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Characterizing the time course and nature of attentional disengagement effects

Daniel P. Blakely [a], Timothy J. Wright [a], Vincent M. Dehili [a], Walter R. Boot [a,*], James R. Brockmole [b]

[a] Department of Psychology, Florida State University, United States
[b] Department of Psychology, University of Notre Dame, United States

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ABSTRACT

Visual features of fixated but irrelevant items contribute to both how long overt attention dwells at a location and to decisions regarding the location of subsequent attention shifts (Boot & Brockmole, 2010; Brockmole & Boot, 2009). Fixated but irrelevant search items that share the color of the search target delay the deployment of attention. Furthermore, eye movements are biased to distractors that share the color of the currently fixated item. We present a series of experiments that examined these effects in depth. Experiment 1 explored the time course of disengagement effects. Experiments 2 and 3 explored the generalizability of disengagement effects by testing whether they could be observed when participants searched for targets defined by form instead of color. Finally, Experiment 4 validated the disengagement paradigm as a measure of disengagement and ruled out alternative explanations for slowed saccadic reaction times. Results confirm and extend our understanding of the influence of features within the focus of attention on when and where attention will shift next.

1. Introduction

The scenes and environments we interact with every day are often far too complex to process and understand all at once. Mechanisms of visual attention help to ensure that, based on momentary goals and task demands, important and relevant visual information is processed while irrelevant information is ignored. Understanding attention and the factors that contribute to decisions regarding when and where attention is allocated is crucial to understanding human cognition and behavior; attention establishes what information in the environment is processed, rises to conscious awareness, enters into decision processes, and is remembered to support future cognition and action.

The allocation of attention is discussed as being influenced by two classes of factors: properties of the visual environment (bottom-up salience) and the expectations and goals of the observer (top-down knowledge, see Connor, Egeth, and Yantis (2004) and Yantis (2000) for reviews). Attention capture paradigms (e.g., Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1994; Yantis & Hillstrom, 1994) examine the relationship between these factors by asking participants to search for a specific target (giving participants a top-down goal) in the presence of a prominent but irrelevant distractor (providing bottom-up salience). An observer might be asked to search for a green disk among green square distractors, with an irrelevant color singleton distractor (a red square) sometimes appearing in the display. Response times are longer in the presence of a salient but irrelevant distractor. Additionally, participants often misdirect their eyes to these distractors (e.g., Boot, Kramer, & Peterson, 2005; Godijn & Theeuwes, 2002; Irwin et al., 2000; Theeuwes et al., 1998; Wu & Remington, 2003). These findings provide evidence for *attention capture*. Certain objects and events can override top-down goals to induce reflexive shifts of attention.

A fundamentally different view suggests that goals and strategies are primarily responsible for the allocation of attention (e.g., Bacon & Egeth, 1994; Boot, Brockmole, & Simons, 2005; Folk, Remington, & Johnston, 1992; Gibson & Kelsey, 1998; Matsukura et al., 2011). Instead of capture being driven by unique objects and events, attention is captured by objects that share common features with the target of our search, even when these objects occur at a time or at a location the target is known to never occur. This type of capture has been termed *contingent capture* because the degree to which an item captures attention is contingent upon the goals of the observer (Folk, Leber, & Egeth, 2002, 2008; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992). For example, identification of a red letter always presented centrally is impaired by the appearance of a red object in the periphery relative to other instances in which the peripheral object does not share the target's color (Folk, Leber, & Egeth, 2002). This has been interpreted as evidence of attention being pulled away from the location of the upcoming target letter. Contingent capture theory posits that observers tune attentional control settings to respond selectively to features associated with the target of their

* Corresponding author. Address: Department of Psychology, Florida State University, 1107 W. Call Street, Tallahassee, FL 32306-4301, United States. Fax: +1 850 644 7739.

E-mail address: boot@psy.fsu.edu (W.R. Boot).

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search, and this results in automatic shifts of attention to non-target items that also share these features.

Although capture has been studied extensively, and the mechanisms behind attention capture continue to be debated, capture paradigms rarely make the distinction between costs associated with a distractor's ability to pull attention to a location and costs associated with its ability to hold attention at a location once attention is allocated. This distinction is important because human experiences such as memory depend on both the locations to which attention is allocated as well as the amount of time attention dwells at a particular location (Hollingworth, Williams, & Henderson, 2001; Williams, Henderson, & Zacks, 2005). Furthermore, recent debate on the nature of attention capture (stimulus-driven or top-down) hinges upon whether disengagement is increasingly delayed as the object within the focus of attention increases in similarity to the target (see Lamy, 2010; Theeuwes, 2010 for details). Thus research on the factors that influence attentional disengagement has important implications for our understanding of capture as well as models and theories of search. However, two recent studies have examined this issue directly by measuring the ability of task-irrelevant objects and features already within the focus of attention to hold overt attention (Boot & Brockmole, 2010; Brockmole & Boot, 2009; see also Belopolsky, Devue, & Theeuwes, 2011). These studies used a search task, which we will refer to as the *disengagement paradigm*, in which participants began each trial by fixating a central placeholder that could never be the search target. A perceptual change to this placeholder (a change in color) accompanied the appearance of the target item, as well as additional distractors in the periphery of the display. Hence, to complete their search, observers had to disengage attention from the central (fixated) item and shift it to the periphery. The disengagement paradigm therefore allows for the nature of the item already within the focus of attention (the placeholder) to be manipulated to examine how various properties of this item might delay attentional disengagement (i.e., hold attention). Disengagement time is computed as the time between the presentation of the search display and the movement of the eyes away from the central placeholder.

Many studies find that color singletons capture attention; however, using the disengagement paradigm Brockmole and Boot (2009) discovered that color singletons on their own had no ability to hold attention. Participants had no difficulty disengaging attention from the irrelevant item at fixation when its color was unique compared to when it was the same color as the other items in the display. However, when this fixated item was a rare color singleton (occurring infrequently), attentional disengagement was significantly delayed. This suggests that top-down expectations and goals may have a larger role in holding attention compared to bottom-up stimulus properties alone.

The influence of top-down factors on disengagement was confirmed in two experiments that melded the disengagement and contingent capture paradigms (Boot & Brockmole, 2010). Participants were asked to search for either a red or green target in the periphery and indicate the letter within this target. Participants began each search trial by fixating a disk that could be red, green, or blue. Disengagement was significantly delayed when the center item matched the color of the target they were looking for, even though this center item could never contain the target. Additionally, initial eye movements were biased towards peripheral items in the display that shared the color of the item at fixation (both when the center item matched the target, and also when the center item matched a salient peripheral distractor). Thus, the disengagement paradigm provides novel evidence that visual properties of a completely irrelevant item within the focus of attention can influence decisions regarding when and where attention will be deployed next.

Recently, interest in the study of the disengagement of attention has increased as a way to reconcile different theoretical perspectives on attention capture (e.g., Belopolsky, Schreij, & Theeuwes, 2010; Folk & Remington, 2006, 2010). Bottom-up theories of capture posit that salience dominates the initial sweep of attention. As long as the search target is less salient than a distractor, attention will initially be allocated to the distractor (Theeuwes, 1992, 1994, 2010). This contrasts with contingent capture theory, which posits that a feature will only capture attention to the extent that it matches the current goal of the observer (e.g., Anderson & Folk, 2010; Folk, Remington, & Johnston, 1992). In the typical cuing paradigm used to support contingent capture theory, a brief cue is presented prior to the search display and capture is assessed by cue validity effects (speeded or slowed search times depending on whether the cue coincides with the eventual target location). The cue that precedes the search display is the most salient element in the display at the time, and according to bottom-up views of capture the cue should always capture attention. However, validity effects are only observed when the cue matches the participant's attention set, inconsistent with a bottom-up view of attention capture. To reconcile this result with a bottom-up perspective, Theeuwes (2010) proposed that the first shift of attention is always allocated to the most salient item in the display, but the time attention dwells on this item is determined by the degree to which it matches the participant's top-down attentional set. If participants are searching for a green target, a red cue prior to the search display will attract attention, but attention will quickly disengage from this item when it is recognized not to be consistent with the search target. Top-down attentional mechanisms result in slower disengagement of target-consistent distractors (in this case, green, but see Folk & Remington, 2010; Lamy, 2010 for important critiques of this view).

Given the relatively limited focus on the factors that hold attention at a location compared to those that pull attention to a location and recent interest in disengagement as a means to reconcile top-down and bottom-up models of capture, we present a series of experiments utilizing a relatively new paradigm to explore attentional disengagement effects and factors that influence disengagement. As mentioned previously, a prior study has examined the time course of disengagement effects by measuring the time required for participants to move their eyes from an irrelevant central item to a peripheral target and found that, when the central item shared the target-defining feature, disengagement was delayed (Boot & Brockmole, 2010). However, this only occurred when the central item shared the feature of the target simultaneous with the appearance of the search target. If the target-defining feature disappeared from the central item 100 ms before the appearance of the search target, disengagement was unaffected by the match between the center item's color and the target color. Other than this coarse time course information, little is known regarding how long-lasting contingent disengagement effects are, and thus we have a limited understanding of their potential impact. Experiment 1 examined the time course of disengagement effects with greater temporal resolution. The center item could match the target's color starting 132, 99, 66, 33, or 0 ms before the presentation of the search display. Additionally, the center color could change color and remain that color (red, green, or blue), or it could change color and then change back to gray. This manipulation allowed us to examine whether attention can easily be disengaged once the central item no longer shares a feature with the target. On the one hand, previous attention capture studies have found *decreased* attention capture when the attention capturing stimuli remained visible compared to when they offset abruptly (Inukai, Kumada, & Kawahara, 2010). On the other hand, attention may be released as soon as the target-consistent feature at fixation is removed (see Saslow, 1967 for a similar phenomenon). Experiment 1 explored these possibilities. Experiments 2 and 3 examined whether contingent disengagement effects generalize beyond color. These experiments focused on whether form (either geometric shape or letter form) might delay disengagement when the form of the central item was similar to the form defining the target. Experiment 4 ruled out an important alternative explanation for delayed eye movements to the target. The combination of Experiments 1 through 4 provide strong evidence regarding the nature and generality of contingent disengagement effects in visual search and validate the disengagement paradigm as a means to explore attention sets and factors that influence disengagement.

2. Experiment 1

Experiment 1 utilized a similar design to that of Boot and Brockmole (2010). Participants saccaded away from an item at fixation that could either match or mismatch the color of the target for which they were looking. The persistence of the center item was manipulated, as well as the time between when the center item changed color and the appearance of the peripheral target to provide precise information regarding the time course of attentional disengagement effects and whether item persistence has an influence on contingent disengagement (slowing based on the match between the fixated item and target item). As discussed later, time course information is important to obtain in order to assess the degree to which contingent disengagement effects might serve a functional purpose during search.

2.1. Methods

2.1.1. Participants

Sixty-seven Florida State University undergraduates participated in a half-hour experimental session for course credit. Five participants were excluded from the experiment because more than 50% of their trials were lost due to calibration problems with the eyetracker and/or the premature initiation of search (i.e., the eyes shifted to the periphery before the target appeared). Data from these participants were subsequently replaced with data from five new participants. Additionally, color blindness resulted in the exclusion of one participant's data from the reported analyses.

2.1.2. Apparatus

The same apparatus were used for all reported experiments. Displays were presented on a 21-in. color CRT monitor with a resolution of 1024 × 768 pixels and a screen refresh rate of 60 Hz. The spatial location of each participant's right eye was sampled at a rate of 1000 Hz by an EyeLink 1000 eyetracking system (SR Research, Inc.). An eye movement was classified as a saccade if its amplitude exceeded .2° and either (a) its acceleration exceeded 9500 deg/s^2 or (b) its velocity exceeded 30 deg/s. Participants viewed the display from a distance of 73 cm. A chin and forehead rest stabilized head position and kept viewing distance constant, and a Microsoft video game controller was used to collect manual responses.

2.1.3. Stimuli

Displays consisted of seven disks (diameter = 2.8°, outline thickness = .03°) on a white background. Disks in the display were red, green, blue, yellow, or gray with a black outline. One disk was located at the center of the screen and contained a black fixation cross that was present throughout the trial (.8°). Six disks were equidistantly spaced along an imaginary circle with a diameter of 7.8° anchored to the screen center (see Fig. 1). Peripheral disks contained small black figure-eight premasks (.4°) that became letters through the removal of line segments from each premask (A, F, H, O, U, and C/backwards C). These items were small enough to require foveation to identify.

2.1.4. Design and procedure

The participants' task was to find the letter C in the search display and to classify it as normal or mirror-reversed as quickly as possible by pushing one of two buttons on the game controller. The target was always within a peripheral disk of a specified color. Some participants identified the target within the red disk, others within the green disk. Participants fixated a cross at the center of the screen and pushed a separate button on the controller to initiate each trial. The premask display appeared immediately afterwards. This display consisted of a fixation cross within a gray disk at the center of the screen and six gray disks in the periphery. Each peripheral disk contained a figure-eight premask. The duration of the premask display varied randomly from 500 to 1000 ms. Then, the center item changed color from gray to red, green, or blue (central color change). This central color change was followed a short time later by the search display which

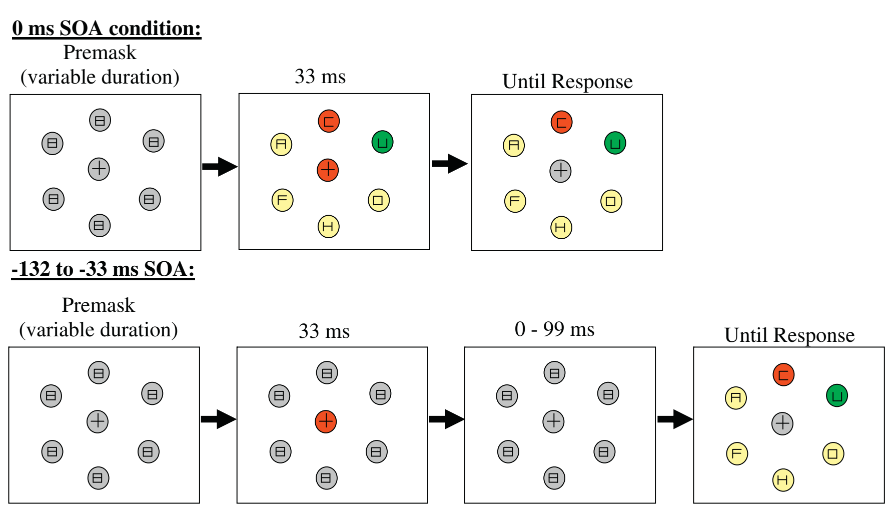

Fig. 1. An illustration of two types of trials in Experiment 1. Both illustrations represent non-persistent center item conditions. The center item matched the color of the target, distractor, or was neutral, either at the same time the search display appeared or before it. In the persistent condition, the center item changed color and remained that color for the duration of the trial. In the non-persistent condition (depicted), this color was present for 33 ms. Figures are not drawn to scale. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

consisted of one red, one green, and four yellow peripheral disks, with letters within each disk except for the center disk (which always contained a fixation cross). The temporal separation (SOA) between the central color change and search display varied across trials. On some trials, the central color change occurred before the search display (−132, −99, −66, and −33 ms SOA conditions). On other trials, they occurred simultaneously (0 ms SOA condition). Saccadic disengagement time was calculated relative to the onset of the search display.

The search target (C or mirror-reversed C) was contained within the red peripheral disk for some participants, and within the green peripheral disk for the other participants (participants were instructed beforehand which color would always contain the target). For some participants, when the center item changed color, it remained that color for the remainder of the trial (persistent center condition). For other participants, the center item changed color from gray to red, green, or blue, and then changed back to gray 33 ms later (non-persistent center condition). Thirty participants searched for the target within the green peripheral disk. Of these participants, the center item was persistent for fifteen participants and non-persistent for fifteen participants. Thirty-one participants were asked to search for the target within the red peripheral disk. Of these participants, the center item was persistent for fifteen participants and non-persistent for sixteen participants. If eye position did not remain within 2° of the center of the screen (i.e., if search began) while the premask screen was visible the trial was terminated, and a message was presented indicating that the participant had initiated search too soon.

Each participant completed 225 trials overall, equally divided between the −132, −99, −66, −33, and 0 ms SOA conditions. Trials were also equally divided between red, green, and blue center disk conditions. Trial order was determined randomly for each participant. Target position and distractor position were counterbalanced within the experiment and target identity (C or backwards C) varied randomly.

3. Results and discussion

The first 25 trials were considered practice and were not analyzed. In addition, we excluded trials on which participants initiated search (executed a saccade) before the presentation of the search display, trials on which the distance of the first saccade did not exceed at least ¼ of the distance from the center of the screen to a peripheral disk, and trials on which the latency of the first saccade was less than 90 ms. This ensured that only search-related eye movements were included in our analyses. These exclusions resulted in 15% of trials being discarded. Our primary interest is saccadic disengagement time. However, it is important to note that in this and in other experiments reported here target identification accuracy was near ceiling (>95% correct).

3.1. Saccadic disengagement

Of primary interest was saccadic disengagement: the lapse in time between the presentation of the search display and the first saccade away from the shape at the center of the screen (i.e., SRT, or saccadic reaction time). Analyses included only trials on which participants accurately saccaded to the target disk (see Table 1 for the proportion of eye movements directed to the target and SRTs). A saccade was classified as being directed towards an item if it fell within a 60° wedge centered on that item.

Contingent disengagement effects are revealed when the color of the center item differentially influences disengagement (SRTs) depending on the nature of the target for which participants searched (Boot & Brockmole, 2010). If such effects are present,

Table 1
Mean saccadic reaction time (ms) and proportion of eye movements to the target and distractor as a function of target color, center color, persistence, and ISI for Experiment 1 (standard deviations are within parentheses).

Target color	Persistence	SOA	Red center					Green center					Blue center				
			−132	−99	−66	−33	0	−132	−99	−66	−33	0	−132	−99	−66	−33	0
Green	Nan-persistent	SRT	236 (22)	240 (33)	235 (26)	253 (36)	267 (34)	243 (35)	241 (23)	240 (30)	253 (22)	266 (27)	236 (23)	233 (29)	239 (27)	248 (28)	260 (29)
		To distractor	.07 (.08)	.07 (.08)	.05 (.09)	.04 (.07)	.04 (.06)	.03 (.05)	.00 (.00)	.01 (.02)	.01 (.03)	.01 (.02)	.03 (04)	.01 (.03)	.01 (.03)	.02 (.04)	.01 (.03)
		To target	.90 (.10)	.90 (.13)	93 (.12)	.94 (.13)	.96 (.06)	.96 (.05)	.99 (.03)	.98 (.04)	.98 (.07)	.99 (.05)	.94 (.10)	.98 (.04)	.99 (.03)	.98 (.04)	.99 (.03)
Red	Non-persistent	SRT	210 (30)	203 (19)	216 (25)	229 (36)	248 (32)	226 (45)	224 (36)	230 (35)	242 (57)	253 (69)	215 (36)	220 (39)	228 (45)	237 (54)	239 (33)
		To distractor	.01 (.02)	.01 (.02)	.00 (.00)	.00 (.00)	.01 (.03)	.02 (.04)	.02 (.04)	.01 (.03)	.00 (.00)	.00 (.00)	.00 (02)	.01 (.03)	.00 (.00)	.02 (.02)	.00 (.02)
		To target	.07 (.05)	.98 (.03)	.99 (.02)	1.0 (.02)	.99 (.03)	.93 (11)	.96 (.07)	.98 (.04)	.99 (.04)	.99 (.02)	.95 (.07)	.97 (.05)	.98 (.03)	.98 (.04)	1.0 (.02)
Green	Persistent	SRT	230 (30)	229 (29)	232 (39)	237 (50)	235 (38)	230 (33)	245 (47)	245 (38)	253 (37)	266 (34)	229 (25)	232 (41)	242 (54)	232 (41)	245 (32)
		To distractor	02 (.05)	.04 (.05)	.02 (.05)	.04 (.09)	.02 (.04)	.04 (.05)	.05 (.08)	.05 (.07)	.01 (.03)	.03 (.05)	.05 (07)	.01 (.03)	.02 (05)	.01 (.03)	.03 (.07)
		To target	.90 (.13)	.91 (.09)	.93 (.10)	.94 (.10)	.97 (.05)	.90 (.09)	.90 (.14)	91 (11)	.95 (.07)	.95 (.09)	.91 (.12)	.94 (.06)	.92 (.13)	.96 (.06)	.94 (11)
Red	Persistent	SRT	212 (26)	216 (30)	223 (34)	225 (26)	239 (36)	215 (30)	219 (30)	219 (30)	215 (29)	232 (27)	219 (33)	211 (25)	229 (41)	216 (26)	225 (29)
		To distractor	.00 (.02)	.01 (.02)	.01 (.03)	.01 (.04)	.02 (.05)	.00 (.00)	.01 (.02)	.01 (.03)	.02 (.04)	.00 (.00)	.01 (03)	.02 (.04)	.01 (.02)	01 (.03)	01 (.03)
		To target	.98 (.04)	.98 (.04)	.97 (.05)	.97 (.05)	.98 (.05)	.99 (.02)	.98 (.06)	.98 (.04)	.97 (.06)	.99 (.03)	.95 (.07)	.97 (.06)	.99 (.02)	.98 (.04)	.98 (.05)

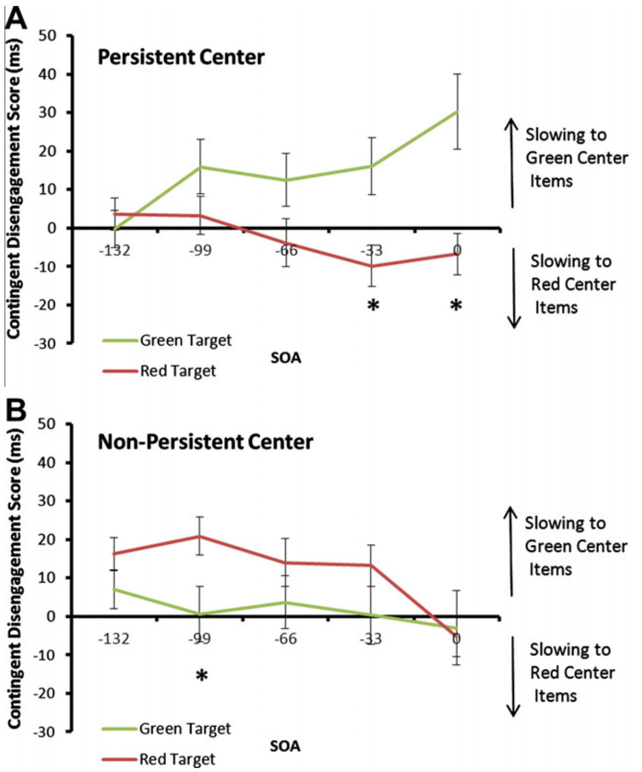

Fig. 2. Contingent disengagement scores (SRT Green Center trials–SRT Red Center trials) are represented as a function of target color, center item persistence, and SOA. Positive values indicate delayed disengagement from green center items while negative values represent delayed disengagement for red center items. When the center item was persistent and the SOA was short, participants were slowed in disengaging attention from the center item when its color matched the color they were searching for. Error bars represent + and −1 SEM. Asterisks signify significant contingent disengagement effects (cases in which disengagement scores were different depending on participants' search goal), $p < .05$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

we expect participants to be slower to disengage from green items when searching for green targets and slower to disengage from red items when searching for red targets. We computed contingent disengagement scores to explore the interaction between target color and center color: SRT Green Center trials – SRT Red Center trials.[1] If disengagement is indeed dependent upon the participant's search goal, we would expect positive values when participants were asked to search for green targets and negative values when participants were asked to search for red targets. If these values are not significantly different depending on the nature of the search target, disengagement is not contingent upon the nature of the target. Fig. 2 depicts these data both for when participants searched for red items and when participants searched for green items as a function of center item persistence and SOA.

We entered contingent disengagement scores into an ANOVA with target color (red or green) and center persistence (persistent or non-persistent) as between-participant factors, and SOA (−132, −99, −66, −33, 0) as a within-participant factor. Target color and persistence interacted ($F(1, 57) = 13.49$, $p < .001$), suggesting that disengagement effects were different for persistent and non-persistent items. To gain a greater understanding of the nature of these disengagement effects, we examined persistent and non-persistent conditions separately.

3.1.1. Persistent center

Focusing first on the persistent center condition, we entered disengagement scores into an ANOVA with target color (red or green) as a between-participant factor and SOA as a within-participant factor. This revealed no effect of SOA ($F(4,112) = .90$, $p = .46$), a main effect of target color ($F(1,28) = 10.08$, $p < .05$), and a significant interaction between target color and SOA ($F(4,112) = 2.78$, $p < .05$). Fig. 2A suggests the existence of a linear trend, with disengagement effects growing as SOA decreased. Within-participants polynomial contrasts (PASW 18) associated with the previous analysis revealed a significant linear trend in the interaction between target color and center color ($F(1,28) = 10.49$, $p < .01$). In general, participants were slower to disengage from the center item when the center item was green and they were searching for green, and they were slower to disengage from the center item when it was red and they were searching for red. This effect increased as the presentation of the search display and center disk color approached simultaneous presentation.

3.1.2. Non-persistent center

A different pattern of results emerged in the non-persistent center condition. We entered disengagement scores into an ANOVA with target color (red or green) as a between-participant factor and SOA as a within-participant factor. This revealed no effect of SOA ($F(4,116) = 1.02$, $p = .39$), no effect of target color ($F(1,29) = 2.96$, $p = .10$), and no interaction between target color and SOA ($F(4,116) = .34$, $p = .85$). No evidence of target-consistent slowing was observed when the center disk's color did not remain persistent. Instead, if anything, there appeared to be a facilitation of disengagement when the center item matched the target's color, though this effect did not reach significance (Fig. 2B, see Boot and Brockmole (2010) for a similar trend).[2]

3.1.3. Saccadic direction

As in Boot and Brockmole (2010), we wanted to examine whether the nature of the center item influenced the direction of subsequent saccades. Specifically, we were interested in whether saccades would be biased to the salient distractor, which was red or green, when the center item matched the color of this distractor (see Table 1 for saccade proportions). Furthermore, we wanted to examine the time course of this effect and whether it was influenced by center item persistence.

Like saccadic disengagement, we aimed to compute a simple metric of bias to look at items similar to the item presented at the center of the screen. Our contingent bias measure subtracted the proportion of eye movements that went to the distractor when the center item was red from the proportion of eye movements that went to the distractor when the center item was green. Positive values represent a bias to saccade to the distractor when the center item was green, negative values represent a bias to saccade to the distractor when the center item was red. Thus, if a bias exists to saccade to distractors the same color as the center item, we would expect positive values when the peripheral distractor was green (i.e., when the target was red), and negative values when the peripheral distractor was red (i.e., when the target was green).

[1] Here and in previous experiments we found the neutral blue center color produced SRTs similar to SRTs when the center color matched the salient distractor (Boot & Brockmole, 2010). Thus, the neutral condition was excluded as it did not provide unique information. See Table 1 for data from the blue center condition.

[2] Analysis of SRTs with center color (red, green, blue) and SOA as within-participant factors and persistence and target color as between-participant factors revealed an unanticipated SOA by persistence interaction ($F(4, 228) = 5.71$, $p < .001$), complicating interpretation of non-persistent conditions. Longer SOAs produced shorter SRTs, likely due to a warning effect. However, short SOA non-persistent conditions produced differentially longer SRTs. Two changes at the center (onset and offset of color) in close temporal proximity of the target may have hindered the disengagement of attention. While this issue, along with the apparent motion effect non-persistent items generated discussed later, limit interpretation of the non-persistent center conditions, they are not issues in interpreting persistent center conditions more typical of natural search.

Fig. 3 plots this bias score as a function of whether the distractor was red or green and whether the center item was persistent or non-persistent. From this figure, it is clear that there was a bias to saccade to distractors that matched the color of the center item, but only when the center item was non-persistent.

We entered bias scores into an ANOVA with distractor color (red or green) and center persistence (persistent or non-persistent) as between-participant factors, and SOA (−132, −99, −66, −33, 0) as a within-participant factor. Importantly, distractor color and persistence interacted ($F(1,57) = 13.91$, $p < .001$). This interaction is consistent with what Fig. 3 suggests: there was a bias to saccade to the green distractor when the center was green, a bias to saccade to the red distractor when the center was red, and this bias was only present when the center item was non-persistent. Next, we explored these effects in greater detail by examining persistent and non-persistent conditions separately.

3.1.4. Persistent center

For the persistent center item conditions, direction bias scores were entered into an ANOVA with distractor color (red or green) as a between-participant factor and SOA as a within-participant factor. This revealed no effect of SOA ($F(4,112) = .71$, $p = .59$), no effect of distractor color ($F(1,28) = 1.00$, $p = .33$) and no interaction between target color and SOA ($F(4,112) = 1.49$, $p = .21$). In sum, erroneous eye movements to the red or green distractor were not influenced by whether the persistent center item was red or green.

3.1.5. Non-persistent center

The same analysis was performed on bias scores for the non-persistent center color condition. This analysis revealed no effect of SOA ($F(4,116) = .36$, $p = .84$), a main effect of distractor color ($F(1,29) = 16.51$, $p < .001$), and no interaction between SOA and distractor color ($F(4,116) = 1.38$, $p = .25$). The main effect of distractor color indicated a bias to look at the distractor when the center item was green, but only when the distractor was green. When distractor was red instead of green, this pattern was reversed. Participants were more likely to look at the red distractor when the center item was red compared to green.

Based on previous findings, we suggested that an automatic bias might exist for observers to fixate items that share the features of currently fixated items (Boot & Brockmole, 2010). The current data do not support our previous assertion. Saccade bias was only observed when the center item was non-persistent (a very infrequent situation during natural search). Instead, we may be observing a kind of oculomotor capture driven by apparent motion. Display timings may have created the perception of an item at the center of the screen "jumping" to the periphery when the center item was the same color as the peripheral distractor color.

In general, we replicated the disengagement and direction effects previously reported (Boot & Brockmole, 2010), but with some important differences. First, we were able to demonstrate that disengagement effects are modulated by the persistence of the item at fixation. More importantly, we observed a trend in the persistent center condition for disengagement effects to increase as SOA decreased. It was harder for participants to disengage attention from the center item when it shared the feature of the target close in time to the presentation of the target. More time allowed participants to more effectively disengage their attention from the target-similar item at fixation, perhaps through a process of inhibition. A mechanism to decrease the signal strength of an item that both shares features of the target and is discovered to be irrelevant would be beneficial to the search process and consistent with some models of visual search (e.g., Wolfe, 1994). Previously, Boot and Brockmole (2010) examined conditions in which a full 100 ms passed between the offset of the center disk's color and

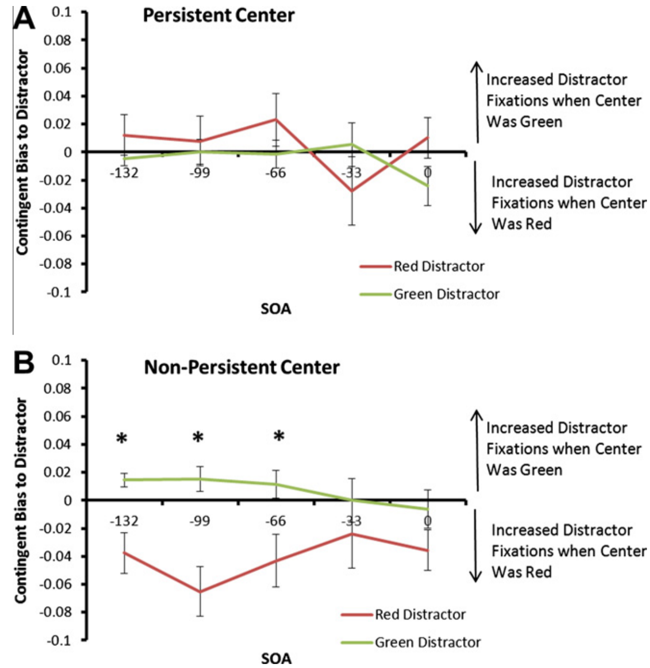

Fig. 3. Bias to look at the salient distractor as a function of the center color (Distractor Fixations Green Center trials–Distractor Fixations Red Center trials). Positive values indicate increased distractor fixations when the center was green, and negative values indicate increased distractor fixations when the center item was red. When the center item was non-persistent, participants were more likely to fixate the green distractor when the center item was green, and were more likely to fixate the red distractor when the center item was red. Error bars represent + and −1 SEM. Asterisks signify significant differences between distractor color conditions, $p < .05$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the presentation of the search display, or they were presented simultaneously (Boot & Brockmole, 2010). No effect was observed when an intervening 100 ms occurred between the center item sharing the target's feature and the appearance of the search display, but a robust disengagement effect was observed when they were presented simultaneously. Boot and Brockmole (2010) speculated that contingent disengagement effects served the purpose of ensuring greater processing of target similar items during search by keeping the eyes on these items longer. However, in order for this to be the case disengagement effects would need to extend beyond this limited 0 ms SOA condition (the 0 ms SOA condition is analogous to the eyes during search landing on an item and instantaneously a decision being made to move to the next item, allowing no time for processing that would typically occur during search). Fig. 2 and the observed linear trend suggests that disengagement effects extend beyond this limited time frame and may in fact be a component of natural visual search.

Up until now, we have exclusively examined disengagement effects in the search for targets defined by color (Boot & Brockmole, 2010; Brockmole & Boot, 2009). Experiment 2 aimed to determine whether contingent disengagement effects are confined to searches for color targets or whether this is a more general principle of attentional disengagement. Accordingly, in Experiment 2, the location of the target was defined by shape, not color.

4. Experiment 2

4.1. Methods

4.1.1. Participants

Thirty-eight undergraduates participated in a half-hour experimental session for course credit.

4.1.2. Stimuli

Displays consisted of 7 blue shapes (approximately 2.8°, outline thickness = .03°) on a white background. One shape was located at the center of the screen, and contained a black fixation cross that was present throughout the trial (.8°). Six shapes were equidistantly spaced around an imaginary disk with a diameter of 7.8° anchored to the screen center. Peripheral shapes contained small black letters. These items were small enough to require foveation to identify.

4.1.3. Design and procedure

The task of the participant was to find the letter C in the search display and to classify it as normal or mirror-reversed. The target was always within a peripheral item of a specified shape (either disk or square). If participants were asked to search for the peripheral disk, displays contained one disk, one diamond, and four squares in the periphery. If participants were asked to search for the peripheral square, the display contained one square, one diamond, and four disks in the periphery. The diamond shape was intended to make displays less homogenous and to encourage a strong attentional set for the specific shape defining the target (Bacon & Egeth, 1994). In addition to these six peripheral items, the center item (which appeared where participants were fixating) could either be a disk or square. SOA between the center and peripheral items was not manipulated, as Experiment 1 found the largest disengagement effects at simultaneous presentation of center and peripheral items. To begin each trial, participants fixated a cross at the center of the screen and the search array appeared 250–1000 ms later. Target location, target identity (C or mirror reversed C), and the shape of the center item were randomized from trial to trial, with target location and center shape counterbalanced within the experiment. Half of all participants searched for a square target and half searched for a disk target. Participants completed 200 trials, the first 25 of which were considered practice and were not analyzed.

5. Results and discussion

We excluded trials on which participants initiated search before the presentation of the search display, trials on which the distance of the first saccade did not exceed at least 1/4 of the distance from the center of the screen to a peripheral disk, and trials on which the latency of the first saccade was less than 90 ms. This ensured that only search-related eye movements were included in our analyses. These exclusions resulted in 5% of trials being discarded. Table 2 depicts SRTs and proportion of eye movements directed to either the target or distractor in each condition.

5.1. Saccadic disengagement

Analyses included only trials on which participants accurately saccaded to the target (see Table 2 for the proportion of eye movements directed to the target and SRTs). We computed a measure of contingent disengagement similar to Experiment 1 to explore the nature of this interaction. This measure represented SRT slowing when the center item was a disk relative to a square: SRT Disk center – SRT Square center. We would expect positive values when participants searched for a disk target, negative values when participants searched for a square, and for these values to be significantly different. A slowing of 15 ms ($SD = 19$) was observed when participants searched for disk targets, and no slowing was observed when participants searched for square targets ($M = 0$ ms, $SD = 22$). These values were significantly different ($F(1,26) = 4.94$, $p < .05$). The presence of a disk at fixation produced a significantly greater delay in the initiation of search when participants were searching for a disk compared to a square.

Table 2
Mean saccadic reaction time (ms) and proportion of eye movements to the target and distractor as a function of target shape and center shape for Experiment 2 (standard deviations are within parentheses).

Target shape		Center shape: Disk	Center shape: Square
Disk	SRT	225 (38)	210 (29)
	To distractor	0.10 (.03)	0.11 (.04)
	To target	0.47 (.05)	0.44 (.04)
Square	SRT	226 (53)	226 (44)
	To distractor	0.11 (.03)	0.11 (.02)
	To target	0.44 (.04)	0.43 (.05)

5.2. Saccadic direction

Persistent center items like the ones used in this experiment had no effect on saccade direction in Experiment 1. Furthermore, the center item never matched the identity of the unique distractor in the periphery (which was a diamond). Thus, we would not expect an effect of the center item on saccadic direction in the current experiment. Table 2 indicates little or no effect of the center item on saccadic direction. To confirm, the proportions of first eye movements to the distractor were entered into an ANOVA with center shape and target shape as factors. This revealed no effect of center shape ($F(1,36) = .33$, $p = .57$), no effect of target shape ($F(1,36) = 2.08$, $p = .16$), and no interaction between center shape and target shape ($F(1,36) = .14$, $p = .71$). The same analysis was performed on the proportion of first eye movements that went to the target. There was an effect of target shape (participants were slightly more accurate saccading to the disk target, $F(1,36) = 7.45$, $p = .16$), but no effect of the center shape ($F(1,36) = 2.30$, $p = .14$) and no interaction between center shape and target shape ($F(1,36) = .45$, $p = .51$).

Overall, we did find evidence for a disengagement effect based on shape, although this effect was small. Ideally, we would have found delayed disengagement also when participants searched for a square target and the center was a square. However, the significant difference in saccadic disengagement scores between the two target conditions provide convincing evidence that disengagement can be delayed based on the nature of the target participants were looking for.

Experiment 3 was designed to extend the generalizability of contingent disengagement effects even further by exploring whether complex shapes (letter form) might also influence disengagement. Participants were asked to move their eyes from the center of the screen to a peripheral red disk, and indicate whether the red disk contained a target letter which was present on 50% of the trials (e.g., i). At the center of the screen, we presented the exact target they were looking for, a similar letter (e.g., j), or a dissimilar letter (e.g., p). Letters were too small to identify without fixation, thus could not be used themselves to guide attention. Saccade direction, given the ease of the targeting task and previous results finding no direction effects for persistent items, was not of interest.

Aside from generalizing disengagement effects to another class of stimuli, the data speak to the nature of attention sets. If the attention sets participants were holding were fairly precise, we would only expect the exact target participants were searching for to hold attention. However, if attention sets were not precise, we would expect letters similar to the target to also hold attention.

6. Experiment 3

6.1. Methods

6.1.1. Participants

Thirty-six undergraduates participated in a half-hour experimental session for course credit. Data from one participant was excluded due to color blindness and data from another participant was excluded because too many trials were excluded as a result of this participant initiating search before the search target appeared (>80% of trials).

6.1.2. Stimuli

Displays were similar to Experiment 1. Displays contained six peripheral disks and one central disk at fixation. Rather than figure-8 premasks and block letters, disks contained asterisks that were replaced with San Serif characters. Gray disks containing asterisks appeared in the premask display. In the search display, disks were all green except for one red peripheral disk, and letters within each disk were a, b, c, d, e, f, i, j, p, or q. The center letter was presented in a larger font compared to the peripheral letters to enhance visibility (20 pt, or .7° compared to 14pt, or .5°).

6.1.3. Design and procedure

Unlike previous experiments, participants were asked to saccade to a color singleton (red) target in the periphery and make an absent/present judgment. For one set of participants, the target letter was p. For another set of participants, the target letter was i. If the target appeared, it was always within the red disk. If it was not present, the red disk randomly contained the letter a, b, c, d, e, or f. Participants began each trial by fixating a cross at the center of the screen and pushing a button on the controller. Immediately, the premask screen appeared. The premask screen contained seven gray disks with asterisks within them. One gray disk was presented at fixation, and six were presented peripherally. After 500–1250 ms, all disks changed color to green except for one peripheral disk which changed to red. Additionally, all asterisks in the display were replaced with letters. Participants were asked to move their eyes quickly from the center disk to the red disk and indicate whether or not the target was present within it by pressing one of two buttons on the controller. If participants were asked to indicate the presence of the letter i, the letter at fixation could be either the target letter (i), a letter similar in shape to the target letter (j), or a letter that was dissimilar in shape from the target letter (p). If participants were asked to indicate the presence of the letter p, the letter at fixation could be either the target letter (p), a letter similar in shape to the target letter (q), or a letter that was dissimilar in shape from the target letter (i). Sixteen participants searched for the letter i, and eighteen participants searched for the letter p. Participants completed 240 trials equally divided between when the center letter was the target letter, was similar to the target letter, or was dissimilar from the target letter. The first 25 trials were considered practice and were not analyzed. The target was present 50% of the time, and target location was randomized.

7. Results and discussion

Previous described exclusion criteria to isolate search-relevant saccades resulted in 25% of trials being discarded. Table 3 depicts SRTs, and proportion of eye movements directed to the target in each condition. Participants were near ceiling in their ability to saccade to the color singleton target, so we discuss only latency data.

7.1. Saccadic disengagement

First, we were interested in whether the similarity of the center item to the target letter had an effect on saccadic reaction time. SRTs were entered into an ANOVA, with target-center item similarity as a within-participant factor (identical, similar, dissimilar). This analysis revealed a main effect of similarity ($F(2,68) = 5.91$, $p < .01$). To further explore this effect, a metric of disengagement was calculated by subtracting latencies when the center was i compared to p (SRT Center i – SRT Center p). We would expect this value to be positive when participants were searching for the target i, negative when participants searched for p, and for this value to be significantly different based on the letter participants were asked to search for. As predicted, a positive disengagement cost of 11 ms ($SD = 19$) was observed when participants searched for the letter i, and a negative disengagement cost was observed when participants searched for the letter p ($M = -20$ ms, $SD = 41$). These values were significantly different ($F(1,32) = 7.83$, $p < .01$). Interestingly, even when the letter at the center did not match the target letter exactly, slowing was still observed. When participants were asked to indicate the presence of an i target, they were 7 ms ($SD = 30$) slower to initiate search when the letter j was presented at the center of the screen compared to the letter p ($F(1,15) = 4.92$, $p < .05$). Additionally, when participants were asked to indicate the presence of a p, they were 6 ms ($SD = 11$) slower to initiate search when the letter q was presented at the center of the screen compared to the letter i ($F(1,17) = 4.21$, $p = .06$).

Although disengagement effects were small, it is notable that they were observed even though the attention guidance signal was completely independent of the information which delayed attention. These results confirm and extend our knowledge regarding the ability of relevant information at irrelevant locations to hold overt attention.

Table 3
Mean saccadic reaction time (ms) and proportion of eye movements to the target as a function of target letter and center letter for Experiment 3 (standard deviations are within parentheses).

		Center letter			
Target letter		i	j	p	q
i	SRT	255 (40)	251 (32)	244 (30)	NA
	To target	.97 (.08)	.95 (.12)	.95 (.13)	NA
p	SRT	255 (30)	NA	275 (59)	260 (28)
	To target	.98 (.03)	NA	.99 (.02)	.99 (.03)

8. Experiment 4

If overt attention (where the eyes are directed) and covert attention (where attention is directed) are not correlated in the disengagement paradigm, slowed saccadic reaction times might not solely reflect attentional disengagement (but see Deubel & Schneider, 1996; Deubel, Schneider, & Paprotta, 1998; Hoffman & Subramanian, 1995; Moore & Fallah, 2001; for evidence of a tight coupling between overt and covert attention). If covert attention is allocated to the periphery in advance of the search display in order to find the target more quickly, delayed saccadic reaction times might reflect the capture of attention from the periphery back to the center item when the center item shares the target-defining feature. This capture effect would not occur when the center item did not match the target. If this were the case, it would undermine the paradigm as a measure of disengagement. Experiment 4 explored this possibility. Experiment 3 suggests that some minimal attention must have been allocated to the center to process the irrelevant letter located there, however we developed a stronger test to contrast these two alternatives (capture vs. disengagement costs). A go/no-go task was added to the paradigm with the go/stop signal being contained within the center disk. This signal informed participants whether or not they should move their eyes from the center disk. Participants had to maintain attention at the center disk in order to perform the task accurately. Other participants completed the same task but did not need to attend to the center item (they were instructed to always saccade to the target). If the magnitude of the disengagement effect is equivalent in both relevant and irrelevant center disk conditions, slowed SRTs must reflect delayed disengagement since attention was not allowed to stray from the center item in the relevant center condition (i.e., the capture of attention from the periphery to the center can be ruled out as an explanation for prolonged SRTs). As in Experiment 1, participants saccaded to red or green target, and the information presented at fixation was either relevant or irrelevant to their task.

8.1. Methods

8.1.1. Participants

Forty undergraduates participated in a half-hour experimental session for course credit.

8.1.2. Stimuli

Stimuli were similar to the 0 ms persistent condition of Experiment 1 except for the inclusion of small black letters within the center disk. In the premask display, the center disk contained an "X" within an "O". Simultaneous with the onset of the search display, either the "X" or the "O" disappeared from the center disk to reveal one letter. Letters were small enough to require foveation to identify (.5°). Central letters were presented within a small disk that always remained gray contained within the center of the larger central disk that could turn red, green, or blue to ensure letter visibility was constant across all center color conditions.

8.1.3. Design and procedure

The design and procedure were similar to Experiment 1. Participants began each trial fixating a disk at the center of the screen and the search array appeared 500–1000 ms later. The relevance of the center item was manipulated between participants. Participants in the relevant center condition were required to attend to the center disk. If the center disk contained an "X", they were instructed to remain fixated until the trial ended. If the center disk contained an "O", participants were instructed to saccade to the target (red or green peripheral disk) as soon as possible. In the irrelevant center disk condition participants were instructed to saccade to the target as quickly as possible after the onset of the search display, regardless of the letter at the center. The search display was present for 600 ms. The center disk that contained the go or stop signal was red, green, or blue. Unlike previous experiments, participants only had to move their eyes to the peripheral target and were not required to make a manual response to the identity of the character within the target. Target location, the letter in the center disk (X, O), and the color of the center disk (red, green, blue) were randomized from trial to trial and counterbalanced across the experiment. Twenty participants were assigned to the relevant center condition and twenty were assigned to the irrelevant center condition. Participants completed 270 trials. One hundred eighty of these trials were "go" trials, and 90 (33%) trials were "stop" trials. The first 20 go trials were considered practice and were not analyzed.

9. Results and discussion

Two participants were excluded due to failure to obtain an accurate calibration and/or excessive trial loss due to anticipatory saccades (>50%). One participant was excluded due to color blindness. To make a direct comparison between conditions, we only analyzed trials on which the center item contained a "go" signal, regardless of whether or not participants were asked to attend to the center. The same trial exclusion described previously led to 20% of trials being excluded. Given the speeded nature of the task and that stop signals only occurred on 33% of all trials, we expected a bias for participants to make an eye movement even when a stop signal was presented. However, consistent with participants attending to the center item, participants did not initiate an eye movement on the majority of stop trials, (M = 57%, SD = 22%). Saccade direction and SRTs data are included in Table 4. SRTs were only calculated based on eye movements that accurately went to the target.

Table 4
Mean saccadic reaction time (ms) and proportion of eye movements to the target and distractor as a function of target color, center color, and center relevance for Experiment 4 (go trials only, standard deviations are within parentheses).

			Center color		
Target color	Center relevance		Red center	Green center	Blue center
Green	Irrelevant	SRT	240 (21)	266 (24)	238 (22)
		To distractor	.03 (.05)	.01 (.03)	.03 (.07)
		To target	.95 (.06)	.97 (.03)	.95 (.09)
Red	Irrelevant	SRT	273 (28)	257 (34)	252 (31)
		To distractor	.01 (.01)	.01 (.01)	.01 (.01)
		To target	.97 (.02)	.99 (.01)	.98 (.02)
Green	Relevant	SRT	372 (63)	399 (40)	372 (56)
		To distractor	.05 (.05)	.02 (.02)	.03 (.03)
		To target	.94 (.05)	.96 (.03)	.94 (.05)
Red	Relevant	SRT	379 (36)	364 (50)	346 (45)
		To distractor	.05 (.09)	.05 (.06)	.08 (.15)
		To target	.94 (.09)	.95 (.05)	.91 (.14)

Contingent disengagement scores were computed (SRT green center – SRT red center), reflecting slowing to green center items relative to red. Disengagement scores were entered into an ANOVA with target color (red or green) and center relevance (relevant or irrelevant) as between-participant factors. A main effect of target color was observed, consistent with contingent disengagement effects ($F(1,36) = 25.07$, $p < .001$). Critically, the relevance of the center item did not interact with the observer's target ($F(1,33) = 0.004$, $p = .95$). In addition, no main effect of the center item's relevance was found ($F(1,36) = 0.01$, $p = .91$. Regardless of the center item's relevance, when the color of the center item matched the color of the observer's target, disengagement was delayed. When observers were searching for red targets, an irrelevant or relevant red item within fixation delayed disengagement (disengagement scores: $M = -16$ ms, $SD = 7$ ms and $M = -15$ ms, $SD = 13$ ms; respectively). Likewise, when observers were searching for green targets, an irrelevant or relevant green item within fixation delayed disengagement (disengagement scores: $M = 27$ ms, $SD = 5$ ms and $M = 27$ ms, $SD = 10$ ms; respectively).[3] Similar disengagement effects in conditions in which initial processing of the center item is necessary suggests that both observers' overt and covert attention are on the central item at fixation prior to the saccade to the target. Accordingly, an alternative account in which the observer's covert attention is initially allocated to the periphery only to be captured back to the center when the center disk shares a feature with the target cannot account for slowing.

Our distractor bias measure subtracted the proportion of eye

[3] Restricting analysis of the relevant center condition to only participants who were able to withhold their responses at least half of the time did not change the observed pattern of results (disengagement scores of 31 ms and −9 ms for green and red target conditions respectively, effect of target color $F(1,10) = 4.36$, $p = .06$).

movements that went to the distractor when the center item was red from the proportion of eye movements that went to the distractor when the center item was green. Positive values represent a bias to saccade to the distractor when the center item was green, negative values represent a bias to saccade to the distractor when the center item was red. When these scores were entered into an ANOVA, no main effect of target color was observed ($F(1,36) = 0.45$, $p = .51$). Furthermore, no main effect of the center item's relevance was observed ($F(1,36) = 0.02$, $p = .90$), and the center item's relevance did not interact with target color ($F(1,33) = 0.40$, $p = .53$). This was not unexpected, as Experiment 1 found saccade direction biases only when the color of the center was non-persistent.

10. General discussion

In general, we confirmed and extended previous studies by providing evidence that the nature of the item within the focus of attention can influence both when and where attention will be subsequently deployed. A consistent finding was that when the item within fixation shared a feature that defined the location or presence of the target and remained persistent, overt attentional disengagement was delayed. This was true for targets defined by color and form (shape, though only in the disk target condition, and letter).

Recently, disengagement has been discussed as a means distinguish between bottom-up and top-down theories of attention capture. Theeuwes (2010) has argued that attention during search always goes first to the most salient item in the search display. This occurs whether the most salient item matches participants' attention set or not. Contingent capture effects, according to this view, are the result of difficulty disengaging from items similar to the target after attention has been allocated. Lamy (2010) and Folk and Remington (2010) discuss reasons to doubt this explanation for contingent capture effects. Results obtained are relevant to this issue. We found evidence that top-down goals do indeed modulate the speed with which attention can disengage from an item within the focus of attention, supporting in part Theeuwes (2010). This finding is consistent with previous work indicating that bottom-up salience alone does not delay attentional disengagement. Instead, disengagement is only delayed when this salient item was rare, highlighting the necessity of top-down expectations (Brockmole & Boot, 2009). However, it is important to recognize that the degree of match between a distractor and the target might modulate both the likelihood that it captures attention and how long attention dwells there. Consistent with similarity influencing capture and dwell time, Leblanc, Prime, and Jolicoeur (2008) found that a distractor's similarity to the target influenced the likelihood that it would capture attention and the degree to which the distractor was processed (as indexed by the ERP component N2pc). Thus, findings do not necessarily disconfirm contingent capture views of attention capture. We propose, however, that the disengagement paradigm may serve as a useful tool to begin to understand the role of disengagement in producing traditional attention capture effects.

Results speak to the precision of attention sets that can be maintained and the relationship between the selection of features and spatial locations. Disengagement was delayed when the letter at the center not only exactly matched the target, but also when it was similar to it. Furthermore, in general, results suggest that participants cannot easily maintain attention sets based on feature-location conjunctions (see also Folk, Leber, & Egeth, 2002). Participants were unable to completely ignore a relevant feature at an irrelevant location. Participants apparently could not maintain an attention set to detect the letter "p", or the color green, only in the periphery. Attention sets were also applied to the item at the center of vision, despite the target always being in the periphery. This is consistent with recent results suggesting that separate attention sets for different colors cannot be maintained for different locations (Adamo, Pun, & Ferber, 2010), and evidence that feature-based attentional selection acts in parallel and may be independent of spatial selection (Bichot, Rossi, & Desimone, 2005). Otherwise participants would have been able to restrict preferential processing to target relevant features at peripheral locations only. Finally, results are consistent with the finding that items at fixation may receive greater attentional weight compared to those same items in the periphery of vision thereby making items within fixation especially difficult to ignore (Beck & Lavie, 2005).

Boot and Brockmole (2010) suggested that disengagement effects did not necessarily need to be attentional in nature. Search models such as Wolfe's Guided Search 2.0 model propose that an initial parallel process codes properties of the search display into a number of feature maps that code for color, orientation, and other basic features (Wolfe, 1994; see also Itti & Koch, 2000). Ultimately, these feature maps are combined into a master activation or salience map to determine the allocation of attention. Competition for representation within these feature maps by multiple items sharing the same feature results in less influence each of these items has in the master activation or salience map. By this logic, prolonged SRTs might represent more time needed to find the target. The current findings do not support this view. In Experiment 3, the feature participants used to locate the target (red) was separate from the information that held attention at center (the letter). The nature of the letter in the center should not have influenced the salience of the red disk. Boot and Brockmole (2010) also suggested that perceptual grouping of the center item and peripheral target might occur when they share the same feature, influencing saccadic reaction times to the target. This explanation also seems implausible given the current results because, although color serves as a strong grouping cue at far distances, shape does not (Quinlan & Wilton, 1989).

Now that attentional disengagement effects have been demonstrated in several experiments and have been shown to be produced by several types of stimuli, a question for future research is whether and how these effects operate during natural visual search situations and, particularly, how the visual system deals with this particular problem during search (ignoring items within fixation that share features of the target but are not the target). A critical difference between our paradigm and natural search is that in our paradigm, the item within fixation is there because participants were required to fixate it to initiate each trial. An important question is whether an item within the focus of attention due to volitional selection has similar (or potentially larger) influences on subsequent deployments of attention. The manner in which attention sets are applied efficiently during natural search episodes to prioritize target-similar items while also allowing easy disengagement and subsequent inhibition of these same items when they are discovered to be non-targets, will have to be understood to gain a complete understanding of how attention sets function and are updated during search.

References

Adamo, M., Pun, C., & Ferber, S. (2010). Multiple attentional control settings influence late attentional selection but do not provide an early attentional filter. *Cognitive Neuroscience, 2*, 102–110.

Anderson, B. A., & Folk, C. L. (2010). Variations in the magnitude of attentional capture: Testing a two process model. *Attention, Perception, & Psychophysics, 72*, 342–352.

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics, 55*(5), 485–496.

Beck, D., & Lavie, N. (2005). Look here but ignore what you see: Effects of distractors at fixation. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 592–607.

Belopolsky, A. V., Devue, C., & Theeuwes, J. (2011). Angry faces hold the eyes. *Visual Cognition, 19*, 27–36.

Belopolsky, A., Schreij, D., & Theeuwes, J. (2010). What is top-down about contingent capture? *Attention, Perception, & Psychophysics, 72*, 326–341.

Bichot, N. P., Rossi, A. F., & Desimone, R. (2005). Parallel and serial mechanisms for visual search in macaque area V4. *Science, 308*, 529–534.

Boot, W. R., & Brockmole, J. R. (2010). Irrelevant features at fixation modulate saccadic latency and direction in visual search. *Visual Cognition, 18*, 481–491.

Boot, W. R., Brockmole, J. R., & Simons, D. J. (2005). Attention capture is modulated in dual-task situations. *Psychonomic Bulletin & Review, 12*(4), 662–668.

Boot, W. R., Kramer, A. F., & Peterson, M. S. (2005). Oculomotor consequences of abrupt object onsets and offsets: Onsets dominate oculomotor capture. *Perception & Psychophysics, 67*(5), 910–928.

Brockmole, J. R., & Boot, W. R. (2009). Should I stay or should I go? Attentional disengagement from unique items at fixation. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 808–815.

Connor, C. E., Egeth, H. E., & Yantis, S. (2004). Visual attention: Bottom-up versus top-down. *Current Biology, 14*(19), R850–R852.

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36*, 1827–1837.

Deubel, H., Schneider, W. X., & Paprotta, I. (1998). Selective dorsal and ventral processing: Evidence for a common attentional mechanism in reaching and perception. *Visual Cognition, 5*, 81–107.

Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics, 64*(5), 741–753.

Folk, C. L., Leber, A. B., & Egeth, H. E. (2008). Top-down control settings and the attentional blink: Evidence for non-spatial contingent capture. *Visual Cognition, 16*, 616–642.

Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception & Performance, 24*, 847–858.

Folk, C. L., & Remington, R. W. (2006). Top-down modulation of preattentive processing: Testing the recovery account of contingent capture. *Visual Cognition, 14*, 445–465.

Folk, C. L., & Remington, R. W. (2010). A critical evaluation of the disengagement hypothesis. *Acta Psychologica, 135*, 103–105.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance, 18*(4), 1030–1044.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception & Psychophysics, 65*, 999–1010.

Gibson, B. S., & Kelsey, E. M. (1998). Stimulus-driven attentional capture is contingent on attentional set for displaywide visual features. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 699–706.

Godijn, R., & Theeuwes, J. (2002). Programming of exogenous and endogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 1039–1054.

Hoffman, J. E., & Subramanian, B. (1995). The role of visual attention in saccadic eye movements. *Perception and Psychophysics, 57*, 787–795.

Hollingworth, A., Williams, C. C., & Henderson, J. M. (2001). To see and remember: Visually specific information is retained in memory from previously attended objects in natural scenes. *Psychonomic Bulletin & Review, 4*, 761–768.

Inukai, T., Kumada, T., & Kawahara, J. (2010). Attentional capture decreases when distractors remain visible during rapid serial visual presentations. *Attention, Perception, & Psychophysics, 72*, 939–950.

Irwin, D. E., Colcombe, A. M., Kramer, A. F., & Hahn, S. (2000). Attentional and oculomotor capture by onset, luminance, and color singletons. *Vision Research, 40*, 1443–1458.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40*, 1489–1506.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43*, 346–354.

Lamy, D. (2010). Reevaluating the disengagement hypothesis. *Acta Psychologica, 135*, 127–129.

Leblanc, É., Prime, D., & Jolicoeur, P. (2008). Tracking the location of visuospatial attention in a contingent capture paradigm. *Journal of Cognitive Neuroscience, 20*, 657–671.

Matsukura, M., Brockmole, J. R., Boot, W. R., & Henderson, J. M. (2011). Oculomotor capture during real-world scene viewing depends on cognitive load. *Vision Research, 51*, 546–552.

Moore, T., & Fallah, M. (2001). Control of eye movements and spatial attention. *Proceedings of the National Academy, 98*, 1273–1276.

Quinlan, P. T., & Wilton, R. N. (1989). Grouping by proximity or similarity? Competition between the gestalt principles in vision. *Perception, 27*, 417–430.

Saslow, M. G. (1967). Effects of components of displacement-step stimuli upon latency for saccadic eye movement. *Journal of the Optical Society of America, 57*, 1024–1029.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics, 51*, 599–606.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 799–806.

Theeuwes, J. (2010). Top-down and bottom-up control of visual attention. *Acta Psychologica, 135*, 77–99.

Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science, 9*(5), 379–385.

Williams, C. C., Henderson, J. M., & Zacks, R. T. (2005). Incidental visual memory for targets and distractors in visual search. *Perception & Psychophysics, 67*(5), 816–827.

Wolfe, J. M. (1994). Guided Search 2.0: A Revised Model of Visual Search. *Psychonomic Bulletin & Review, 1*(2), 202–238.

Wu, S. C., & Remington, R. W. (2003). Characteristics of covert and overt visual orienting: Evidence from attentional and oculomotor capture. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 1050–1067.

Yantis, S. (2000). Goal-directed and stimulus-driven determinants of attentional control. In S. Monsell & J. Driver (Eds.). *Attention and performance* (Vol. 18, pp. 73–103). Cambridge, MA: MIT Press.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance, 20*(95), 107.