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Contingent attentional engagement: stimulus- and goal-driven capture have qualitatively different consequences

Alon Zivony & Dominique Lamy

Tel Aviv University

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RUNNING HEAD: Attentional engagement is contingent on goal-driven factors

Alon Zivony

School of Psychological Sciences

Email: alonzivo@post.tau.ac.il

Abstract

We examined whether shifting attention to a location necessarily entails extracting the features at that location, a process referred to as “attentional engagement”. In three spatial-cueing experiments (N=60) we found an onset cue to capture attention both when it shared the target’s color and when it did not. Yet, the effects of the match between the response associated with the cued object’s identity and the responses associated with the target (compatibility effects), which are diagnostic of attentional engagement, were observed only with relevant-color onset cues. These findings demonstrate that stimulus- and goal-driven capture have qualitatively different consequences: before attention is reoriented to the target, it is engaged to the location of the critical distractor following goal-driven capture, but not following stimulus-driven capture. The reported dissociation between attentional shifts and attentional engagement suggests that attention is best described as a “camera”: one can shift its zoom lens without pressing the shutter-button.

We can process only a limited amount of information at any given time. Selective attention helps us overcome this limitation by enhancing the processing of prioritized events at the expense of other events. What factors determine such prioritization has been intensely debated (e.g., Awh, Belopolsky & Theeuwes, 2012; Lamy, Leber & Egeth, 2012; Theeuwes, 2010). To answer this question, researchers have attempted to characterize objects that capture attention against our will, which led them to espouse one of two opposing viewpoints.

Proponents of the salience-based view claim that salient stimuli summon attention irrespective of the observer's goals (e.g., Theeuwes, 2010; Yantis & Jonides, 1984), whereas proponents of the contingent-capture view suggest that only stimuli matching the observer's goals (or attentional set) attract attention (e.g., Folk, Remington & Johnston, 1992)[1]. Although the latter have gained considerable support (e.g., Eimer & Kiss, 2008; Lamy, Leber & Egeth, 2004), recent research suggests that purely stimulus-driven capture can occur (e.g., Folk & Remington, 2015). In particular, Gaspelin, Ruthruff and Lien (2016) showed that abrupt onsets automatically capture attention, but whether such capture is observed depends on how long attention dwells at their location before the nontarget occupying it is rejected. Thus, the field is moving towards a consensus according to which both stimulus-driven and goal-driven factors can determine attentional priority.

Our focus here was not on the determinants of attentional priority but on its aftermath. It is widely agreed that when attention shifts towards the location of a prioritized object, a burst of transient enhancement speeds the extraction of information at that location and gates its consolidation into working memory (e.g., Goldfarb &

Treisman, 2010; Wolfe, 2007), a process often referred to as “attentional engagement” (e.g., Folk, Ester & Troemel, 2009; Nieuwenstein, Chun, van der Lubbe & Hooge, 2005; Posner & Petersen, 1990)[2]. Accordingly, several studies showed that attentional engagement follows attentional capture (e.g., Carmel & Lamy, 2014; Folk & Remington, 2006; Theeuwes, Atchley & Kramer, 2000; Zivony & Lamy, 2016a). Attentional engagement was typically assessed by measuring response compatibility effects. The identity of the attention-grabbing distractor was associated with either the same response as the current target or with the alternative response. Poorer performance on incompatible- relative to compatible-response trials attested that the distractor’s identity was processed, since the response associated with it was prepared (Eriksen & Eriksen, 1974).

Note that in these studies, attention was captured by a distractor matching the observers’ attentional set. In some cases, it shared the target’s defining feature (e.g., its color). In other cases, as both the distractor and target were singletons, observers could adopt a general “singleton-detection” mode (Bacon & Egeth, 1994) and the distractor therefore matched their attentional set. Thus, attentional engagement seems to be a mandatory consequence of goal-driven attentional capture.

Here, our objective was to determine whether stimulus-driven attentional capture also necessarily entails attentional engagement. The answer to this question has important implications for attentional capture research but also, more broadly, for current models of selective attention. A negative answer would entail that while both stimulus-driven and goal-driven factors can control attentional shifts, they elicit qualitatively different perceptual processes at the attended location. It would also entail that in contrast with most leading models of attention (e.g, Posner, Rueda & Kanske, 2008; Sperling & Weichselgartner, 1995; Goldfarb & Treisman, 2010; Wolfe, 2007), shifting attention to a location does not entail mandatory processing of the features at that location.

We relied on a variant of Gaspelin et al.'s (2016) spatial cueing paradigm, which is sensitive enough to reveal spatial capture by irrelevant abrupt onsets. Participants reported the identity of a target defined by its known color and presented among distractors similar to the target in color. Prior to the target display, an abruptly onset cue appeared at one of the four potential target locations. It either shared the target color (relevant-color onset cue) or did not (irrelevant-color onset cue). Attentional capture was measured as the performance benefit when the target appeared at a cued vs. uncued location. We expected both the relevant-color (e.g., Folk & Remington, 1998; Carmel & Lamy, 2014) and the irrelevant-color (Gaspelin et al., 2016) onset cues to capture attention. Attentional engagement was measured as the compatibility effect associated with the distractor letter at the cued location. We expected attention to be engaged to the location of the relevant-color onset (e.g. Carmel & Lamy, 2014). Of main interest was whether this would also occur for cues that did not share the target color.

Experiment 1

Method

Sample size selection

Based on Gaspelin et al. (2016, Experiment 4), we calculated the sample size required in order to observe a significant location benefit when the cue is an irrelevant-color onset. We conducted this analysis with G*Power (Faul, Erdfelder, Buchner & Lang, 2013), using an alpha of 0.05, power of 0.80, and the effect size reported in Gaspelin et al. (2016). We found the minimum sample size required to be 5 participants.

Participants

Participants were 20 (17 women) Tel-Aviv University undergraduate students who participated for course credit. The participants' mean age was 22.45 (*SD* = 2.16). All reported normal or corrected-to-normal visual acuity and color vision.

Apparatus

Displays were presented in a dimly lit room on a 23" LED screen, using 1920X1280 resolution graphics mode and 120Hz refresh rate. Responses were collected via the computer keyboard. Viewing distance was set at 50 cm from the monitor.

Stimuli

The sequence of events on each trial is presented in Figure 1. All stimuli were drawn with 3-pixel thick lines and appeared against a black background. The fixation display consisted of a 0.2° × 0.2° plus sign in the center of the screen, surrounded by four 1.7° × 1.7° outline square placeholders that appeared at the corners of an imaginary 3.66° × 3.66° square centered at fixation. The cue and target displays were similar to the fixation display except for the following differences. In the cue display, four filled dots (0.25° in diameter) appeared at cardinal locations around one of the placeholders, with dot-placeholder center-to-center distance set at 1.2°. These dots were either red (RGB 255,0,0) or white (255,255,255). In the target display, a letter, E or H, subtending 1° × 1°, appeared in the center of each placeholder. One letter, the target, was red (255,0,0), one distractor was pink (210,0,80), and the other two were orange (210,80,0).

Design

The experiment included 20 practice trials followed by 500 experimental trials divided into 50-trial blocks. Subjects were allowed a self-paced rest between blocks. Cue-relevance conditions, red (relevant-color onset) or white (irrelevant-color onset) were blocked, with block order counterbalanced between subjects. The cue and target locations were randomly set on each trial. Therefore, the cue and target appeared at the same location on 25% of the trials (same-location trials). Since each display contained exactly two Es and two Hs, on different-location trials the letter that appeared at the cued location was the same as the target on third| of the trials (compatible-distractor condition), and different from the target on two thirds of the trials (incompatible-distractor condition).

Procedure

Participants were instructed to report as quickly and as accurately as possible whether the target was an “E” or an “H” by pressing 1 or 3 on the numerical pad keyboard, respectively. Each trial began with the fixation display that appeared for a random duration ranging from 700 to 1300 ms. Then, the cue display appeared for 100 ms. It was followed by the fixation display for 50 ms and then by the target display that remained on the screen for 100 ms. The response duration was limited to 2000 ms. Errors were followed by a 500-ms beep. After response, a blank screen appeared for 500 ms, after which a new trial began. Participants were instructed to maintain their eyes on the fixation cross. They were informed about the presence of the cues and instructed to ignore them.

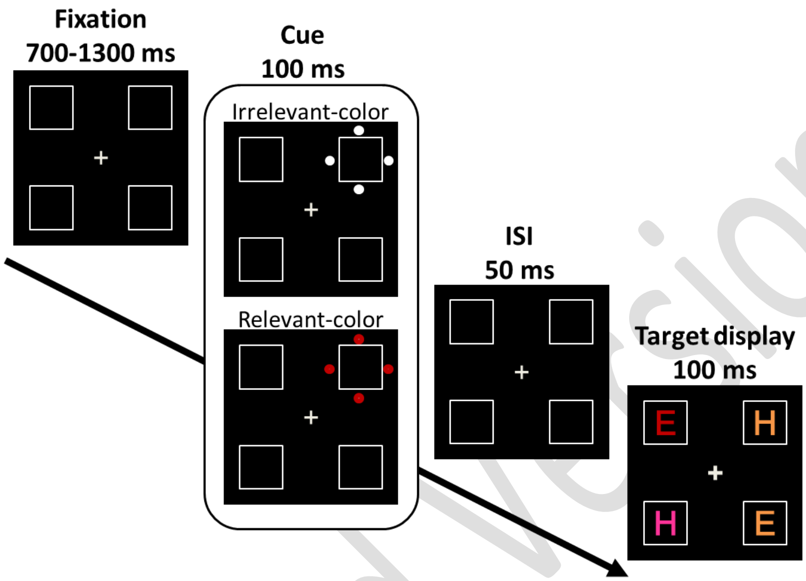

Figure 1. Sample sequence of events in Experiment 1. Here, the target is an E. This example corresponds to the different-location, incompatible-distractor condition.

Results

All reaction time (RT) analyses were conducted on correct trials (96.8%). Outlier-RT trials (i.e., trials faster than 200ms or exceeding the mean of their cell by more than 2.5 standard deviations - 2.14% of all correct trials) were also excluded. Analyses of accuracy rates were conducted on the arcsine-square root transformation of mean accuracy rates (Winer, 1962). Overall mean reaction times and accuracy rates are presented in Table 1.

In this and the following experiment, Bayesian analyses of the theoretically most meaningful effects were conducted using the anovaBF function from the BayesFactor package in R (Morey & Rouder, 2015) with participant intercepts as random effects. We used the default medium prior (r = 0.50), yet in all experiments, we obtained similar results with wider priors (r = 0.707 or r = 1.0). Importantly, this analysis allowed us to assess the evidence for null effects, which is not possible with frequentist hypothesis testing. Following Dienes and Mclatchie (2017) we consider a BF_{10} to provide evidence for H0 if it smaller than 0.33 (i.e., $BF_{01} > 3$), "inconclusive" evidence if it stands between 1/3 and 3 and evidence for H1 if it exceeds 3 (with a BF_{10} between 3 and 10, 10 and 30, 30 and 100 and > 100 providing substantial, strong, very strong and decisive evidence, respectively, for H10, Jeffreys, 1961). Evidence for two-way interactions was evaluated by comparing the model including all effects to the model including only the main effects. We report the Bayes factor for H1 (BF_{10}) or for the null hypothesis (BF_{01}), depending on whether an effect was statistically significant or non-significant, respectively.

Table 1. Overall reaction times and accuracy rates in Experiments 1-3. Standard errors are presented in parentheses.

	Reaction times (ms)	Accuracy (%)
Experiment 1	615.5 (16.2)	95.4 (0.8)
Experiment 2	695.0 (22.3)	92.9 (1.3)
Experiment 3	632.5 (17.3)	95.5 (0.7)

Attentional Capture (location effect).

We conducted a repeated-measures ANOVA with cue location relative to the target (same vs. different) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Mean cue location effects on RTs and accuracy are presented in Figure 2.

Reaction times. The main effect of cue location was significant, $F(1,19) = 84.41$, $p < .0001$, $\eta^2_p = .82$, and interacted with cue color relevance, $F(1,19) = 64.657$, $p < .0001$, η^2_p

= .77, indicating that the relevant-color onset cue yielded a larger location effect than the irrelevant-color onset cue , BF_{10} > 100. Follow-up analyses revealed that both effects were significant, *M* = 566 ms (*SE* = 4 ms) vs. *M* = 638 ms (*SE* = 5 ms), $F(1,19) = 100.76$, $p < .0001$, $\eta^2_p = .84$, and *M* = 599 ms (*SE* = 4 ms) vs. *M* = 613 ms (*SE* = 3 ms), $F(1,19) = 10.27$, $p = .005$, $\eta^2_p = .35$, respectively. Bayesian analyses revealed that the evidence for a location effect was decisive in the relevant-color onset cue condition, BF_{10} > 100 and very strong in the irrelevant-color onset cue condition, $BF_{10} = 91.17$. There was no main effect of cue color relevance, $F<1$.

Accuracy. The results mirrored those of the RT analysis. The main effect of cue location was significant, $F(1,19) = 7.00$, $p = .016$, $\eta^2_p = .27$ and interacted with cue color relevance, $F(1,19) = 8.39$, $p = .009$, $\eta^2_p = .30$. Yet, Bayesian analyses revealed that the evidence for this interaction was inconclusive, $BF_{10} = 2.19$. Follow-up analyses revealed that the location effect was significant when the cue color was relevant, *M* = 96.8% (*SE* = 0.7%) vs. *M* = 94.2% (*SE* = 0.4%), for same- vs. different-location trials, respectively, $F(1,19) = 14.77$, $p = .001$, $\eta^2_p = .44$, and not when it was irrelevant, *M* = 95.9% (*SE* = 0.5%) vs. *M* = 95.8% (*SE* = 0.6%), $F<1$. Evidence for a location effect in the relevant-color onset cue condition was decisive, BF_{10} > 100, and evidence in favor of the null hypothesis in the irrelevant-color onset cue condition was very strong, $BF_{01} = 25.78$. There main effect of cue color relevance was not significant, $F<1$.

Attentional Engagement (compatibility effect).

We conducted a repeated-measures ANOVA with distractor compatibility (compatible vs. incompatible) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Same-location trials were excluded from this analysis. Mean distractor compatibility effects on RTs and accuracy are presented in Figure 2.

Reaction times. The main effect of cue color relevance was significant, with slower RTs when the cue was in the relevant vs. irrelevant color, $F(1,19) = 6.15$, $p = .023$, $\eta^2_p = .24$. This effect interacted with cue compatibility, $F(1,19) = 6.16$, $p = .02$, $\eta^2_p = .25$, $BF_{10} > 100$. Follow-up analyses revealed that the compatibility effect was significant when the cue color was relevant, $M = 627$ ms ($SE = 8$ ms) vs. $M = 644$ ms ($SE = 5$ ms) for compatible vs. incompatible trials, respectively, $F(1,19) = 6.46$, $p = .02$, $\eta^2_p = .25$, and not when it was irrelevant, $M = 618$ ms ($SE = 6$ ms) vs. $M = 610$ ms ($SE = 3$ ms), $F(1,19) = 1.78$, $p = .20$, $\eta^2_p = .08$. Evidence for a compatibility effect when the cue was in the relevant color was decisive, $BF_{10} > 100$. Evidence for the null hypothesis when the cue was in the irrelevant color was substantial, $BF_{01} = 3.55$. The main effect of cue compatibility was not significant, $F(1,19) = 1.50$, $p = .23$, $\eta^2_p = .07$.

Accuracy. The results mirrored those of the RT analysis. The main effect of cue color relevance approached significance, $F(1,19) = 4.15$, $p = .056$, $\eta^2_p = .18$, indicating that accuracy was lower when the cue color was relevant than when it was irrelevant. This effect interacted with distractor compatibility, $F(1,19) = 8.34$, $p = .009$, $\eta^2_p = .30$, $BF_{10} = 23.28$. Follow-up analyses indicated that the effect of distractor compatibility approached significance when the cue color was relevant, $M = 95.6\%$ ($SE = 0.5\%$) vs. $M = 93.5\%$ ($SE = 0.7\%$) for compatible vs. incompatible trials, respectively, $F(1,19) = 4.09$, $p = .057$, $\eta^2_p = .17$, and was not significant when the cue color was irrelevant, $M = 96.0\%$ ($SE = 0.7\%$) vs. $M = 95.4\%$ ($SE = 0.6\%$), $F(1,19) = 1.22$, $p = .28$, $\eta^2_p = .05$. Bayesian analyses revealed that evidence for these effects was inconclusive, BF_{10} = 1.36 and, BF_{01} = 1.55, respectively. The main effect of cue compatibility was not significant, F<1.

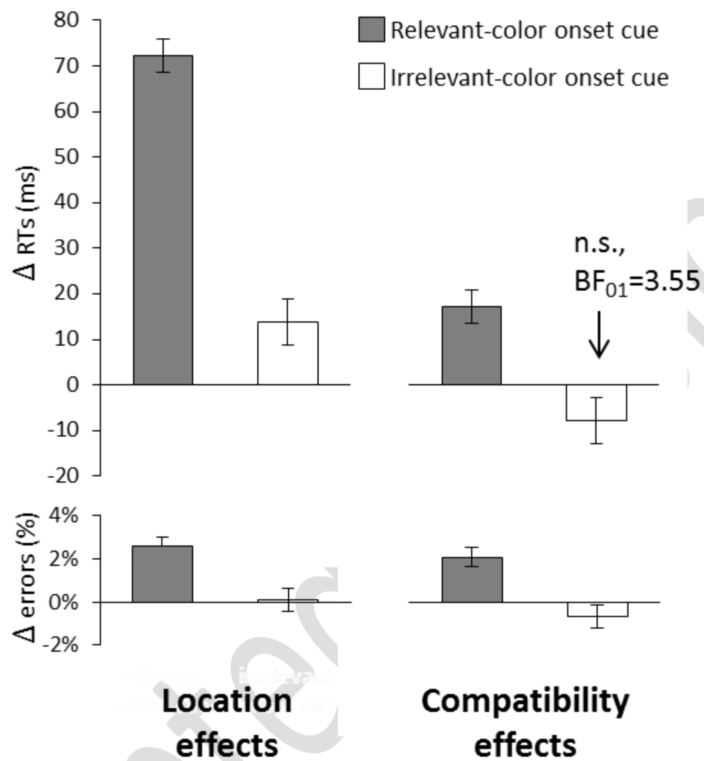

Figure 2. Location effects (different location minus same location) and distractor compatibility effects (incompatible distractor minus compatible distractor) on reaction times (top panels) and error rates (bottom panels) in Experiment 1, as a function of cue color relevance (relevant vs. irrelevant). Distractor compatibility effects were calculated on different-location cue trials. Error bars denote within-subject standard errors (Morey, 2008).

Discussion

We found that while both relevant- and irrelevant-color onsets[3] captured attention, attentional engagement occurred only with relevant-color onsets. Thus, attentional engagement following an involuntary shift of attention is contingent on goal-driven factors.

This conclusion is open to two alternative explanations. First, as location effects were substantially larger for relevant- than for irrelevant-color onsets, the null compatibility effect in the latter condition may reflect a scaling effect. This possibility is addressed in the results section of Experiment 3. Second, attentional engagement might follow capture by irrelevant-color onsets, but its time window might be brief, in line with the fast-disengagement account (e.g., Schreij, Owens, & Theeuwes, 2008; Theeuwes et al., 2010). This account suggests that attention is automatically shifted and engaged to the location of the most salient object, but that these processes fail to produce observable location or compatibility effects when the target follows the salient distractor by enough time for attention to disengage. Since in Experiment 1 the letters driving the compatibility effect appeared only in the target display, attentional engagement following attentional capture by the irrelevant-color onset may have terminated during the 150-ms cue-target SOA.

In Experiment 2 we examined this alternative account by having the letters appear from the trial's beginning: they were therefore present when the cue appeared. If attentional engagement is brief rather than withheld following capture by an irrelevant-color onset, compatibility effects should emerge in this experiment.

Experiment 2

Method

Sample size selection

Based on the previous experiment, we calculated the sample size required in order to observe a significant location benefit for the irrelevant-color onset cue condition. We conducted this analysis with G*Power (Faul et al., 2013), using an alpha of 0.05, power of 0.80, the effect size reported in Experiment 1 (η^2_p = .35), and the correlation between observations (*r* = .94). We found the minimum sample size required to be 4 participants.

Participants

Participants were 20 (17 women) Tel-Aviv University undergraduate students who participated for course credit. The participants' mean age was 22.75 (*SD* = 3.57). All reported normal or corrected-to-normal visual acuity and color vision.

Apparatus, Stimuli, Design and Procedure

The apparatus, stimuli, design and procedure were similar to those of Experiment 1 except that the letter inside each placeholder appeared in all displays (fixation, cue and target) and was drawn in grey in the fixation and cue displays. The target display was the same as in Experiment 1. The sequence of events on each trial is presented in Figure 3.

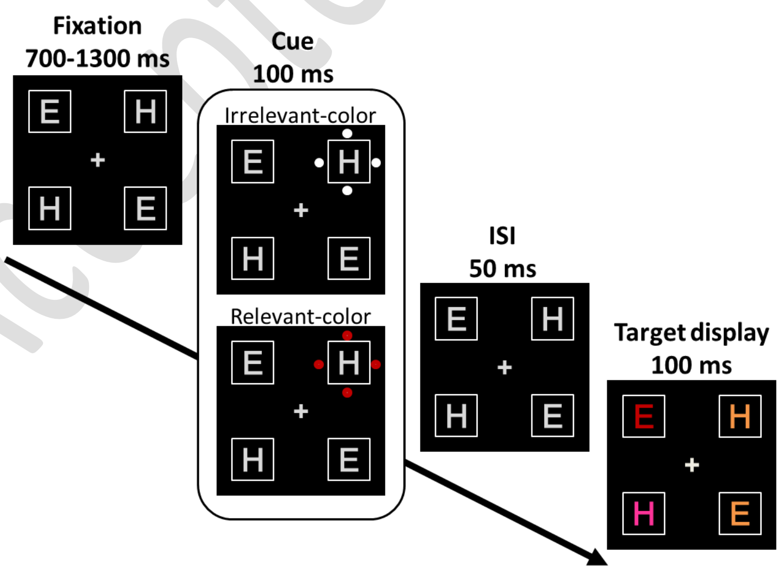

Figure 3. Sample sequence of events in Experiment 2. Unlike in Experiment 1, the letter stimuli appeared from the fixation display and were therefore present when the cue appeared. Here, the target is an E. This example corresponds to the different-location, incompatible-distractor condition.

Results

All reaction time (RT) analyses were conducted on correct trials (92.9%). Outlier-RT trials (2.16% of all correct trials) were also excluded. Overall mean reaction times and accuracy rates are presented in Table 1.

Attentional Capture (location effect).

We conducted a repeated-measures ANOVA with cue location relative to the target (same vs. different) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Mean cue location effects on RT and accuracy are presented in Figure 4.

Reaction times. The main effects of cue color relevance and cue location were significant, $F(1,19) = 33.25$, $p < .0001$, $\eta^2_p = .64$, and $F(1,19) = 7.82$, $p = .01$, $\eta^2_p = .29$, respectively. So was the interaction between the two effects, $F(1,19) = 23.08$, $p < .001$, $\eta^2_p = .55$, indicating that the relevant-color onset cue yielded a larger location effect than the irrelevant-color onset cue, $BF_{10} > 100$. Follow-up analyses revealed that both effects were significant, $M = 644$ ms ($SE = 7$ ms) vs. $M = 744$ ms ($SE = 8$ ms), $F(1,19) = 37.66$, $p < .0001$, $\eta^2_p = .66$, for same- vs. different-location trials, respectively, and $M = 658$ ms ($SE = 6$ ms) vs. $M = 685$ ms ($SE = 5$ ms), $F(1,19) = 7.95$, $p = .011$, $\eta^2_p = .28$, respectively. Bayesian analyses revealed that the evidence for a location effect was decisive in the relevant-color onset cue condition, $BF_{10} > 100$ and very strong in the irrelevant-color onset cue condition, $BF_{10} > 100$.

Accuracy. The results mirrored the main findings of the RT analysis. The main effect for cue location was significant, $F(1,19) = 17.94$, $p < .001$, $\eta^2_p = .49$ and interacted with cue color relevance, $F(1,19) = 15.60$, $p < .001$, $\eta^2_p = .45$, $BF_{10} > 100$. Follow-up analyses revealed that the location effect was significant when the cue color was relevant, M = 92.6% (SE = 0.5%) vs. M = 90.2% (SE = 0.9%), for same- vs. different-location trials, respectively, $F(1,19) = 31.46$, $p < .0001$, $\eta^2_p = .62$, and not when it was irrelevant, M = 93.3% (SE = 0.7%) vs. M = 94.3% (SE = 0.4%), F<1. The evidence for a location effect in the relevant-color onset cue condition was decisive, $BF_{10} > 100$, and the evidence in favor of the null hypothesis was very strong in the irrelevant-color onset cue condition, $BF_{01} = 24.15$. There was no main effect of cue color relevance, F<1.

Attentional Engagement (compatibility effect).

We conducted a repeated-measures ANOVA with distractor compatibility (compatible vs. incompatible) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Same-location trials were excluded from this analysis. Mean distractor compatibility effects on RTs and accuracy data are presented in Figure 4.

Reaction times. The main effect of cue color relevance was significant, $F(1,19) = 20.84$, $p < .001$, $\eta^2_p = .52$. This effect interacted with cue compatibility, $F(1,19) = 9.74$, $p = .006$, $\eta^2_p = .33$, $BF_{10} > 100$. Follow-up analyses revealed that the compatibility effect was significant when the cue color was relevant, M = 723 ms (SE = 9 ms) vs. M = 754 ms (SE = 14 ms), for compatible vs. incompatible trials, respectively, $F(1,19) = 6.77$, $p = .017$, $\eta^2_p = .26$, and not when it was irrelevant, M = 692 ms (SE = 6 ms) vs. M = 682 ms (SE = 9 ms), $F(1,19) = 1.43$, $p = .25$, $\eta^2_p = .07$. The evidence for a compatibility effect was decisive when the cue was in the relevant color, $BF_{10} > 100$, and the evidence for the null hypothesis when the cue was in the irrelevant color was substantial, BF_{01} = 6.94. The main effect of cue compatibility was not significant, $F(1,19) = 1.74$, $p = .20$, $\eta^2_p = .08$.

Accuracy. The results mirrored those of the RT analysis. The main effect of cue color relevance was significant, $F(1,19) = 7.75$, $p = .012$, $\eta^2_p = .28$, indicating that accuracy was lower when the cue color was relevant than when it was irrelevant. The interaction between this effect and distractor compatibility approached significance, $F(1,19) = 3.06$, $p = .10$, $\eta^2_p = .13$, but Bayesian analyses revealed that the evidence for this interaction was inconclusive, $BF_{10} = 0.62$. Follow-up analyses indicated that the effect of distractor compatibility approached significance when the cue color was relevant, M = 92.5% (SE = 0.5%) vs. M = 90.1% (SE = 1.2%), for compatible vs. incompatible trials, respectively, $F(1,19) = 3.96$, $p = .06$, $\eta^2_p = .16$, and was not significant when the cue color was irrelevant, M = 93.4% (SE = 0.8%) vs. M = 94.4% (SE = 0.5%), $F<1$. The evidence for a compatibility effect when the cue color was relevant was inconclusive, $BF_{10} = 0.78$, but the evidence in favor of the null hypothesis when the cue color was irrelevant was substantial, $BF_{01} = 20.16$. The main effect of cue compatibility was not significant, $F<1$.

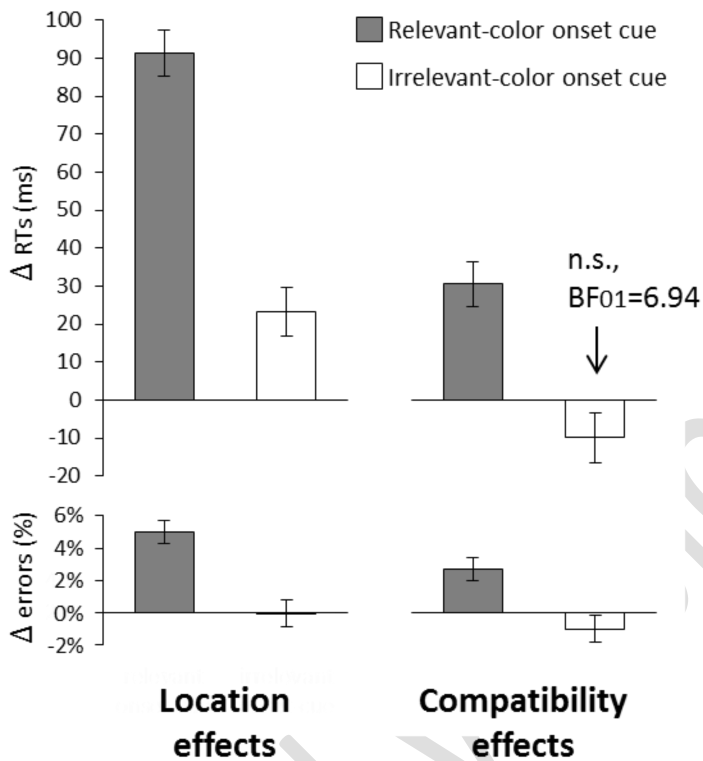

Figure 4. Location effects (different location minus same location) and distractor compatibility effects (incompatible distractor minus compatible distractor) on reaction times (top panels) and error rates (bottom panels) in Experiment 2, as a function of cue color relevance (relevant vs. irrelevant). Distractor compatibility effects were calculated on different-location cue trials. Error bars denote within-subject standard errors (Morey, 2008).

Discussion

We replicated the findings of Experiment 1: although the feature driving the compatibility effect was present at cue onset, irrelevant-color onsets produced no compatibility effects. This result suggests that attentional engagement is withheld following capture by events outside the attentional set.

In both experiments the relevant-color was always red, whereas the irrelevant-color was always white, such that cue color relevance was confounded with cue color. To address this problem, in Experiment 3, the target was red for half of the participants and grey for the other half, and for both groups, the cue color was either grey or red. We expected attentional engagement to occur only with relevant-color onsets, irrespective of cue color.

Experiment 3

Method

Participants

Participants were 20 (15 women) Tel-Aviv University undergraduate students who participated for course credit. The participants' mean age was 22.42 (*SD* = 1.77). All reported normal or corrected-to-normal visual acuity and color vision.

Apparatus, Stimuli, Design and Procedure

The apparatus, stimuli, design and procedure were similar to those of Experiment 1 except for the following changes. The background color was light grey (195,195,195). Half of the participants searched for a red target among two orange distractors and one pink distractor (as in Experiments 1 and 2), whereas the other half searched for a dark grey target (125,125,125) among two black distractors (0,0,0) and one white distractor (255,255,255). The cue was either red or dark grey. Cue color relevance was therefore determined by the cue color’s match with the target’s color (see Figure 5).

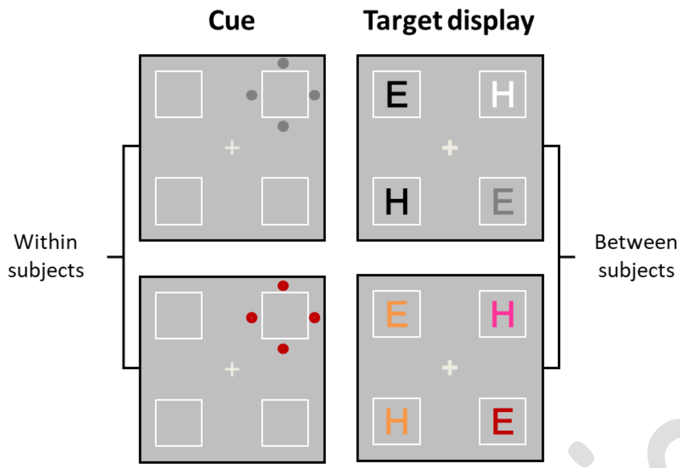

Figure 5. Sample target displays in Experiment 3 and the corresponding cue color conditions. Target color (left column: grey – upper panel or red – lower panel) was manipulated between-subjects and cue color (right column: grey – upper panel or red – lower panel) was manipulated within-subjects. Thus, the same cue color was relevant for half of the participants, and irrelevant for the other half.

Results

The data from one participant were excluded from further analysis because his accuracy was lower than the group's mean by more than 2.5 standard deviations (66% vs. M = 95.4%, SD = 3.2%). All reaction time (RT) analyses were conducted on correct trials. Outlier-RT trials (2.01% of all correct trials) were also excluded. Overall mean reaction times and accuracy rates are presented in Table 1.

Attentional Capture (location effect).

We conducted an ANOVA with target color (red vs. grey) as a between-subject variable, and with cue location relative to the target (same vs. different) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Mean cue location effects on RTs and error rates are presented in Figure 6.

Reaction times. The main effect of cue location was significant, $F(1,17) = 45.76$, $p < .0001$, $\eta^2_p = .73$. The interaction between cue color relevance and cue location was also significant, $F(1,17) = 18.81$, $p < .001$, $\eta^2_p = .54$, $BF_{10} > 100$, indicating that the relevant-color onset cue yielded a larger location effect than the irrelevant-color onset cue. Follow-up analyses revealed that both effects were significant, *M* = 592 ms (*SE* = 14) vs. *M* = 645 ms (*SE* = 14), for same- vs. different-location trials, respectively, $F(1,17) = 51.70$, $p < .0001$, $\eta^2_p = .75$, and *M* = 607 ms (*SE* = 13) vs. *M* = 624 ms (*SE* = 14), $F(1,17) = 8.51$, $p = .01$, $\eta^2_p = .33$, respectively. Bayesian analyses revealed that the evidence for a location effect was decisive in both the relevant- and the irrelevant-color onset cue conditions, both $BF_{10} > 100$. No other effect was significant, all *p*s > .10.

Accuracy. There was no significant effect (see figure 6).

Attentional Engagement (compatibility effect).

We conducted a repeated-measures ANOVA with target color (red vs. grey) as a between-subject variable, and with distractor compatibility (compatible vs. incompatible) and cue color relevance (relevant vs. irrelevant) as within-subject variables. Same-location trials were excluded from this analysis. Mean distractor compatibility effects on RTs and error rates are presented in Figure 6.

Reaction times. The main effects of cue color relevance and distractor compatibility were significant, $F(1,17) = 11.71$, $p = .003$, $\eta^2_p = .40$, and $F(1,17) = 4.99$, $p = .039$, $\eta^2_p = .23$, respectively, and so was the interaction between the two factors, $F(1,17) = 9.56$, $p = .007$, $\eta^2_p = .36$, $BF_{10} = 7.09$. Follow-up analyses revealed that the compatibility effect was significant when the cue color was relevant, *M* = 634 ms (*SE* = 5) vs. *M* = 651 ms (*SE* =

4), for compatible vs. incompatible trials, respectively, $F(1,17) = 16.10$, $p < .001$, $\eta^2_p = .48$, and non-significant when it was irrelevant, $M = 626$ ms ($SE = 6$) vs. $M = 623$ ms ($SE = 4$), $F < 1$, $\eta^2_p = .02$. The evidence for a compatibility effect was very strong for relevant-color onset cues, $BF_{10} = 59.56$, and the evidence for the null hypothesis was strong for irrelevant-color onset cues, $BF_{01} = 21.60$. No other effect was significant, all *p*s > .19. In particular the three-way interaction between target color, cue color relevance and distractor compatibility was not significant, $F < 1$. As is clear from Figure 6, when the cue was in the relevant color, the compatibility effect was significant both when the target was red and when it was grey, $F(1,17) = 5.55$, $p = .03$, $\eta^2_p = .25$, and $F(1,17) = 10.86$, $p = .004$, $\eta^2_p = .39$, respectively. In contrast, when the cue was in the irrelevant color, there was no compatibility effect when the target was grey (red cue) nor when it was red (grey cue), $F(1,17) = 1.06$, $p = .32$, $\eta^2_p = .02$, and $F < 1$, respectively.

Accuracy. There was no significant effect (see Figure 6).

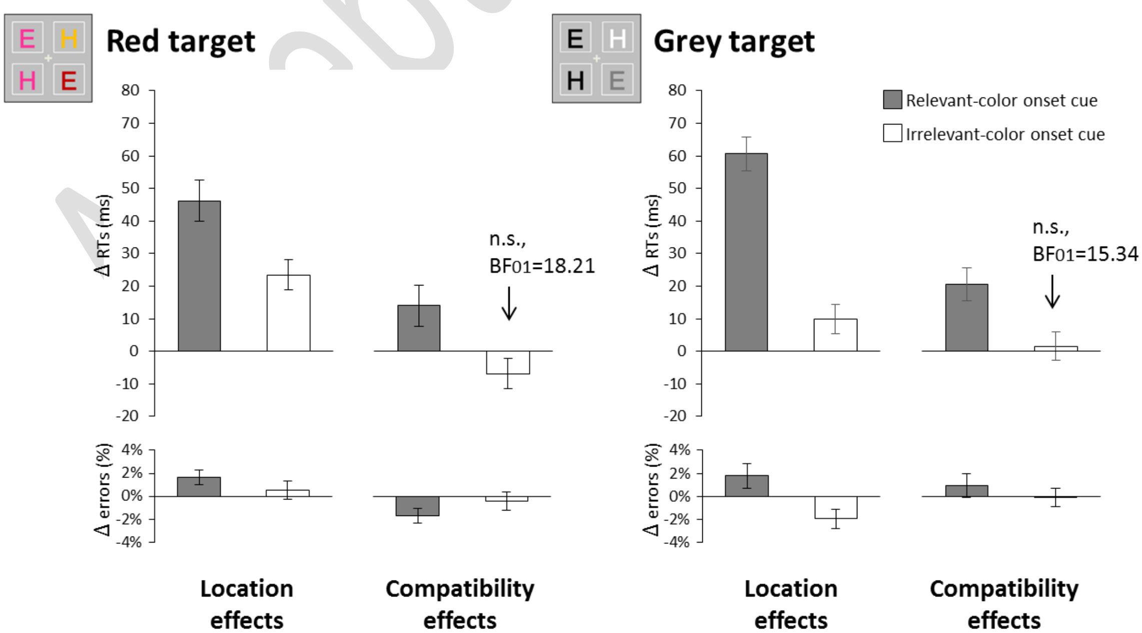

Figure 6. Location effects (different location minus same location) and compatibility effects (incompatible distractor minus compatible distractor) on reaction times (top panels) and error rates (bottom panels) in Experiment 3, as a function of target color (red vs. grey) and cue color relevance (relevant vs. irrelevant). Distractor compatibility effects were calculated on different-location cue trials. Error bars denote within-subject standard errors (Morey, 2008).

Combined analysis of Experiments 1-3: addressing potential scaling effects

The location effect indexing attentional capture was considerably larger with relevant- than with irrelevant-color onset cues in all experiments. This observation raises the possibility that relative to relevant-color onset cues, the compatibility effects associated with irrelevant-color onset cues may have been proportionally smaller and thus reflected a scaling effect. This account predicts that participants who show a large location effect in the irrelevant-color onset cue condition should also show a sizeable compatibility effect. We pooled the data of all experiments and conducted two analyses to test this prediction.

First, we divided the participants into four groups: a low- and a high-location benefit group (relative to the median location effect) for each cue-relevance condition. We then analyzed the compatibility effect of each group with a series of t-tests (see Table 2). The results showed that although the location effect was similar in magnitude in the high-benefit group for irrelevant-color onset cues and in the low-benefit group for relevant-color onset cues (M = 38 ms, SE = 4 vs. M = 39 ms, SE = 3 respectively), the compatibility effect was significant in the latter group, $t(29) = 3.52$, $p = .001$, $BF_{10} > 100$, and not in the former, $t(28) = 1.46$, $p = .15$, $BF_{01} = 4.27$. Second, to address the potential problems associated with dichotomizing continuous data, we also calculated the correlation between location effects and compatibility effects. This correlation was significant with relevant-color onset cues, $r(57) = .38$, $p = .003$, and not with irrelevant-color onset cues, $r(57) = .09$, $p = .50$.

Table 2. Mean location benefits and distractor compatibility effects as a function of cue-relevance condition (relevant vs. irrelevant) and location benefits group (small vs. large). *Note.* *p<.05, **p<.01, ***p<.001.

	Relevant-color onset cue		Irrelevant-color onset cue	
	Large location benefit group	Small location benefit group	Large location benefit group	Small location benefit group
Location benefit	106.9***	39.4***	38.0***	-1.29(ns)
Distractor compatibility	28.3**	15.3**	-8.6(ns)	-5.3(ns)

Discussion

Again, both irrelevant- and relevant-color onset cues captured attention, yet irrespective of their color, only the latter were associated with distractor compatibility effects. Although the location effect was smaller for irrelevant- than for relevant-color cues across experiments, two additional findings suggest that the null compatibility effect following capture by irrelevant-color onsets did not result from a scaling effect: (1) a positive correlation between location and compatibility effects was observed with relevant- but not with irrelevant-color onsets, suggesting that attentional capture by an onset increased the probability that attention was also engaged to its location only when this object matched the attentional set; and (2) even individuals with large location benefits for irrelevant-color onsets showed no compatibility effects. We conclude that attentional engagement was not merely weaker in the irrelevant-color onset condition, but was altogether withheld, and that attentional engagement is contingent on goal-driven capture.

General Discussion

We examined whether shifting attention to a location necessarily entails that all features at that location are processed. Using a spatial cueing paradigm, we found an onset cue to capture attention when it did not share the target's color, but more so when it did, suggesting that both stimulus-driven and goal-driven factors determine attentional priority (e.g., Awh et al., 2012). Yet, compatibility effects, which are diagnostic of attentional engagement, were observed with relevant-color and not with irrelevant-color onset cues. These findings indicate that stimulus- and goal-driven capture have qualitatively different consequences and that shifts of attention are not necessarily followed by attentional engagement.

Note that the target color was held constant, such that relevant-color onsets always matched the previous target's color, whereas irrelevant-color onsets never did. Thus, the dissociation on attentional engagement between the two cue types may result only (or also) from such selection history differences (see Folk & Remington, 2008, for a similar potential alternative account of contingent capture). However, while priming from previously selected features speeds attentional engagement (e.g., Biderman, Biderman, Zivony & Lamy, 2017; Yashar & Lamy, 2010), it cannot *determine* whether attentional engagement will occur: when a relevant-color object captures attention, processing properties other than its color (i.e., attentional engagement) is necessary for deciding whether this object is the target or a distractor. Therefore, attentional engagement will occur whenever the task-relevant color is detected and cannot depend solely on whether this color was recently selected.

The present findings have important implications for models of spatial attention, most of which assume that attentional engagement necessarily follows a shift of attention towards a prioritized stimulus in healthy individuals (see Posner & Petersen, 1990, for evidence that brain damage can selectively impair attentional shifts and engagement). These models typically relied on paradigms in which attention is voluntarily moved for the purpose of extracting information from prioritized locations. Here, we used an involuntary attentional capture paradigm, in which it is counterproductive to engage attention to the salient distractor. Under these conditions, we found "shallow" attentional shifts, during which attention is moved but not engaged, to occur following stimulus-driven capture.

What purpose might shallow shifts of attention serve and what processes are speeded following such shifts, leading to location effects? We suggest that when an object elicits an attentional shift, basic features such as its location or color, are rapidly extracted, a process that is resource-free (Lamy, Alon, Carmel & Shalev, 2015; Zivony & Lamy, 2016b) and occurs during feed-forward processing (Lamme & Roelfsema, 2000; Töllner, Rangelov, & Müller, 2012). When this information suffices to conclude that the attended object is of no interest, the shift is not followed by attentional engagement. Because aligning the spatial attention must occur before attention is engaged, performance is nevertheless better when the target appears at the shift's location – although the measured benefit can be small (e.g., Gaspelin et al., 2016). When potentially relevant information is detected at the location of the shift, extraction of higher-level information (i.e., attentional engagement) is initiated and results in recurrent processing that is more resource-demanding.

Our findings are consistent with a "camera" metaphor of attention (Zivony & Lamy, 2016b): one can align the lens (shifting attention) without pressing the shutter-button (engaging attention). Given that engagement in a non-target incurs a higher cost than merely shifting attention towards it, stricter boundary conditions for attentional engagement (which allow shallow shifts of attention) are a functional and desired feature of our perceptual system.

References

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in cognitive sciences*, *16*(8), 437-443.

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

Biderman, D., Biderman, N., Zivony, A., & Lamy, D. (2017). Contingent capture is weakened in search for multiple features from different dimensions. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(12), 1974-1992.

Carmel, T., & Lamy, D. (2014). The same-location cost is unrelated to attentional settings: an object-updating account. *Journal of experimental psychology: human perception and performance*, *40*(4), 1465-1478.

Dienes, Z., & McLatchie, N. (2017). Four reasons to prefer Bayesian over orthodox statistical analyses. *Psychonomic Bulletin and Review*.

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of cognitive neuroscience*, *20*(8), 1423-1433.

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*(1), 143-149.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2013). G* Power Version 3.1. 7 [computer software]. Uiversität Kiel, Germany.

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*(3), 847-858.

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

Folk, C. L., & Remington, R. W. (2008). Bottom-up priming of top-down attentional control settings. *Visual Cognition*, *16*(2-3), 215-231.

Folk, C. L., & Remington, R. W. (2015). Unexpected abrupt onsets can override a top-down set for color. *Journal of experimental psychology: human perception and performance*, *41*(4), 1153-1165.

Folk, C. L., Ester, E. F., & Troemel, K. (2009). How to keep attention from straying: Get engaged! *Psychonomic Bulletin & Review*, *16*(1), 127-132.

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.

Gaspelin, N., Ruthruff, E., & Lien, M. C. (2016). The problem of latent attentional capture: Easy visual search conceals capture by task-irrelevant abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(8), 1104-1120.

Goldfarb, L., & Treisman, A. (2010). Are some features easier to bind than others? The congruency effect. *Psychological science*, *21*(5), 676-681.

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). New York, NY:Oxford University Press.

Lamme, V. A., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in neurosciences*, *23*(11), 571-579.

Lamy, D., Alon, L., Carmel, T., & Shalev, N. (2015). The role of conscious perception in attentional capture and object-file updating. *Psychological science*, *26*(1), 48-57.

Lamy, D., Leber, A. B., & Egeth, H. E. (2012). Selective Attention. In A.F. Healy & R.W. Proctor (Eds.), *Experimental Psychology*. Volume 4 in I.B. Weiner (Editor-in-Chief), Handbook of Psychology, New York: Wiley.

Lamy, D., Leber, A., & Egeth, H. E. (2004). Effects of Task Relevance and Stimulus-Driven Salience in Feature-Search Mode. *Journal of Experimental Psychology: Human Perception and Performance, 30*(6), 1019-1031.

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & cognition*, *22*(6), 657-672.

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

Morey, R. D., & Rouder, J. N. (2015). BayesFactor 0.9. 12-2. Comprehensive R Archive Network.

Nieuwenstein, M. R., Chun, M. M., van der Lubbe, R. H., & Hooge, I. T. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1463-1475.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual review of neuroscience*, *13*(1), 25-42.

Posner, M. I., Rueda, M. R. & Kanske, P. (2007). Probing the mechanisms of attention. In J. T. Cacioppo, J. G. Tassinary & G. G. Berntson (eds), *Handbook of*

Psychophysiology, Third Edition. Cambridge U.K.: Cambridge University Press (pp 410-432).

Schreij, D., Owens, C., & Theeuwes, J. (2008). Abrupt onsets capture attention independent of top-down control settings. *Perception & Psychophysics*, *70*(2), 208-218.

Sperling, G., & Weichselgartner, E. (1995). Episodic theory of the dynamics of spatial attention. *Psychological review*, 102(3), 503-532.

Theeuwes, J. (2010). Top–down and bottom–up control of visual selection. *Acta psychologica*, *135*(2), 77-99.

Theeuwes, J., Atchley, P., & Kramer, A. F. (2000). On the time course of top-down and bottom-up control of visual attention. *Control of cognitive processes: Attention and performance XVIII*, 105-124.

Töllner T. Rangelov D. Müller H. J. (2012). How the speed of motor-response decisions, but not focal-attentional selection, differs as a function of task set and target prevalence. *Proceedings of the National Academy of Sciences, USA, 109*, E1990–E1999.

Winer, B. J. (1962). *Statistical principles in experimental design*. New York: McGraw-Hill, 1971.

Wolfe, J. M. (2007). Guided search 4.0. *Integrated models of cognitive systems*, 99-119.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 601-621

Yashar, A. & Lamy, D. (2010). Intertrial repetition facilitates selection in time: Common mechanisms underlie spatial and temporal search. *Psychological Science*, *23*, 243-251.

Zivony, A. & Lamy, D. (2016a). The role of dimension relevance in features' access to response-selection mechanisms. *Journal of experimental psychology: Human perception and performance*, *42,* 11, 1873-1885.

Zivony, A. & Lamy, D. (2016b). Attentional capture and engagement during the attentional blink: A "camera" metaphor of attention. *Journal of experimental psychology: Human perception and performance*, *42,* 11, 1886-1902.

Author's note

Correspondence should be addressed to Alon Zivony (alonzivony@gmail.com). Support was provided by the Israel Science Foundation (ISF) grant no.1286/16 to Dominique Lamy.

Footnotes

1.It has been suggested that features of previously attended items are also prioritized (Maljkovic & Nakayama, 1992) regardless of the current search goals. The implications of such selection history effects for our study are considered in the General Discussion.

2.We do not use the term “attentional selection”, because it is often used more broadly, to describe both pre-attentive filtering, which precedes attentional shifting and attentional enhancement, which follows it (e.g., Bacon & Egeth, 1994).

3.The effect was smaller in our study than in Gaspelin et al.’s (2016), 14 ms vs. 30 ms, probably because in order to reduce the probability that participants made eye movements, we used smaller display sizes (3.66°x3.66° vs. 10°x10°).