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Attentional engagement is not sufficient to prevent spatial capture

Alon Zivony · Dominique Lamy

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Abstract What conditions, if any, can fully prevent attentional capture (i.e., involuntary allocation of spatial attention to an irrelevant object) has been a matter of debate. In a previous study, Folk, Ester, and Troemel (Psychonomic Bulletin & Review 16:127–132, 2009) suggested that attentional capture can be blocked entirely when attention is already engaged in a different object. This conclusion relied on the finding that in a search for a known-color target in a rapid serial visual presentation stream, a peripheral distractor with the target color did not further impair target identification performance when a distractor also with the target color that appeared in the stream had already captured attention. In the present study, we argue that this conclusion is unwarranted, because the effects of the central and peripheral distractors could not be disentangled. In order to isolate the effect of the peripheral distractor, we introduced a distractor–target letter compatibility manipulation. Our results showed that the peripheral distractor summoned attention, irrespective of whether attention had just been engaged. We conclude that neither spatially focused attention nor attentional engagement is sufficient to prevent attentional capture.

Keywords Space-based attention · Attentional capture · Attentional blink

When searching for an object in a noisy visual field, a vast amount of data compete for limited processing resources. Attention acts as a filter that controls which information is processed and which is ignored. However, attentional control is not perfect. Certain irrelevant distractors can break through the attentional filter and trigger involuntary attentional shifts to their locations. Nominally irrelevant stimuli possessing properties that are similar to those used to guide attention belong to this category (see, e.g., Folk, Remington, & Johnston, 1992). Thus, for instance, when searching for a red shop sign on a busy street, the appearance of a red car should capture attention and interfere with the search.

When tight attentional control is critical, attentional capture by irrelevant stimuli may have grave consequences. For example, an operating surgeon performing surgery or a pilot in delicate situations would do well to disregard all irrelevant information or distractions. Therefore, it is important to understand whether such capture can be resisted, and under what conditions. Yantis and Jonides (1990; see also Theeuwes, 1991) were the first to delineate conditions under which capture could presumably be entirely prevented. They had participants search for a target letter, the location of which was cued with 100 % validity. One stimulus (either the target or one of the distractors) was abruptly onset, and the cue-to-target display onset asynchrony was manipulated. The abrupt onset failed to capture attention when enough time was available to spatially focus attention on the cue location.

Folk, Leber, and Egeth (2002) pointed out that in Yantis and Jonides's (1990) study, not only did the early cue focus attention on the known target location (which eliminated spatial uncertainty), but it also eliminated the need for selection. To determine which factor is critical for preventing capture—spatial uncertainty or the need for selection—Folk et al. (2002) designed a task in which spatial uncertainty was eliminated but observers nonetheless had to search for the target among nontarget letters. They used a variant of the rapid stream visual presentation (henceforth, RSVP) paradigm that has been used to study the attentional blink. Thus, all stimuli, including the target, appeared serially at the same position, and attentional focusing was therefore maximal.

In a typical attentional blink experiment (e.g., Raymond, Shapiro, & Arnell, 1992), two targets are embedded within an RSVP stream, and identification of the second target is

A. Zivony (✉) · D. Lamy
Department of Psychology, Tel Aviv University, Ramat-AvivP.O.B. 39040Tel Aviv 69978, Israel
e-mail: alonzivony@gmail.com

impaired when this target appears 150–500 ms after the first target (an interval of time referred to as the *blink period*). Folk et al. (2002) added a twist to this paradigm: Instead of searching for two targets, participants searched for a single target letter that was preceded by a peripheral distractor at different temporal lags. The target was defined by its prespecified color (e.g., red) and was embedded within a stream of heterogeneously colored letters. The peripheral distractor consisted of four number signs (#). In the critical conditions, the peripheral distractor could either include a color singleton in the same color as the target (henceforth, a *relevant-color singleton peripheral distractor*) or include only gray signs (henceforth, a *no-singleton peripheral distractor*).

Folk et al. (2002) reasoned that if a tight focus of spatial attention is insufficient for preventing involuntary attention shifts, a peripheral distractor should capture attention. The contingent-capture hypothesis (Folk et al., 1992) states that only objects possessing the target-defining feature (e.g., red) capture attention. Relying on this hypothesis, Folk et al. (2002) predicted that relevant-color singletons should produce an attentional blink; that is, target identification accuracy should be lower when the target follows a relevant-color singleton distractor within the blink period (distractor–target lags of 1 and 2) than when the target occurs outside of the blink period (distractor–target lags of −1 and 0). They also predicted that no blink should be observed when the peripheral distractor contains either a singleton with an irrelevant color or no singleton at all. The results fully confirmed these predictions.

In addition, Folk, Ester, and Troemel (2009) proposed that *attentional engagement*, defined as the "opening of a gate between perceptual processing at a particular location/time and higher level cognitive processes" (p. 128) might be a necessary condition for capture lock-out. They used a modified version of Folk et al.'s (2002) paradigm, with one significant difference: Prior to the peripheral distractor, an additional distractor was presented inside the central stream (henceforth, a *central distractor*; see Fig. 1). Thus, three critical events were presented consecutively: a central distractor, a peripheral distractor, and the target. Previous findings had shown that a central distractor in the target's color (henceforth, a *relevant-color central distractor*) produces an attentional blink, whereas a central distractor in a different color (henceforth, an *irrelevant-color central distractor*) does not (Folk, Leber, & Egeth, 2008). Folk et al. (2009) reasoned that if attentional engagement is indeed sufficient to prevent attentional capture, a relevant-color singleton peripheral distractor should no longer impair target identification performance when it is preceded by a relevant-color central distractor at an appropriate lag, because attention should still be engaged at the central distractor.

The results confirmed this prediction. First, control comparisons showed that the relevant-color singleton peripheral distractor captured attention when the central distractor that preceded it was not in the target color (thus replicating the critical finding of Folk et al., 2002). In addition, the relevant-color central distractor produced an attentional blink when the peripheral distractor that followed it did not include the target color (thus replicating the critical finding of Folk et al., 2008). The most important finding, however, was that when the central distractor was in the target color, the attentional blink was of equal magnitude, whether the peripheral distractor that followed included or did not include a target-color singleton. These results were replicated when the peripheral distractor was positioned closer to the central stream (Folk et al., 2009, Exp. 2), thereby increasing its potential for capturing attention. Folk et al. (2009) concluded that the relevant-color singleton peripheral distractor did not capture attention when attention was already engaged by a relevant-color central distractor.

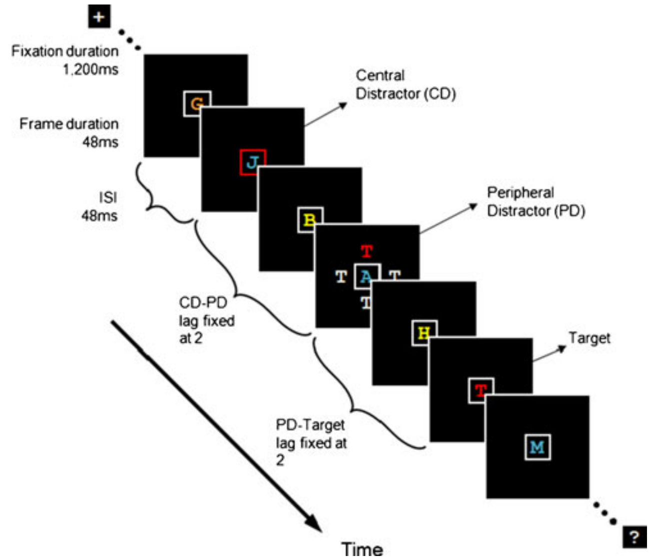

Fig. 1 Illustration of the stimulus sequence in Experiment 1. This example corresponds to the red-target, relevant-color central distractor (CD) and relevant-color singleton peripheral distractor (PD) conditions. The PD letter is compatible with the target letter

However, Folk et al.'s (2009) conclusion that attentional engagement completely prevents attentional capture by a peripheral distractor may be premature, for methodological reasons. The crucial aspect of Folk et al.'s (2009) study that makes their findings ambiguous is that the effects of the central and peripheral distractors were gauged using the same measure—namely, a decrement in target identification performance. It follows that the relative influences of each of the two distractor types could not be distinguished. Folk et al.'s (2009) interpretation relies on the assumption that any effect of the peripheral distractor should be observed "over and above" the effects of the central distractor (p. 130). That is, it is implicitly assumed that the effects of the central and peripheral distractors should be additive. If we do not assume additivity, however, the results are also compatible with the notion that the peripheral distractor captured attention but that its effect did not add to the impairment already produced by the central distractor. In other words, because a single measure was used, the effect of the peripheral distractor may have been masked by the effect of the central distractor.

The objective of the present study was to resolve this ambiguity by probing the effects of the central and peripheral distractors using different measures, thereby allowing us to disentangle them. The stimuli and procedure were similar to those of Folk et al.'s (2009) study. Each target was preceded by two distractors. The central distractor (henceforth, CD) was either in the target color (relevant-color CD) or in a different color (irrelevant-color CD). It was followed by a peripheral distractor (henceforth, PD), that either included a singleton of the target color (relevant-color singleton PD) or contained no singleton (no-singleton PD). In Experiments 1 and 2, the temporal lags between the CD and PD and between the peripheral distractor and the target were fixed at 2, because many previous studies have shown the attentional blink to be maximal at lag 2 (e.g., Chun & Potter, 1995; Raymond et al., 1992). Therefore, in order to assess the disruptions produced by the distractors, we compared target identification performance when the critical distractor was in the relevant versus an irrelevant color, rather than comparing performance at different distractor-to-target lags (i.e., within vs. outside the blink period).

The major change that we introduced was the addition of a condition in which the peripheral distractor consisted of letters that either matched (compatible condition) or did not match (incompatible condition) the identity of the target letter. Attentional capture by the PD was therefore measured by the size of the "compatibility effect"—that is, by the benefit in target identification performance when the letters making up the peripheral distractor were compatible versus incompatible with the target identity (see also Folk et al., 2002; Theeuwes, 1996).

If attentional engagement indeed locks out capture, we would expect to find compatibility effects only when the CD's color was different from the target's, not when it was the same. In contrast, if attentional capture can occur even when attention has just been engaged, we would expect to find a compatibility effect regardless of the CD's color—that is, improved target identification when the relevant-color PD included a letter that was compatible versus incompatible with the target letter.

Experiment 1

Method

Participants The participants were 14 Tel-Aviv University undergraduate students (ages between 20 and 32 years) who participated in the experiment for course credit. All reported normal or corrected-to-normal visual acuity and normal color vision.

Apparatus The displays were presented on a 17-in. CRT monitor, using the 1,024×768 resolution graphics mode in a dimly lit room. Responses were collected via the computer keyboard. A chinrest was used to set the viewing distance at 50 cm from the monitor.

Stimuli The fixation display was a gray 0.2º×0.2º plus sign against a black background. The stimulus display consisted of an RSVP stream of 15 frames (see Fig. 1). Each frame contained a letter enclosed in an outline square, centered at fixation. The letters were drawn from the English alphabet (excluding I, O, W, and Z). The target letter was either red or green. The remaining (distractor) letters in the stream were randomly cyan, yellow, or orange. The square (three pixels thick and 1.5º per side) in each frame was gray, except for one square, the central distractor, that was either red or green. Thus, the CD was either in the target color (*relevant-color CD* condition) or in a different color (*irrelevant-color CD* condition).

Each stream included a peripheral distractor frame in which four identical characters were added 0.3º above, below, to the left, and to the right of the square frame enclosing the central letter (the center-to-center distance was thus 1.8º). The additional characters were either hash signs (*#-PD* condition) or letters (*letter-PD* condition), which were either the same letter as the target (*compatible-letter PD* condition) or different from it (*incompatible-letter PD* condition). In the *no-singleton PD* condition, all of the peripheral characters were gray. In the *relevant-color singleton PD* condition, a character in the target color (either red or green) replaced one of the gray characters. All of the characters were drawn in bold Courier New font and subtended 1.3º in height. The CD position was randomly selected between the third and ninth positions in the stream. The PD always followed the CD by exactly two frames, and the target followed the PD by exactly two frames.

Procedure The sequence of events on each trial consisted of the fixation frame (1,200 ms), followed by a 700-ms blank screen and by the RSVP stream. Each frame appeared for 48 ms and was followed by a 48-ms blank screen, yielding a presentation rate of 96 ms per letter. A question mark then prompted the participant to respond. A new trial began 700 ms after the participant had responded.

Participants searched for a target letter, defined by its prespecified color, in the central RSVP stream. They had to report its identity as accurately as possible with no time pressure, by typing the corresponding key on a standard keyboard, and to guess if unable to identify the target. No feedback was given on accuracy. Participants were instructed to focus their gaze on the fixation point and to attend only to the letters in the stream. They were informed that distracting stimuli might appear, and they were instructed to ignore them.

Design On each trial, all the letters in the RSVP stream were randomly selected from the 22-letter set without replacement. Target Color (either red or green) was a between-subjects factor. CD Color (relevant color vs. irrelevant color), PD Type (relevant-color singleton vs. no singleton), and PD Shape (# signs vs. compatible letter vs. incompatible letter) were within-subjects factors and were randomly mixed. The PD consisted of letters on two thirds of the trials and of # signs on the remaining third. The CD color conditions were equiprobable, and so were PD compatibility conditions.

The experiment included 20 practice trials, followed by 480 experimental trials presented in 40-trial blocks. Participants were allowed a short rest between blocks.

Results

One participant completed only 300 trials due to a technical error. All of the analyses were conducted with mean accuracy as the dependent variable.[1] In both experiments, preliminary analyses showed no main effect of target color and no interaction involving this variable, all ps>.05. The data were therefore collapsed across conditions of target color.

To determine whether we would replicate Folk et al.'s (2009) findings, we conducted a 2×2 repeated measures analysis of variance (ANOVA) on #-PD trials (i.e., excluding all letter-PD trials), with CD Color (relevant color vs. irrelevant color) and PD Type (relevant-color singleton vs. no singleton) as within-subjects factors. The mean accuracy data are presented in Fig. 2. The main effects of both CD color and PD type were significant, $F(1, 13)=4.88$, $p=.046$, $\eta_p^2=.27$, and $F(1, 13)=7.21$, $p=.019$, $\eta_p^2=.36$, respectively. Participants were less accurate on relevant- than on irrelevant-color CD trials, and on relevant-color singleton PD trials than on no-singleton PD trials. The interaction between CD color and PD type was significant, $F(1, 13)=16.22$, $p=.002$, $\eta_p^2=.56$. Simple-effects analyses revealed that, as in Folk et al.'s (2009) study, target identification was significantly impaired on irrelevant-color CD trials when the PD contained a relevant-color singleton relative to when it did not, $F(1, 13)=10.58$, $p=.006$, $\eta_p^2=.45$ ($M=73.2$ %, $SE=4.0$ %,

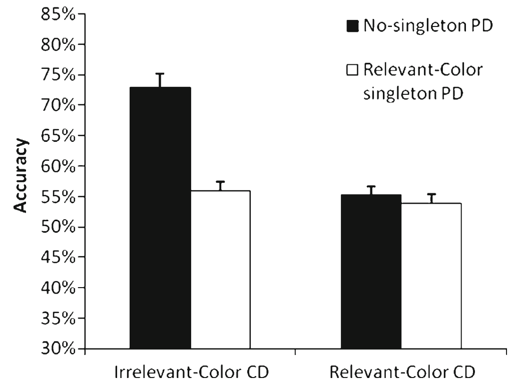

Fig. 2 Replication of Folk et al. (2009) with hash signs (#) as peripheral distractors (PDs): Accuracy (as percentages) by conditions of central distractor (CD) color (relevant vs. irrelevant) and PD type (relevant-color singleton vs. no singleton). Bars represent within-subjects confidence intervals (Morey, 2008)

vs. $M=54.1$ %, $SE=6.0$ %); no such difference was found on relevant-color CD trials, $F<1$ ($M=54.8$ %, $SE=5.8$ %, vs. $M=53.9$ %, $SE=6.3$ %). Thus, we fully replicated Folk et al.'s (2009) findings.

Next, we conducted a three-way ANOVA on letter-PD trials (i.e., excluding all #-PD trials), with CD Color (relevant color vs. irrelevant color), PD Type (relevant-color singleton vs. no singleton), and PD Compatibility (compatible vs. incompatible) as within-subjects factors. The mean accuracy data are presented in Fig. 3. All of the main effects were significant: Participants were less accurate when the CD was in the relevant color than when it was in an irrelevant color, $F(1, 13)=10.37$, $p=.007$, $\eta_p^2=.44$; when the display included a relevant-color singleton PD than when it included no color singleton, $F(1, 13)=24.95$, $p<.001$, $\eta_p^2=.66$; and when the PD letter was incompatible with the target letter relative to when it was compatible, $F(1, 13)=10.18$, $p=.007$, $\eta_p^2=.44$.

The two-way interaction between CD color and PD type was significant, $F(1, 13)=18.10$, $p<.001$, $\eta_p^2=.58$. Simple-effects analyses revealed a pattern of results that mirrored the findings observed when the PD included # signs instead of letters: When the PD included no singleton, accuracy was significantly poorer on relevant- than on irrelevant-color CD trials, $F(1, 13)=16.22$, $p=.001$, $\eta_p^2=.56$ ($M=52.9$ %, $SE=5.9$ %, vs. $M=71.7$ %, $SE=3.7$ %, for relevant- vs. irrelevant-color trials, respectively). By contrast, we found no CD color effect on relevant-color singleton PD trials, $F(1, 13)=1.09$, $p=.31$, $\eta_p^2=.078$ ($M=50.0$ %, $SE=4.7$ %, vs. $M=53.0$ %, $SE=4.1$ %, for relevant- vs. irrelevant-color trials, respectively).

The two-way interaction between PD compatibility and PD type was also significant, $F(1, 13)=15.09$, $p=.002$. Simple-effects analyses showed that when the PD included a relevant-color singleton, performance was significantly better on compatible than on incompatible trials, $F(1, 13)=14.03$, $p=.002$, $\eta_p^2=.52$ ($M=64.4$ %, $SE=5.6$ %, vs. $M=38.6$ %, $SE=5.4$ %, respectively). By contrast, when the PD included no color

[1] We conducted the same analyses on arcsine square-root transformed accuracy data. In all experiments, the results were fully replicated: All of the significant effects remained significant, and all of the nonsignificant effects remained nonsignificant. In order to conform to Folk et al.'s (2009; Folk et al., 2002) analyses, we only present the analyses on untransformed target identification performance.

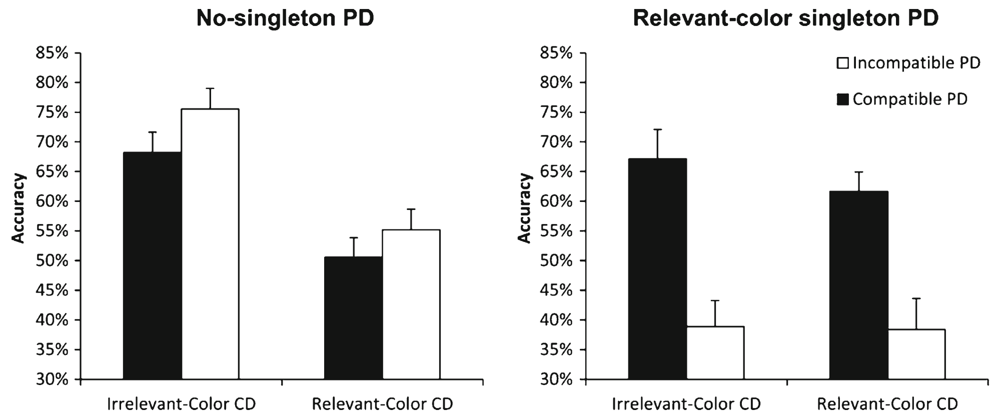

Fig. 3 Accuracy (as percentages) in Experiment 1 by conditions of central distractor (CD) color (relevant vs. irrelevant) and peripheral distractor (PD) type (no singleton vs. relevant-color singleton) when the PD included only target-compatible letters versus only incompatible letters. Bars represent within-subjects confidence intervals (Morey, 2008)

singleton, a small yet significant compatibility effect in the opposite direction emerged, $F(1, 13)=6.73$, $p=.02$, $\eta_p^2=.34$: Participants were actually slightly less accurate on compatible than on incompatible trials ($M=59.4$, $SE=4.7$ %, vs. $M=65.3$ %, $SE=4.3$ %, respectively).

Finally, the three-way interaction between CD color, PD type, and PD compatibility was significant, $F(1, 13)=4.86$, $p=.046$, $\eta_p^2=.27$. To clarify this interaction, we conducted separate ANOVAs for no-singleton PD trials and relevant-color singleton PD trials, with CD Color and PD Compatibility as within-subjects factors. On no-singleton PD trials, the interaction between CD color and PD compatibility was not significant, $F<1$. On relevant-color singleton PD trials, this interaction also did not reach significance, $F(1, 13)=3.31$, $p=.092$, $\eta_p^2=.20$. Crucially, although the compatibility effect tended to be slightly reduced when the CD color was relevant, relative to when it was irrelevant (23.3 % vs. 28.2 %, respectively), this effect remained highly significant in the relevant-color CD condition, $F(1, 13)=12.88$, $p=.002$, $\eta_p^2=.50$.

In addition, we analyzed the number of "identity intrusions" of the distractor on the participants' responses to the target. That is, we examined the percentages of trials on which participants mistakenly reported the identity of the incompatible peripheral letter instead of the identity of the actual target when the peripheral singleton was in the relevant color. The identity-intrusion occurrence rate was high and was not affected by whether the CD was in the relevant or the irrelevant color, $F<1$ (38.0 % vs. 39.8 %, respectively).

Taken together, these results strongly suggest that the relevant-color peripheral distractor captured attention despite the fact that attention had just been engaged by the central distractor.

Discussion

The findings of this experiment indicate that attentional engagement is not sufficient to prevent attentional capture by stimuli that match the observer's attentional set. Even when attention had just been engaged in a relevant-color central distractor, a relevant-color singleton peripheral distractor produced a significant compatibility effect, suggesting that it captured attention. Although the numerical trend toward a smaller compatibility effect when attention had just been engaged by the relevant-color central distractor indicates that attentional engagement might nevertheless lower the probability that attention will be subsequently captured, such a finding, if confirmed, would not challenge the conclusion that attentional engagement does not effectively block capture.

This conclusion has two potential limitations. First, because in this experiment half of the peripheral letter trials were compatible trials, the peripheral distractor predicted the target letter on 50 % of the trials, and was therefore informative. Thus, participants might have adopted the strategy of purposely shifting their attention toward the peripheral distractor. Second, as all four peripheral distractor letters were identical, one may argue that the compatibility effect did not necessarily result from the capture of spatial attention. For example, if participants distributed their attention more widely whenever they perceived the target color, the peripheral letters might produce compatibility effects without attention being shifted to the location of the relevant-color singleton peripheral distractor. The next experiment was designed to address these issues.

Experiment 2

Method

Participants The participants were 14 Tel-Aviv University undergraduate students (ages between 21 and 28 years) who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design The apparatus, stimuli, procedure, and design were identical to those of Experiment 1, except for the following changes. First, the #-

PD condition was removed. Second, the PD array included four different letters instead of identical letters. Third, for each participant, the target letter was one of ten letters randomly drawn from the original 22-letter set (but participants were not notified of this restriction). The color singleton letter in the PD display was also randomly drawn from this restricted set, whereas the other three letters in the PD display were drawn from the remaining possible letters. The color-singleton peripheral letter was therefore compatible with the target letter on only 10 % of the trials. That is, for each combination of CD color and PD type, 12 compatible PD trials and 108 incompatible PD trials were presented (i.e., 480 experimental trials overall). This modification eliminated the correlation between the identities of the target letter and the relevant-color singleton, and therefore shifting attention toward it would yield no strategic advantage. Finally, the PD array was presented at a center-to-center distance of 2.8º from fixation, instead of 1.8º, to reduce the probability that its identity might be perceived without shifting attention to its location.

Results

In the first analysis, we examined only the decrement in performance accuracy when the singleton distractor was in the target color, relative to when it was not, irrespective of its compatibility with the target color. However, the ratio of compatible- to incompatible-PD trials was highly unbalanced: Out of ten trials in which the peripheral display included a color singleton, one trial was compatible and nine were incompatible. Thus, we did not enter this factor in the first analysis in order to avoid overrepresentation of the compatible PD condition in the assessment of the effect of PD color on target identification. As we conducted two analyses on the same data, we used a Bonferroni alpha correction to retain the overall alpha level at 5 %. Thus, significance was assessed against an alpha of 2.5 %.

A 2×2 ANOVA with CD Color (relevant vs. irrelevant color) and PD Type (relevant-color singleton vs. no singleton) revealed marginal main effects for both factors: Participants tended to be less accurate when the CD was in the relevant color relative to when it was in an irrelevant color, $F(1, 12)=4.35$, $p=.059$, $\eta_p^2=.27$, and when the PD included a relevant-color singleton than when it included no singleton, $F(1, 12)=4.19$, $p=.063$, $\eta_p^2=.26$. The interaction between the two factors was significant, $F(1, 12)=11.93$, $p=.004$, $\eta_p^2=.50$. Follow-up analyses revealed that the performance decrement observed when the PD contained a relevant-color singleton versus no singleton was significant only when the CD was in the irrelevant color, $F(1, 12)=11.06$, $p=.006$, $\eta_p^2=.48$ ($M=65.2$ %, $SE=4.8$ %, vs. $M=76.3$ %, $SE=3.5$ %, respectively), and was nonsignificant when the CD was in the relevant color, $F<1$ ($M=67.4$ %, $SE=4.8$ %, vs. $M=68.1$ %, $SE=5.0$ %, respectively). Thus, we again fully replicated Folk et al.'s (2009) findings.

We then examined the compatibility effect in a three-way ANOVA with CD Color (relevant vs. irrelevant color), PD Type (relevant-color vs. no singleton), and PD Compatibility (compatible vs. incompatible) as within-subjects factors. The mean accuracy data are presented in Fig. 4. The main effect of PD compatibility was not significant, $F(1, 13)=3.13$, $p=.10$, $\eta_p^2=.21$. However, the two-way interaction between PD type and PD compatibility was significant, $F(1, 12)=10.83$, $p=.006$, $\eta_p^2=.48$. Follow-up analyses showed that when the PD included a relevant-color singleton letter, participants were more accurate when this letter was compatible than when it was incompatible with the target letter, $F(1, 12)=16.20$, $p=.002$, $\eta_p^2=.57$ ($M=74.0$ %, $SE=5.1$ %, vs. $M=65.4$ %, $SE=4.8$ %, respectively). By contrast, no compatibility effect was apparent on no-singleton PD trials, $F<1$ ($M=70.5$ %, $SE=4.7$ %, vs. $M=72.4$ %, $SE=4.2$ %).

Unlike in the previous experiment, the three-way interaction was not significant, $F<1$. That is, unlike in Experiment 1, we observed no trend toward a smaller compatibility effect in the relevant-color CD than in the irrelevant-color CD conditions (if anything, the numerical trend was in the opposite direction—9.9 % vs. 7.3 %, respectively). Again, crucially, the compatibility effect on relevant-color PD trials was highly significant when the CD color was relevant, $F(1, 12)=12.73$, $p=.002$, $\eta_p^2=.51$. In addition, the identity-intrusion rate was again high and was unaffected by whether the central distractor was in the relevant or in an irrelevant color, $F<1$ (28.6 % vs. 30.9 %).

Discussion

The results of Experiment 2 closely replicated those of Experiment 1. On the one hand, when target identification performance served as a measure of attentional capture for both the central and peripheral distractors, the findings reported by Folk et al. (2009) were fully replicated: Relative to an irrelevant-color peripheral distractor, a relevant-color peripheral distractor impaired performance only when it followed an irrelevant-color central distractor. On the other hand, however, when compatibility effects were used to specifically measure attentional capture by the peripheral distractor, we found performance to be enhanced when the peripheral relevant-color letter was compatible with the target letter relative to when it was incompatible, even when attention had just been engaged by a relevant-color central distractor. This effect was substantially smaller in this experiment than in the previous one, due to the changes introduced to eliminate alternative accounts, yet it was still highly significant. Thus, the findings of Experiment 2 again suggest that attentional engagement of attention is not sufficient to prevent attentional capture.

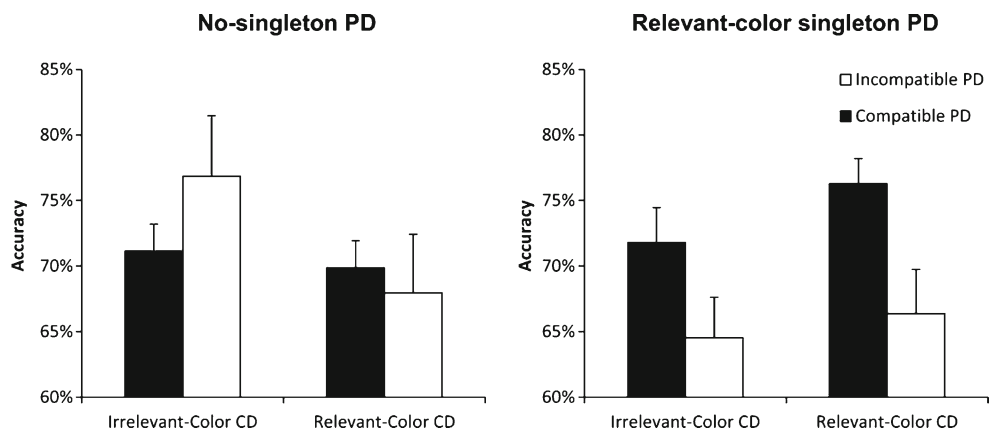

Fig. 4 Accuracy (as percentages) in Experiment 2 by conditions of central distractor (CD) color (relevant vs. irrelevant) and peripheral distractor (PD) type (no singleton vs. relevant-color singleton) when the PD included a target-compatible letter versus only incompatible letters. Bars represent within-subjects confidence intervals (Morey, 2008)

However, alternative interpretations could still account for our findings. First, it is possible to claim that engagement does not lock spatial attention but sharpens observers' attentional set. Specifically, engagement might allow the adoption of an attentional set for stimuli that match *all* of the target's task-relevant features instead of only some—for example, a set that matches not only its color but also its response feature (i.e., here, its letter shape). Accordingly, a peripheral red number sign (that matched the target's color but not its shape) did not capture attention when attention had just been engaged (e.g., Folk et al., 2009), whereas a red peripheral letter did.

Second, one may still argue that the compatibility effect found in Experiment 2 did not result from *spatial* capture of attention by the peripheral singleton letter. According to this argument, the identity of the relevant-color singleton might produce a compatibility effect even if attention were not focused at its location. A stricter test of spatial attention would require temporal separation of the stimulus that presumably elicits a shift of attention to its location (i.e., the spatial prime) and the stimulus that triggers the compatibility effect (i.e., the probe). Accordingly, if the relevant-color singleton peripheral distractor indeed captures spatial attention, compatibility effects should be observed only when the locations of the spatial prime and probe coincide (see Folk et al., 2002, Exp. 4, for a similar rationale). Experiment 3 was designed to address these alternative accounts.

Experiment 3

In this experiment, the peripheral distractor included four squares, one of which was either a relevant-color or an irrelevant-color singleton among gray squares. The peripheral-distractor frame was followed by four gray peripheral letters (henceforth, the *PD+1 letter* frame) occupying the same locations as the squares in the previous frame. On each trial, one of these peripheral letters was the same as the target (see Fig. 5). The positions of the color-singleton square and of the compatible letter were uncorrelated, such that the colored square appeared at the same position as the target-compatible letter on 25 % of the trials.

We reasoned that if performance accuracy is better when the compatible letter rather than an incompatible letter appears in the spatial location just occupied by the relevant-color singleton, this would indicate (1) that a relevant-color peripheral distractor captures attention even if it is not a letter, thereby invalidating the claim that the engagement of attention sharpens the attentional set, and (2) that the peripheral relevant-color singleton triggers a *spatial* shift of attention, because better identification of the subsequent letter at that location would entail that it received focal attention.

The main disadvantage in this procedure, however, is that it is likely to yield weaker effects than the procedure used in Experiments 1 and 2: Indeed, since the target is known to appear at the center of the screen, observers should disengage their attention from the relevant-color peripheral square as

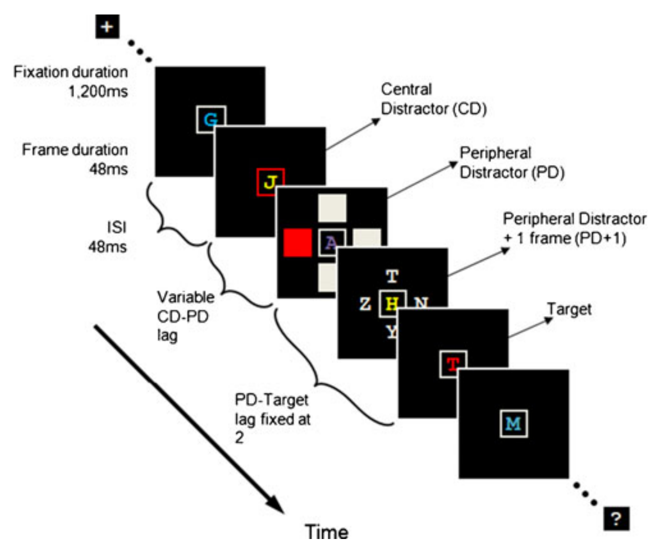

Fig. 5 Illustration of the stimulus sequence in Experiment 3. The central distractor–peripheral distractor (CD–PD) lag was either 1 or 3 in Experiment 3a, and either 2 or 4 in Experiment 3b. In this example, the target color is red, a lag of 1 separates the central and peripheral distractors, the PD frame contains a relevant-color singleton, and the frame following the peripheral distractor (PD+1) is incompatible with the target

quickly as possible, with only residual attention lingering at the location of this distractor and accruing to the subsequent letter.

An additional goal of Experiment 3 was to assess the effect of the relevant-color central distractor separately from the effect of the peripheral distractor. Although the compatibility manipulation introduced in the previous experiments allowed us to determine whether the peripheral distractor captured attention, the effect of the central distractor was still confounded with that of the peripheral distractor, because the latter could also modulate target identification accuracy. We therefore manipulated the lag between the central distractor and the target, while keeping the peripheral distractor at a constant lag from the target (lag 2). We reasoned that any modulation of target identification accuracy by this lag manipulation could be attributed only to the central distractor. Thus, unlike in Experiments 1 and 2, the effect of the central distractor was measured as the difference between lags and not between color conditions. In order to examine several lags while not making the experiment prohibitively long, we manipulated the lag between the central distractor and the target in two separate experiments. Accordingly, Experiment 3a included lags 3 and 5 (corresponding to lags of 1 and 3 between the central and peripheral distractors; henceforth, the *CD–PD lag*), and Experiment 3b included lags 4 and 6 (CD–PD lags of 2 and 4). If the central distractor were indeed to affect target identification, even when a subsequent peripheral distractor with the target color captured attention (Exps. 1 and 2), we should observe an attentional blink (i.e., a lag effect) when the central distractor was in the relevant color, but not when it was in an irrelevant color.

Experiment 3a

Method

Participants The participants were 19 Tel-Aviv University undergraduate students (ages between 23 and 29 years) who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design The apparatus, stimuli, procedure, and design were identical to those of Experiment 1, except for the following changes. First, the PD frame appeared at a variable lag of 1 or 3 after the CD frame. Second, the PD frame included four filled squares, one of which (the color singleton) was either green or red and the remaining three were gray. Thus, all PD frames included either a relevant-color or an irrelevant-color singleton (*PD-color* condition). Third, the PD frame was followed by four gray peripheral letters (PD+1 letter frame) occupying the same locations as the squares in the previous frame. On each trial, one of these peripheral letters was the same as the target (compatible letter). The positions of the color-singleton square and of the compatible letter were randomly determined across trials and uncorrelated. Thus, on one-fourth of the trials, the PD+1 letter following the color singleton was compatible with the target letter (*compatible PD+1* condition), whereas on the remaining trials it was incompatible with it (*incompatible PD+1* condition). The PD and PD+1 stimuli were presented at a center-to-center distance of 2.3º.[2] The experiment included 600 experimental trials divided into 12 blocks of 50 trials per block. Thus, for each combination of CD color, PD type, and CD–PD lag, approximately 19 compatible PD+1 trials and 57 incompatible PD+1 trials were presented.

Results

The data from one participant were removed from the analyses because his mean accuracy was lower than the mean by more than two standard deviations (M=52.1 % vs. M=76.4 %, SD=11.1 %). The same analyses as in Experiment 2 were conducted, including the Bonferroni correction to 2.5 %. However, as preliminary analyses revealed a marginal main effect for target color, $F(1, 16)=5.13$, $p=.037$, $\eta_p^2=.24$, target color was added in the analyses.

We first conducted a four-way ANOVA with Target Color (red vs. green) as a between-subjects factor and CD Color (relevant vs. irrelevant color), PD Color (relevant vs. irrelevant color), and CD–PD Lag (lag 1 vs. lag 3) as within-subjects factors. This analysis yielded main effects of CD color and CD–PD lag: Participants were less accurate when the CD was in the relevant color than when it was in the irrelevant color, $F(1, 16)=8.44$, $p=.01$, $\eta_p^2=.35$, and with CD–PD lag 1 than with CD–PD lag 3, $F(1, 16)=18.77$, $p<.001$, $\eta_p^2=.54$. The main effect of PD color was not significant, $F<1$.

The interaction between CD color and CD–PD lag was significant, $F(1, 16)=10.07$, $p=.006$, $\eta_p^2=.39$. Follow-up comparisons revealed that accuracy was lower for lag 1 than for lag 3 when the CD was in the relevant color, $F(1, 16)=25.07$, $p<.001$ $\eta_p^2=.61$ (M=71.8 %, SE=3.0 %, vs. M=80.0 %, SE=2.5 %, respectively), whereas we observed no lag effect when the CD was in the irrelevant color, $F(1, 16)=1.00$, $p=.33$ $\eta_p^2=.06$ (M=78.9 %, SE=2.1 %, vs. M=

[2] We reduced the center-to-center distance used in Experiment 2 by 0.5º because pilot studies with the same design as Experiment 3 but using the original center-to-center distance had revealed little evidence of capture. Crucially, we found no capture by the relevant-color PD even when the CD color was *irrelevant*, suggesting that the capturing power of the PD was weak under these conditions. This change was orthogonal to our research questions in Experiment 3 and was only aimed at increasing the PD effect.

80.4 %, SE=2.1 %, for lags 1 vs. 3, respectively). The three-way interaction was not significant, $F<1$. This analysis suggests that the relevant-color CD produced an attentional-blink effect, irrespective of whether the subsequent PD was in the relevant or in an irrelevant color, therefore replicating Folk et al.'s (2009) findings.

Unlike in the previous experiments, PD color did not significantly modulate performance accuracy, irrespective of whether the CD color was relevant, $F<1$ (M=75.6 %, SE= 2.9 %, vs. M=76.2 %, SE=2.7 %, for the irrelevant- vs. relevant-color PD, respectively), or irrelevant, $F(1, 16)$= 1.55, p=.12 (M=80.4 %, SE=2.1 %, vs. M=78.9 %, SE= 2.0 %, for the irrelevant- vs. relevant-color PD, respectively). All other effects were also nonsignificant, all ps>.15.

We then examined the compatibility effect in a five-way ANOVA with Target Color (red vs. green) as a between-subjects factor and CD Color (relevant vs. irrelevant color), PD Color (relevant vs. irrelevant color), CD–PD Lag (lag 1 vs. lag 3), and PD+1 Compatibility (compatible vs. incompatible) as within-subjects factors. The mean accuracy data are presented in Fig. 6. Planned comparisons revealed that the PD+1 compatibility effect was marginally significant (i.e., did not reach significance after Bonferroni correction) when the PD singleton color was relevant, $F(1, 17)$=3.20, p=.046, η_p^2=.17 (M=78.7 %, SE=3.9 %, vs. M=77.2 %, SE= 4.1 %, for compatible vs. incompatible trials, respectively). The effects of PD+1 compatibility were similar, whether the CD was in the relevant or the irrelevant color, $F<1$ (1.8 % vs. 1.5 %, respectively). Note, however, that even though the compatibility effect on relevant-color CD trials was slightly larger than the main effect, the simple effect failed to reach significance, $F(1, 16)$=1.04, p=.16, η_p^2=.06. In this experiment, the identity-intrusion rate on relevant-color PD trials was low and was again unaffected by whether the CD color was relevant or irrelevant, $F<1$ (1.0 % vs. 2.0 %, respectively). No other significant effects were apparent. In particular, the PD+1 compatibility effect was not significant when the PD color was irrelevant, $F<1$ (M=78.0 %, SE=4.4 %, vs. M=77.9 %, SE=4.4 %, for compatible vs. incompatible trials, respectively).

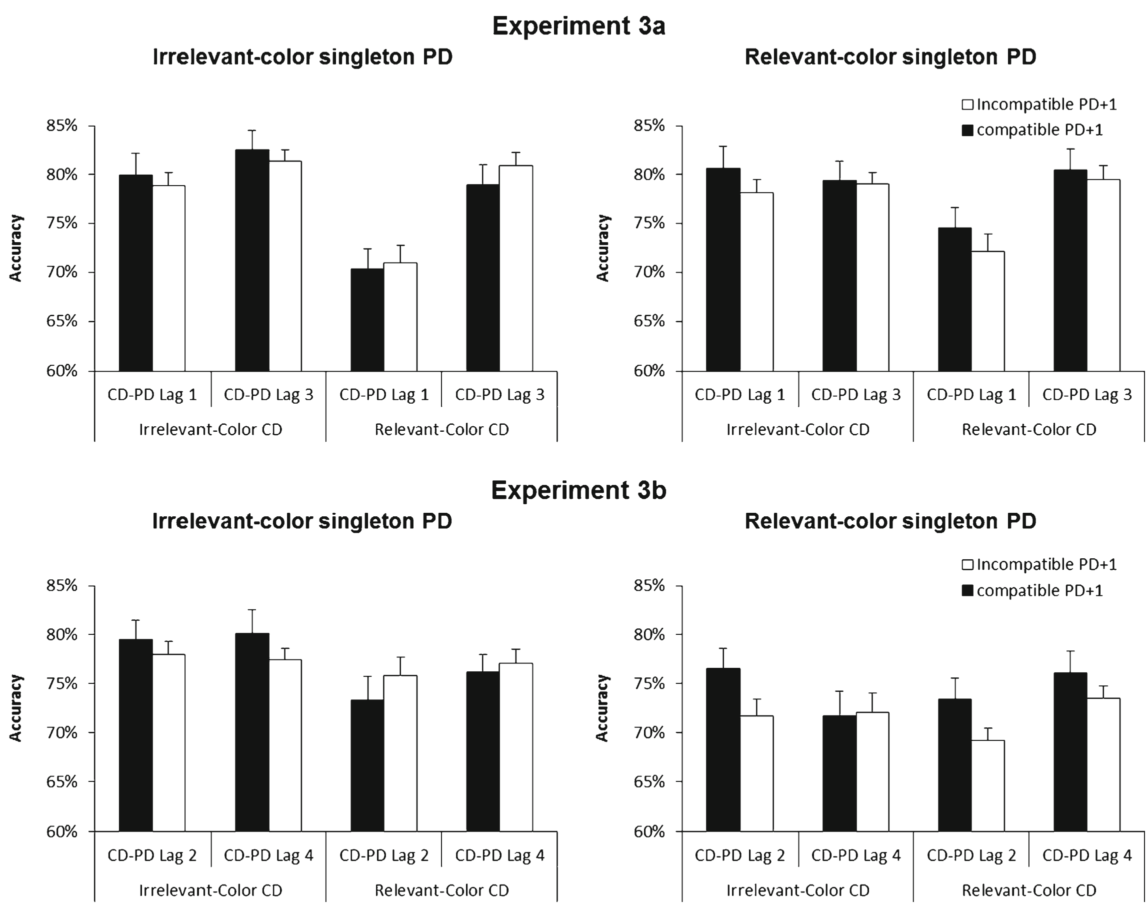

Fig. 6 Accuracy (as percentages) in Experiments 3a (upper panels) and 3b (lower panels), by conditions of peripheral distractor (PD) color (relevant vs. irrelevant), central distractor (CD) color (relevant vs. irrelevant), and CD–PD lag (lags 1 and 3 in Exp. 3a, lags 2 and 4 in Exp. 3b) when the letter at the location just occupied by the singleton PD was compatible versus incompatible with the target. Bars represent within-subjects confidence intervals (Morey, 2008)

Experiment 3b

Method

Participants The participants were 20 Tel-Aviv University undergraduate students (ages between 20 and 31 years) who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, and design The apparatus, stimuli, procedure, and design were identical to those of Experiment 3a, except that lags 2 and 4 were used instead of lags 1 and 3.

Results

The data from two participants were removed from the analyses because their mean accuracies were lower than the overall mean by more than two standard deviations (Ms=54.1 % and 44.9 % vs. overall mean=75.4 %, SD=9.6 %). Again, preliminary analyses revealed an effect of target color. Specifically, the interaction between target color and CD color was marginally significant, $F(1, 16)=5.17$, $p=.037$, $\eta_p^2=.24$.

We first conducted a four-way ANOVA with Target Color (red vs. green) as a between-subjects factor and CD Color (relevant vs. irrelevant color), PD Color (relevant vs. irrelevant color), and CD–PD Lag (lag 2 vs. lag 4) as within-subjects factors. The main effect for PD color was significant, $F(1, 16)=14.07$, $p=.002$, $\eta_p^2=.47$: Participants were less accurate when the PD color was relevant than when it was irrelevant (M=72.3 %, SE=2.8 %, vs. M=77.1 %, SE= 2.5 %, respectively). Neither the main effect of CD color nor the main effect of CD–PD lag was significant, both ps>.2.

The interaction between CD color and CD–PD lag was marginally significant, $F(1, 16)=4.86$, $p=.042$. Follow-up comparisons revealed that, as in Experiment 3a, when the CD color was relevant, accuracy was lower for CD–PD lag 2 than for CD–PD lag 4, $F(1, 16)=3.78$, $p=.035$, $\eta_p^2=.23$ (M=72.7 %, SE=2.9 %, vs. M=75.4 %, SE=2.8 %, respectively), but not when CD color was irrelevant, $F<1$ (M=75.6 %, SE=2.5 %, vs. M=75.0 %, SE=2.5 %, respectively). No other effect was significant. In particular, the three-way interaction between CD color, PD color, and CD–PD lag was not significant, $F<1$. The results of Experiments 3a and 3b thus replicated Folk et al.'s (2009) findings: They suggest that the relevant-color central distractor produced an attentional blink, irrespective of whether the subsequent peripheral distractor was in the relevant or in the irrelevant color.

Next, we examined the compatibility effect in a five-way ANOVA with Target Color (red vs. green) as a between-subjects factor and CD Color (relevant vs. irrelevant color), PD Color (relevant color vs. irrelevant color), CD–PD Lag (lag 2 vs. lag 4), and PD+1 Compatibility (compatible vs. incompatible) as within-subjects factors. The mean accuracy data are presented in Fig. 6.[3] Planned comparisons revealed that accuracy was significantly higher on compatible than on incompatible trials when the PD color was relevant, $F(1, 17)=4.96$, $p=.025$, $\eta_p^2=.22$ (M=74.5 %, SE=2.6 %, vs. M= 71.6 %, SE=2.9 %). As in Experiment 3a, this effect was not modulated by any other variable. In particular, the PD+1 compatibility effects were similar, whether the CD was in the relevant or the irrelevant color, $F<1$ (3.4 % vs. 2.2 %, respectively). Crucially, in this experiment (as in Exps. 1 and 2), the compatibility effect was significant when the CD color was relevant, $F(1, 16)=6.53$, $p=.021$, $\eta_p^2=.29$. In addition, the compatibility effect was not modulated by either CD color or CD–PD lag, both ps>.20. The identity-intrusion rate on relevant-color PD trials was again low and was smaller when the CD color was relevant than when it was irrelevant, $F(1, 17)=6.77$, $p=.02$ (0.7 % vs. 2.0 %). None of the other theoretically important interactions were significant.[4] In particular, the compatibility effect was not significant when the PD color was irrelevant, $F<1$ (M=77.3 %, SE=2.41 %, vs. M=77.0 %, SE=2.6 %).

Discussion

Experiments 3a and 3b produced similar results: The identity of a peripheral letter presented at the location just occupied by a relevant-color distractor affected target identification accuracy. This compatibility effect was more reliable in Experiment 3b than in Experiment 3a. This difference between the two experiments might have resulted from the different CD–PD lag manipulation or from random individual differences between participants. We favor the latter explanation, because in Experiment 3a we failed to observe a significant effect of the peripheral distractor color on target identification when the CD color was irrelevant. Yet, on the basis of previous research (Folk et al., 2009; Folk et al., 2002), as well as on the results of Experiments 1 and 2, we expected that, relative to an irrelevant-color PD, a relevant-color PD should

[3] Although the interaction between CD color, CD–PD lag, and PD+1 compatibility on relevant-color PD trials was not significant, $F<1$, the figure shows a clear compatibility effect for the relevant-color PD under all conditions except the irrelevant-color CD condition at CD–PD lag 4, where the compatibility effect seems to be absent. No theoretical reason accounts for why the compatibility effect should be absent in this condition; if anything, compatibility effects should be stronger when the CD color is irrelevant (Folk et al., 2009). We have no explanation at this point for why this condition was particularly noisy.

[4] The three-way interaction between target color, CD color, and compatibility was significant, $F(1, 17)=8.36$, $p=.01$. However, this interaction was not theoretically relevant and had not been observed in any of the previous experiments. Therefore, we do not discuss it further.

impair target identification—an effect that provides an uncontaminated measure of the relevant-color PD's capturing power. Thus, it appears that the participants' attention was less likely to be captured by the PD in Experiment 3a than in the previous experiments, and it is therefore not surprising that the PD+1 frame produced a weaker compatibility effect. The findings that the magnitude of the compatibility effect went hand in hand with the magnitude of the overall effect of PD color on target identification and that it was not modulated by CD color strengthen the notion that the compatibility effect indeed indexed attentional capture by the PD.

Taken together, the results from Experiment 3 replicate the main findings of Experiments 1 and 2, and therefore allow us to reject alternative accounts. First, they show that attentional engagement does not sharpen the attentional set, as a peripheral distractor that did not possess the target response feature (i.e., a filled red square rather than a letter) nonetheless captured attention. Second, they show that such capture is spatial, because a peripheral distractor that contained a letter compatible with the target letter improved performance only when this compatible letter coincided with the location of a relevant-color square immediately preceding it. Thus, our findings confirm that attentional engagement does not prevent spatial capture of attention by relevant-color stimuli.

Finally, whereas the compatibility manipulation allowed us to assess the effects of the peripheral distractor independently of the effects of the central distractor, the design of Experiment 3 allowed us to assess the effects of the central distractor independently of the effects of the peripheral distractor. The lag manipulation pertained to the temporal distance between the central distractor and the target, whereas the temporal distance of the peripheral distractor from the target remained fixed. Thus, the effect of lag on target identification (i.e., the attentional-blink effect) provided an independent measure of the effects of the relevant- versus irrelevant-color central distractors. The results clearly showed that the central distractor produced a larger attentional blink when it was in the relevant versus the irrelevant color, regardless of the peripheral distractor's color, in line with Folk et al.'s (2009) results. Taken together, the results of Experiment 3b (and, to a lesser extent, Exp. 3a) therefore suggest that the effects on target identification of both capture by the central distractor and capture by the peripheral distractor coexist. Implications of this finding for mechanisms that underlie the attentional blink are proposed in the General Discussion.

However, although the main findings were replicated across experiments, several notable differences distinguished the results of Experiments 1 and 2 from those of Experiments 3a and 3b. First, as expected, the compatibility effects (when the peripheral distractor was a relevant-color singleton) were substantially smaller in the latter experiments than in Experiments 1 and 2: The sizes of the compatibility effect were 25.8 % (η_p^2=.52) and 8.6 % (η_p^2=.57), respectively, in Experiments 1 and 2 but were 1.6 % (η_p^2=.17) and 2.8 % (η_p^2=.22) in Experiments 3a and 3b, respectively. Since the task required the participants to disengage their attention from the capturing stimuli and to return to the central stream in order to detect the target, it is reasonable to assume that on some trials, they may have disengaged their attention from the relevant-color peripheral square fast enough, so that on these trials, the peripheral letter following the square may not have been perceived at all.

Second, the identity-intrusion rates were also much smaller in Experiments 3a and 3b (0.7 % and 1.3 %, respectively) than in Experiments 1 and 2 (38.9 % and 29.7 %, respectively). Fast disengagement is also likely to have contributed to this reduction. In addition, it may be useful to ponder on the source of identity intrusions, in order to further understand this result. In Experiments 1 and 2, the peripheral letters were drawn in the target's color. Because participants searched for a letter in a specific color, a similarly colored letter should have been registered in working memory as a candidate target (contrary to letters in irrelevant colors). Furthermore, when the relevant-color distractor occurred in the blink period for the target letter, it is likely that the peripheral letter in the relevant color was the only response-appropriate stimulus maintained in working memory. By contrast, in Experiments 3a and 3b, when attention was captured by the peripheral color singleton, the letter that subsequently appeared at the same location was in an irrelevant color. Thus, even if this letter was attended and stored in working memory, it was less likely to qualify as an appropriate response candidate. Given these differences, the small effects found in Experiment 3 do not reflect the "true" magnitude of capture when attention is focused and engaged, and the existence of a replicable, albeit small, compatibility effect thus provides strong evidence that the stimuli indeed captured spatial attention.

Third, whereas the results of Experiment 2 closely replicated those of Folk et al. (2002), the results of Experiment 3 did not. The procedure and design of Experiment 2 were very similar to those of Folk et al.'s (2002) Experiment 3, and accordingly, both the compatibility and identity-intrusion effects were of similar magnitudes to those from the earlier study. By contrast, although Experiment 3 in our study was very similar to Folk et al.'s (2002) Experiment 4, the results were quite dissimilar. Specifically, the compatibility effect in Folk et al.'s (2002) Experiment 4 was around 10 %, and the distractor-intrusion rate was around 20 %. These effects were substantially smaller in our study. One noteworthy difference between the two experiments is that we used filled-in squares as peripheral distractors, whereas Folk et al. (2002) used outlined squares. Thus, one might argue that our peripheral distractor squares may have masked the subsequent letters at their locations. However, this stimulus difference is unlikely to account for the discrepancy between our results and Folk et al.'s (2002): We actually resorted to filled squares following a pilot experiment with outlined frames, which produced even weaker results. Thus, we have no satisfactory explanation at this point for the discrepancy between the results of the two experiments.

Finally, in both experiments, we observed a numerical trend toward a compatibility effect when both the central and peripheral distractors were drawn in the irrelevant color (see Fig. 6). This trend is surprising, because irrelevant-color peripheral distractors have been shown not to capture attention (e.g., Folk et al., 2002). To account for it, one may speculate that exposure to the irrelevant color during presentation of the central distractor primed this color, and as a result increased the chance that a subsequent peripheral distractor in the same color would capture attention. Note, however, that the compatibility effect was nonsignificant in both experiments (ps > .37 and .11 in Exps. 3a and 3b, respectively), and therefore may represent a spurious finding rather than a real phenomenon. Further investigation will be required in order to clarify this issue.

General discussion

The results from the present study clearly show that neither spatial focusing of attention nor attentional engagement prevents attentional capture by a distractor matching the observer's attentional set. Folk et al. (2009) suggested that when attention is spatially focused, attentional engagement by a stimulus within the focus of attention locks attention, thereby producing temporary immunity against attentional capture. In support of this claim, they showed that a peripheral hash-sign singleton in the target color does not appear to capture attention if attention has been previously engaged in a central distractor. We replicated this finding, but by using a compatibility measure to disentangle the effects of the central and peripheral distractors, we showed that a peripheral letter singleton in the target color (Exps. 1 and 2), as well as a letter occupying the location of an immediately preceding square in the target color (Exps. 3a and 3b), did capture attention. Specifically, we showed that even when attention had just been engaged in a central distractor, a peripheral letter in the target color was associated with higher accuracy when its identity was the same as the target's versus when it was different. We thus concluded that engagement is not sufficient for locking out attentional capture.

One may claim that these findings do not necessarily entail that engagement in a relevant-color central distractor prevents the capture of attention. The argument goes as follows: Target identification performance when the central distractor was in the relevant color did not fall to chance: It was on the order of 60 %, and the chance performance level was less than 5 %, which entails that the relevant-color central distractor did not capture attention on every trial. Thus, one may argue that the compatibility effect resulted only from those trials in which the central distractor did *not* capture attention. In other words, engagement in the central distractor *may have* locked attention, but the peripheral distractor captured attention only on trials in which participants were able to ignore the central distractor. According to the same rationale, however, if attentional engagement did prevent capture, the average size of the compatibility effect should have been substantially reduced when the central distractor's color was relevant relative to when it was irrelevant. This is predicted because although the relevant-color central distractor might not always capture attention, it would do so more often than an irrelevant-color central distractor. However, this result was apparent only in Experiment 1, and not in Experiments 2 and 3, which makes this alternative account unlikely.

If, as we claim, neither focused attention nor attentional engagement can prevent attentional capture, how then can we explain Yantis and Jonides's (1990) finding that a salient object—the unique abruptly onset object—that captured attention when the target location was unknown failed to do so when attention was focused and engaged at the upcoming target location? Several important differences separate their study from ours. In Yantis and Jonides's study, attention was focused on the target location, and the target and potentially disrupting distractor appeared simultaneously. Thus, one might assume that the target identity could be processed before capture by the onset distractor could have any effect. Here, in contrast, the object by which attention was engaged (the central distractor) was not the object to which observers had to respond. In addition, the target appeared after the critical peripheral distractor. Therefore, as the peripheral distractor captured attention and was processed before the target appeared, its effect on performance could be measured. A stricter test would be to present the onset distractor after the 100 %-valid cue but before the target. Although, according to Yantis and Jonides's hypothesis, this modification should not affect the results, we predict that the effects of attentional capture by the onset would now become apparent.

Our results show that attentional engagement at fixation cannot prevent capture by a peripheral distractor. This finding constrains the possible mechanisms underlying the attentional blink. Namely, it suggests that the ability of a certain object to capture attention when attention has just been engaged by a different object may be limited to situations in which the two objects occupy different spatial positions. Consistent with this possibility, Kristjánsson and Nakayama (2002) conducted an attentional blink study in which each of the two targets randomly appeared in one of several possible RSVP streams. They showed that the second target suffered the strongest blink when it appeared in the same stream (i.e., at the same location) as the first target, and the weakest blink when it appeared in the most distant stream. Thus, according to this view, engaging attention at a location does not result in locking out a resource or process (e.g., Raymond et al., 1992), but in momentarily preventing attention from reengaging at the same location due to inhibitory processes. If this account is correct, then engaging attention at a central distractor should prevent the allocation of attention to a second *central* distractor that also matches the attentional set and appears shortly thereafter, because this distractor suffers from spatial inhibition (whereas the peripheral distractor in the present study did not). We are currently testing this possibility.

To conclude, we have not yet found the conditions in which attentional control is perfect and capture can be completely avoided. Yet, one may wonder whether foolproof shielding from attentional capture would be a desirable feature of our attentional system (see Müller, Reimann, & Krummenacher, 2003, for a similar suggestion). In our study, participants could not ignore objects that were similar to the target that they were currently looking for, even though these appeared at irrelevant locations. Such flexibility may be desirable, given the dynamic nature of the real world.

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References

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21*(1), 109–127. doi:10.1037/0096-1523.21.1.109

Folk, C. L., Ester, E. F., & Troemel, K. (2009). How to keep attention from straying: Get engaged! *Psychonomic Bulletin & Review, 16,* 127–132. doi:10.3758/PBR.16.1.127

Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics, 64,* 741–753. doi:10.3758/BF03194741

Folk, C. L., Leber, A. B., & Egeth, H. E. (2008). Top-down control settings and the attentional blink: Evidence for nonspatial contingent capture. *Visual Cognition, 16,* 616–642. doi:10.1080/13506280601134018

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. doi:10.1037/0096-1523.18.4.1030

Kristjánsson, Á., & Nakayama, K. (2002). The attentional blink in space and time. *Vision Research, 42,* 2039–2050. doi:10.1016/S0042-6989(02)00129-3

Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology, 4,* 61–64.

Müller, H. J., Reimann, B., & Krummenacher, J. (2003). Visual search for singleton feature targets across dimensions: Stimulus and expectancy-driven effects in dimensional weighting. *Journal of Experimental Psychology: Human Perception and Performance, 29,* 1021–1035. doi:10.1037/0096-1523.29.5.1021

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18,* 849–860. doi:10.1037/0096-1523.18.3.849

Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception & Psychophysics, 49,* 83–90. doi:10.3758/BF03211619

Theeuwes, J. (1996). Perceptual selectivity for color and form: On the nature of the interference effect. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual attention* (pp. 297–314). Washington, DC: American Psychological Association.

Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 121–134. doi:10.1037/0096-1523.16.1.121