The attentional blink unveils the interplay between conscious perception, spatial attention and working memory encoding

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Abstract

The attentional blink refers to the deficit in reporting the second of 2 targets (T2), when it appears within 600ms after the first (T1). We examined which aspect of T1 processing triggers the AB. In three experiments, we disentangled the roles of spatial attention, conscious perception and working memory (WM) in causing the blink. We show that while allocating spatial attention to T1 is neither necessary nor sufficient for eliciting a blink, consciously perceiving it is necessary but not sufficient. When T1 was task irrelevant, consciously perceiving it triggered a blink only when it matched the attentional set for T2. We conclude that consciously perceiving a task-relevant event causes the blink, possibly because it triggers encoding of this event into WM. We discuss the implications of these findings for the relationship between spatial attention, conscious perception and WM, as well as for the distinction between access and phenomenal consciousness.

Keywords: Conscious perception; attentional blink; attentional capture; spatial attention; awareness; consciousness; working memory; fragile memory; phenomenal consciousness

Despite the impressive abilities of our cognitive system, attention research has consistently revealed the surprising finding that we can process only one or at most just a few objects within the same time interval. One consequence of this limitation is that when two objects enter our visual system in close temporal proximity, processing the first object is associated with a cost at processing the second object.

In the lab, this phenomenon has been intensively investigated using a paradigm known as the attentional blink (AB) (see Dux & Marois, 2009; Martens & Wyble, 2010 for reviews). In a typical AB study, two successive targets (T1 and T2) are embedded within a rapid serial visual presentation (RSVP) stream of distractors. Identification of the second target (T2) is most impaired when this target appears 200–300ms after T1 (i.e., T1–T2 lags 2 and 3) and gradually returns to baseline after 600ms (i.e., lag 6 and above). The blink is often greatly reduced when T2 immediately follows T1 and appears at the same location, an effect known as lag-1 sparing (Chun & Potter, 1995).

In a recent paper (Ophir, Sherman & Lamy, 2018), we attempted to clarify what aspects of T1 processing generate the attentional blink. Specifically, our goal was to disentangle the roles of spatial attention to and conscious report of the first target in eliciting the blink. We were mainly motivated by two sets of findings.

On the one hand, the results from many studies showed that a blink can be observed when T1 is replaced with a distractor that is not associated with any task and can thus be ignored (e.g., Arnell, Killman & Fijavz, 2007; Barnard et al., 2005; Folk, Leber & Egeth, 2008; Leblanc & Jolicoeur, 2005; Wyble, Folk & Potter, 2013; Zivony & Lamy, 2016). For instance, Folk, et al. (2008) presented their participants with a central RSVP of letters surrounded by a square and asked them to search for a target defined by its known color. On various lags prior to the target, a brief color change in the surrounding square, the distractor, occurred. Although the distractor was not associated with any task, it produced a blink, but only if it shared the target's color (but see Folk et al., 2002, Exp.2). It should be noted that in general, the objective of these studies was to determine the conditions under which involuntary capture of attention occurs. The blink was used only as an indicator of such capture, based on the assumption that the decrement in processing the second target during the blink resulted from attentional selection of the first target (e.g., Folk et al., 2002). For the present purposes, however, such findings suggest that attention allocation may be a sufficient condition for the blink to occur.

On the other hand, Nieuwenstein et al. (2009) showed that when the first target (T1) is masked and liminal, it elicits a blink when it is consciously perceived, but not when it is missed. Nieuwenstein et al. (2009) concluded that conscious perception of T1 is a necessary and sufficient condition for the blink to occur.

In order to clarify the respective roles of attention and conscious perception, we designed a variant of the AB paradigm in which the stimuli were presented in two RSVP streams and T1 was replaced with a distractor (henceforth, the "cue"). This cue was liminal, such that it could be either entirely missed or consciously perceived at different degrees of clarity. On each trial, participants had to identify T2 (henceforth, the "target"), which appeared at various lags following the cue, and then report the subjective visibility of the cue. We could thus measure the blink when the cue was consciously perceived and when it was not. In addition, because the target could appear either in the same stream as the cue or in the alternative stream, we could measure attentional capture by comparing target identification performance between these two conditions; based on the contingent capture theory, we expected cues to capture attention when they shared the target color and not when they did not (e.g., Folk, Remington & Johnston, 1992; Folk et al., 2002). The resulting conditions (the cue is consciously perceived vs. missed X the cue benefits from attentional processing vs. does not) allowed us to disentangle the roles of attention and conscious perception in eliciting the blink.

The results of our study (Ophir et al., 2018) suggested that conscious perception is a necessary condition for the blink, whereas deploying attention to the cue is neither necessary nor sufficient. These conclusions relied on the findings that (1) the blink was observed whenever the cue was consciously perceived, both when it captured attention and when it did not (although the blink was more pronounced when it did capture attention) and (2) a cue that captured attention but was not consciously perceived did not produce a blink.

In recent years, a hitherto neglected problem in the study of conscious perception has received increasing consideration: conscious perception per se is difficult to isolate from its consequences (Aru, Bachman, Singer & Melloni, 2012; De Graaf, Hsieh & Sack, 2012). In particular, it is difficult to disentangle it from processes related to report (e.g., Tsuchiya, Wilke, Frässle, & Lamme, 2015; Pitts, Martinez & Hillyard., 2012; Schlicht, 2018; Phillips, 2018). In Ophir et al.'s (2018) study, the cue was associated with a task: participants had to report its subjective visibility. Thus, conscious perception of the cue was confounded with encoding of the cue representation in working memory (WM) for report. Although many models of the attentional blink posit that the blink occurs because the process of encoding T1 (here, the cue) into working memory must be completed before processing of T2 can proceed (e.g., Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1999; Jolicoeur, 1999; Vogel, Luck & Shapiro, 1998), direct evidence for this claim is still lacking, because conscious perception and encoding into working memory co-occurred in most AB studies. Therefore, the objective of the present study was to disentangle the roles of conscious perception and working memory in eliciting the blink.

In order to achieve this goal, we relied on the sustained inattentional blindness paradigm pioneered by Pitts et al. (2012), which builds on Mack and Rock's (1998) seminal inattentional blindness studies. This paradigm includes three phases. In the first phase, subjects perform a demanding filler task on a display that also contains the critical stimulus, which the subjects do not expect. At the end of this first phase (henceforth, "inattentional blindness" phase), the subjects are queried about their awareness of this stimulus and typically, about half of all them report being completely unaware of the critical stimulus. The second phase is identical to the first one, except that the subjects are assumed to be aware of the critical stimulus, because of the questions asked at the end of the first phase. That they are indeed aware of it is verified using similar questions at the end of the second phase. Crucially, during the second phase (henceforth, "no-report" phase), because no task is associated with the critical stimulus, subjects do not need to access information about this stimulus for immediate perceptual report. Finally, in the third phase of the experiment (henceforth, "report" phase), subjects are no longer required to perform the filler task and instead only perform a discrimination task in which the critical stimulus becomes task-relevant.

Pitts and colleagues (e.g., Pitts et al., 2012; Shafto & Pitts, 2015) were mainly interested in isolating the neural correlates of conscious perception vs. post-perceptual (report-related) processes, which they could achieve by contrasting the neural activity associated with the critical stimulus in the first vs. the second phase, and in the second vs. the third phase, respectively. Here, we used the same rationale in order to determine whether conscious perception of the cue per se, or encoding the cue into working memory to report its visibility, elicits the blink. To do that, we applied the sustained inattentional blindness procedure (Pitts et al., 2012) to Ophir et al.'s (2018) task.

In the inattentional-blindness phase, subjects had to identify the color-defined target that appeared in one of the two streams and were not informed of the existence of the cue. They were queried about their awareness of the cue at the end of this phase. The "no-report" phase was identical, except that subjects were now assumed to be aware of the cue, as a result of the intervening questions, which was verified at the end of this phase. The report phase was a replication of Ophir et al.'s (2018) study: participants first reported the identity of the target (as in the previous two phases) and then rated the subjective visibility of the cue. As in Ophir et al.'s (2018) study, we again manipulated the match between the cue's and target's colors.

We expected to replicate previous findings. (1) In line with the contingent capture account (e.g., Folk et al., 2002) the cue should capture attention, that is, performance should be higher when the target appears in the same stream as the cue than in the alternative stream, only when it shares the target's color (Experiment 1), and not when it does not (Experiment 2). (2) Attentional capture by the target-color cue should be independent of whether or not the cue was consciously perceived (Lamy et al., 2015; Ophir et al., 2018; Travis, Dux & Mattingley, 2018). (3) Allocating attention to the first event should not suffice to elicit an attentional blink: no blink should be observed in either the inattentional phase or unaware-cue trials of the report phase, irrespective of whether or not the cue captures attention.

Crucially, with this design unlike in previous experiments, we could assess the role of conscious perception of the cue, uncontaminated by report of the cue: If conscious perception is sufficient for the blink, the lag-dependent impairment should emerge in the no-report phase and not in the inattentional-blindness phase. Conversely, we could assess the role of reporting the cue, uncontaminated by conscious perception: if report, which entails encoding of the cue in working memory, is necessary for the blink, the lag-dependent impairment should emerge only in the report phase and not in the no-report phase.

Experiment 1

Method

Participants

Because the distribution of visibility ratings using PAS typically varies widely among participants, we used an analytic tool that is well suited to the treatment of unbalanced data, namely, linear mixed-effect models (see Boisgontier & Cheval, 2016 for a detailed argumentation). In addition, because we used accuracy as our dependent measure, the appropriate model was the generalized linear mixed-effects model (GLMM; Jaeger, 2008). However, we are not aware of any existing method for estimating power with GLMM. In order to determine the sample size in the present study, we therefore relied on our previous study (Ophir et al., 2018), where the critical finding - a significant interaction between lag and visibility - was found in three different experiments using 16 participants each. Here, we increased this number to 20 in each experiment. The participants were Tel-Aviv University undergraduate students (mean age=23.1 years, SD=3.41, 16 females, 4 males) who participated in the experiment for course credit. All reported normal or corrected-to-normal visual acuity and normal color vision. All protocols were approved by Tel Aviv University ethics committee.

Apparatus

Stimuli were presented on an LCD monitor (23-in. Samsung SyncMaster) with a 1,920x1,080-pixel resolution and 120-Hz refresh rate. Responses were collected via the computer keyboard. Viewing distance was set at 50 cm from the monitor. The experiment was conducted in a dimly lit room.

Stimuli

A sample trial is depicted in Figure 1. On each trial, a fixation frame, consisting of a "+" sign (0.2º×0.2º) in the center of the screen appeared for 330ms and was followed by two RSVP streams presented as a sequence of 20 frames. Each frame appeared for 58ms and was separated from the next frame by a 50ms blank screen, yielding an SOA of 108ms. The RSVP streams were followed by a response display consisting of a central question mark.

Each frame consisted of two letters (drawn in bold Courier New font, 1.4º in height), presented to the left and right of fixation at a center-to center distance of 2.1°. Each letter was enclosed in a gray outline circle (5-pixel thick and subtending 1.2º in radius, RGB = 158, 158, 158). The two letters in any given frame were randomly drawn from the English alphabet (excluding the letters I, O, X, T and Z), with the constraints that any given letter could appear only once in each of the streams, and letters presented simultaneously in the two streams or in temporally contiguous frames were never the same.

The target letter was defined by its color. For half of the subjects it was red (RGB = 190, 30, 30) and for the other half it was green (RGB = 20, 220, 20). The remaining (non-target) letters in the streams were randomly blue (RGB = 106, 106, 255), purple (RGB = 140, 0, 175) or dark yellow (RGB = 212, 169, 47). All stimuli were presented against a black background.

On each trial the target appeared randomly in the ninth, eleventh or thirteenth position in one of the two streams. A cue appeared at lag 1, 3 or 7 prior to the target. On cue-present trials (85% of the trials), one of the two enclosing circles became colored (the cue) during the last 25ms of the frame duration. On cue-absent trials (15% of the trials), both circles remained gray throughout the frame duration. The cue was made liminal by presenting it very briefly and using the gray circles in the frames that preceded and followed it as forward and backward masks, respectively. The cue and target were always in the exact same color: red for the red-target group, and green for the green-target group.

Procedure and design

The experiment consisted of three phases. During the first phase or "inattentional blindness" (IB) phase, participants were not informed of the existence of the cue. They had to identify the target letter as accurately as possible and with no time pressure, by typing the corresponding key on a standard keyboard with their right hands. They were encouraged to guess if unable to identify the target. A blank interval of 450ms followed the response before a new trial started. No feedback was given on accuracy. Upon completion of this phase, participants were administered a questionnaire including four questions: 1. Did you notice anything on the screen that was not mentioned in the instructions? 2. Did you see any stimulus in the target color apart from the target letter? 3. Did you notice that one of the circles surrounding the letters changed its color briefly? 4. In case you saw anything in the target color besides the target letter, on what percentage of the trials, approximately, did you see it? Following this phase, participants were shown an image of the cue as well as a slow-motion version of a typical trial, and asked whether they recognized having seen the cue during the previous phase. They were then told that this colored circle would be present again on some of the trials in the next phase and explicitly informed that it would not be predictive of the target, either temporally or spatially, and was therefore irrelevant to the task.

The second and third phases were the “report” phase and the “no-report” phase, and their order was counterbalanced between participants. The no-report phase was similar to the IB phase, except that it was administered after participants had been notified of the presence of the cue. After completion of this phase, participants were only asked the fourth question.

The report phase was similar to the no-report phase except for the following changes. Participants were required to provide two responses on each trial: first, they had to identify the target letter as in the other two phases. Immediately following this response, two question marks prompted them to report on the clarity of their subjective visual experience of a red (or green) circle preceding the target, on a scale ranging from 0 (not visible at all) to 3 (clearly visible). The awareness ratings were provided by pressing the relevant digit on the keyboard number pad with their left hands. A new trial began 500ms after the second response. Throughout each trial, participants were instructed to focus their gaze on the fixation cross.

In each phase, conditions of cue-target lag (1, 3 or 7) and cue-target location (same vs. different) were equiprobable. All conditions were randomly mixed. Each phase was divided into 3 blocks, and participants were allowed a short break between them. Participants completed 159 trials in the IB-phase as well as in the no-report phase, and 477 trials in the report-phase. Thus, they completed 795 trials in total.

Statistical analyses

Statistical software. The experiments codes, data and analyses are available at https://osf.io/gs4ky/. All statistical analyses were carried out using "R" statistical software (version 3.3.2, R Core Team, 2015) and RStudio version 1.0.136 (http://www.rstud io.com). The p values for the models were calculated using the Anova function in the Car package (vers. 2.0–25), and the p values for the paired comparisons were calculated using the glht function in the multcomp package (vers. 1.4.6). Note that when visibility ratings were used, a cell could be empty for a given subject (if, for instance, this subject did not use any 3-visibility rating for a given condition). Therefore, degrees of freedom may vary across effects.

The blink and lag 1 sparing. Because blink and lag 1 sparing had different theoretical implications for the present purposes, the two effects were examined in separate planned comparisons. We assessed the blink by comparing performance on lag 3 vs. 7 across cue-target locations. We assessed lag 1 sparing by comparing performance on lag 1 vs. 3, separately for the same- and for the different-location conditions, based on the finding that lag 1 sparing is location specific (Visser et al., 1999). Note, however, that lag 1 sparing was inevitably confounded with attentional capture here, because both effects should manifest as enhanced performance when the cue and target are presented in the same location at lag 1.

Attentional capture. To verify that the target-color cue captured attention, we conducted planned comparisons between same- and different-location trials for both the IB and no-report phases, and separately for unaware- and aware cue trials in the report phase. We restricted this analysis to lag 1 because longer lags may give participants enough time to disengage their attention from the cue location.

Showing that the cue did not benefit from spatial attention when it did not share the target's color (Exps. 2 & 3) was of high theoretical importance. We therefore used Bayesian statistics (BayesFactor package with the default parameter settings and the BAS package with the uniform prior) to assess the likelihood of the null hypothesis. We compared the null model (which included only subjects as a random effect) to a model also including cue-target location as a fixed effect. We report separate BF_{01} for aware-cue and unaware-cue trials. Following Kass and Raftery (1995; see also Jeffreys, 1998) we consider a BF of less than 3 as "weak" evidence, a BF between 3 and 10 as "substantial" evidence, a BF between 10 and 100 as "strong" evidence, and a BF greater than 100 as "decisive".

Distinction between aware vs. unaware trials in the report phase. As in Ophir et al.'s (2018) study, we verified that visibility ratings corresponded to different perceptual states rather than being randomly distributed, by testing their predictive value as to whether the cue was present or absent. Accordingly, in Experiments 1 and 2, given that the proportion of cue-present trials was 85%, if a visibility rating indicating some subjective awareness (all ratings except 0) is predictive of cue presence, more than 85% of the trials receiving this visibility rating should be cue-present trials. We thus compared the random distribution (85%, 15%) and the observed rating distributions in a series of binomial tests on the raw number of ratings for each visibility rating separately for each experiment.

Full statistical model in the report phase. As is to be expected when using multi-point scales for subjective reports, different participants used each visibility rating on a different proportion of the trials. To overcome the resulting distortions and to avoid excluding participants based on considerations of balanced visibility rating distribution we used a generalized linear mixed-effects model (GLMM) to analyze the proportion of correct target letter identifications. Cue-absent trials were excluded from all analyses. The data was fitted by likelihood ratio test using the glme function and a logit link function (Jaeger, 2008) with cue-target location (same vs. different), cue-target lag (1 vs. 3 vs. 7) and cue visibility (unaware vs. aware, in the report phase only) as fixed factors, and subject-specific intercept as a random factor. Preliminary analyses revealed significant effects involving color group (red target vs. green target), target letter (A-Z, excluding I, O, Q), and phase order (between the report-phase and the no-report phase of Experiments 1 and 2). However, including these factors in the analyses did not alter the pattern of results. Thus, target letter, color group and phase order were added to the model as random effects. The full resulting model was expressed as: glmer(accuracy ~ 1 + lag + visibility + location + lag *visibility + lag*location + visibility*location + lag*visibility*location + (1|subject) + (1|ColorGroup) + (1|TargetLetter) + (1|PhaseOrder), family = binomial).

For the sake of conciseness, in the results section we report only the relevant effects, as described above. All the significant effects of the full model are reported in the appendix.

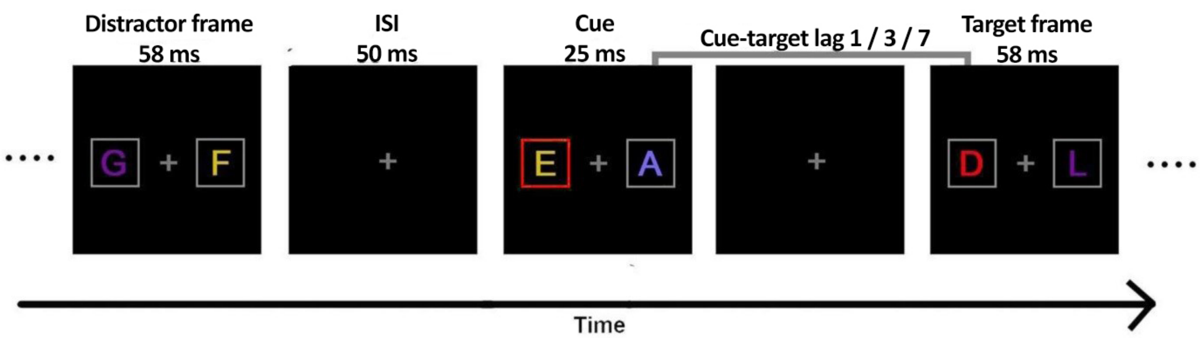

Figure 1. Sample trial sequence in Experiments 1 and 2. Each trial consisted of the successive presentation of heterogeneously colored letters enclosed in gray squares. The target was defined by a known color. The cue appeared either 1, 3 or 7 frames prior to the target, and consisted of a color

change in one of the frames for the last 25 ms of its presentation. The color of the cue was either the same as the target color (Experiment 1) or different (Experiment 2). This example corresponds to the lag 1, cue present, same-location condition for the red target group in Experiment 1. Each experiment was divided into 3 phases with identical stimuli. In the inattentional blindness and no-report phases, participants made an unspeeded response to the target's identity (here, the red D). In the report phase, after identifying the target, participants were also asked to rate their subjective perception of the color cue on a scale ranging from 0 (not visible at all) to 3 (clearly visible).

Results

Inattentional-blindness phase

Participants were split into two groups (noticers vs. non-noticers) based on their responses to the surprise awareness questionnaire administered at the end of the inattentional blindness phase. As is clear from table 1 (see appendix) responses were highly consistent across questions. Because our hypothesis was that conscious *detection* of the cue elicits the blink, any subject who responded positively to any of the questions was considered to be aware of the cue and labeled as "noticer". Accordingly, eleven out of the 20 participants were noticers. The remaining 9 participants were labeled as non-noticers: they provided no indication that they ever consciously experienced the cue, as they responded negatively to all four questions and did not change their minds after being shown an image of the cue. The following analyses were conducted with noticers and non-noticers as separate groups.

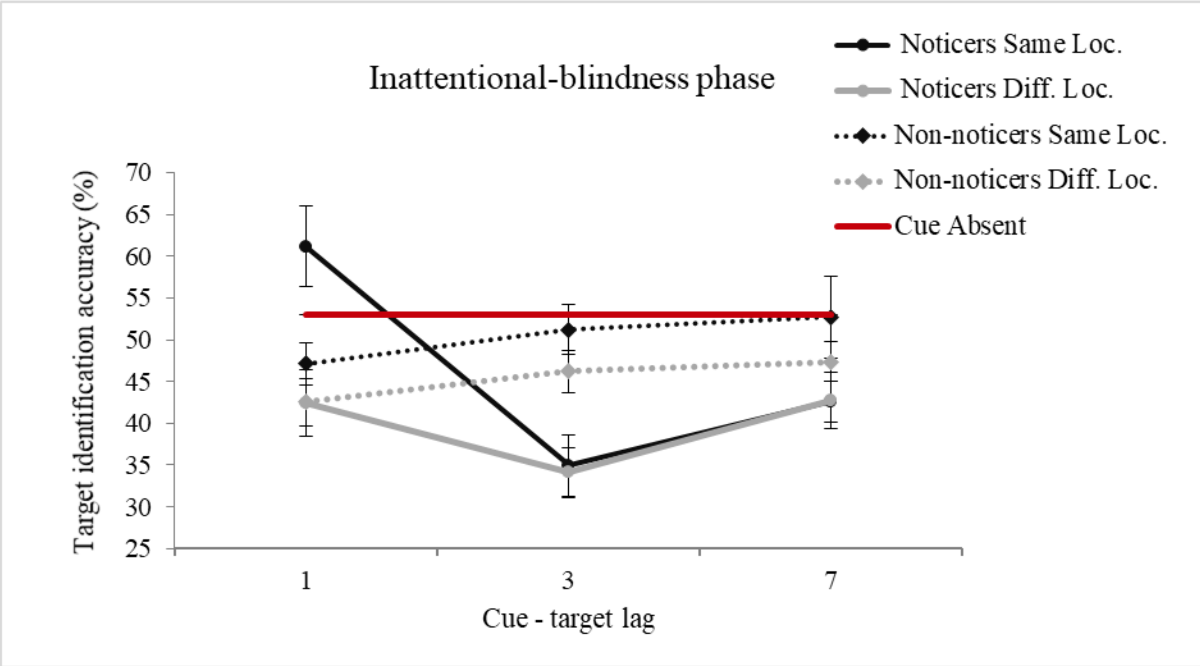

Figure 2. Mean target identification accuracy rates (in percentages, model-based) in the IB phase of Experiment 1 by conditions of cue-target lag (1, 3 or 7), cue-target location (same vs. different) and cue visibility (noticers vs. non-noticers). Performance on cue-absent trials is indicated by the red horizontal line. Error bars represent within-participants standard errors.

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 2. For the noticers group, there was a significant blink: performance was poorer at lag 3 vs. 7 across locations, 34.5% vs. 42.6%, respectively, $Z=2.41$, $p=.007$. The lag 1 sparing effect was also significant: performance was better at lag 1 vs. 3, both when the cue and target were presented at the same location, 61.1% vs. 34.9%, respectively, $Z= 5.31$, $p<.001$, and when they were not, 42.3% vs. 34.1%, respectively, $Z=1.74$, $p=.04$, although it was clearly smaller in the latter condition. For the non-noticers group, there was neither a blink nor lag-1 sparing, all $Zs<1$.

Attentional capture. For the lag-1 condition, accuracy was higher in the same- than in the different-location condition, 61.1% vs. 42.3%, respectively, $Z = 3.84$, $p < .001$, confirming that the target-color cue captured attention in the noticers group. However, counter to our predictions, no such effect was observed in the non-noticers group, 47.1% vs. 42.5%, for same- vs. different-location trials respectively, Z<1, although the numerical trend was in the expected direction.

No-report phase

When queried at the end of the no-report phase, 19 participants reported being aware of the cue on at least a portion of the trials (mean=31.3%, SD=25.3, range 5% - 95%), and one participant reported having no awareness of the cue. However, since excluding this participant's data did not change any of the findings reported below, these data were included in the analyses.

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 3. In line with our predictions, there was a significant blink: performance was poorer at lag 3 vs. 7 across locations, 44.4% vs. 49.9%, respectively, Z=2.14, p=.016. Lag 1 sparing was significant in the same-location condition, with better performance on lag 1 vs. 3, 55.5% vs. 42.9%, respectively, Z=3.48, p<.001, and not in the different-location condition, 45.3% vs. 46%, respectively, Z<1.

Attentional capture. For the lag-1 condition, accuracy was higher on same- than on different-location trials, 55.5% vs. 45.3%, respectively, Z = 2.99, p < .001, confirming that the cue captured attention.

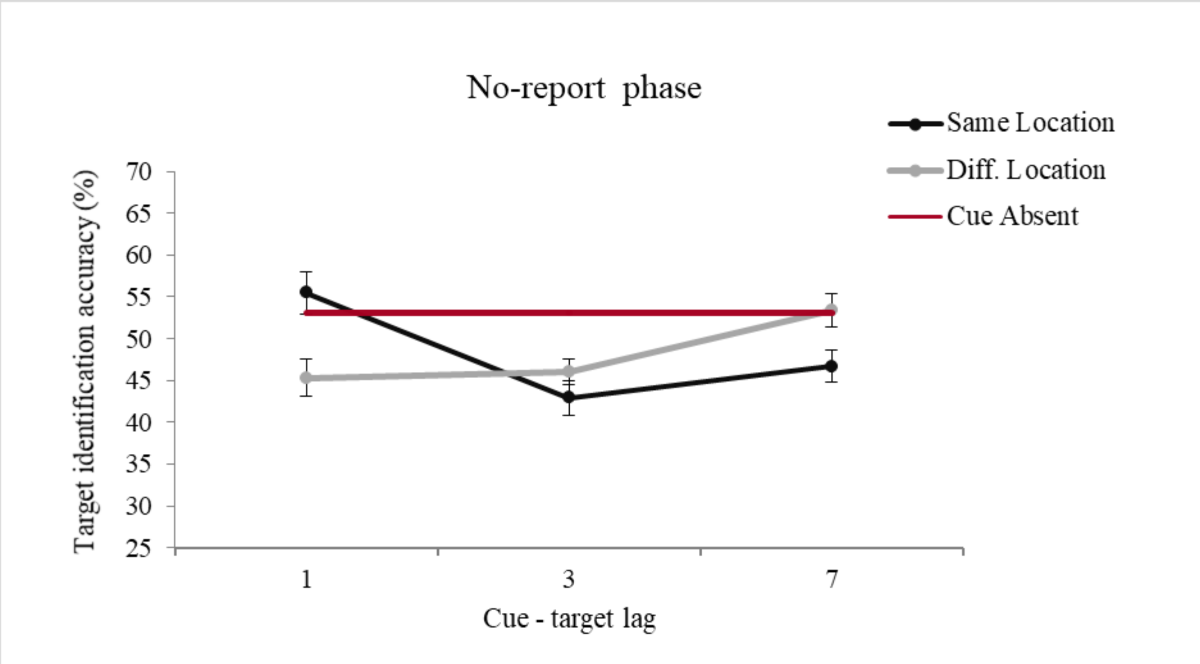

Figure 3. Mean target identification accuracy rates (in percentages, model based) in the no-report phase of Experiment 1 by conditions of cue-target lag (1, 3 or 7) and cue-target location (same vs. different). Performance on cue-absent trials in indicated by the red horizontal line. Error bars represent within-participants standard errors.

Report phase

Visibility ratings. The participants rated cue visibility to be 0, 1, 2 and 3 on 47%, 20%, 14%, and 19% of the trials, respectively, on cue-present trials and on 77%, 14%, 6% and 3%, respectively, on cue-absent trials. A series of binomial tests revealed that all visibility ratings above 0 were predictive of cue presence, p(1568/1756,85%) <.0001, p(1101/1172,85%) < .0001, and p(1477/1518,85%) <.0001, for ratings of 1, 2 and 3, respectively. Therefore, aware-cue trials included trials with a visibility rating of 1, 2 or 3 and unaware-cue trials included only 0-visibility trials.

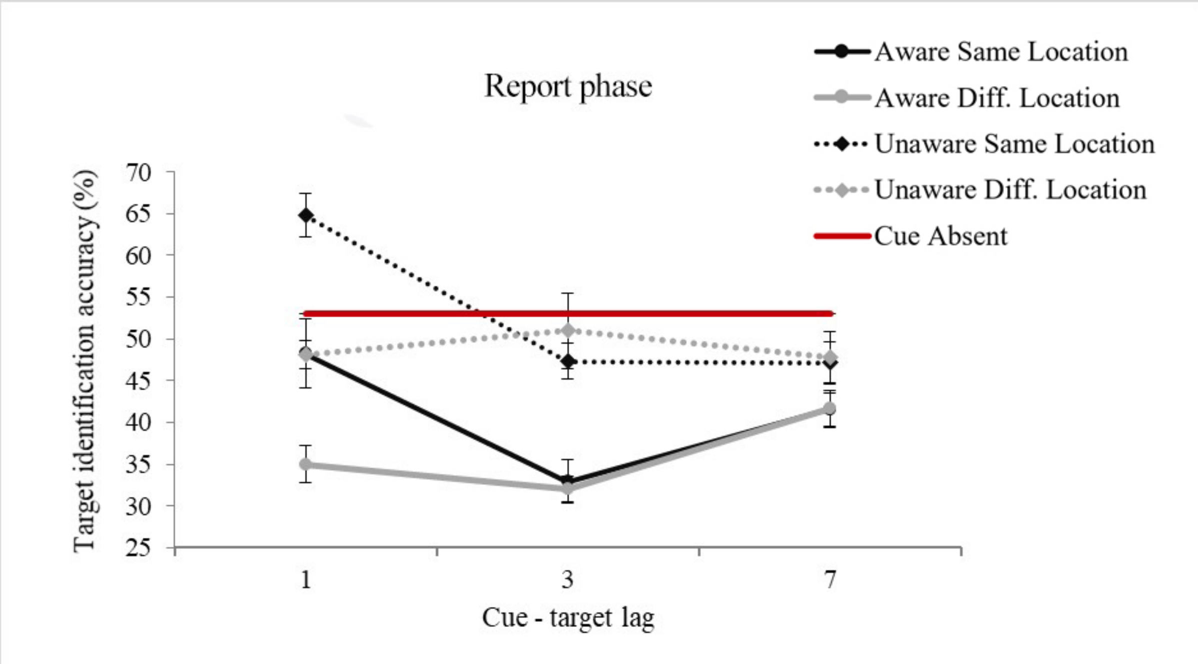

Figure 4. Mean target identification accuracy rates (in percentages, model based) in the report phase of Experiment 1 by conditions of cue-target lag (1, 3 or 7), cue-target location (same vs. different location) and cue awareness (unaware: PAS = 0 vs. aware: PAS=1, 2 or 3). Performance on cue-absent trials in indicated by the red horizontal line. Error bars represent within-participants standard errors.

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 4. A blink was observed only following a consciously perceived cue: performance was lower at lag 3 than at lag 7, 32.4% vs. 42.5%, respectively, Z=4.91, p<.001, with no such difference when the cue was entirely missed (i.e., for visibility rating = 0), 49.1% vs. 47.4%, respectively, Z<1. In addition, lag 1 sparing (better performance at lag 1 vs. 3 on aware-cue trials) was found only in the same-location condition, 48.2% vs. 32.8%, respectively, Z=5.01 p<.001, and not in the different-location condition, 35% vs. 32%, respectively, Z=1.13, p=.12.

Attentional capture. For the lag-1 condition, accuracy was higher in the same- than in the different-location condition, both on aware-cue trials, 48.2% vs. 35%, respectively, Z = 4.1, p <.001 and on unaware-cue trials, 64.8% vs. 48.1%, respectively, Z = 5.8, p < 0.0001, with no significant difference between these conditions, $\chi2(1)<1$. Thus, the cue captured attention and to the same extent whether or not it was consciously perceived.

Discussion

The novel and main finding of Experiment 1 is that conscious perception of the first event is sufficient for the blink (at least when this event matches the observer's attentional set). We found a blink whenever the cue was consciously perceived: this occurred when participants had to report on the cue (aware-cue trials of the report phase), a finding that replicates Ophir et al. (2018), but crucially, also when the cue was not associated with any task (noticers group in the IB phase and no-report phase). The latter finding suggests that having to report on the first event is not necessary for the blink.

The present results also further support our claim that conscious perception of the first event is necessary for the blink, whereas deploying attention to this event is not sufficient (Ophir et al., 2018): missed cues never produce a blink (non-noticers groups in the IB phase and unaware-cue trials of the report phase), although they captured attention.

Finally, we replicated previous findings showing that attentional capture is independent of conscious perception (Lamy et al., 2015; Ophir et al., 2018; Travis et al., 2018), but only in the report phase: the same- vs. different-location effect was of the same magnitude on aware- and unaware-cue trials. However, in the IB phase, contrary to our predictions, the target-color cue captured attention for noticers but not for non-noticers - although in the latter group, the numerical trend was in the expected direction.

Experiment 2

Taken together, the results of Experiment 1 suggest that consciously perceiving the cue is a necessary and sufficient condition for the attentional blink, while allocating attention to this cue is not sufficient and encoding its representation in WM is not necessary. However, before we can fully endorse these conclusions, it is important to examine whether they are also valid when the cue does not match the observer's attentional set and therefore does not benefit from attention. This was the objective of Experiment 2. It was similar to Experiment 1, except that the cue did not share the target color and was therefore not expected to capture attention.

Method

Participants

The participants were 20 Tel-Aviv University undergraduate students (mean age=24.15 years, SD=3.49, 13 females) who participated in the experiment for course credit. All reported normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, design and statistical analyses

The apparatus, stimuli, procedure, design and statistical analyses were similar to those of Experiment 1, except that the cue color and the target color did not match. Thus, half of the participants were presented only with red targets and green cues and the other half only with green targets and red cues.

Results

Following the inattentional-blindness phase, 16 participants provided no indication of ever consciously perceiving the cue (see Table 2 in the appendix): they responded negatively to all four questions regarding the cue and did not change their minds after being shown an image of it. The remaining four participants reported being aware of the cue (average detection rate

52%, as estimated by the participants during the awareness query at the end of this phase). On the one hand, unlike in Experiment 1, they were too few to analyze separately as noticers, and on the other hand they could not be included in the non-noticers group. In order to keep the results of the three phases comparable, these participants were excluded from all analyses, which therefore included only 16 participants.

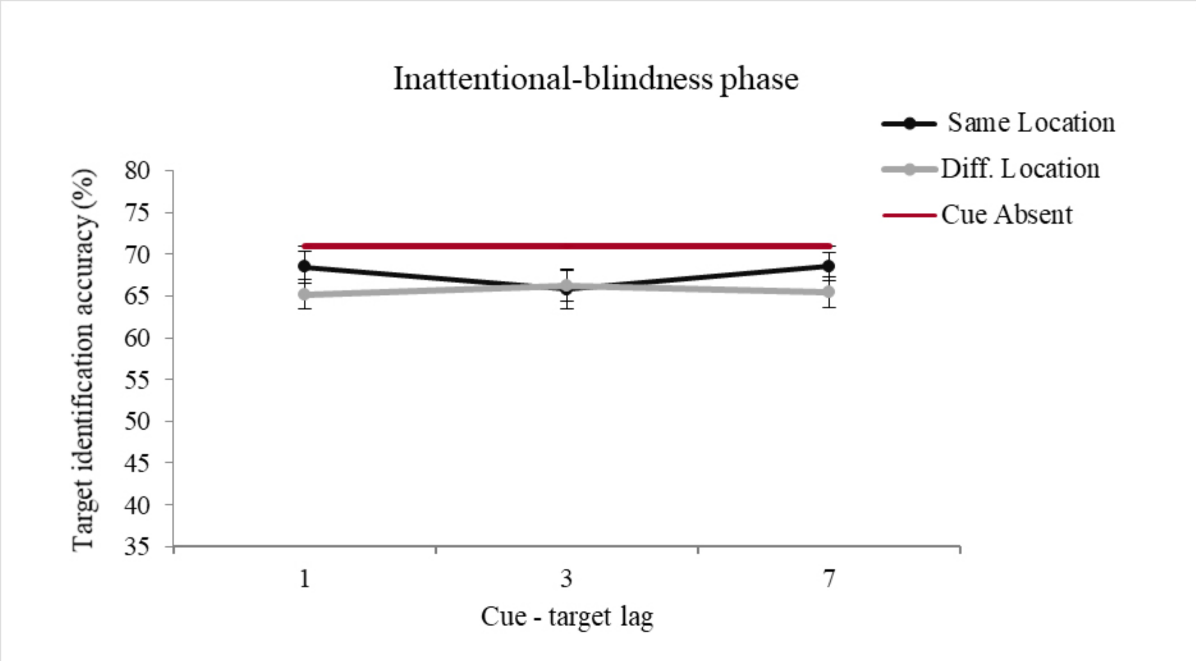

Figure 5. Mean target identification accuracy rates (in percentages, model-based) of the inattentionally blind participants in the IB phase of Experiment 2 by conditions of cue-target lag (1, 3 or 7) and cue-target location (same vs. different location). Performance on cue-absent trials in indicated by the red horizontal line. Error bars represent within-participants standard errors.

Inattentional-blindness phase

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 5. there was no blink and no lag 1 sparing: performance was similar for lag 3 and lag 7, $Z<1$, and for lag 1 and lag 3 in the same- and in the different-location conditions, both $Zs<1$.

Attentional capture. For the lag 1 condition, performance on same- and different-location trials did not differ, $Z<1$. A Bayes Factor analysis provided substantial evidence for this null effect, BF_{01} = 5.95. Thus, the cue, which did not share the target color in this experiment, did not capture attention, as expected.

No-report phase

In the post-phase questionnaire, all 16 participants reported being aware of the cue on at least a portion of the trials (mean=38.5%, SD= 27%).

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 6. In contrast with the no-report phase of Experiment 1, there was no blink: performance did not differ significantly between lag 3 and 7, 40.9% vs. 44.4%, respectively, Z=1.2, p=.11. Furthermore, we found no lag 1 sparing in the same-location condition, Z<1, and performance was in fact significantly poorer for lag 1 than for lag 3 in the different-location condition, 53.2% vs. 62.4%, respectively, Z=2.26, p=0.01.

Attentional capture. For the lag-1 condition, the difference between same- and different-location trials did not reach significance, 58.9% vs. 53.2%, respectively, Z=1.41, p=0.08.

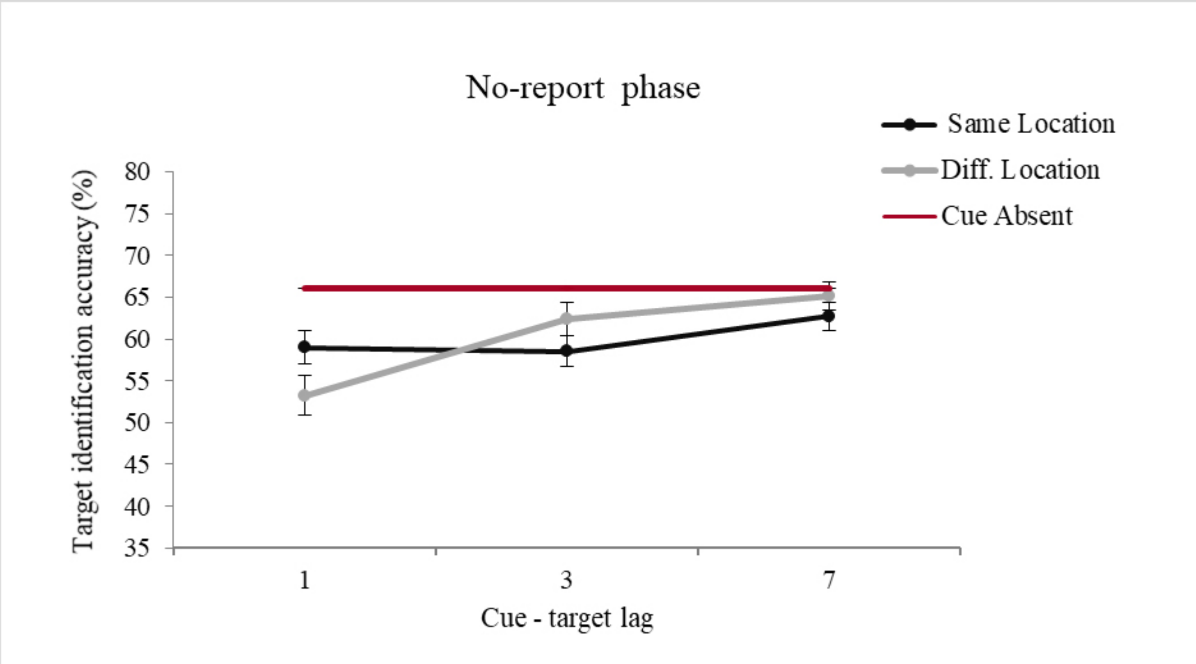

Figure 6. Mean target identification accuracy rates (in percentages, model-based) in the no-report phase of Experiment 2 by conditions of cue-target lag (1, 3 and 7) and cue-target location (same vs. different location). Performance on cue-absent trials in indicated by the red horizontal line. Error bars represent within-participants standard errors.

Report phase

Visibility ratings. Participants rated cue visibility to be 0, 1, 2 and 3 on 38%, 22%, 12%, and 28% of the trials, respectively, on cue-present trials and on 72%, 14%, 6% and 8%, respectively, on cue-absent trials. A series of binomial tests revealed that all visibility ratings above zero were predictive of the cue presence, $p(1402/1560, 85\%) < .0001$, $p(792/858, 85\%) < .0001$, and $p(1832/1923, 85\%) < .0001$, for ratings of 1, 2 and 3, respectively. Therefore, aware-cue trials included trials with a visibility rating of 1, 2 or 3 and unaware-cue trials included only 0-visibility trials.

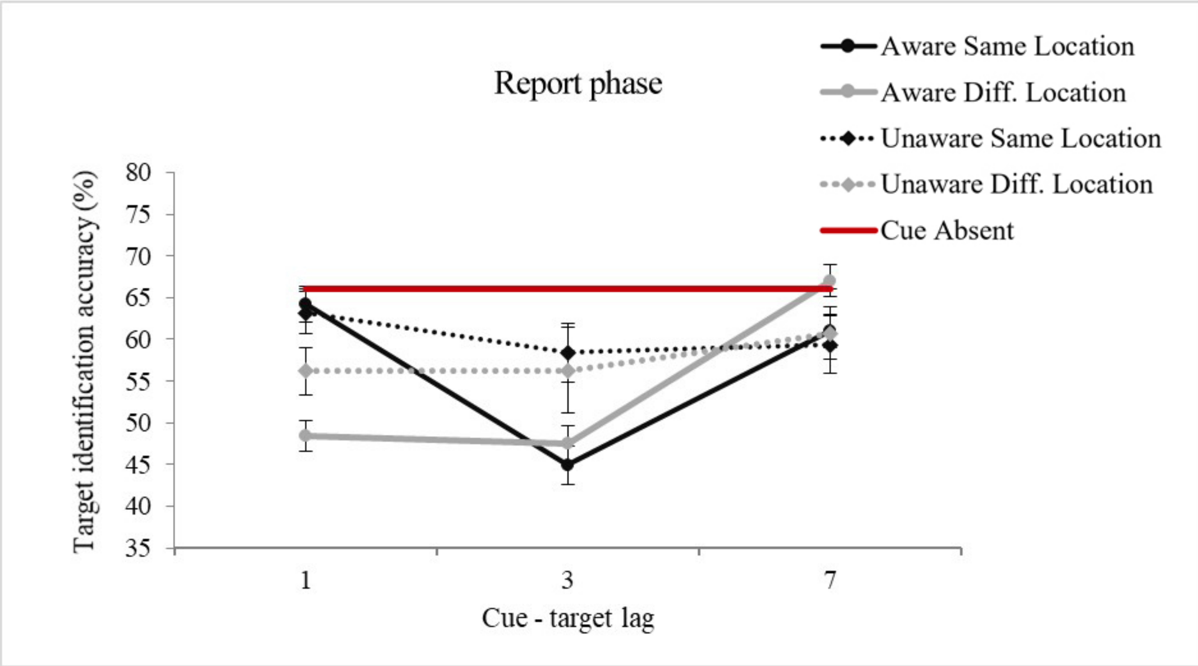

Figure 7. Mean target identification accuracy rates (in percentages, model based) in the report phase of Experiment 2 by conditions of cue-target lag (1, 3 or 7), cue-target location and cue awareness and cue awareness (unaware: PAS = 0 vs. aware: PAS=1, 2 or 3). Performance on cue-absent trials in indicated by the red horizontal line. Error bars represent within-participants standard errors.

Attentional blink and lag 1 sparing. Mean accuracy rates are presented in Figure 7. In line with our predictions, the blink that was contingent on cue awareness: performance was lower at lag 3 than at lag 7 when the cue was consciously perceived, 46.2% vs. 64.1%, respectively, $Z=8.59$, $p<.001$, with no such difference following a missed cue, 57.3% vs. 60%, respectively, $Z<1$. Lag 1 sparing was found in the same-location condition, 64.2% vs. 44.9%, respectively, $Z=6.43$ $p<.001$, and not in the different-location condition, 48.4% vs. 47.4%, respectively, $Z<1$.

Attentional capture. For the lag-1 condition, accuracy was higher in the same- than in the different-location condition on aware-cue trials, 64.2% vs. 48.4%, respectively, $Z = 5.18$, $p <.001$. This finding could result from lag 1 sparing rather than indicating that the nontarget-color cue captured attention. However, contrary to this conjecture, this location benefit also emerged on unaware-cue trials, 63.1% vs. 56.2%, respectively, Z = 1.95, p = .025 and this effect was only marginally smaller than on aware-cue trials, $\chi 2(1)=3.69$, p=.054.

Discussion

The results of Experiment 2 confirm that conscious perception of the first event is necessary for the blink: in all the conditions in which the cue failed to reach consciousness (in the IB phase and on unaware-cue trials of the report phase), the blink was absent. Crucially, however, the results also reveal that conscious perception of the first event is not sufficient for the blink: in the no-report phase of Experiment 2, there was no blink, although the cue was consciously perceived on at least a portion of the trials. Taken together with the results of Experiment 1, this finding suggests that a match between the first event and the task set is also necessary for the blink. Such a match occurs when the cue shares the target-defining color and / or when participants are required to report the presence of the cue.

It is noteworthy that, in the report phase, performance at lag 1 was higher when the cue and target were presented in the same vs. different locations. When the cue was consciously perceived, this finding was expected and was ascribed to lag 1 sparing. However, the same-location advantage was also observed when the cue was missed, which we take to indicate that it captured attention. This finding is at odds with the contingent capture theory (e.g., Folk et.al., 2002). In addition, it stands in direct contradiction with the results of Ophir et al. (2018), where the non-target color cue did not capture attention with very similar stimuli. The main difference between our previous study and Experiment 2 is that here, we concealed the existence of the cue from the participants in the IB phase and then questioned them about the cue at the end of this and the following (no-report) phase. This procedure may have increased the subjective relevance of the cue and led the participants to allocate some attention to the cue in the phases that followed. Yet, unlike in Experiment 1 where the cue shared the target-defining feature, here, the nontarget-color cue did not elicit a blink in the no-report phase.

Experiment 3

The absence of a blink in the no-report phase of Experiment 2 suggests that consciously perceiving the cue is not sufficient for the blink: reporting its presence (as in the report phase) or / and its match with the attentional set (as in Experiment 1) seem to be also necessary. However, an alternative interpretation is possible. This interpretation relies on Ophir et al.'s (2018, Exp. 3) finding that a consciously perceived cue elicits a substantially larger blink when it shares the target color than when it does not. Since participants reported being aware of the cue on fewer than half of the trials in both Experiments 1 and 2, this percentage may have been enough to produce a detectable blink with target-color cues (Experiment 1) but not with nontarget-color cues (Experiment 2). If this was the case, the conclusion that conscious perception of the cue is sufficient for the blink would still hold.

We further tested this conclusion in Experiment 3. This experiment included only the no-report phase. To render the cue fully visible (i.e., supraliminal), we eliminated masking by removing the grey circles surrounding the letters. In addition, to directly compare the impact of the match between the cue and the defining feature of the target within the same group of participants and under the same experimental conditions, target- and nontarget-color cues trials were randomly intermixed. As clearly supraliminal objects can escape observers' conscious perception (e.g., Simons & Chabris, 1999), participants were informed of the presence of the cues, in order to ensure that they would consciously perceive them.

It is noteworthy that this experiment is conceptually similar to Folk et al.'s (2002): they too examined whether a supra-liminal singleton distractor either matching or not matching the target color and requiring no response, produces a blink. Yet, their study did not yield a clear-cut answer to this question. In Experiment 2, they found both distractor types to produce a blink, although this effect was much larger when the distractor shared the target color than when it did not. However, in subsequent experiments of the same study, only target-color distractors produced a blink. As in the previous experiment we did find a weak numerical trend towards a blink by liminal nontarget-color cues that required no report, it was important to further examine whether a blink would emerge when this cue was clearly supraliminal.

Method

Participants

The participants were 20 Tel-Aviv University undergraduate students (mean age=23.3 years, SD=2.36, 13 females) who participated in the experiment for course credit. All reported normal or corrected-to-normal visual acuity and normal color vision.

Apparatus, stimuli, procedure, design and statistical analyses

The apparatus, stimuli, procedure, design and statistical analyses were similar to those of the no-report phases of Experiments 1 and 2 (where participants were instructed to report only the identity of the target-color letter), except for the following changes. The grey circles surrounding the letters were removed. The cue was randomly either in the target color (red for 50% of the participants and green for the remaining 50%) or in the alternative color (green and red, respectively). Lastly, the participants were shown pictures of both the target and non-target color cues during the instructions and were informed that these were completely non-predictive of the target's location or onset time.

Upon completion of the experiment, participants were administered a questionnaire including four questions: 1. You were informed of the presence of colored circles and shown pictures of them during the instructions. Did you notice these colored circles during the experiment? 2. On what percentage of the trials, approximately, did you see a colored circle (regardless of its color)? 3. Which circle color do you think appeared more frequently? 4.

The full model of Experiment 3 was expressed as: glmer(accuracy ~ 1 + lag + SameDiffCueColor+ location + lag * SameDiffCueColor + lag*location + SameDiffCueColor *location + lag* SameDiffCueColor *location + (1|subject) + (1|ColorGroup) + (1|TargetLetter), family = binomial).

Results

At the end of the experiment, the participants reported consciously perceiving the cue on 45% of the trial on average (SD=21%, range 10%-90%). Thus, our procedure was successful at increasing the cue's visibility relative to Experiments 1 and 2. Table 3 (see appendix) summarizes the results of the cue awareness questionnaire. Three participants reported ever seeing only target

-color circles, and one participant, only non-target-color circles. These 4 participants were excluded from the analysis, although including them did not change the pattern of results. The remaining 16 participants estimated seeing cues in both colors, on 42 % of the trials overall. On average, they estimated that the target-color cue occurred more often than the nontarget color cue, 57% vs. 43% of all visible cues, respectively.

Attentional blink and lag 1 sparing. The blink was dependent on the match between the cue and target colors. Performance was lower at lag 3 than at lag 7, Z=3.41, $p<.001$, when the cue shared the target's color. By contrast, performance was actually slightly higher at lag 3 than at lag 7, Z=2.04, p=.02, when the cue was in the non-target color. This difference was reflected in a significant three-way interaction between cue-target lag, location and color, $\chi2$ (2) = 6.39, p=.04. There was no lag 1 sparing in any of the conditions. In the target-color condition, accuracy tended to be numerically higher for lag 1 than for lag 3 in the same-location condition, 62.9% vs. 58%, respectively, Z=1.26, p=.1, while in the different location condition performance was significantly lower for lag 1 than for lag 3, 39.9% vs, 60.5%, Z=5.18, p<.001, respectively. In the non-target color condition, performance was significantly lower for lag 1 than for lag 3 in the different location condition, 66% vs, 77.6%, Z=3.4, p<.001, with a similar numerical trend in the same location condition, 70.2% vs. 74.1%, Z=1.2, p=.12.

Attentional capture. For the lag-1 condition, accuracy was significantly higher in the same- than in the different-location condition for target-color cues, 62.9% vs. 39.9%, respectively, Z = 5.74, p <.0001. This difference was not significant for non-target-color cues, 70.2% vs. 66%, respectively, Z=1.2, p=.11. Thus, as predicted, only target-color cues captured attention.

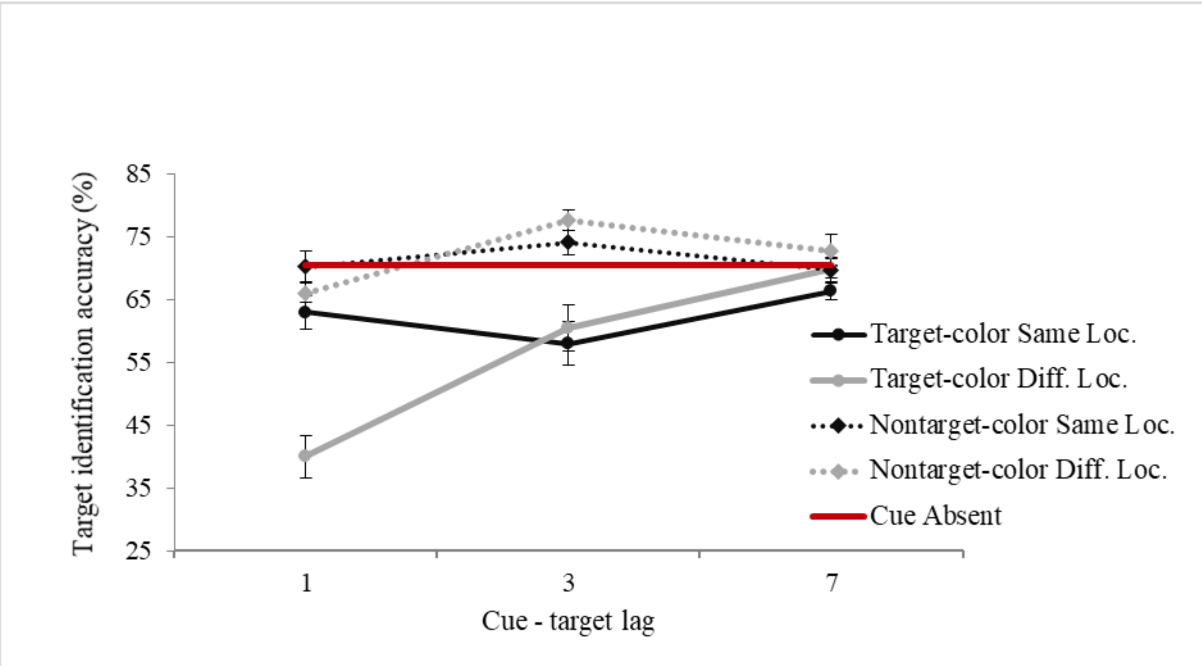

Figure 8. Mean target identification accuracy rates (in percentages, model-based) in Experiment 3 by conditions of cue-target lag, cue-target location and cue color. Performance on cue-absent trials in indicated by a horizontal line. Error bars represent within-participants standard errors.

Discussion

The results of Experiment 3 replicated the critical finding of the no-report phases of Experiments 1 and 2: a consciously perceived cue that was not associated with any task triggered a blink when it shared the target color, but triggered no blink when it did not share the target color. In addition, as expected, target-color cues captured attention, whereas non-target color cues did not. These findings suggest that conscious perception of the first event is not sufficient for the blink.

General discussion

The present study is the first systematic attempt to disentangle the roles of conscious perception, spatial attention and encoding in WM in eliciting the attentional blink. The main findings are summarized in Table 4. We replicated previous findings by showing that allocating spatial attention to the first event is not sufficient for the blink (Ophir et al., 2018), reporting it is not necessary (e.g., Folk et al., 2002), whereas consciously perceiving it is necessary (Nieuwenstein et al., 2009; Ophir et al., 2018). The novel finding, however, is that conscious perception is not sufficient: in order to trigger a blink, a consciously perceived event must either be reported or share the target-defining feature.

These observations can be parsimoniously subsumed under the conclusion that a match between a conscious percept and any aspect of the task set is the necessary and sufficient condition for the blink. This condition is met by most previous reports of a blink in the extant literature. In traditional AB studies (e.g., Raymond et.al., 1992), participants are asked to report two supraliminal targets. Thus, T1 is consciously perceived and matches the task set. In attentional capture studies of the AB (e.g., Folk et al., 2002), the distractor that replaces T1 is supraliminal and is thus likely to be consciously perceived on a substantial proportion of the trials. The distractor does not require a response, yet it produces a blink only when it shares the target defining feature, that is, when it matches the task set. Finally, in AB studies that specifically examined the role of conscious perception, a blink was observed when T1 was liminal and associated with a report, but only on trials in which it was consciously perceived (Ophir et al., 2018; Nieuwenstein et.al., 2009, Exp..4), or when T1 was supra-liminal, did not require a report but matched the task set (Nieuwenstein et.al., 2009, Exp.3[1]).

Challenging evidence: AB by distractors outside the attentional set

Two lines of research, however, seem to challenge our conclusions. On the one hand, two recent studies suggest that conscious perception is not necessary for the blink (Oriet et.al., 2017; Meijs, Slagter, de Lange & van Gaal, 2018). However, as discussed in Ophir et.al. (2018), in both of these, the authors' operational definition of conscious perception was very conservative. For instance, in Meijs et al. (2018, Exp. 3), a participant was held to consciously perceive T1 only when she correctly identified it, and to be unconscious of it otherwise. By contrast, in our study, mere detection of T1 sufficed for a trial to be classified as "aware". Since Meijs et al. (2018) calibrated the critical stimulus' parameters so as to obtain 75%-correct T1 identification performance, we can safely assume that T1 was detected on a substantial proportion of incorrect-identification trials (see Ophir et al. 2018 for a similar argumentation regarding Oriet et al.'s (2018) study). To accommodate these findings, we

[1] In that study, the to be-reported target (T2) was a letter and the distractor preceding it (T1) was always an O. Thus, just as T2, it was a letter and therefore matched the task set.

posit that while conscious identification of T1 is not necessary for the blink to occur, conscious detection is.

On the other hand, several studies suggest that a stimulus that neither requires report nor matches the task set, produces a blink. Specifically, in a subset of attentional capture studies, T1 was replaced with an emotion-laden stimulus, such as a taboo word (e.g., Arnell et al., 2007; Barnard et al., 2005; Stein, Zwickel, Ritter, Kitzmantel, & Schneider, 2009a), a face (e.g., Oriet et al. 2017) or an aversive scene (e.g., Most , Chun, Widders & Zald, 2005). Even though T1 was not associated with any task and did not share the target-defining feature, it triggered a blink. However, such evidence is controversial, as in several other AB studies, the irrelevant emotional T1 failed to produce a blink (e.g., Brown, Berggren, Forster, 2018; Stein, Zwickel, Ritter, Kitzmantel, & Schneider, 2009b). The discrepancy between these two lines of findings can be attributed mainly to two reasons.

First, in some studies demonstrating a blink by the emotion-laden distractor (e.g., Arnell et al., 2007; Barnard et al., 2005), T2 differed from nontargets only by its meaning. Thus, as suggested by Stein et al. (2009b), observers had to semantically process all RSVP items, including the to-be-ignored emotional T1, in order to successfully identify T2. In other words, although the distractor that served as T1 was nominally irrelevant to the task, it had to be encoded into WM in order to be compared to the target template and rejected. In line with this suggestion, Huang, Baddeley and Young (2008) found that the emotionality of to-be-ignored words serving as T1 had an effect on the blink only when the task required semantic processing of T2, but not when it required perceptual or phonological processing of T2. Lastly, Stein et.al. (2009b) found that when the target was defined perceptually (i.e., a scene among scrambled images), emotional faces could be entirely ignored and did not trigger any blink unless associated with a task.

Second, in some studies (e.g., Most et al., 2005), the target was defined by a unique property, which may have induced participants to adopt a singleton-detection strategy (see Bacon & Egeth, 1994 for the distinction between singleton-detection and feature-search strategies in attentional capture). In that case, although the critical distractor was nominally irrelevant, it may have matched the effective attentional set adopted by the observers, because it was the only emotional stimulus in the stream.

We conclude that taken together with the present findings, the current literature is generally consistent with the conclusion that a match between a conscious percept and any aspect of the task set is the necessary and sufficient condition for the blink.

Table 4. Summary of the results. While spatial attention is neither necessary nor sufficient for eliciting the blink, conscious perception is necessary, yet not sufficient: a match with the target-defining feature or a task associated with the first event are also necessary for the blink.

	First event reported	
	Awareness	**No awareness**
Match with attentional set	Blink	No blink
No match with attentional set	Blink	No blink
	First event not reported	
	Awareness	**No awareness**
Match with attentional set	Blink	No blink
No match with attentional set	No blink	No blink

Necessary and sufficient conditions for encoding into WM

A small conceptual leap leads us to speculate that conscious perception of a stimulus that matches any aspect of the task set may in fact be the necessary and sufficient condition for encoding into WM – whereas spatial attention is neither necessary nor sufficient. This conjecture is in line with the premise shared by many models of the attentional blink, according to which encoding in WM is the cause for the blink (e.g., Bowman & Wyble, 2007; Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1999; Jolicoeur, 1999; Vogel, Luck & Shapiro, 1998; Wyble, Bowman & Nieuwenstein, 2009). Our proposal has several important implications for the links between spatial attention and working memory on the one hand, and between conscious perception and working memory on the other hand.

Spatial attention and WM. A first implication is that allocating attention to a stimulus does not guarantee its encoding into WM. This claim contrasts with previous reports suggesting that irrelevant information that captures attention is automatically transferred into working memory (e.g., Schmidt, Vogel, Woodman & Luck, 2002; Belopolsky, Kramer & Godijn, 2008). For instance, Schmidt et al.'s (2002) used a change detection paradigm, in which participants memorized an array of color squares. Attention was summoned to the location of one of the squares by an abrupt-onset cue. Participants were more likely to detect the change when it occurred at the cued location than at an uncued location. The authors concluded attended objects are automatically encoded into WM. Note, however, that all the squares, including the cued square, had to be encoded in WM on each trial. Thus, participants could adopt the strategy of encoding the cued item at no cost, and encoding of the cued item into WM may therefore have been voluntary rather than automatic. A similar line of reasoning can explain Belopolsky et al.'s (2008) findings.

A second implication is that a stimulus that does not benefit from spatial attention can nevertheless be encoded in WM. Although this claim may appear to be controversial (see

Fougnie, 2008, for a review), it is important to keep in mind that it is limited to instances in which the critical stimulus, defined by a simple feature, has to be reported and only its presence (detection) must be encoded in WM. Thus, while a shift that would bring the stimulus into the focus of attention is not necessary for encoding into WM, some (distributed) attention is likely to be necessary.

Conscious perception and WM. Our suggestion that the boundary conditions for the blink overlap the boundary conditions for encoding into WM entails that only consciously perceived information is transferred into WM. Although many authors converge with this assertion (e.g., Baddeley, 2003; Baars & Franklin, 2003; Prinz, 2012; Carruthers, 2015), recent studies suggest that unconscious information can enter WM (e.g., Soto, 2011; Bergström & Eriksson, 2014; 2015; Dutta, Shah & Silvanto, 2014; King, Pescetelli & Dehaene, 2016; Trübutschek et al., 2017). However, these findings have been criticized on various grounds and remain highly controversial (e.g., Stein, Kaiser & Hesselmann, 2016). Following an extensive review of this literature, Persuh, LaRock and Berger (2018) concluded that there is as yet, no definitive evidence for unconscious visual working memory.

The most intriguing implication of the present work, however, is that conscious perception of an object may not be sufficient for encoding it into working memory. This claim relies on our failure to find a blink by a consciously perceived cue that neither matched the attentional set nor required any report (Experiments 2 and 3). Yet, such a claim begs the question of how participants could report being aware of the cue without encoding it in WM in real time.

In order to answer this question, the distinction between two types of consciousness, pioneered by Block (1995), may be useful. “Access consciousness” (or “type A” consciousness) refers to a representation that is “made available to cognitive processing”, whereas "phenomenological consciousness" (or "P consciousness") refers to "what it is like for a subject to have an experience" (Block, 2011). These definitions assume a direct relation between A type consciousness and the content of WM (for a conceptual analysis relating A consciousness and WM see Overgaard, 2018). Similarly to WM, the capacity of A type consciousness is limited, and therefore, only part of the information that is consciously perceived at a given moment can be accessed concurrently (Block, 2011).

Lamme (2003) suggested that while A consciousness corresponds to the limited content of WM, P consciousness corresponds to the content of another, higher-capacity form of memory - fragile visual short-term memory (FM). According to this view, FM is an intermediary store between iconic memory (Sperling, 1960) and WM, characterized by a large capacity, relatively long-term storage, and proneness to interference. Attending to a conscious representation in FM transfers it into WM and renders it reportable (i.e., transfers information from P consciousness to A consciousness). Koivisto et al. (2018) further suggested that A type consciousness shares resources with WM, while P consciousness does not.

Relying on these ideas, we suggest that in order to report being aware of the non-target color cue during the post-experiment questionnaire of the no-report phase (Experiments 2 and 3), participants had to attend to its conscious representation *offline*. We speculate that during the experiment, they consciously experienced the presence of the cue, but this information was stored in FM: it was not accessed and therefore it was not encoded into WM nor did it trigger a blink. When asked to assess whether and how often they had seen the cue, participants retrieved the representations of the cues from the few trials still active in FM, in order to transfer them to WM for report. We further speculate that participants then extrapolated the number of consciously perceived cues across the experiment, based on these few trials. According to this interpretation, encoding information into WM (or A consciousness) comes at a price, whereas P consciousness does not.

Conclusions

We investigated the factors that account for the limitations of our perceptual system in processing successive events, limitations that are illustrated by the attentional blink (AB). We attempted to disentangle the roles of spatial attention, conscious perception and encoding of the first event into working memory, in triggering the blink. Our results showed that spatial attention to the first event is neither necessary nor sufficient for the blink, conscious perception is necessary but not sufficient, and report is not necessary. We concluded that a match between a conscious percept and any aspect of the task set is the necessary and sufficient condition for the blink, and suggested that this condition determines whether or not an event is encoded into WM. The conclusion that the AB is triggered by encoding of T1 in WM may seem trivial in light of the numerous theories that have been making that claim since the AB phenomenon was first reported (e.g., Bowman & Wyble, 2007; Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1999; Jolicoeur, 1999; Vogel, Luck & Shapiro, 1998; Wyble, Bowman & Nieuwenstein, 2009). However, these models remained fairly vague as to the respective roles of spatial attention and conscious perception in eliciting the blink. The present findings thus constrain current models of the blink. More generally, they raise testable predictions as to what conditions are critical for transferring information into working memory.

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