Journal of Experimental Psychology:
Human Perception and Performance
2015, Vol. 41, No. 1, 17–21

0096-1523/15/$12.00 http://dx.doi.org/10.1037/xhp0000016

OBSERVATION

Functional Fixedness: The Functional Significance of Delayed Disengagement Based on Attention Set

Timothy J. Wright and Walter R. Boot
Florida State University

James R. Brockmole
University of Notre Dame

During search, the disengagement of attention is automatically delayed when a fixated but task-irrelevant object shares features of the search target. We examined whether delayed disengagement based on top-down attention set is potentially functional, resulting in additional processing of the fixated item. To accomplish this, we adapted the oculomotor disengagement paradigm. Participants saccaded to a peripheral object of a particular color and responded to the identity of the letter within it. To initiate search participants made a saccade away from an always irrelevant object at the center of the screen that matched or mismatched the target's color and contained a letter that was congruent or incongruent with the target letter. We found that delayed disengagement based on attention set was associated with deeper processing of the center item: a congruency effect between the center letter and peripheral target letter was only observed when the center object's color matched participants' attention set. Results are consistent with the proposal that delayed disengagement based on attention set is functionally significant, automatically encouraging deeper levels of processing of target-like objects that fall within the focus of attention.

Keywords: disengagement, contingent capture, eye-movements, visual search

Recently the top-down control mechanisms that determine how long attention dwells on an attended object have received increased interest (Biggs, Kreager, Gibson, Villano, & Crowell, 2012; Blakely, Wright, Dehili, Boot, & Brockmole, 2012; Boot & Brockmole, 2010; Born & Kerzel, 2011; Born, Kerzel, & Theeuwes, 2011; Wright, Boot, & Jones, in press). For example, in the debate over the nature of attention capture effects (top-down vs. stimulus-driven), top-down control of attentional disengagement has been proposed as a way to reconcile conflicting findings. In this debate, proponents of contingent capture have consistently presented evidence to suggest that attention is automatically pulled to peripheral locations based on the match between an irrelevant stimulus and the search target (e.g., Folk, Remington, & Johnston, 1992; Leber & Egeth, 2006). Salient stimuli that do not match the observers' attention set do not capture attention. Proponents of stimulus-driven capture argue that in the first sweep of attention, attention always goes to the most salient object in view (e.g., Theeuwes, 1994; 2004). To account for contingent capture effects, it has been proposed that all salient items, regardless of whether they match an observer's attention set, capture attention, but attention dwells longer after capture on items similar to the observer's search target (Theeuwes, 2010). That is, top-down mechanisms influence disengagement rather than capture and are responsible for contingent capture effects (but see also Egeth, Leonard, & Leber, 2010; Folk & Remington, 2010; Nordfang & Bundesen, 2010). The potential for top-down disengagement effects to inform theories of capture suggests that a more complete understanding of the causes and consequences of delayed attentional disengagement is an important area of research.

Top-down attention sets do appear to be the primary determinant of attentional dwell time. In their oculomotor disengagement paradigm, Brockmole and Boot (2009) asked participants to saccade away from an always irrelevant object at the center of the screen to a peripheral target of a certain color, and to identify the target letter within it. Compared with when the center object was any other color, saccades away from the center object were significantly delayed when it matched the color of the object to which participants were asked to saccade (Boot & Brockmole, 2010). The result of this study and replications suggest an automatic delay in disengagement away from items consistent with an observer's goals (Blakely et al., 2012; Wright et al., in press). Of interest to the authors, bottom up salience of the fixated but irrelevant item was found not to influence disengagement times (Brockmole & Boot, 2009; see Born, Kerzel, & Theeuwes, 2011, for similar findings).

In summary, a consistent finding is that it is more difficult to disengage attention from objects known to be completely irrelevant but match one's attention set, suggesting delays in disengagement based on top-down control mechanisms are relatively auto-

---

Timothy J. Wright and Walter R. Boot, Department of Psychology, Florida State University; James R. Brockmole, Department of Psychology, University of Notre Dame.

Correspondence concerning this article should be addressed to Timothy J. Wright, Florida State University, Department of Psychology, 1107 W. Call Street, Tallahassee, FL 32306-4301. E-mail: timwright@psy.fsu.edu

matic. We propose that these delays are functional in that items more likely to be the target of search automatically receive more scrutiny before attention is reallocated elsewhere. Wasted fixations during search can be attributed to disengagement times too short for the target to be recognized, requiring additional eye movements to refixate the target again (Peterson, Kramer, Wang, Irwin, & McCarley, 2001). A mechanism to automatically prolong dwell times based on the similarity between an attended item and the target has the potential to improve search performance by ensuring items most likely to be consistent with one's goals receive extra processing. However, this assumes that the extra time spent fixating a target-similar object is devoted to greater processing of that item, an assumption that has not been tested until now. Alternative accounts might hold that instead of facilitating processing, delayed disengagement represents the additional time needed to locate the target in the presence of a competing distractor or the time needed to filter or inhibit this object to prevent it from having an effect on the detection and identification of the actual target item (see Kahneman, Treisman, & Burkell, 1983; Folk &, Remington, 1998; for filtering accounts of attention capture).

The goal of the current experiment was to examine the functional significance of delayed disengagement based on attention sets. Specifically, the current experiment examined whether a fixated item undergoes additional processing when the fixated item shares features with the target. To address this question, the oculomotor disengagement paradigm (Brockmole & Boot, 2009) was adapted to incorporate a target-distractor congruency component (Eriksen & Eriksen, 1974; see Peterson, Kramer, & Irwin, 2004; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999, for similar manipulations). Participants were asked to indicate the identity of a target letter within a peripheral object of a certain color, and the always irrelevant item participants saccaded away from either contained a congruent or incongruent letter. If the delayed disengagement resulting from a match between a fixated item and the target item is associated with extra processing, target-distractor congruency effects should be larger for fixated but irrelevant items that match a participant's attention set. If delays in disengagement simply represent additional time to locate the correct target, or filter/inhibit the irrelevant information within fixation, congruency effects might be absent, or a reverse-congruency effect might be observed because of inhibitory processes (faster reaction times [RTs] on incongruent trials compared with congruent trials).

Method

An Eye-Link 1000 (SR Research, Ltd., Mississauga, Ontario, Canada) tracked the eye movements of 51 (24 target green, 27 target blue) observers (40 females; 18 to 23 years of age) as they viewed a 21-inch CRT monitor from a distance of 73 cm. Figure 1 depicts the trial sequence. Initially a display of seven gray circles (1.4° radii) was presented (see Figure 1). One circle was positioned at the center of the display and six circles were located 7.8° into the periphery. Each of the six peripheral circles contained a smaller gray circle within it (.3° radii), while the central circle contained both a smaller gray circle (.6° radius) and also a black square (0.6° × 0.6°) as a placeholder. To begin each trial, participants fixated the circle at the center of the screen, and the search array appeared 500 to 1,000 ms later. Once the search array appeared, the center circle changed to one of three colors: red, green, or blue. Simultaneous with this color change the peripheral circles changed color as well (one to the target color (blue or green), one to red, and four to yellow) and the letters (A, F, H, O, U, and C/backward C; 0.4° × 0.4°) appeared in the peripheral circles. In addition, the black square premask in the central circle changed to reveal a C or backward C (congruent or incongruent with the peripheral target letter). We refer to this as the search display. This central letter was masked (became a square again) following a saccade away from the central circle.

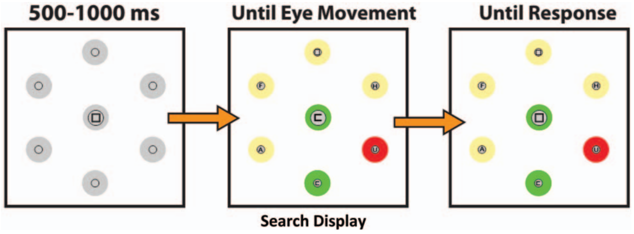

Figure 1. A between-participant manipulation asked participants to saccade from the center of the screen to a peripheral circle of a specific color (green or blue) and identify the letter within it (C or backwards C). Participants began with their eyes at the center of the screen. After 500–1,000 ms the search display appeared and participants were required to make an eye movement from the center of the screen to a peripheral circle of a specific color (green in this example) and identify the letter within it. A letter congruent or incongruent with the identity of the peripheral letter was presented at the center of the screen when the search display appeared, but was masked as participants moved their eyes from the center item to prevent it from having a continued effect once the eyes disengaged from the irrelevant center item. The center item's color was either consistent with the participant's search target (in this case green), consistent with the other group's target (in this case blue), or consistent with a salient distractor in the display (red for both groups). See the online article for the color version of this figure.

Participants were instructed to shift gaze to their designated peripheral target (green or blue) as quickly as possible and to indicate whether it contained a C or backward C with a button press. Participants were told that the center circle and center letter were irrelevant to their task, as neither were predictive of the target location or identity. Error messages were presented if participants moved their eyes before the presentation of the search display or identified the target incorrectly. Target location, distractor location, target identity (C or mirror reversed C), center letter identity (C or backward C), and the color of the center circle were randomized from trial to trial, with all these variables also counterbalanced within the experiment. Participants completed 360 trials, the first 20 of which were considered practice and were not analyzed.

An eye movement was classified as a saccade if its distance exceeded 0.2° and its acceleration reached 9500 deg/s^2 or its velocity reached 30 deg/s. Disengagement was measured by saccadic RTs (SRTs), the time between the presentation of the search display and the first eye movement away from the center item. Only accurate saccades (toward the target) were considered. The processing of the irrelevant center letter was measured with congruency effects: the slowing in response time between when the center item was congruent versus incongruent. Response times were measured from the time of the first fixation after an accurate saccade to the target item. To reduce the influence of outliers, median rather than mean SRTs and response times were analyzed.

Results and Discussion

Trial Exclusion

Nine participants were excluded from analyses because they either reported abnormal color vision or because they incorrectly answered at least one slide from a sample of two slides from the Ishihara (1972) color blindness test. One additional participant was excluded because more than 50% of trials were lost because of calibration issues. To ensure that we analyzed search-related eye movements, we excluded trials on which participants initiated search or blinked before the presentation of the search display (16% of trials, $SD = 8\%$), trials on which the distance of the first saccade did not exceed at least one-quarter of the distance from the center of the screen to a peripheral circle (4% of trials, $SD = 4\%$), and trials on which the latency of the first saccade was less than 90 ms (3% of trials, $SD = 3\%$). These exclusions resulted in 21% of trials ($SD = 10\%$) being discarded. Valid trial data from the remaining 41 (20 target green, 21 target blue) participants are presented below.

Replication of Boot and Brockmole (2010)

SRT difference scores (center green SRT—center blue SRT) were calculated to examine differences in disengagement time as a function of target and center item color (see Table 1 for raw SRT data). From these calculations, positive values indicate slower disengagement when the center item was green, and negative values suggest slower disengagement when the center item was blue (see Blakely et al., 2012 for similar calculations of disengagement effects). SRT difference scores were entered into an analysis of variance with target color (green or blue) as a between-subjects factor. Results of this analysis were in line with our hypotheses, as a main effect for target color was observed, $F(1, 39) = 68.53$, $p < .001$. Replicating Boot and Brockmole (2010), when the irrelevant item within fixation matched the target item's color, disengagement away from that item was delayed (see Figure 2). Observers searching for green were approximately 18 ms ($SD = 9$ ms) slower on average to disengage when the irrelevant center item was also green compared with when it was blue. Likewise, observers searching for blue were 16 ms ($SD = 16$ ms) slower on average to disengage when the irrelevant center item was also blue compared with when it was green.

Table 1
Saccadic Reaction Time (ms) as a Function of Center Color and Target Color

	Center color		
Target	Red	Green	Blue
Green	207 (16)	231 (25)	213 (19)
Blue	210 (22)	215 (24)	232 (35)

Note. *SD* are within parentheses.

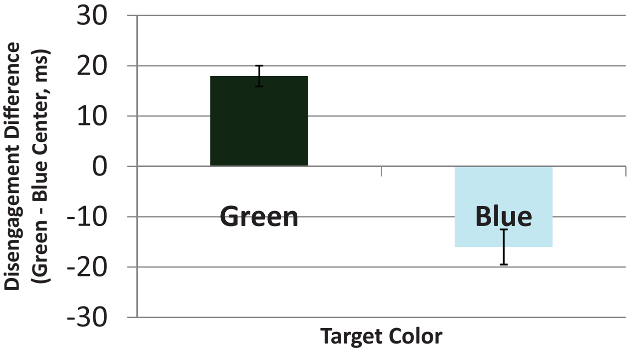

Figure 2. Saccadic reaction time (SRT) difference scores as a function of target color. Positive values indicate slowing when the center item was green, and negative values indicate slowing when the center item was blue. Error bars = ±1 *SEM*. See the online article for the color version of this figure.

Functional Significance of Delayed Disengagement

To examine the functional significance of the observed delayed disengagement, congruency effect scores were calculated (see Table 2 for RT and accuracy data). These scores represented the increase in manual response times to the target letter when the letter within the center circle was incongruent with the target compared to congruent. These congruency effect scores were entered into an analysis of variance with center color (green, blue, and red) as a within-subjects factor and target color (green or blue) as a between-subjects factor. Results of this analysis were in line with our hypotheses, as the critical center color and target color interaction was significant, $F(2, 78) = 6.46$, $p < .01$. The feature (color) of an observer's target determined the depth of processing of an irrelevant fixated item (see Figure 3). Compared against a value of zero, a significant congruency effect was observed when participants searched for green and the center item was green, $t(19) = 2.87$, $p < .05$. Congruency effects were not observed when the center item was red or blue ($ps > .67$). Similarly, when participants searched for a blue target, a significant congruency effect was observed when the center item was blue, $t(20) = 2.93$, $p < .01$. No significant congruency effects were observed when the center item was red or green ($ps > .78$).[1] We also examined whether there was a correlation at the participant level between (a) delayed disengagement when the center item was the search target's color compared to the color of the other group's target (scores depicted in Figure 2 modified so that positive values

---

[1] Response accuracy data were generally consistent with RT data. Congruency scores (Accuracy Congruent—Accuracy Incongruent) were computed for each condition, and although the interaction between center color and target color was not significant ($F(2,78) = 1.74$, $p = .18$), the only significant congruency effect (less accurate responses when the center letter was incongruent) occurred when the center item was blue and the target was blue ($t(20) = 5.35$, $p < .001$). A similar trend was observed when the center item was green and the target was green ($t(19) = 1.82$, $p = .09$).

Table 2
Manual Response Accuracy and Response Time (ms) as a Function of Target Color, Center Color, and Center Letter Congruency

	Congruent			Incongruent		
	Center color			Center color		
	Red	Green	Blue	Red	Green	Blue
Target: Green						
RT	515 (113)	496 (105)	514 (126)	512 (118)	523 (113)	510 (103)
% correct	.96 (.04)	.97 (.03)	.97 (.04)	.96 (.04)	.95 (.08)	.95 (.05)
Target: Blue						
RT	534 (118)	536 (121)	523 (114)	532 (113)	537 (109)	553 (104)
% correct	.95 (.03)	.95 (.05)	.98 (.03)	.95 (.04)	.96 (.05)	.94 (.04)

always represented target-consistent slowing) and (b) the strength of the congruency effect when the center item matched the participant's target. Individuals who demonstrated a larger disengagement effect also demonstrated a larger congruency effect, $r(39) = .41$, $p < .01$. Target-related disengagement effects were not correlated to the strength of the congruency effect observed when the center color was that of the other groups' target, $r(39) = -.12$, $p = .46$.

Conclusion

When a fixated distractor item shares characteristics with an observer's search target (e.g., they are the same color), the disengagement of attention is delayed, postponing shifts of attention toward other objects (Boot & Brockmole, 2010). What causes these delays? One possibility is that delayed disengagement stems from a need to allocate additional time to locating the peripheral target or to filtering/inhibiting the fixated item (cf., Folk & Remington, 1998; Kahneman et al., 1983). Another possibility is that delayed disengagement is functional in the sense that it encourages deeper levels of processing when target-like objects fall within the focus of attention. Our data support this second hypothesis: When the center (fixated) and target (peripheral) item were the same color, the additional time participants spent fixating the center item was associated with a robust and significant letter congruency effect. Without this match, no congruency effects were observed at all, despite the fact that participants spent over 200 ms looking at the central item. It seems then, that attention sets determine how long attention dwells on an object and the amount of processing that object undergoes.

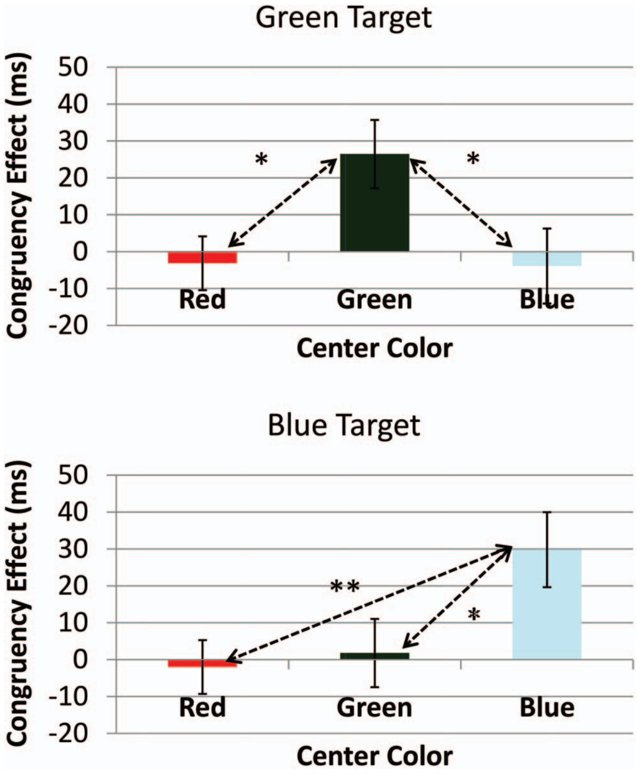

Figure 3. Congruency effects (calculated as slowing on inconguent trials) as a function of target color and irrelevant center object color. When the irrelevant item within fixation shared a feature defining the target, information within that irrelevant item was processed to a greater extent. Error bars = ±1 *SEM*. $^{*}p < .05$, $^{**}p < .01$. See the online article for the color version of this figure.

Although our data do not speak directly to the debate regarding the bottom-up or top-down mechanisms underlying capture (see Folk & Remington, 2010; Theeuwes, 2010), they do provide insight into a potential mechanism that supports visual search. Belopolsky, Schreij, and Theeuwes (2010) and Wright et al. (in press) have suggested that automatic delays in disengagement based on the similarity between an item and the search target function to help prevent observers from overlooking target items. These delays may prevent the premature disengagement of attention from the target before it can be recognized, but would only be beneficial if they also resulted in a deeper processing of the item within the focus of attention. For the first time, we demonstrate that these delays are potentially functionally significant in that they are accompanied by deeper processing of the item within fixation. The functional nature of these delays, along with their interrelationship with other factors such as attention set and attentional dwell time, now constitute important avenues for future research.

References

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

Biggs, A. T., Kreager, R. D., Gibson, B. S., Villano, M., & Crowell, C. R. (2012). Semantic and affective salience: The role of meaning and preference in attentional capture and disengagement. *Journal of Experimental Psychology: Human Perception and Performance, 38,* 531–541. http://dx.doi.org/10.1037/a0027394

Blakely, D. P., Wright, T. J., Dehili, V. M., Boot, W. R., & Brockmole, J. R. (2012). Characterizing the time course and nature of attentional disengagement effects. *Vision Research, 56,* 38–48. http://dx.doi.org/10.1016/j.visres.2012.01.010

Boot, W. R., & Brockmole, J. R. (2010). Irrelevant features at fixation modulate saccadic latency and direction in visual search. *Visual Cognition, 18,* 481–491. http://dx.doi.org/10.1080/13506280903356780

Born, S., & Kerzel, D. (2011). Time-course of feature-based top-down control in saccadic distractor effects. *Journal of Experimental Psychology: Human Perception and Performance, 37,* 1689–1699. http://dx.doi.org/10.1037/a0024282

Born, S., Kerzel, D., & Theeuwes, J. (2011). Evidence for a dissociation between the control of oculomotor capture and disengagement. *Experimental Brain Research, 208,* 621–631. http://dx.doi.org/10.1007/s00221-010-2510-1

Brockmole, J. R., & Boot, W. R. (2009). Should I stay or should I go? Attentional disengagement from unique and unexpected items at fixation. *Journal of Experimental Psychology: Human Perception and Performance, 35,* 808–815. http://dx.doi.org/10.1037/a0013707

Egeth, H. E., Leonard, C. J., & Leber, A. B. (2010). Why salience is not enough: Reflections on top-down selection in vision. *Acta Psychologica, 135,* 130–132. http://dx.doi.org/10.1016/j.actpsy.2010.05.012

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16,* 143–149. http://dx.doi.org/10.3758/BF03203267

Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 847–858. http://dx.doi.org/10.1037/0096-1523.24.3.847

Folk, C. L., & Remington, R. (2010). A critical evaluation of the disengagement hypothesis. *Acta Psychologica, 135,* 103–105. http://dx.doi.org/10.1016/j.actpsy.2010.04.012

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,* 1030–1044. http://dx.doi.org/10.1037/0096-1523.18.4.1030

Ishihara, S. (1972). *Test for colour-blindness*. Tokyo: Hongo Harukicho.

Kahneman, D., Treisman, A., & Burkell, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 510–522. http://dx.doi.org/10.1037/0096-1523.9.4.510

Leber, A. B., & Egeth, H. E. (2006). It's under control: Top-down search strategies can override attentional capture. *Psychonomic Bulletin & Review, 13,* 132–138. http://dx.doi.org/10.3758/BF03193824

Nordfang, M., & Bundesen, C. (2010). Is initial visual selection completely stimulus-driven? *Acta Psychologica, 135,* 106–108. http://dx.doi.org/10.1016/j.actpsy.2010.04.013

Peterson, M. S., Kramer, A. F., & Irwin, D. E. (2004). Covert shifts of attention precede involuntary eye movements. *Perception & Psychophysics, 66,* 398–405. http://dx.doi.org/10.3758/BF03194888

Peterson, M. S., Kramer, A. F., Wang, R. F., Irwin, D. E., & McCarley, J. S. (2001). Visual search has memory. *Psychological Science, 12,* 287–292. http://dx.doi.org/10.1111/1467-9280.00353

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. http://dx.doi.org/10.1037/0096-1523.20.4.799

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture. *Psychonomic Bulletin & Review, 11,* 65–70. http://dx.doi.org/10.3758/BF03206462

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica, 135,* 77–99. http://dx.doi.org/10.1016/j.actpsy.2010.02.006

Theeuwes, J., Kramer, A. F., Hahn, S., Irwin, D. E., & Zelinsky, G. J. (1999). Influence of attentional capture on oculomotor control. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 1595–1608. http://dx.doi.org/10.1037/0096-1523.25.6.1595

Wright, T. J., Boot, W. R., & Jones, J. (2014). Exploring the breadth of the top-down representations that control attentional disengagement. *Quarterly Journal of Experimental Psychology*.

Received July 1, 2014
Revision received September 30, 2014
Accepted October 2, 2014 ■