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Dominique Lamy, Limor Alon, Tomer Carmel, and Nir Shalev

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Abstract

A mental process that is independent of conscious perception should run equally well with or without it. Previous investigations of unconscious processing have seldom included this comparison: They typically demonstrated only processing without conscious perception. In the research reported here, we showed that attentional capture is largely independent of conscious perception and that updating the episodic information stored about an object is entirely contingent on conscious perception. We used a spatial-cuing paradigm, in which the cue was a color-singleton distractor rendered liminal by continuous flash suppression or brief exposure. When the cue matched the participant's attentional set, it strongly captured attention whether it was subliminal or consciously perceived. In contrast, a nonmatching cue did not capture attention but instead produced a same-location cost, which was contingent on consciously perceiving the cue. Our findings demonstrate a dissociation between attention and conscious perception and unveil an important boundary condition of object-file updating.

Keywords

selective attention, attentional capture, object files

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Which mental processes are independent of conscious perception, and which benefit from it? The answer to this question is key to understanding the functions of consciousness. Yet research on unconscious processing has most often addressed a fundamentally different question. It has explored the limits of unconscious processing by investigating which mental operations can be performed without any consciousness of the eliciting stimulus and which cannot (Jiang, Costello, Fang, Huang, & He, 2006; Mudrik, Breska, Lamy, & Deouell, 2011; Van Opstal, de Lange, & Dehaene, 2011). To do that, much effort has been expended to render the critical stimuli subliminal, while showing that such stimuli nevertheless affect subjects' behavior, thoughts, memory, or feelings. In pursuing this goal, the gold standard to date has been an experimental block in which a subliminal prime is shown to affect responses to a subsequent target, followed by a prime-awareness test block in which null sensitivity, that is, chance performance at judging some property of this prime, is demonstrated (e.g., Ansorge, Kiss, & Eimer,

2009; Hsieh, Colas, & Kanwisher, 2011; Jiang et al., 2006; Van Opstal et al., 2011).

However, to demonstrate that a mental process is independent of conscious perception, showing that it can run without it is not enough: One should show that it runs equally well with or without conscious perception. Indeed, a mental operation that is shown not to be contingent on conscious perception might nevertheless strongly benefit from it. If, for instance, exposure to a liminal prime speeds responses to a subsequent target by 20 ms when this prime is not consciously perceived and by 120 ms when it is, it would be awkward to conclude that processing of the prime was independent of conscious perception. Investigations of unconscious processing have seldom included the relevant comparison,

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because priming was demonstrated when the critical stimuli were subliminal on most trials, and there was therefore no conscious priming against which to compare unconscious priming (but see Van den Bussche et al., 2013).

In the research reported here, we investigated whether spatial capture of attention can occur independently of conscious perception. This question has not been addressed to date: Previous studies have shown only that subliminal objects can capture attention (see Hsieh et al., 2011; Ivanoff & Klein, 2003; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; for reviews, see Ansorge, Horstmann, & Scharlau, 2011; Lamy, Leber, & Egeth, 2012; Mulckhuyse & Theeuwes, 2010). To rectify this, we adapted the spatial-cuing paradigm pioneered by Folk and Remington (1998). In the feature-search variant of this paradigm, observers search for a color-defined target (e.g., red) among heterogeneously colored objects. A spatially noninformative color-singleton cue appears shortly before the target display. In this situation, the color singleton typically captures spatial attention only when it matches the target-defining color. Such orienting of attention, which is referred to as contingent capture (e.g., Folk, Remington, & Johnston, 1992), is manifested by improved performance when the target appears at the same location as the cue than at a different location (henceforth, *same-location benefit*; e.g., Folk & Remington, 1998; Lamy, Leber, & Egeth, 2004).

Several studies have shown that with the same paradigm, an equally salient cue that has a color not matching that of the target produces a *same-location cost* (e.g., Anderson & Folk, 2012; Belopolsky, Schreij, & Theeuwes, 2010; Eimer, Kiss, Press, & Sauter, 2009; Folk & Remington, 2008; Lamy et al., 2004; Schönhammer & Kerzel, 2013). The mechanisms underlying this cost are currently debated. Some authors argue that the same-location cost reflects fast disengagement following attentional capture by a cue with a to-be-ignored feature (Belopolsky et al., 2010; Theeuwes, Atchley, & Kramer, 2000). Others suggest a feature-inhibition account, according to which attending to the location of a to-be-ignored feature is delayed (Eimer et al., 2009; Lamy et al., 2004). Finally, we recently proposed that this same-location cost is unrelated to attentional allocation and reflects the cost of updating the episodic information stored about an object in visual memory when this object changes (Carmel & Lamy, 2014; see also Kahneman, Treisman, & Gibbs, 1992; Park & Kanwisher, 1994).

In the present study, we used continuous flash suppression (Experiments 1 and 2) and brief exposure (Experiment 3) to render the cue liminal. We probed subjective perception of the cue on each trial, using a scale ranging from 0 (*not visible at all*) to 3 (*clearly visible*), while also verifying that reports of null cue visibility corresponded to chance-level performance at localizing the

cue (Experiment 2). We showed that spatial capture by a relevant-color cue is largely independent of conscious perception of that cue and that the same-location cost associated with irrelevant-color cues is entirely contingent on it. We thus demonstrated dissociations between spatial attention and conscious perception, on the one hand, and between the mechanisms underlying attentional capture and same-location costs, on the other hand.

Experiment 1

Method

Participants. Fourteen Tel Aviv University undergraduate students (12 right-handed, 2 left-handed; 12 females, 2 males; mean age = 22.28 years, $SD = 3.03$) participated for course credit. All participants reported having normal or corrected-to-normal visual acuity and normal color vision. The number of participants was preset between 10 and 15.

Apparatus. Stimuli were presented on an LCD monitor (23-in. Samsung SyncMaster) with a 1,920-pixel \times 1,080-pixel resolution and 120-Hz refresh rate. To create stereoscopic perception, we had participants view stimuli through Samsung SSG-M3150GB 3-D Active Glasses, which let an image through to one eye while blocking stimulation to the other, with a 120-Hz rate of alternation between the two eyes that is beyond the perceptual threshold.

Stimuli and procedure. The sequence of events is illustrated in Figure 1. Each trial consisted of a fixation display, followed by a cue display, and then by a target display. In the suppressed eye, the fixation display was blank for 500 ms, and then a fixation cross appeared in the center of the screen. Four 1-pixel-thick gray circles (1° radius and 2.8° distant from fixation) were gradually faded in within 500 ms at the cardinal positions around the fixation cross. In the subsequent cue display (150 ms), all circles were 2-pixels thick, and one circle (the cue) changed to one of two possible colors. The target display was identical to the display prior to the cue display.

In the nonsuppressed eye, an array of outline circles and solid discs of various sizes and shades of gray (the Mondrian suppressor) was visible throughout the trial. These stimuli randomly onset and offset at a frequency of 20 Hz, and a fixation cross appeared in the center of the array. During the fixation and cue displays, four gray "T" shapes ($0.5^\circ \times 0.5^\circ$) rotated by 90° (two to the left and the other two to the right) appeared at locations corresponding to the centers of the circles presented to the

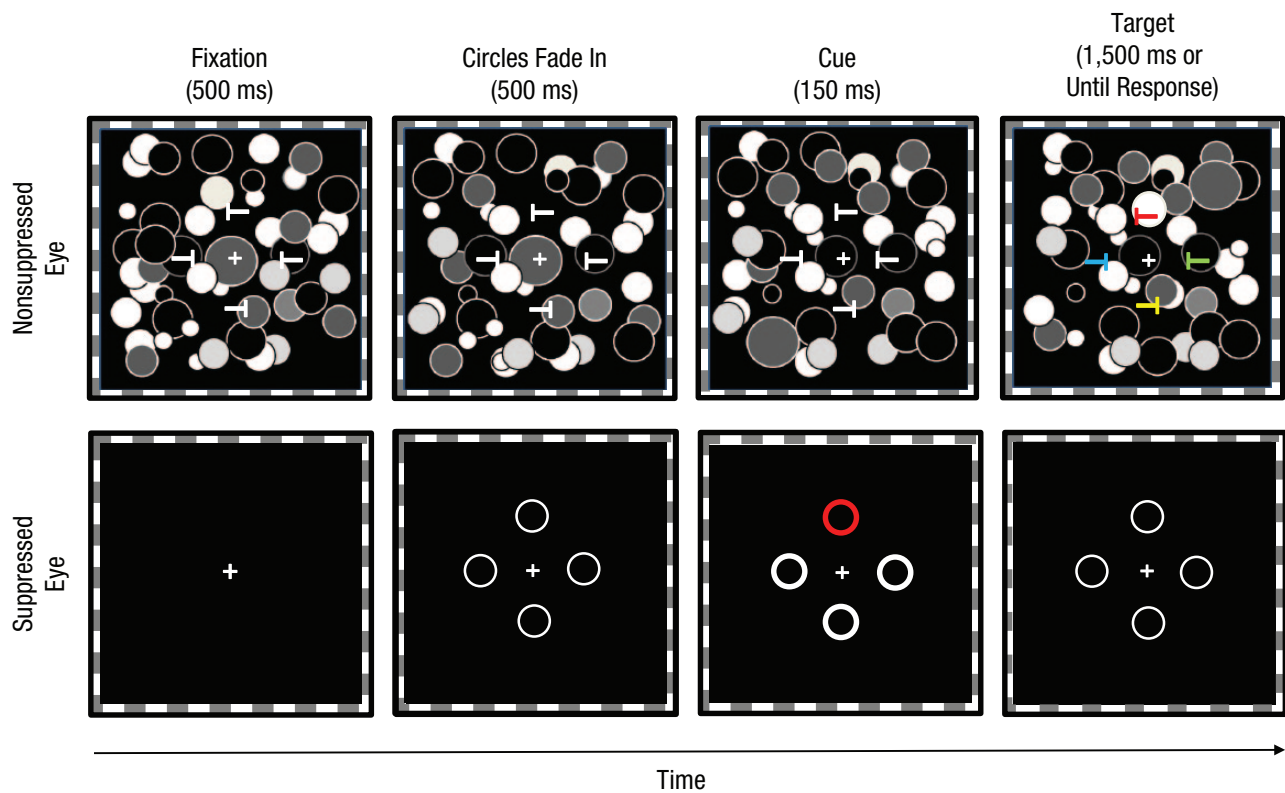


Fig. 1. Sample trial sequence in Experiments 1 and 2. A dynamic Mondrian pattern was presented to the nonsuppressed eye throughout each trial, together with four “T” shapes, two oriented 90° to the left and two 90° to the right. These “T” shapes remained gray until the target display appeared, when each changed to a different color (red, blue, yellow, or green). Participants searched for a color-defined target and reported its orientation (right or left). The suppressed eye was presented with four circles, which faded in after a fixation period. In the cue display, these circles thickened, and on cue-present trials one of them changed to a color that either matched or did not match the target color. Participants first made a speeded response to the target and then reported their subjective perception of the color-circle cue on a scale ranging from 0 (*not visible at all*) to 3 (*clearly visible*). The color-singleton cue and target locations were uncorrelated.

suppressed eye. In the target display, each “T” took on a different color (red, blue, yellow, or green). The target display remained visible for 1,500 ms or until response.

For each participant, the target color remained constant throughout the experiment and was counterbalanced between participants. For participants in the red- and green-target groups, the possible singleton-cue colors were red and green, and for participants in the yellow- and blue-target groups, the possible singleton-cue colors were yellow and blue. The relevant-color-cue condition, in which the cue shared the target color, and the irrelevant-color-cue condition, in which it had a different color, were equally probable. The cue was absent on 20% of the trials. The cue and target locations were randomly set on each trial and were uncorrelated.

On each trial, participants had to provide two responses. They first made a speeded response to the orientation of the color-defined target (left or right) with their dominant hand. Then they provided a subjective report of their perception of a colored circle appearing prior to the target (the cue), using a scale ranging from 0

(*not visible at all*) to 3 (*clearly visible*), with their other hand. The participants were informed that on some proportion of the trials, the colored circle would be absent. As the Mondrian pattern included no colors, any failure to report seeing the cue could not result from mistakenly construing it as a part of the Mondrian mask. A new trial began after a 500-ms interval. A 40-trial practice block was followed by 400 experimental trials divided into eight blocks.

Results

Participants rated cue visibility to be 0, 1, 2, and 3 on 68%, 17%, 8%, and 7% of the trials, respectively, on cue-absent trials and on 53%, 13%, 10%, and 24%, respectively, on cue-present trials. There were not enough cue-present trials with intermediate ratings (1 and 2) to allow meaningful analysis of each visibility level. We therefore adopted the most conservative criterion for conscious perception: The unaware condition included only trials on which visibility was rated 0, and the aware

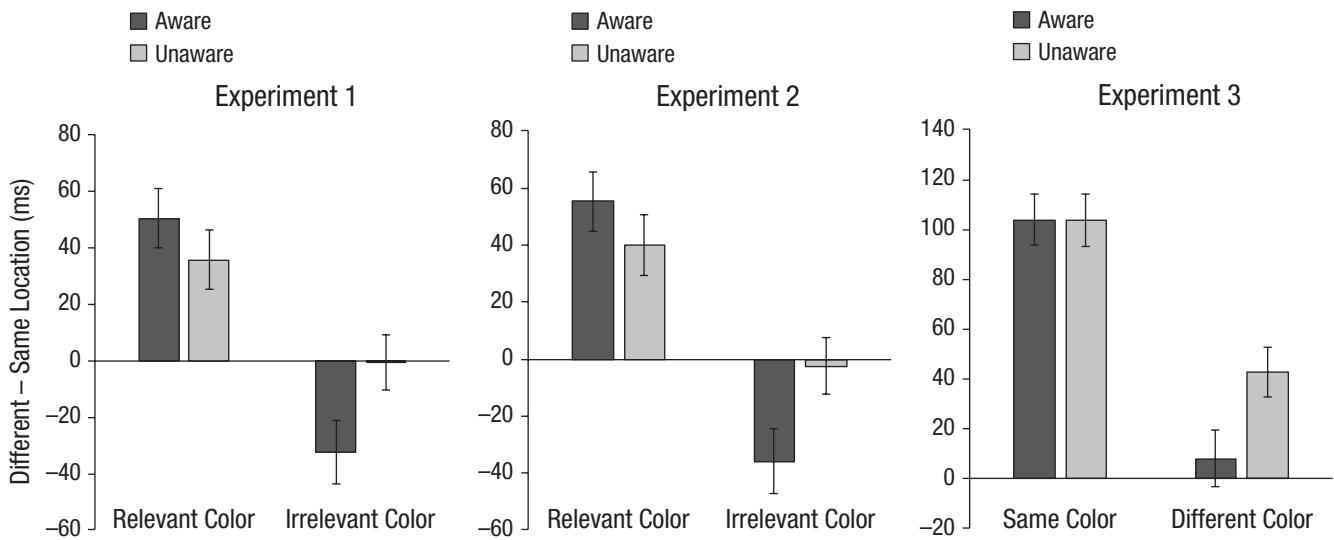


Fig. 2. Mean location effect as a function of cue color and participants' reported awareness of the cue. Results are shown separately for the three experiments. In Experiments 1 and 2, the cue color was in either the relevant (target) or the irrelevant (nontarget) color; in Experiment 3, the target and cue colors were either the same or different. Location effects were calculated by subtracting reaction times for targets appearing at the same location as the cue from reaction times for targets appearing at different locations from the cue. The unaware condition included only trials on which participants indicated that the cue was not visible at all, whereas the aware condition included all trials in which the cue was rated as having some degree of visibility. Error bars represent standard errors.

condition included all the remaining trials (i.e., on which visibility was rated 1, 2, and 3).

Similar analyses with the aware condition including only trials on which visibility was rated 3 yielded similar results. A linear mixed model with cue awareness (aware vs. unaware), cue color (relevant vs. irrelevant), and target location (same as cue vs. different from cue) as independent variables was run on the reaction times (RTs) for trials with correct responses (96.0% of all trials), excluding RT outliers (any trial exceeding the mean of its cell by more than 2.5 standard deviations; 1.6% of all trials with correct responses).

The three-way interaction was significant, $F(4, 52) = 14.99$, $p < .000$ (Fig. 2). Follow-up analyses focused on location effects, which were calculated by subtracting RTs for targets appearing at the same location as the cue from RTs for targets appearing at different locations from the cue. They revealed that when the cue was in the relevant color, it captured attention whether it was consciously perceived ($M = 50$ ms, $SE = 10.35$ ms), $F(1, 52) = 28.71$, $p < .0001$, Cohen's $d = 1.22$, or not consciously perceived ($M = 36$ ms, $SE = 10.62$ ms), $F(1, 52) = 11.35$, $p < .0002$, Cohen's $d = 0.90$. There was no significant difference between these two location effects, $F(1, 52) = 1.76$, $p > .19$. In contrast, when the cue was in the irrelevant color, it produced a significant same-location cost when it was consciously perceived ($M = 33$ ms, $SE = 11.29$ ms), $F(1, 52) = 8.31$, $p < .006$, Cohen's $d = 0.77$, but not when it was invisible ($M = 1$ ms, $SE = 9.82$ ms), $F < 1$, Cohen's $d = 0.02$. The difference between these two

location effects was significant, $F(1, 52) = 4.54$, $p < .04$. Mean error rates did not yield any significant effect, all $p > .12$, but followed the same pattern as RT data. Both are shown in Table 1.

It is noteworthy that the RTs to the target were much slower when participants were aware of the cue ($M = 783$ ms, $SE = 25$ ms) than when they were unaware of the cue ($M = 712$ ms, $SE = 25$ ms), $F(1, 13) = 236.57$, $p < .0001$. An additional analysis including all four levels of cue awareness showed that the more visible participants rated the cue to be, the slower they were at responding to the target, $F(3, 36) = 106.44$, $p < .0001$ (Fig. 3). Accuracy between the aware and unaware conditions did not differ significantly, $F < 1$.

Finally, a Pearson chi-square test for the contingency table of cue color (relevant vs. irrelevant) and number of cue-aware versus cue-unaware trials showed that relevant-color cues were significantly more likely to gain conscious access (50.77% of all trials) than irrelevant-color cues (43.46% of all trials), $\chi^2(1, N = 14) = 23.01$, $p < .0001$.

Discussion

Our results demonstrate that an observer's attentional set can be applied to invisible displays and that attentional capture by a distractor matching this set does not only occur in total absence of conscious perception but is also largely independent of it. In contrast, the same-location cost associated with irrelevant-color cues was contingent on conscious perception. In Experiment 1, we relied on a

Table 1. Mean Reaction Time (RT) and Mean Error Rate by Cue Color and Awareness Condition

Experiment and target location	Relevant/same-color cues				Irrelevant/different-color cues			
	Unaware condition		Aware condition		Unaware condition		Aware condition	
	RT (ms)	Error rate (%)	RT (ms)	Error rate (%)	RT (ms)	Error rate (%)	RT (ms)	Error rate (%)
Experiment 1								
Same as cue	686 (27)	4.7 (1.8)	770 (27)	2.2 (1.8)	715 (27)	3.9 (1.8)	792 (27)	6.0 (1.9)
Different from cue	722 (26)	5.1 (1.5)	820 (26)	5.4 (1.5)	714 (26)	4.0 (1.5)	759 (26)	3.8 (1.5)
Experiment 2								
Same as cue	877 (60)	0.3 (1.4)	914 (59)	1.1 (1.0)	891 (60)	2.2 (1.3)	970 (59)	4.1 (1.4)
Different from cue	917 (59)	3.2 (0.9)	969 (59)	3.7 (0.7)	889 (59)	1.2 (0.8)	935 (59)	3.9 (1.1)
Experiment 3								
Same as cue	643 (34)	5.5 (2.6)	701 (34)	7.8 (2.7)	701 (34)	10.3 (2.9)	794 (34)	6.4 (2.5)
Different from cue	747 (35)	15.1 (2.0)	805 (35)	13.0 (2.0)	744 (36)	17.9 (2.1)	802 (35)	14.1 (1.9)

Note: Standard errors are given in parentheses.

subjective measure to assess participants' conscious perception of the cue because this was necessary for comparing the effects in the aware condition with those in the unaware condition. However, as sensitive as a 4-point awareness scale may be (e.g., Ramsøy & Overgaard, 2004), one could still claim that subjective measures are not as exhaustive as objective measures (e.g., Eriksen, 1960; Holender, 1986; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010). If so, partial awareness of the cue may account for the attentional capture by subjectively invisible cues.

We addressed this potential criticism in Experiment 2 by adding an awareness-check block similar to the experimental blocks, in which participants localized the cue and then rated its visibility. If participants were partially aware of the cue when reporting 0 visibility, their forced-choice performance at localizing it should exceed chance.

Experiment 2

Method

Participants. Twelve Tel Aviv University undergraduate students (all right-handed; 7 females, 5 males; mean age = 25.33 years, $SD = 4.44$) participated for course credit. All participants reported having normal or corrected-to-normal visual acuity and normal color vision. The number of participants was preset between 10 and 15.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were the same as in Experiment 1, except that a cue-awareness test block followed the experimental phase. This 100-trial test block was similar to the experimental blocks, except that prior to reporting on their awareness of the cue, participants made a forced-choice response to the location of the cue (which was its

relevant property with regard to attentional capture) instead of responding to the target. If participants were truly unaware of the cue when reporting a visibility of 0 in the experimental phase, then their performance at localizing the cue should be at chance when reporting a visibility of 0 in the cue-awareness test.

Results

Mean RTs and error rates are shown in Table 1. The findings of Experiment 1 were closely replicated (Fig. 2). In the main experimental phase, participants rated cue visibility to be 0, 1, 2, and 3 on 71%, 16%, 5%, and 8% of cue-absent trials, respectively, and on 39%, 13%, 7%, and 41% of cue-present trials, respectively. Trials with errors (2.9% of all trials) as well as RT outliers (2.8% of all trials with correct responses) were excluded from all analyses. The three-way interaction among cue awareness (aware vs. unaware), cue color (relevant vs. irrelevant), and target location (same as cue vs. different from cue) was again significant, $F(4, 44) = 12.30, p < .0001$.

Follow-up analyses on location effects showed that the relevant-color cue captured attention both when it was consciously perceived ($M = 55$ ms, $SE = 9.54$ ms), $F(1, 44) = 33.55, p < .0001$, Cohen's $d = 1.47$, and when it was not consciously perceived ($M = 40$ ms, $SE = 13.06$ ms), $F(1, 44) = 8.98, p < .005$, Cohen's $d = 1.02$. The difference between these two location effects was not significant, $F < 1$. With irrelevant-color cues, the same-location cost occurred only when the cue was consciously perceived ($M = 35$ ms, $SE = 10.11$ ms), $F(1, 44) = 12.55, p < .0009$, Cohen's $d = 1.03$, but not when it was invisible ($M = 2$ ms, $SE = 9.91$ ms), $F < 1$, Cohen's $d = 0.07$. The difference between these conditions was significant, $F(1, 44) = 4.50, p < .04$. Crucially, performance on the cue-awareness test block was at chance when participants reported null

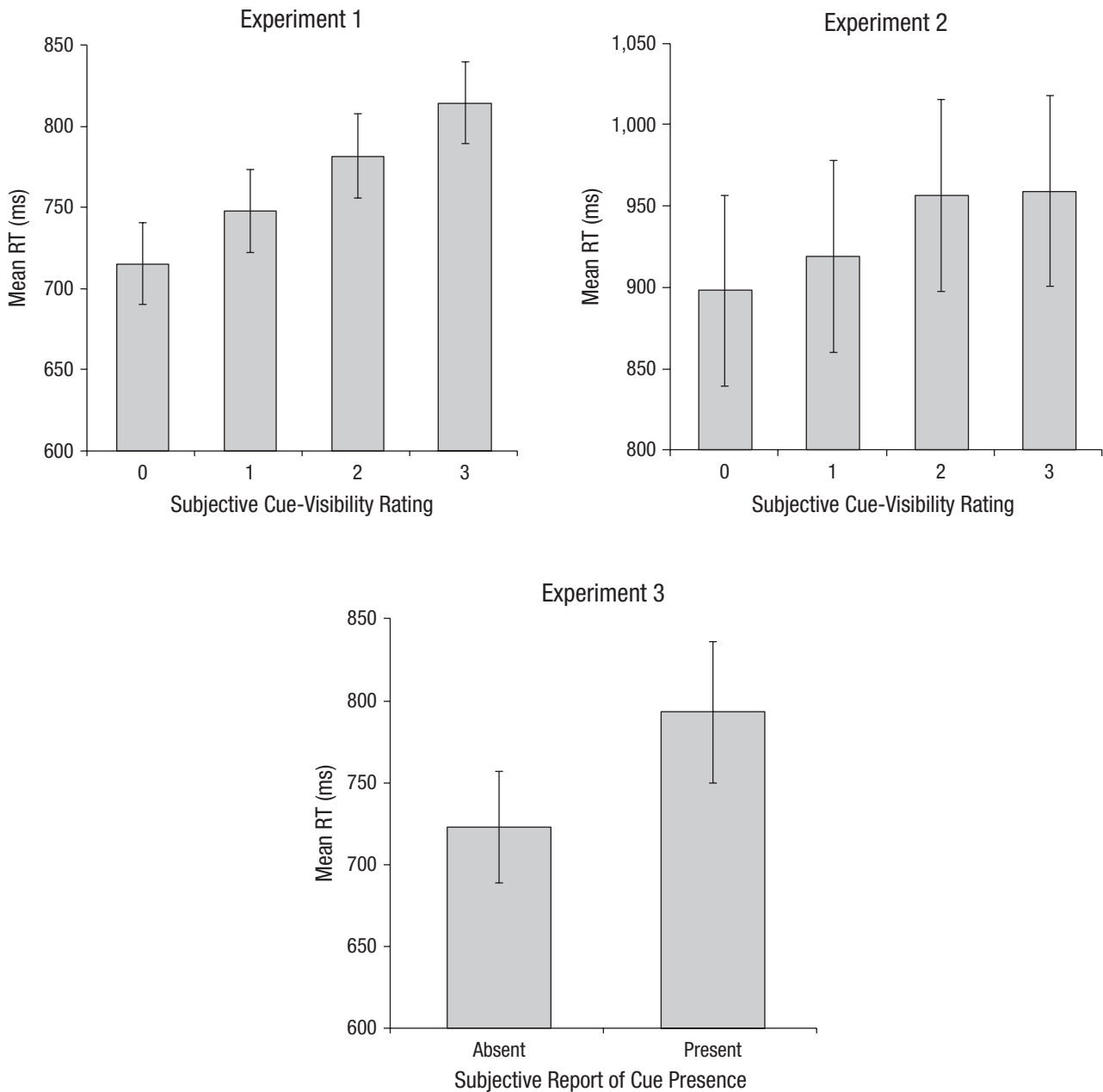


Fig. 3. Mean reaction time (RT) as a function of participants' ratings of cue visibility in the three experiments. Error bars represent standard errors.

visibility of the cue (25.07%, $SE = 3.24\%$), $t < 1$, which confirms that the subjective 4-point scale of conscious perception was as exhaustive as an objective perceptual-sensitivity measure. Cue-localization performance for each subjective-visibility rating is shown in Figure 4.

Again, RTs were slower when participants were aware of the cue ($M = 949$ ms, $SE = 60$ ms) than when they were not ($M = 897$ ms, $SE = 59$ ms), $F(1, 11) = 136.29$, $p < .0001$, and error rates were also higher in the aware (3.5%) than in the unaware (1.9%) condition, $F(1, 11) = 7.84$, $p < .02$.

An additional analysis including all four levels of cue awareness showed that the more visible participants rated the cue to be, the slower they were at responding to the target, $F(3, 33) = 56.43$, $p < .0001$ (Fig. 3).

For accuracy data, only the main effect of cue awareness was significant: There were fewer errors when the cue was perceived consciously than when it was not. No other effect was significant, all $ps > .2$.

Finally, a Pearson chi-square test for the contingency table of cue color (relevant vs. irrelevant) and number of

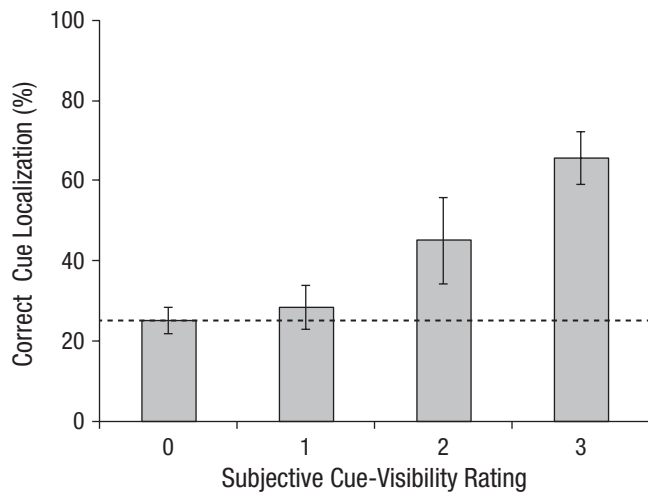


Fig. 4. Mean cue-localization performance as a function of participants' ratings of cue visibility in Experiment 2. Error bars represent standard errors. The dashed line represents chance-level performance.

cue-aware vs. cue-unaware trials showed that relevant-color cues were again significantly more likely to gain conscious access (67.0% of all trials) than irrelevant-color cues (56.9%), $\chi^2(1, N = 12) = 40.63, p < .0001$.

Experiment 3

In Experiments 1 and 2, we showed that the same-location benefit is largely independent of conscious perception, whereas the same-location cost is contingent on it. However, this difference might be only quantitative rather than qualitative, because in both experiments, both spatial effects were numerically smaller in the unaware condition than in the aware condition. The main objective of Experiment 3 was to invalidate this claim by creating a situation in which the spatial effect was expected to be larger in the unaware than in the aware condition.

To test our hypothesis, we relied on our previous finding (Carmel & Lamy, 2014) showing that the same-location benefit and cost are additive: In the search for an unpredictable color singleton, the spatial-cuing effect was smaller when the cue and target colors differed than when they were the same. As all cues had the same attentional status, this difference was taken to reflect a same-location cost that is independent of attentional selection. In Experiment 3, we used a similar singleton-search task, and, to generalize our findings beyond continuous flash suppression, we used a brief cue exposure found to yield liminal perception in a pilot experiment. When the cue and target colors were different, we expected a larger same-location advantage with invisible than with consciously perceived cues, because the same-location cost should reduce the net same-location advantage only on aware trials. When the cue and target had

the same color, we expected similar effects in the two awareness conditions.

Method

Participants. Fourteen Tel Aviv University undergraduate students (all right-handed; 10 females, 4 males; mean age = 21.25 years, $SD = 2.71$) participated for course credit. All participants reported having normal or corrected-to-normal visual acuity and normal color vision. The number of participants was preset between 10 and 15.

Apparatus, stimuli, and procedure. Stimuli were presented on a CRT monitor (1,024-pixel \times 768-pixel resolution, 85-Hz refresh rate). The stimuli and procedure were similar to those of Experiment 1, except for the following changes. We limited conscious perception by presenting the cues for a very brief duration instead of using continuous flash suppression. All stimuli were presented binocularly, such that the "T" shapes were enclosed in the circles. There was no dynamic Mondrian pattern. The target was an unpredictable color singleton, randomly either green or red among gray nontargets for one half of the subjects and either yellow or blue among gray nontargets for the other half, and so was the color singleton cue. Thus, the cue color was equally likely to be the same color as the target or a different color.

On each trial, the cue display was presented for 40 ms instead of 150 ms and was followed by the fixation display for a 110-ms interstimulus interval before the target display appeared. The target display was presented for 150 ms. Instead of rating their subjective perception of the cue using a scale from 0 to 3, participants made a yes ("I saw it") or no ("I did not see it") response by pressing one of two designated keys with their nondominant hand. Because the results of Experiments 1 and 2 showed attentional capture to be independent of conscious perception of the cue, contamination of "no" responses by partial awareness should not affect the pattern of results in the same-color-cue condition: The same-location benefit should again be similar whether participants were aware or unaware of the cue. For different-color cues, such contamination should reduce the difference between the aware and unaware conditions and thus work against our predictions.

Results

One participant was excluded from the analyses because she reported seeing the cue on 90% of no-cue trials. Participants reported not seeing the cue on 85% of cue-absent trials and on 42% of cue-present trials. Trials with errors (9.4% of all trials) and RT outliers (3.1% of all trials

with correct responses) were excluded from all analyses. Preliminary analyses showed no effect involving target color, and the data were therefore collapsed across target-color conditions. Mean RTs and error rates are shown in Table 1. The results conformed to our predictions. The three-way interaction among cue awareness, cue color (same as target vs. different from target), and target location (same as cue vs. different from cue) was significant, $F(4, 45) = 13.74, p < .0001$.

Follow-up analyses on location effects showed that on same-color trials, attentional capture was as large when the cue had been consciously perceived ($M = 104$ ms, $SE = 11$ ms), $F(1, 45) = 75.66, p < .0001$, Cohen's $d = 2.55$, as when it had been invisible ($M = 104$ ms, $SE = 12$ ms), $F(1, 45) = 84.25, p < .0001$, Cohen's $d = 2.41$. There was no difference between these two location effects, $F < 1$. On different-color trials, there was a significant same-location benefit when the cue was invisible ($M = 43$ ms, $SE = 13$ ms), $F(1, 45) = 9.95, p < .003$, Cohen's $d = 0.90$, but not when the cue was consciously perceived ($M = 8$ ms, $SE = 13$ ms), $F < 1$, Cohen's $d = 0.17$. The difference between these two effects approached significance, $F(1, 45) = 3.92, p < .055$ (Fig. 2).¹ Similar analyses on error rates showed only a significant main effect of location, $F(1, 12) = 28.30, p < .0001$, with higher accuracy on same- than on different-location trials. No other effect approached significance, all $ps > .11$.

RTs to the target were again slower following visible cues ($M = 793$ ms, $SE = 34$ ms) than following invisible cues ($M = 723$ ms, $SE = 34$ ms), $F(1, 12) = 11.29, p < .0001$ (Fig. 3), but they were more accurate (visible cues: $M = 88.5\%$ correct, $SE = 1.8\%$; invisible cues: $M = 85.86\%$ correct, $SE = 1.6\%$), $F(1, 11) = 5.01, p < .05$, which suggests that there was a speed/accuracy trade-off.

General Discussion

This study is the first to measure the extent to which capture of spatial attention depends on conscious perception of the attention-grabbing object. We found such capture to be largely independent of conscious perception. Previous studies have found attentional capture by invisible objects, but they did not compare visible and invisible objects: The aware condition was either missing because the attention-capturing object was invisible throughout the experiment (e.g., Ansorge et al., 2009; Hsieh et al., 2011; Mulckhuyse et al., 2007) or not comparable with the unaware condition because the objects physically differed in the two conditions (e.g., Ivanoff & Klein, 2003; McCormick, 1997).

We also showed that such capture is contingent on the participant's attentional set. Although purely goal-directed capture by invisible objects has been convincingly demonstrated in previous studies (e.g., Ansorge et al., 2009;

Kanai, Tsuchiya, & Verstraten, 2006), there is no strong evidence to date for purely salience-based capture by invisible stimuli. Authors who showed attentional capture by subliminal singletons or abrupt onsets interpreted their findings as demonstrating stimulus-driven orienting (e.g., Hsieh et al., 2011; McCormick, 1997; Mulckhuyse et al., 2007). However, the target was also typically a singleton or had an abrupt onset, so attentional capture may have been contingent on adopting a set for unique objects (e.g., Bacon & Egeth, 1994). Here, we showed that subliminal color singletons strongly capture attention, but only when their unique color matches the target-defining feature. Notably, requiring participants to report on the cue's visibility failed to induce goal-directed capture by this cue (Ivanoff & Klein, 2003).

We recently reported that the same-location cost is unrelated to the participant's attentional set and disappears when the spatiotemporal continuity between cue and target is broken (Carmel & Lamy, 2014). We concluded that the effect reflects the cost of updating an object's episodic representation in visual memory when this object changes. Such episodic object representations (or object files; Kahneman et al., 1992) have been invoked to account for a range of phenomena such as negative priming (Park & Kanwisher, 1994), object-specific preview effects (Kahneman et al., 1992), repetition blindness (Kanwisher, 1987), and feature binding (Hommel, 1998). Here, we showed that object-file updating occurs only when the object's initial state is consciously perceived, which suggests that conscious perception of a visual object may be necessary for setting up an object file representing this object. Note that for such conscious perception, attention broadly distributed across the visual field seems to suffice: In our study, irrelevant-color cues did not benefit from focused attention (as they did not capture attention), yet they entered participants' visual consciousness on a substantial proportion of the trials.

Our findings also have general implications for the study of unconscious processing. By uncovering a mental process that is largely independent of conscious perception, we demonstrated a qualitative discontinuity between unconscious and conscious processing. Conversely, by identifying a mental process that is contingent on conscious perception, we identified an objective and indirect behavioral marker of conscious perception. Finally, the finding that forced localization of the cue was at chance when reported cue visibility was null demonstrates that subjective measures of conscious perception can be as sensitive as objective measures (e.g., Peremen & Lamy, 2014). We suggest that the present approach, the main features of which are (a) that we measured subjective perception on a sensitive scale on each trial, thereby (b) allowing for the comparison of a conscious and an unconscious condition, and (c) verifying that the

subjective measure was exhaustive by corroborating that null visibility corresponds to chance performance, provides a promising tool for the study of consciousness.

An incidental finding recurred in all three experiments: Higher cue-visibility reports were associated with slower RTs to the target. We speculate that the slow responses following consciously perceived cues may reflect an “awareness blink” by which being conscious of an event makes perception of a temporally close subsequent event difficult. We are currently investigating this issue.

Finally, in both Experiments 1 and 2, we showed that relevant-color cues were more likely to gain conscious access than irrelevant-color cues. This result replicates Most, Scholl, Clifford, & Simons's (2005) finding that the likelihood of consciously perceiving an object is strongly influenced by the participants' attentional set and extends this finding beyond their inattentional-blindness paradigm.

Author Contributions

D. Lamy conceived the idea for the study. D. Lamy, L. Alon, and N. Shalev designed Experiments 1 and 2, and L. Alon and N. Shalev ran them. T. Carmel designed Experiment 3 and ran it. N. Shalev adapted the continuous-flash-suppression equipment and calibrated the experiments. D. Lamy wrote the manuscript.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Note

1. In the unaware condition, the same-location benefit was smaller with different-color than with same-color cues, although similar effects were expected in the two conditions because both should reflect only contingent attentional capture. However, our use of a relatively coarse measure of conscious perception can account for this finding. With a binary yes/no measure, partial awareness was likely to occur on a portion of the unaware trials (e.g., Kouider & Dehaene, 2007): On such trials, a same-location cost should have occurred in the different-color condition, thus reducing the same-location benefit.

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