12) = 2.74$, $p < .05$]. Note, however, studies using set sizes larger than four items often do not find perfectly flat search slopes for abrupt onsets (see Franconeri & Simons, 2003).

3. The comparison between onset-target slopes in the single- and dual-task conditions would likely attain a .05 level of statistical significance with a bigger sample size. However, we think that it is inappropriate to increase the number of participants postanalysis simply to adjust *p*. In this secondary analysis, the trend for significance complements the critical measure of prioritization, that is, the within-participants comparison of the difference between target-singleton and distractor-singleton slopes across task type.

4. A mixed model ANOVA revealed that error rates did not differ depending on task condition [$F(1,22) = 1.69$, $p = .21$] or set size [$F(1,22) = 0.02$, $p = .90$]. However, participants were more accurate when the color singleton was the target than when the color singleton was a distractor [$F(1,22) = 3.87$, $p = .06$]. No interactions were close to reaching significance (all *p*s > .24).

5. Although many studies find no prioritization of color singletons in this task (e.g., Jonides & Yantis, 1988), similar studies using larger set sizes have (Todd & Kramer, 1994). It is unclear why we found mild but significant prioritization given that our largest set size contained only seven items. However, Todd and Kramer discuss search difficulty as an important determinant of color capture. Although our set sizes were similar to the set sizes used by Jonides and Yantis, search slopes provide evidence that our search was indeed more difficult (possibly because our letter stimuli were closer together), with color-singleton distractor slopes nearly double the slopes obtained by Jonides and Yantis. Additionally, Jonides and Yantis controlled for luminance differences by having half of the participants search displays in which the colors of the color singleton and noncolor singletons were reversed. We did not do so, and it is possible that because our color singleton was also a luminance singleton, we obtained mild prioritization.

6. The differential impact of a dual task on attention capture by onsets and color singletons does not appear to result from different effects of a dual task on overall slowing of responses. Response latency differences between the dual- and single-task conditions for distractor-singleton trials (which should be relatively unaffected by attention capture effects compared with the target-singleton trials) for both onset and color singletons reveal approximately equal slowing effects of about 180 msec for set size three and 150 msec for set size seven. Consequently, differential slowing cannot explain why we find increased prioritization for color and decreased prioritization for onsets, and slowing is not somehow masking our ability to detect attention capture.

7. We thank Steven Luck for suggesting this possibility.

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