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# Attribute amnesia can be modulated by foveal presentation and the pre-allocation of endogenous spatial attention

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## Abstract

Even in sparse visual environments, observers may not be able to report features of objects they have just encountered in a surprise question. *Attribute amnesia* and *seeing without knowing* describe report failures for irrelevant features of objects that have been processed to some extent in the primary task. Both phenomena are attributed to the exclusive selection of relevant information for memory consolidation or for awareness, respectively. While *attribute amnesia* was found even for irrelevant attributes of the target in the primary task, *seeing without knowing* was not observed when a single object was presented foveally. To elucidate this discrepancy, we examined report failures for irrelevant attributes of single target objects, which were presented either in the fovea or in the periphery, and either at cued or uncued locations. On a surprise trial, observers were able to report the irrelevant shape and color of the target object when it was presented foveally. However, presenting the same object just slightly away from the fovea led to report failures for shape. Introducing a valid peripheral cue prior to target presentation reduced report failures for shape when the cue was predictive of the target location, suggesting that the pre-allocation of endogenous spatial attention promoted the processing of irrelevant shape information. In accordance with previous research, we suggest that these modulations are due to differences in late selection for conscious awareness or consolidation in working memory.


**Keywords** Visual working memory · Attention and memory · Visual awareness

## Introduction

How good are we at recalling recently experienced events? We have learned from eyewitness testimonies that our ability to accurately report visual details like the color of someone's coat is limited. While this may be understandable in the context of dynamic and often ambiguous situations in real-world scenarios, basic laboratory research on perception, memory, and consciousness has demonstrated similar failures with very simple visual stimuli. One well-known example is *inattentional blindness* (e.g., Rock, Linnett, Grant, & Mack, 1992): When engaged in a computerized task of comparing the length of two lines forming a cross, around 25% of participants failed to notice an additional item (e.g., a small square) presented in a surprise question. These lapses occurred even though all stimuli were presented within a small radius (2.5° of visual angle, dva) around fixation and only the cross and the additional item were shown on screen.

While *inattentional blindness* may be due to participants never being aware of the additional square, Eitam and colleagues (Eitam, Shoval, & Yeshurun, 2015; Eitam, Yeshurun, & Hassan, 2013) recently presented examples of poor recognition performance when conscious awareness of the stimulus was ensured experimentally. In one study (Eitam et al., 2015), they presented a Kanizsa rectangle (Kanizsa, 1976), induced by four "Pacman" stimuli, for 500 ms at the center of the screen and asked participants to report the color of the inducers and the orientation of the induced rectangle. Before this critical trial, participants had already completed seven or eight baseline trials with similar displays for which one group of participants had been instructed only to report the color of the "Pacmans," and another group the orientation

**Significance statement** Even after only 1 s, memory for objects or attributes can be quite poor when there was no prior instruction to memorize them. In laboratory settings, this is examined through surprise questions. Although previous work has convincingly argued that report failures are not always due to inattention, the current experiments suggest that foveal presentation or the allocation of endogenous spatial attention can modulate late selection for awareness or consolidation in working memory.

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of the Kanizsa rectangle. While performance was near perfect for the instructed attribute, around 30–45% of participants failed to report the other attribute when unexpectedly asked for it. This is quite remarkable, in particular for the group that had been instructed to report orientation: Participants needed to be consciously aware of the inducers in order to report the orientation of the Kanizsa rectangle, yet 30% of these participants were not able to report the inducers' color.

The authors (Eitam et al., 2015; Eitam et al., 2013) proposed that there are two types of induced blindness (see also Block, 1996; Lamme, 2004). On the one hand, a phenomenal blindness without visual awareness, resulting in a visual stimulus truly not seen; on the other hand, a blindness due to a lack of knowledge activation, in which we are aware that there was a stimulus, but cannot tell what it was, referred to as *seeing without knowing*. In accordance with previous accounts, they speculate that classic demonstrations of *inattentional blindness* (e.g., Rock et al., 1992; Simons & Chabris, 1999) reflect phenomenal blindness, which is critically dependent on a depletion of attentional resources due to visually or cognitively challenging primary tasks. In other words, the additional square in the study by Rock et al. (1992) was not noticed because participants' attentional resources were largely taken up by the difficult length comparison task. In contrast, to explain their own findings, Eitam et al. (2013, 2015) suggest that the lack of knowledge activation critically depends on the irrelevance of the information to be reported, which is why they initially labelled their finding *irrelevance-induced blindness*. Thus, *seeing without knowing* describes a state in which we cannot report attributes of a noticed stimulus (e.g., the color of the inducers) because of exclusive selection of relevant information, even though plenty of attentional resources should be available for processing the irrelevant information. Interestingly, in a second experiment, Eitam et al. (2015) describe a boundary condition for *seeing without knowing*: On each trial, they presented a single-colored geometric shape for 500 ms at fixation and asked half their participants to report its color, and half to report its shape during seven baseline trials. On the critical trial, participants were unexpectedly asked to report the other attribute. In this setup, 90% of participants gave a correct response, irrespective of whether they were surprised by the color or shape question. The authors concluded that pure relevance-based selection cannot occur within the same object. When an object is selected under minimal load, knowledge activation occurs for both its relevant and irrelevant attributes.

Contrary to this assumption, Chen and Wyble (2015, 2016, Swan, Wyble, & Chen, 2017) have recently described the phenomenon of *attribute amnesia*. In one of their experiments (Chen & Wyble, 2015; Exp. 3), they asked participants to report the location of a color singleton target shown alongside three black distractor letters at a parafoveal distance from fixation (~ 4.4 dva). Displays were shown briefly (150 ms) and masked. After some trials, participants were asked to report the color of the last target letter on a surprise trial. Only 35% of participants indicated the correct color. In contrast, on four subsequent control trials, performance for both color and location was at ceiling (95–100% correct throughout). In terms of cognitive load, the task was thus extremely easy and selection of the color singleton was assured, as it was the target for the primary task. Following Eitam and colleagues' framework (Eitam et al., 2015; Eitam et al., 2013), knowledge activation should have occurred for all attributes of the target object, including its color. However, 65% of participants failed to report the correct color. Chen and Wyble (2015, 2016) proposed that their findings reflect a lack of consolidation of the irrelevant attributes in working memory. Hence, they termed their observation *attribute amnesia*.

Are *attribute amnesia* and *seeing without knowing* different phenomena, based on different mechanisms (knowledge activation vs. consolidation in working memory)? Why were participants in Eitam and colleagues' experiment (Eitam et al., 2015; Exp. 2) able to report the color and shape of the foveally presented target while participants in Chen and Wyble's (2015; Exp. 3) experiment were not able to report the singleton's color? In the current study, we set out to elucidate this discrepancy. Although both tasks were extremely easy, stimuli and procedures differed in a number of ways. The timing of stimuli, the presentation of masks and distractors, the size of the stimuli, the primary task (localization vs. report of color or shape), and the locus of presentation (at fixation vs. in the parafoveal region) were different. Recently, we have demonstrated that the mask does not explain the discrepancy, because *attribute amnesia* was observed with unmasked stimuli shown for 500 ms (Born, Puntiroli, Jordan, & Kerzel, 2019; see also Chen & Wyble, 2015; Exp. 1b). We further observed that preparing a saccade towards the target does not eliminate the effect. However, more participants were able to report the identity of the target letter when it was foveated for some time after the eyes had reached the target. Thus, we tested whether foveal versus parafoveal presentation of a single geometric shape affects the ability to report the irrelevant attribute on a surprise trial (Experiment 1). To preview the results, we found that parafoveal presentation of the target object resulted in more failures to report its shape than foveal presentation. Following up on this result, we explored the effect of a peripheral cue on participants' ability to report the target shape. The cue either predicted (Experiment 3) or did not predict (Experiment 2) the target location. While results from the non-predictive cuing procedure remained inconclusive, the predictive cue increased the number of correct reports of target shape. We conclude that foveal presentation and the pre-allocation of endogenous spatial attention may improve conscious awareness or memory consolidation of irrelevant information. As we cannot affirm or exclude that participants were consciously aware of the irrelevant attribute at some point in our experiments, we favor an interpretation in terms of memory consolidation, that is, *attribute amnesia*.

## Experiment 1

In Experiment 1, we examined whether the ability to report an irrelevant attribute of a single object differs for foveal and parafoveal presentation. In essence, stimulus timing followed Eitam et al. (2015), while the size of the stimuli and the placement of the parafoveal targets was adopted from Chen and Wyble (Chen & Wyble, 2015, 2016; Swan et al., 2017). As mentioned, in a previous study, we found that foveating the target after a saccade resulted in better performance. Further, it has been demonstrated that performance for correctly identifying the shape of briefly flashed targets declines with eccentricities from 1 to 6 dva from fixation (e.g., Holmes, Cohen, Haith, & Morrison, 1977). Moreover, change detection during inspection of natural scenes is more difficult when foveal vision is impaired by a simulated scotoma (a gray blob moving along with the participant's gaze; Geringswald, Porracin, & Pollmann, 2016). Therefore we hypothesized that *attribute amnesia* or *seeing without knowing* may indeed occur in parafoveal vision, but, in accordance with Eitam et al. (2015), not in foveal vision.

### Methods

#### Participants

In total, 82 participants (48 women) aged between 17 and 32 years ($m$ = 21.0, $SD$ = 2.60) were tested in Experiment 1. Mostly first-year psychology students participated for course credit. They were assigned to four experimental groups, in accordance with previous *attribute amnesia* studies using a sample size of 20 participants per group (Chen & Wyble, 2015, 2016; Jiang, Shupe, Swallow, & Tan, 2016). All participants gave written consent before testing. The procedures followed the principles laid down in the Code of Ethics of the World Medical Association (Declaration of Helsinki) and were approved by the Ethics Committee of the Faculté de Psychologie et des Sciences de l'Education of the University of Geneva.

#### Apparatus and software tools

Experiments were programmed in Matlab (The MathWorks Inc., Natick, MA, USA) using the Psychtoolbox and Eyelink toolbox extensions (Cornelissen, Peters, & Palmer, 2002; Kleiner, Brainard, & Pelli, 2007). Stimuli were displayed on a VIEWPixx monitor (VPixx Technologies Inc. Saint-Bruno, QC, CA), with a resolution of 1,920 x 1,200 pixels, running at 100 Hz. Fixation was monitored using an EyeLink1000 desk-mounted eye tracker (SR Research Ltd., Ottawa, ON, Canada) at a sampling rate of 1,000 Hz. Participants' heads were stabilized by a chin and forehead rest at approximately 55 cm from the screen. They were tested in a room with dimmed overhead lighting. All statistics were conducted using JASP (2018). For the Bayes factors, we always compared the H0 against a two-sided alternative hypothesis, using the independent, multinomial sampling option (Jamil et al., 2017) with a default prior concentration of 1. Either the Bayes factor favoring H0 ($BF_{01}$) or favoring H1 ($BF_{10}$) is reported, depending on which of the two was larger than 1 (note that $BF_{10} = 1/BF_{01}$).

#### Stimuli, design and procedure

Figure 1A illustrates the sequence and timing of events on each trial. After a fixation interval of 500 ms, the colored target shape was presented for 500 ms, followed by a blank screen for 500 ms. The colored shape was presented either foveally or parafoveally, depending on the experimental group. Stimuli were displayed on a light gray background (x = 0.27, y = 0.34, 27 cd/m$^2$). The central fixation cross (bar length 0.6 dva, 1 pixel thick) was shown in a slightly darker gray (x = 0.27, y = 0.34, 17 cd/m$^2$). The target on each trial had one of four possible shapes: a circle, a square, a diamond, or a cross, randomized across trials. Each of these shapes subtended approximately 0.6 × 0.6 dva. Further, the target could be presented in one of four possible colors: red (x = 0.67, y = 0.31, 17 cd/m$^2$), green (x = 0.10, y = 0.74, 60 cd/m$^2$), blue (x = 0.10, y = 0.09, 9 cd/m$^2$), or yellow (x = 0.40, y = 0.52, 74 cd/m$^2$), randomized across trials. In the foveal condition, targets were centered on fixation. In the parafoveal condition, targets were presented on the corners of an invisible square (side length: 6.25 × 6.25 dva, i.e., at an eccentricity of 4.4 dva from fixation on the diagonal axis). The exact location (i.e., which corner of the invisible square) was also randomized across trials.

Each participant was assigned to one of four experimental groups: across groups, stimuli were either presented foveally or parafoveally; further, participants were instructed to report either the color or shape of the target, henceforth called the "relevant" attribute. The other attribute served as the "irrelevant" attribute. A response display was shown at the end of each trial, presenting the four possible alternatives. Participants had to type in the number that corresponded to the respective target attribute on a conventional keyboard. The assignment of attributes to response keys changed randomly from trial to trial (e.g., "red" was not always assigned to response key "3"). Gaze direction was checked online during the presentation of the target display, sampling horizontal and vertical coordinates every 10 ms. If a break of fixation (any gaze coordinate more than 1.5 dva away from screen center) or a blink was detected in any of these samples, participants were informed through a short feedback message during the blank display.

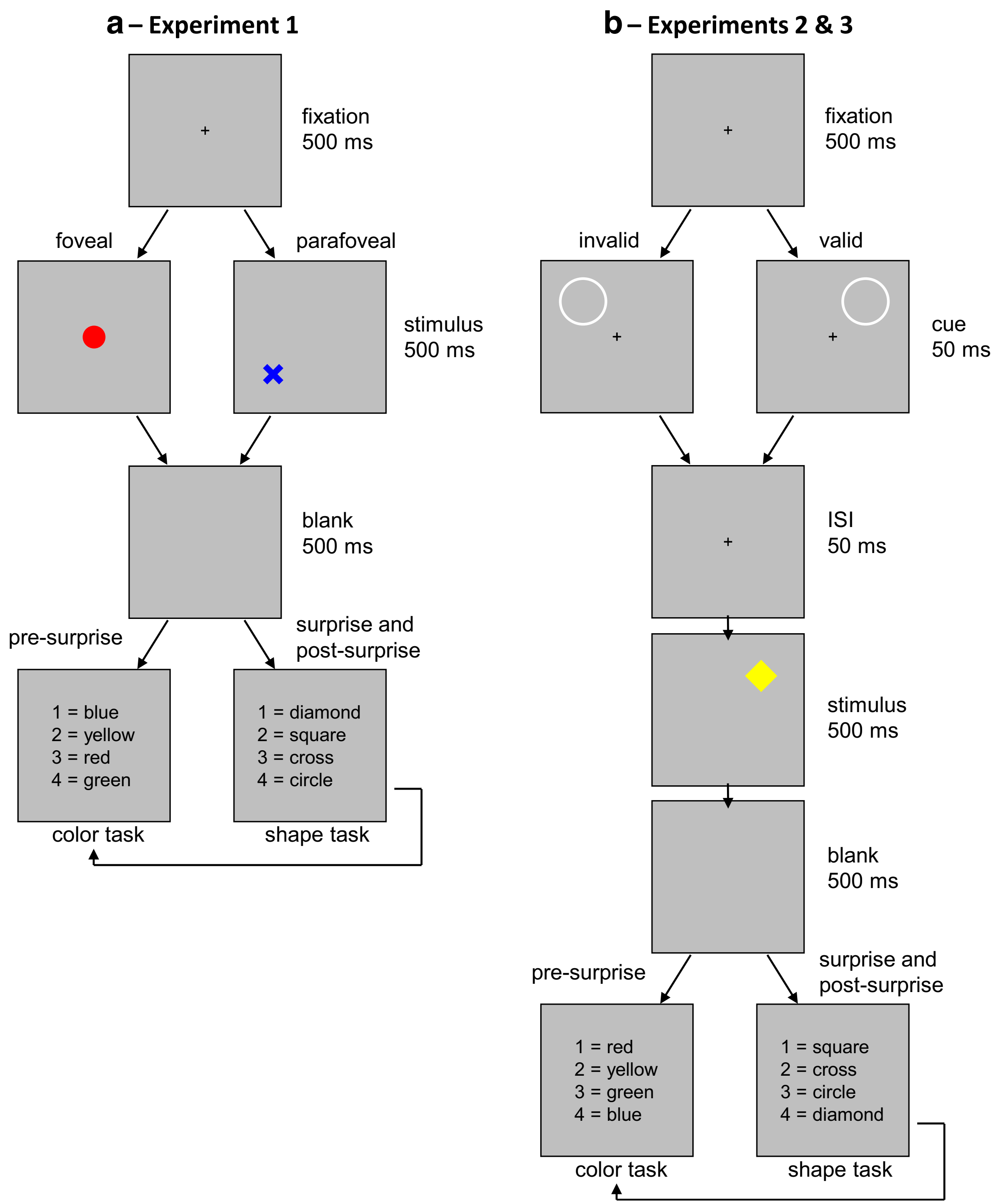


**Fig. 1** Illustration of experimental procedures. (**A**) Trial sequence in Experiment 1. Participants were instructed to report either the color (as in the example in the figure) or the shape of the target at the end of a trial (= relevant attribute). The 12th trial was the surprise trial, where participants were asked to report the other target attribute (e.g., its shape if they reported its color before). The surprise query was followed by the usual report of the relevant attribute. After the surprise trial, four post-surprise trials followed in which both target attributes had to be reported. (**B**) Trial sequence in Experiments 2 and 3. Between fixation and target display, a white outline circle cue was flashed for 50 ms followed by a 50-ms inter-stimulus interval (ISI). In Experiment 2, the cue was non-predictive of the target location (25% valid). In Experiment 3, it predicted the target location (75% valid). Stimuli are not drawn to scale

The experiment started with a five-point eyetracker calibration procedure. Then, an instruction display was shown on-screen with the following text (in French): “PRACTICE [line break] Condition: foveal [peripheral] / color [shape] [line break] You will have to remember the color [shape] of the stimulus presented on screen, then report it by means of the keys 1 / 2 / 3 / 4. Wait until the response display to give your response. Keep your gaze at the center of the screen, without blinking, for the duration of the trials." Additionally, participants received the following instructions verbally by the experimenter (in French): "Look carefully at the fixation cross. Then, the fixation cross will disappear to give way to a stimulus [in the periphery of your visual field. Make sure to keep your gaze in the center, and not be captured by the stimulus]. You will have to identify the color [shape] of the stimulus. Respond by means of the numbers 1, 2, 3, or 4, but be careful: the numbers do not always correspond to the same color [shape]. After that, press ENTER to get to the next trial. You may already position your right hand close to the numbers and your left hand on ENTER." They were further instructed that the experiment will start with some practice trials and to start those whenever ready by pressing ENTER. Participants completed 17 practice trials in their assigned task (color or shape report, depending on group). After another calibration check, the instruction screen reappeared on screen (without the word PRACTICE) and participants were informed that the experimental trials will follow, which they initiated by another key press on ENTER. Participants first completed 11 trials in their assigned task (pre-surprise trials). If no gaze error was detected on the 12th trial, a surprise question immediately followed the blank screen, asking the participant for the irrelevant attribute of the target, instead of the relevant attribute. That is, if participants had initially been instructed to report shape, they were now asked to report color (and vice versa). The surprise trial response screen did not contain any additional announcement that there was a change in the to-be-reported attribute. Instead, to draw participants' attention to the change, the experimenter read aloud the instruction phrase ("What was the color [shape] of the last stimulus?") that always appeared on screen along with the four response alternative (as shown schematically in Fig. 1). If a break of fixation or a blink was detected on the 12th trial, the surprise question was postponed until the next trial with accepted gaze behavior. This was done to ensure that the target had not been fixated in the parafoveal condition. After the surprise question, participants were additionally asked to report the relevant attribute. Following the surprise trial, participants were explicitly informed that four more trials followed (post-surprise trials) on which they would be asked to report both the color and the shape of the target, in the same order as on the surprise trial. The experiment took around 5–10 min to complete.

## Results

In the foveal presentation condition, breaks of fixation or blinks occurred on 6.4% of trials and the surprise trial had to be postponed to a later trial for two participants (once to the 13th, once to the 14th trial) due to a gaze error on the 12th trial. In the parafoveal presentation condition, as could be expected, breaks of fixation occurred more frequently, leading to an overall gaze error percentage of 13.2% of trials. The surprise trials had to be postponed to the 13th trial for four participants due to a gaze error on the 12th trial.

Table 1 lists average performance for the relevant (i.e., the attribute participants were instructed to report) and the irrelevant attribute (i.e., the attribute first queried on the surprise trial), separately across all pre-surprise trials, the single surprise trial, and across all four post-surprise trials in the four experimental groups. As expected in such a simple task, performance for the relevant attribute was at ceiling throughout the experiment. The only exception occurred in groups that reported target shape. On the surprise trial, performance dropped to 85% correct. Note that drops in performance for the relevant attribute were also observed in previous studies when the relevant attribute was queried after the surprise attribute (Chen & Wyble, 2016; Eitam et al., 2015). Also, note that participants had no difficulty whatsoever in reporting both target attributes, including the irrelevant attribute, on the post-surprise trials.

In addition to Table 1, Fig. 2 illustrates the percentage of participants giving a correct response for the irrelevant attribute on the surprise as well as the first post-surprise trial. Following Chen & Wyble (Chen & Wyble, 2015, 2016; Swan et al., 2017), we first tested for report failures of the irrelevant attribute by comparing performance on those two

**Table 1** Performance (% correct) for the report of the relevant and irrelevant attribute in pre-surprise, surprise, and across all four post-surprise trials across experimental groups in Experiment 1 (each row represents data from one group)

| Groups | | Response attribute | | | | |
|---|---|---|---|---|---|---|
| | | Relevant attribute | | | Irrelevant attribute | |
| | | Pre-surprise | Surprise | Post-surprise | Surprise | Post-surprise |
| Relevant attribute | Presentation | | | | | |
| Color | Foveal | 99.2% | 95.2% | 98.8% | 86.7% | 97.6% |
| | Parafoveal | 99.6% | 95.2% | 100.0% | 38.1% | 97.6% |
| Shape | Foveal | 98.2% | 85.0% | 98.8% | 100.0% | 100.0% |
| | Parafoveal | 96.7% | 85.0% | 96.3% | 95.0% | 100.0% |

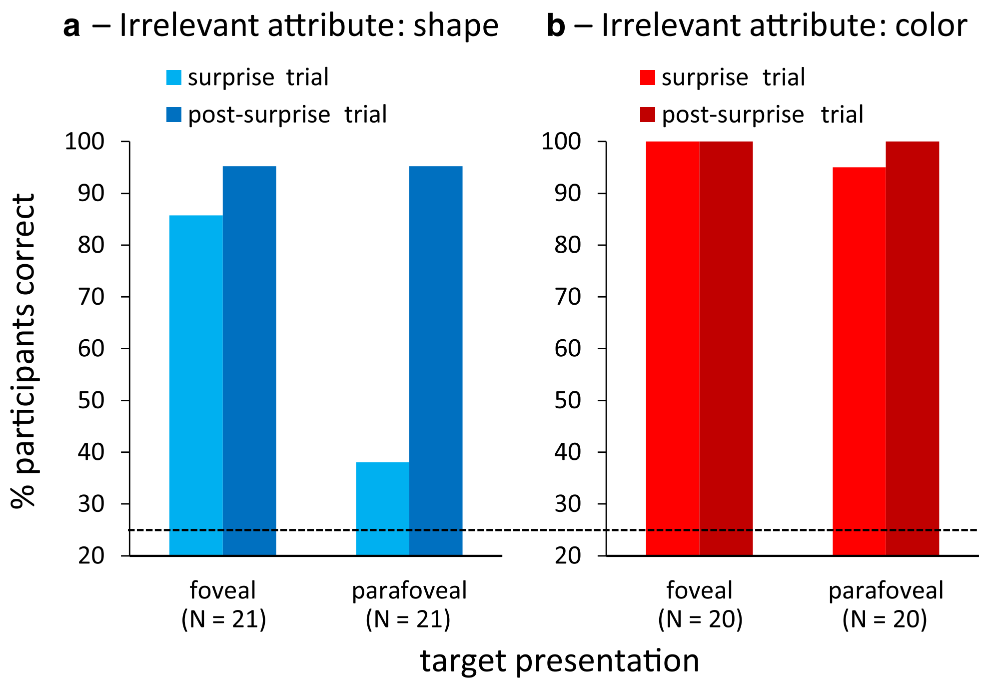


**Fig. 2** Results from Experiment 1 for the irrelevant attribute. **Panel A:** Percentage of participants indicating the correct shape on the surprise (light blue) as well as the first post-surprise trial (dark blue). **Panel B:** Percentage of participants indicating the correct color on the surprise (light red) as well as the first post-surprise trial (dark red). *Note:* No error bars are shown in the figure as data is based on the raw percentage of participants giving a correct response in each group (N: number of participants tested in the respective group). Dotted line indicates chance level (25%)

trials separately for each experimental group. Then, to examine our hypothesis that parafoveal presentation decreased performance compared to foveal presentation, we compared performance on the surprise trial between experimental groups. Figure 2A illustrates results for participants with shape as irrelevant attribute. In the foveal condition, almost all participants indicated the correct shape and there was no significant difference between the surprise (18/21) and the first post-surprise trial (20/21), $\chi^2(1, N = 42) = 1.11$, $p = .293$, $\phi = 0.16$, with a Bayes factor slightly in favor of H0, $BF_{01} = 2.81$. In the parafoveal condition, however, significantly fewer participants indicated the correct shape on the surprise (8/21), compared to the first post-surprise trial (20/21), $\chi^2(1, N = 42) = 15.43$, $p < .001$, $\phi = 0.61$, and the Bayes factor indicated very strong evidence in favor of H1, $BF_{10} = 1098.98$. Further, the difference between responses on the surprise trial in the foveal (18/21) and parafoveal (8/21) groups was significant (the two light blue bars in Fig. 2A), $\chi^2(1, N = 42) = 10.10$, $p = .001$, $\phi = 0.49$, with very strong evidence in favor of H1, $BF_{10} = 54.66$. In sum, results from groups with shape as the irrelevant attribute confirmed lower performance on the surprise trial with parafoveal presentation, but no effect with foveal presentation. In contrast, Fig. 2B shows that participants with color as the irrelevant attribute showed no decrease in performance on the surprise compared to the first post-surprise trial, no matter whether the target was presented foveally or parafoveally. As both conditions resulted in 100% correct performance (20/20), no $\chi^2$ could be computed across surprise and first post-surprise trial in the foveal condition in JASP, but the Bayes factor was clearly in favor of H0, $BF_{01} = 10.76$. Further, neither comparing performance on the surprise to the first post-surprise trial in the parafoveal condition, nor comparing foveal versus parafoveal presentation on the surprise trial revealed a significant difference (both comparisons were based exactly on the same raw numbers: 19/20 vs. 20/20), $\chi^2(1, N = 40) = 1.03$, $p = .311$, $\phi = 0.16$, and the Bayes factor was moderately in favor of H0, $BF_{01} = 5.38$.

## Discussion

As expected, performance on pre- and post-surprise trials (see Table 1) confirmed that reporting one or both attributes of the target was very easy, no matter whether the target was presented foveally or parafoveally. In the foveal condition of Experiment 1, we replicated the results from Eitam et al. (2015; Exp. 2): Participants easily managed to report the irrelevant attribute of the target, even on the surprise trial. In the parafoveal condition, however, results only partly matched our predictions: Whereas we found report failures for shape as surprise attribute, there were none for color as surprise attribute. Previous *attribute amnesia* studies did not observe this asymmetry (Chen & Wyble, 2015, 2016). In contrast, better performance for color than shape has already been observed in the *inattentional blindness* study by Rock et al.

(1992): Of the 75% of participants who actually had noticed the additional item, nearly all were able to correctly report its color and location, whereas they were at chance when asked to indicate its shape. Irrespective of the observed asymmetry, Experiment 1 shows that an irrelevant attribute can be reported on a surprise trial when presented foveally, but may become inaccessible when presented just slightly off fixation. It seems remarkable that such a small difference in eccentricity changed performance, but previous research has already shown that there are performance decrements in shape identification and change detection in the parafoveal range (e.g., Geringswald et al., 2016; Holmes et al., 1977).

There are at least two non-exclusive explanations for these decrements. On the one hand, performance may be better in the fovea simply because of high visual acuity. On the other hand, spatial attention may already be pre-allocated to the fovea, whereas attention needs to shift towards the target in the parafoveal condition. Therefore, Experiments 2 and 3 examined whether the pre-allocation of spatial attention may have an effect on the report of irrelevant shape information on the surprise trial.

## Experiment 2

In Experiment 2, we used a peripheral cuing procedure to test whether the pre-allocation of exogenous attention affects participants' ability to retrieve irrelevant shape information. The cue was non-predictive of the target location so that there was no incentive to voluntarily attend to it. Only the parafoveal condition with color as relevant attribute and shape as irrelevant attribute was run. On the surprise trial, the non-predictive cue was either valid or invalid.

### Methods

#### Participants

In Experiment 2, 40 new participants (17 men) aged between 18 and 49 years (mean: $m$ = 24.4, $SD$ = 6.82) were tested, again mostly first-year psychology students participating for course credit.

#### Apparatus, stimuli, design, and procedure

Apparatus, stimuli, design and procedure were as in Experiment 1 with the following exceptions. The monitor was changed, stimuli were now displayed on a VIEWPixx/3D (VPixx Technologies Inc., Saint-Bruno, QC, Canada), with a resolution of 1,920 x 1,080 pixels, running at 120 Hz. All targets were presented parafoveally and only the condition with color as relevant and shape as surprise attribute was run. Most importantly, a non-predictive cue was introduced before target presentation (see Fig. 1B). The cue consisted of a white outline circle (x = 0.28, y = 0.35, 275 cd/m$^2$), 1 dva in diameter (outline 2 pixels thick), and was presented in one of the four possible target locations. The cue was presented for 50 ms and was followed by a 50-ms ISI. During practice and in pre- and post-surprise trials, the cue was shown at the target location on 25% of trials (valid trials) and at one of the three remaining positions on the remaining 75% of trials (invalid trials). Further, participants were explicitly informed that the cue was non-predictive of the target location and were asked to ignore it: Instructions were the same as for the parafoveal condition of Experiment 1, but the instruction screen contained an additional phrase ("Ignore the first stimulus (the flashed ring)") and the experimenter specified this in his verbal instructions ("Before the appearance of the stimulus, a small white flash will be shown somewhere on screen. You do not need to pay any attention to this"). Stimulus validity was controlled, however, on the surprise trial. Participants were assigned to two groups, with one group receiving a valid and the other group receiving an invalid cue on the surprise trial. Cue validity on the post-surprise trial was again random.

### Results

Breaks of fixation or blinks occurred on 17.1% of trials and the surprise trials had to be postponed to the 13th trial for five participants (three from the invalid, two from the valid group) due to a gaze error on the 12th trial (note that those postponed trials always had the same validity as the surprise trial).

Table 2 lists average performance for the relevant (i.e., color) and irrelevant (i.e., shape) attribute, separate across all pre-surprise trials, the single surprise trial, and across all four post-surprise trials. Again, performance was high (> 90% correct) throughout the experiment, but dropped slightly even for the relevant attribute on the surprise trial.

In addition to Table 2, Fig. 3A illustrates performance for the irrelevant attribute shape on the surprise and the first post-surprise trial. First, we tested for report failures on the surprise trial compared to the first post-surprise trial. We obtained a significant difference for the invalid group (12/21 on surprise vs. 18/21 on first post-surprise), $\chi^2$(1, N = 42) = 4.20, $p$ = .040, ϕ = 0.32, and a close-to-significant difference for the valid group (12/19 on surprise vs. 17/19 on first post-surprise), $\chi^2$(1, N = 38) = 3.64, $p$ = .056, ϕ = 0.31. In both cases, the Bayes factor was weakly in favor of H1, $BF_{10}$ = 2.51 for invalid and $BF_{10}$ = 1.85 for valid cues, respectively. Directly comparing performance after valid and invalid cues on the surprise trial did not reveal a significant difference, $\chi^2$(1, N = 40) = 0.15, $p$ = .698, ϕ = 0.06, and the corresponding Bayes factor was weakly in favor of H0, $BF_{01}$ = 2.53.

**Table 2** Performance (% correct) for the relevant (always color) and irrelevant (always shape) attribute in pre-surprise, surprise and across all four post-surprise trials across experimental groups in Experiments 2 and 3 (each row represents data from one group). Note that "validity" refers to the between-subjects variable "validity on surprise trial" (i.e., the different rows do not reflect performance on valid vs. invalid pre- or post-surprise trials, but show the proportion of participants with a correct response in the respective group)

| Groups | | Response attribute | | | | |
|---|---|---|---|---|---|---|
| | | Relevant attribute (color) | | | Irrelevant attribute (Shape) | |
| | | Pre-surprise | Surprise | Post-surprise | Surprise | Post-surprise |
| Experiment (cue type) | Validity | | | | | |
| 2 (non-predictive) | Invalid | 99.6% | 85.7% | 97.6% | 57.1% | 92.9% |
| | Valid | 99.5% | 79.0% | 92.1% | 63.2% | 94.7% |
| 3 (predictive) | Invalid | 96.2% | 81.0% | 94.1% | 38.1% | 83.3% |
| | Valid | 99.2% | 90.5% | 98.8% | 76.2% | 96.4% |

## Discussion

Results from Experiment 2 remain somewhat inconclusive. On the one hand, cue validity on the surprise trial did not have a substantial effect on performance. On the other hand, the Bayes factor indicated only weak evidence in favor of the null hypothesis. A larger sample size will be needed to draw any firm conclusions. That being said, the current results are consistent with previous failures to show that non-predictive peripheral cues improve performance at the cued location, especially with accuracy measures (Kerzel, Gauch, & Buetti, 2010; Kerzel, Zarian, & Souto, 2009; Pack, Carney, & Klein, 2013; Prinzmetal, McCool, & Park, 2005). Also, non-predictive cues do not modulate the precision of visual working memory representations with post-cue display durations of more than 400 ms (Bays, Gorgoraptis, Wee, Marshall, & Husain, 2011).

Further, the mere presence of *blindness* or *amnesia* for the surprise attribute shape could not be established in the current experiment. The $\chi^2$ tests revealed p-values close to $p = .05$ and

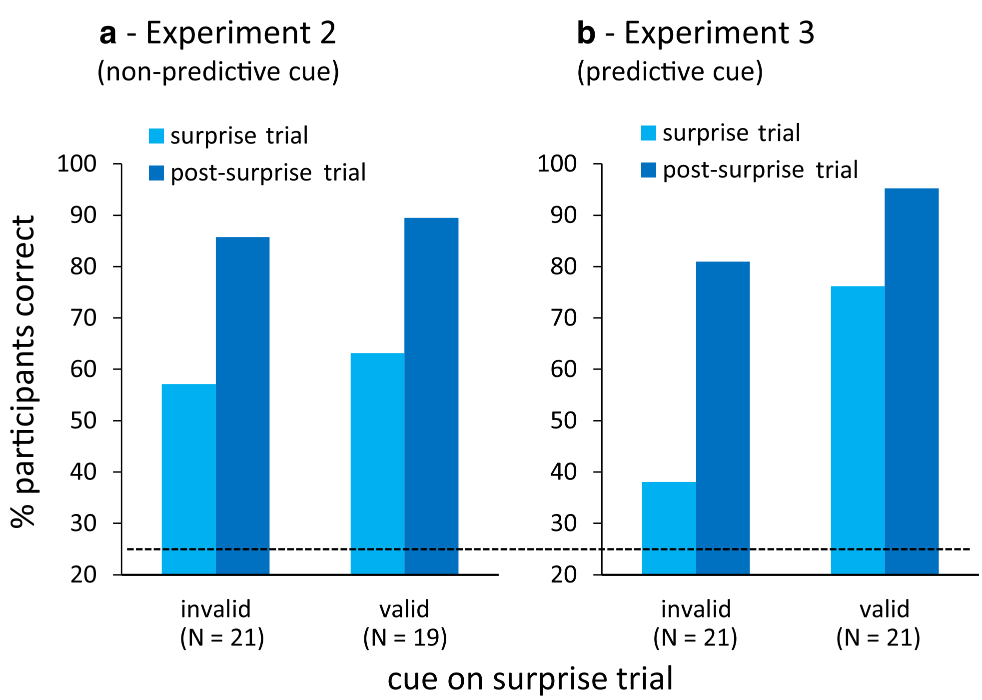


**Fig. 3** Results for the irrelevant attribute from Experiment 2 (**panel A**) and Experiment 3 (**panel B**). Percentage of participants giving the correct response for target shape on the surprise (light blue) as well as the first post-surprise trial (dark blue). In both experiments, "invalid" and "valid" refer to the between-subject variable "validity on surprise trial." Cues on the first post-surprise trial may not have the same validity as on the surprise trials, but were random in Experiment 2 and always invalid in Experiment 3. *Note:* No error bars are shown in the figure as percentages reflect the raw number of participants giving a correct response in each group (N: number of participants tested in the respective group). Dotted line indicates chance level (25%)

the Bayes factors suggested only weak evidence in favor of a difference between the surprise and the first post-surprise trial. Numerically, around 60% of participants were correct on the surprise trial, which is a slightly higher percentage than typically observed in *attribute amnesia* studies (Born et al., 2019; Chen & Wyble, 2015, 2016; Jiang et al., 2016; Swan et al., 2017), but roughly corresponds to the percentage of participants being able to report the irrelevant information in the studies by Eitam and colleagues (Eitam et al., 2015; Eitam et al., 2013). It is possible that the effect was attenuated by the cue, for instance by providing an alerting signal that may automatically activate attentional resources (possibly irrespective of location). Just as for cue validity, a larger sample size will be needed to draw any firm conclusions.

## Experiment 3

In Experiment 3, we examined whether predictive spatial cuing has an effect on the ability to report irrelevant shape information on the surprise trial.

### Methods

#### Participants

For Experiment 3, 50 new participants (39 women) aged between 17 and 51 years (mean: $m$ = 23.7, $SD$ = 7.15) were recruited. Data of eight participants were subsequently removed from analyses, however, as they had already participated in another *attribute amnesia* study in the lab.

#### Apparatus, stimuli, design, and procedure

Apparatus, stimuli, design, and procedure were identical to Experiment 2 with the following exceptions. The cue was predictive of the target location and was shown at the target location on 75% of trials. Participants were informed that the cue appeared at the target location on a majority of trials and were asked to shift their attention to the cued location: Instructions were the same as for the parafoveal condition of Experiment 1, but the instruction screen contained an additional phrase ("The first stimulus (the flashed ring) indicates the location of the target in most cases") and the experimenter specified this in his verbal instructions ("Before the appearance of the stimulus, a small white flash will be shown that indicates the location of the stimulus in 75% of cases. Shift your attention to this white circle, without moving your eyes"). For the practice trials, the order of the 13 valid and four invalid trials were randomized for each participant. On experimental trials, the order was fixed. Invalid trials always occurred on the second, fourth and seventh trial, whereas the remaining pre-surprise trials were valid. Thus, on the last four trials before the surprise test (pre-surprise trials 8–11), the cues were valid for all participants to induce an expectancy for a valid trial also on the surprise trial. On the surprise trial, however, the cue was valid for half the participants and invalid for the other half. Further, validity on the post-surprise trials was likewise fixed such that the first and third post-surprise trials were always invalid, whereas the second and fourth post-surprise trials were always valid.

### Results

Breaks of fixation or blinks occurred on 14.7% of trials and the surprise test had to be postponed to the 13th trial for five participants (four from the invalid, one from the valid group) and to the 16th trial for one participant from the valid group due to a gaze error on the 12th and subsequent trials (note that those postponed trials always had the same validity as the surprise trial).

Table 2 lists performance for the relevant (i.e., color) and irrelevant (i.e., shape) attribute, separately for pre-surprise, surprise, and post-surprise trials. There was a drop in performance on the surprise trial in the color task, which was more pronounced in the group with an invalid cue on the surprise trial. Further, performance was comparatively low for the shape task on the post-surprise trials in the invalid group. Note, however, that this difference was not due to cue validity on those trials, as post-surprise trials were the same in both groups. It seems that irrespective of the specific conditions, group performance was somewhat lower in the invalid group.

We compared performance on the surprise trial to the first post-surprise trial (see Fig. 3B) and observed a significant difference for the invalid group (8/21 on surprise vs. 17/21 on first post-surprise), $\chi^2(1, N = 42) = 8.01$, $p = .005$, $\phi = 0.44$, and a Bayes factor indicating strong evidence for H1, $BF_{10} = 18.58$. For the valid group, the difference to the first post-surprise trial was close to significant (16/21 on surprise vs. 20/21 on first post-surprise), $\chi^2(1, N = 42) = 3.11$, $p = .078$, $\phi = 0.27$, but the Bayes factor neither favored H1 nor H0, $BF_{10} = 1.09$. We also compared performance on the surprise trial and found more correct participants with a correct response in the valid than in the invalid group (8/21 in valid vs. 16/21 in invalid group), $\chi^2(1, N = 42) = 6.22$, $p = .013$, $\phi = 0.39$, with moderate evidence in favor of H1, $BF_{10} = 7.59$. Figure 3 suggests that there may also be a difference between valid and invalid groups on the first post-surprise trial (17/21 in valid vs. 20/21 in invalid group). The corresponding test was not significant, though, $\chi^2(1, N = 42) = 2.04$, $p = .153$, $\phi = 0.22$, with a Bayes factor slightly in favor of H0, $BF_{01} = 1.66$.

### Discussion

In Experiment 3, the valid cue reduced report failures for shape on the surprise trial. Thus, the pre-allocation of endogenous spatial attention may modulate the processing of irrelevant information. However, a valid cue did not completely eliminate shape *amnesia* or *blindness* because performance in the valid group was lower on the surprise compared to the first post-surprise trial, even if this effect was not quite significant.

## General discussion

We investigated whether report failures for irrelevant attributes of target objects differed between the fovea and the periphery, and between attended and unattended locations. When prompting participants for irrelevant attributes in a surprise question, simple shapes and colors could be reported when the object was presented foveally, in accordance with previous research (Eitam et al., 2015). However, presenting the same object just slightly away from the fovea led to more than 60% of participants failing to report the correct shape in a four-alternative forced choice task (Experiment 1). Presenting a predictive peripheral cue (75% valid) prior to the target modulated this effect. A valid cue on the surprise trial resulted in more successful shape reports compared to an invalid cue (Experiment 3). Thus, the pre-allocation of endogenous spatial attention can promote the processing of irrelevant shape information. This may also have played a role in the good performance in the foveal condition of Experiment 1, where the target stimulus was presented in the natural focus of spatial attention. A non-predictive cue (25% valid) did not seem to have the same impact as the informative cue, although results remain highly inconclusive (Experiment 2). Finally, when color was the irrelevant attribute prompted on the surprise trial, participants had no difficulty in selecting the correct alternative, no matter whether the object was presented foveally or parafoveally (Experiment 1).

As mentioned, based on previous results (Born et al., in 2019; Chen & Wyble, 2015, 2016), we had not expected an asymmetry between color and shape (but see Rock et al., 1992). Note also that in other studies with comparatively simple color pop-out displays, the majority of participants were not able to indicate the last target color in a surprise question (Born et al., 2019; Chen & Wyble, 2015). In these studies, the target was likewise presented parafoveally and the presented distractors were either black or gray, such that on each trial, the target was the only colored object. In the case of our own previous study (Born et al., 2019), the target was not masked and presented for 500 ms (Experiment 2), just as in the current experiments. These previous studies demonstrate that parafoveally presented color information does not always result in a robust representation available for conscious report in a surprise question. Thus, the boundary conditions for report failures may differ between color and shape. For irrelevant shape information, a slight offset from the fovea may be sufficient to result in report failures. For color, the presentation of distractors or placeholders prior to the target display may be necessary to induce report failures. The crucial point of the current study is that small changes in the display or task can have a big impact on performance. Thus, it is possible that the small differences in procedure explain the discrepancies between previous findings (Chen & Wyble, 2015; Eitam et al., 2015). Indeed, it has been demonstrated that under different conditions, even foveally presented attributes may not always be reportable on a surprise trial (see, e.g., Chen, Swan, & Wyble, 2016; Chen & Wyble, 2016; Eitam et al., 2013; Swan, Collins, & Wyble, 2016; Tapal, Yeshurun, & Eitam, 2019). For instance, in one variant of the surprise paradigm (see Eitam et al., 2013; Wyble, Hess, O'Donnell, Chen, & Eitam, 2019), a disc with a differently colored surrounding ring is presented right at screen center for 500 ms. When asked to focus on the color of the outer ring, participants failed to report the color of the central disc on a surprise trial. Eitam et al. (2015) speculated that this failure may have been due to the fact that circle and ring are interpreted as two distinct objects. Contrary to their conclusions, the current results demonstrate that report failures under minimal load (i.e., one single object) can even occur when relevant and irrelevant attributes belong to the same object, at least when the object is presented outside the fovea.

The second manipulation that had a dramatic effect in the current experiments was the presentation of a predictive spatial cue prior to the target display. It is quite remarkable that the cue was effective because the target appeared with a sudden onset and thus should have attracted attentional resources automatically (Yantis & Jonides, 1984). It was presented for 500 ms without mask, a comparatively long duration (e.g., Shibuya & Bundesen, 1988). Any advantage in the speed of processing resulting from valid cues should have no impact on measures of the quality of perceptual representation, as there was enough time to process the target. In addition, the object was the only response-relevant item in the primary task and therefore should have been selected by an attentional mechanism, favoring the processing of irrelevant object attributes (Duncan, 1984; Kahneman, Treisman, & Gibbs, 1992). Moreover, the target was presented on its own, that is, the target did not have to be filtered out from distractors competing for processing resources (Lavie, 1995). Finally, feature binding (Treisman & Gelade, 1980) was not even necessary to solve the task. Without competing stimuli that may induce misbindings, participants could simply base their answer on the last shape or color seen. Therefore, why should it matter that endogenous spatial attention was pre-allocated at the upcoming target location?

### Attentional allocation and inattentional blindness

One possibility is that attention alone determined success or failure on the surprise trial, but that participants pursued different strategies of attentional allocation across the different tasks in the current study. In the color group of Experiment 1 (and potentially also in the non-informative cuing condition of Experiment 2), participants may have kept attention narrowly focused at fixation. In order to avoid breaks of fixation, they may also have succeeded in inhibiting any covert capture of attention by the cue or target despite their sudden onsets. In other words, report failures may have been due to inattention. As mentioned above, a binding of features to objects was not necessary to do the task and keeping a narrow focus on fixation may have been sufficient to report color. In contrast, with predictive cuing (Experiment 3), participants may have followed the explicit instructions to shift attention to the cued location. Further, when shape was the relevant attribute (Experiment 1), they may have allowed attention to be captured by the target as the shape task may have benefitted more from covert attention than the color task. However, in contrast to classic inattentional blindness phenomena (Rock et al., 1992; Simons & Chabris, 1999), we can exclude that the current findings were due to complete "phenomenal blindness" (Eitam et al., 2015): Although participants may not be able to report the shape of the target, they were definitely aware of the fact that there was "something." Further, inattention cannot explain report failures in *attribute amnesia* studies where the surprise attribute was relevant for target selection (Chen & Wyble, 2016; see next paragraph). Overall, we do not think our effects were caused by inattention. Put into a slightly different framework, we think report failures are unlikely to result from early selection, but may rather be due to late selection mechanisms for memory, response selection or conscious awareness (see e.g., Lavie, Hirst, de Fockert, & Viding, 2004).

## Consolidation in working memory: *attribute amnesia*

Instead of a lack of attentional processing, Chen and Wyble (2016) propose that a lack of consolidation of the irrelevant attribute in visual working memory is responsible for report failures. In one experimental series (Chen & Wyble, 2016; Exp. 3a–3c), they presented four colored letters on each trial and asked participants to report the location of the letter that had the same color as the fixation cross, with colors varying from trial to trial. When the fixation cross and the target display were presented simultaneously, the majority of participants failed to report the last target color on a surprise trial. However, when the fixation cross was presented first, followed by a mask and only then the target display was shown without the fixation cross, 80% of participants were able to correctly report the last target color on the surprise trial. The authors argue that in both cases, an attentional selection by color occurred, but it was only necessary to consolidate this color in visual working memory when the target-defining color was presented slightly before the target display. They further propose that consolidation in working memory does not only depend on general task relevance of the attribute, but on the expected usefulness of consolidation (Chen & Wyble, 2016). In other words, an attribute needs to be relevant for a delayed response to be consolidated. The current results demonstrate that while this selection mechanism works even in surprisingly easy tasks (Chen & Wyble, 2015, 2016; Eitam et al., 2015; Eitam et al., 2013), there may nevertheless be boundary conditions. When perceptual and cognitive demands are truly minimal, information could be "accidentally" consolidated although it is neither task-relevant nor useful in the near future. For instance, easy categorical color or shape information may slip into the consolidation process when a single object is presented within the focus of gaze or spatial attention as in the current experiments. Interestingly, foveal presentation or spatial pre-cuing may facilitate an already very easy task even further to a task with minimal perceptual and cognitive demands. In contrast, consolidation may not be guaranteed by visual pop-out (Born et al., 2019; Chen & Wyble, 2015) or by the mere absence of distractors when the target is presented parafoveally (see current experiments). Importantly, ceiling performance in the primary task or in control trials when both attributes are expected to be queried is clearly not a good predictor of whether irrelevant attributes may be represented in visual working memory or not on surprise memory tests.

## Relevance-based selection for visual awareness: *seeing without knowing*

On a slightly different note, Eitam and colleagues (Eitam et al., 2015; Eitam et al., 2013) interpret their findings in terms of selection for visual awareness. More precisely, they differentiate between phenomenal blindness where one may not even be aware that there was "something," and lack of knowledge activation (*seeing without knowing*) where one is aware that there was a stimulus but cannot report what it was (see also Block, 1996; Lamme, 2004). Knowledge activation is supposed to depend on a selection mechanism purely based on the relevance of information. As already mentioned, we can indeed exclude phenomenal blindness as a source for the current effects, as participants were definitely aware of the fact that there was a target. In accordance with Eitam and colleagues (Eitam et al., 2015; Eitam et al., 2013), selection was also clearly based on relevance. However, in the current setup, we cannot affirm or exclude that participants were consciously aware of the irrelevant attribute at some point, especially given the 500-ms blank interval after target presentation. Chen and Wyble (2015) argue that at least in some of their experiments, participants must have been aware of the surprise attribute, as it determined target selection; for instance, when they asked participants to report the location of the letter that had the same color as the fixation cross (Chen & Wyble, 2016; Exp. 3c). On one further point, however, Chen and Wyble (2016) and Eitam et al. (2015) agree: Report failures are not due to representations that are formed, but quickly forgotten; rather all authors assume that consolidation in working memory or knowledge activation never occurred. The current experiments do not speak to this issue. However, one possible way of exploring this question is to use a procedure with an informative retro-cue, presented sometime after the target display (Souza & Oberauer, 2016; Theeuwes, Kramer, & Irwin, 2011): if there was no consolidation or knowledge activation of the irrelevant information, such a retro-cue should have no effect.

## Conclusions

The current experiments demonstrate that irrelevant attributes of a target object presented on its own and for a relatively long duration may not always be available for conscious report after the object has disappeared. However, predictive spatial cuing and foveal presentation of the object can increase the proportion of successful reports substantially. In accordance with previous research (e.g., Chen & Wyble, 2016), we suggest that these modulations are not due to differences in perceptual processing, but result from late selection for working memory or visual awareness.

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**Data availability** Data for all experiments are available on OSF: https://osf.io/2xc7d/

None of the experiments were preregistered.

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