Amnesia for object attributes: Failure to report attended information that had just reached conscious awareness

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Abstract (150 words)

We intuitively believe that when we become consciously aware of a visual stimulus, we will be able to remember it for immediate report. The present study provides a series of striking demonstrations that are inconsistent with such an intuition. Four experiments showed that in certain conditions, participants cannot report an attribute (e.g. letter identity) of a stimulus, even when that attribute had been attended and reached a full state of conscious awareness just prior to the question. We term this effect *attribute amnesia* and it occurs when participants locate a target using one attribute for several repetitions and are then surprisingly asked to report that attribute. This discovery suggests that attention to a stimulus attribute and being aware of it are insufficient to ensure its reportability immediately afterwards. Furthermore, our results strongly imply that cognitive processes have separate designations of what information will be attended and what will be remembered.

Keywords: Attribute Amnesia; Awareness; Attention; Working memory

Introduction

Although we experience a rich, detailed visual world, the memory traces that we form are quite fragmented, as shown in two striking phenomena: *inattentional blindness* and *change blindness*. Inattentional blindness occurs when neurologically normal participants are incapable of detecting an unexpected, clearly visible stimulus that appears in the visual field (e.g., Mack & Rock, 1998; Most et al., 2001; Most, Scholl, Clifford, & Simons, 2005; Scholl, Noles, Pasheva, & Sussman, 2003; Simons & Chabris, 1999). For instance, many participants failed to notice a woman wearing a gorilla suit who unexpectedly walked across the display in a short video (Simons & Chabris, 1999). Change blindness refers to findings that people are poor at detecting large changes in a visual image or scenario, such as a real-life conversation (e.g., Mitroff, Simons, & Levin, 2004; Rensink, O'Regan, & Clark, 1997; Scholl, 2000; Simons & Levin, 1998; Simons & Rensink, 2005).

These effects indicate a failure to notice something (an unexpected stimulus or a change) that should otherwise be easy to perceive and were of critical importance not just because they violate our intuitions about memory (Simons & Chabris, 2011), but also because they have fundamentally changed our understanding of how the mind interacts with the world.

The distinction between blindness and amnesia

The aforementioned effects are described as “blindness” (i.e. a failure to perceive, Mack & Rock, 1998) and set the stage for examining the distinction between what is visible to the eye and what is stored in memory. For example, there has been an exploration of the possibility that stimuli may be consciously perceived at one moment, yet fail to produce a memory trace that could be reported. This putative phenomenon has been described as amnesia (Moore & Egeth, 1997; Wolfe 1999) [1] but there has not yet been evidence that directly confirms the amnesia hypothesis, despite some observations that indirectly support it. For example Moore & Egeth (1997) found that unreportable stimuli influence perception but it is not clear that participants were aware of those stimuli.

The present study attempts a more direct demonstration of such amnesia by determining whether people can even fail to report an attribute of a stimulus that had reached awareness. We define an attribute as any aspect of a stimulus (e.g. color, identity) as suggested by Kanwisher & Driver (1992).

We begin by delineating between two levels of conscious awareness (see Lamme 2004; Block 1996). Some stimuli are perceived in the background without being the focus of attention (phenomenal awareness), while another level of conscious awareness refers to stimuli that are the focus of attention (access awareness).

It is easily demonstrated that participants may not be able to report individual stimuli that reach only *phenomenal* awareness as exemplified by classic experiments involving iconic memory and rapid presentation. Specifically, when the visual system is overloaded with information, participants have phenomenal

1 Moore & Egeth (1997) suggested that inattentional blindness might reflect a failure to remember a perceived stimulus (which may not reach awareness), which was termed "inattentional amnesia" by Wolfe (1999) who suggested that even stimuli reaching full awareness may not be remembered.

awareness of many stimuli, but have difficulty recognizing or reporting them in a subsequent test (Coltheart, 1980; Sperling, 1960; Potter, 1976).

Conversely, information that is attended and reaches an *access* level of awareness is assumed to be reportable (e.g., Lamme, 2004). However it remains unknown whether this assumption must be true. In other words, if a person becomes aware of an attended attribute of a visible stimulus, will they necessarily be able to report that attribute immediately afterwards? A finding that a stimulus that had reached access awareness was not immediately reportable would constitute evidence of amnesia. This logic leads to our present study. Henceforth, the terms awareness and conscious perception will be used interchangeably to refer to access awareness.

The present study

We have discovered a method to reliably induce neurologically normal participants to be aware of a stimulus attribute (e.g. color), and yet be unable to report that attribute in an immediately following surprise memory test similar to those used by inattentional blindness studies (e.g., Rock, Linnett, Grant, & Mack, 1992). In our paradigm, participants saw a series of trials in which they were required to report the *location* of the target (e.g., letter) among a set of three distractors (e.g., numbers). The target was localized by a critical attribute which was varied among the experiments (e.g., find a letter among numbers in Experiments 1 and 4, find an even number among odd numbers in Experiment 2, and find a colored letter among black letters in Experiment 3).

Then, on one critical trial respondents were unexpectedly asked to report the same critical attribute that they had just used to find the target by choosing the critical attribute among distractor attributes in a forced-choice array. If respondents cannot recognize this attribute, then the data would suggest that respondents were aware of this attribute, but could not remember it – *attribute amnesia*. Note that this paradigm only allows one critical trial of data per participant, because once participants experience a surprise test trial, they would develop an expectation to remember the critical attribute. This was demonstrated by four additional control trials following the critical trial, in which participants were asked also to report the critical attribute of the target.

Using this method, we demonstrate that participants can select a target from a set of three distractors and yet be unable to report all of its attributes, including even the critical attribute that they had just used to find the target less than a second before.

Experiment 1

In the first experiment, in a modification of the surprise test used by Rock, Linnett, Grant, & Mack (1992), we investigated whether participants can report the attributes of a consciously perceived object.

Method

Sample size. For this and all subsequent experiments we used a predetermined sample size of 20 participants per experiment. This sample size was based on pilot work that indicated the magnitude of the effect that could be expected. No participants were excluded or replaced in any of these experiments.

Participants. Twenty Pennsylvania State University undergraduates participated in this experiment in exchange for course credits. All of them reported normal or corrected-to-normal visual acuity.

Apparatus. Stimuli were presented on a 17-in CRT monitor with a resolution of 1024×768 pixels. Participants viewed the screen from approximately 50 cm away and entered responses via a computer keyboard. The experiment was programmed by using MATLAB with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997).

Stimuli and Procedure. As is shown in Figure 1, each trial began with a black fixation cross (0.62° of visual angle in size) and four black placeholder circles (0.62°) on a gray background (RGB: 150/150/150). The four placeholders were displayed on the four corners of an invisible square (6.25° × 6.25°) centered in the screen, with the fixation cross in its center. After a variable duration (800-1800 ms), the stimulus array was presented for 150 ms. The stimulus array included one English letter target (A, B, D, or E; 0.86°×0.62°) and three Arabic number distractors (2-9, 0.86°×0.62°). Each stimulus was randomly assigned one of four colors: red (RGB: 200/0/0), blue (RGB: 0/200/200), yellow (RGB: 200/200/0), or purple (RGB: 190/45/200) with no repetition of color on each trial. The mask then appeared for 100 ms. The mask consisted of a black symbol (@) and a pattern of 4 colored lines (displayed in a hashmark configuration, see Figure 1), one of each of the aforementioned four colors. After a 400 ms blank screen following the disappearance of the mask, four black numbers (1-4) were presented at the same locations of the four placeholders until participants respond with the number corresponding to the location of the target.

Participants completed 160 trials in this experiment. In the first 155 trials, participants were asked to report the location of the letter by pressing one of four corresponding number keys (1-4). On the 156th trial (i.e. the critical trial) the participants were unexpectedly presented with two forced-choice arrays in succession and asked to report the identity (they saw 4 different letters in black ink and were asked to pick the target letter) and the color of the target letter (they saw 4 different colored lines and were asked to pick the colored line that matches the color of the target letter), prior to reporting its location. The four possible choices for each question (four black letters or four colored lines) were presented in an order that was randomly selected on each trial. The order of the identity and color report tasks was counterbalanced across participants. The participants then received four more control trials that were identical to the critical trial.

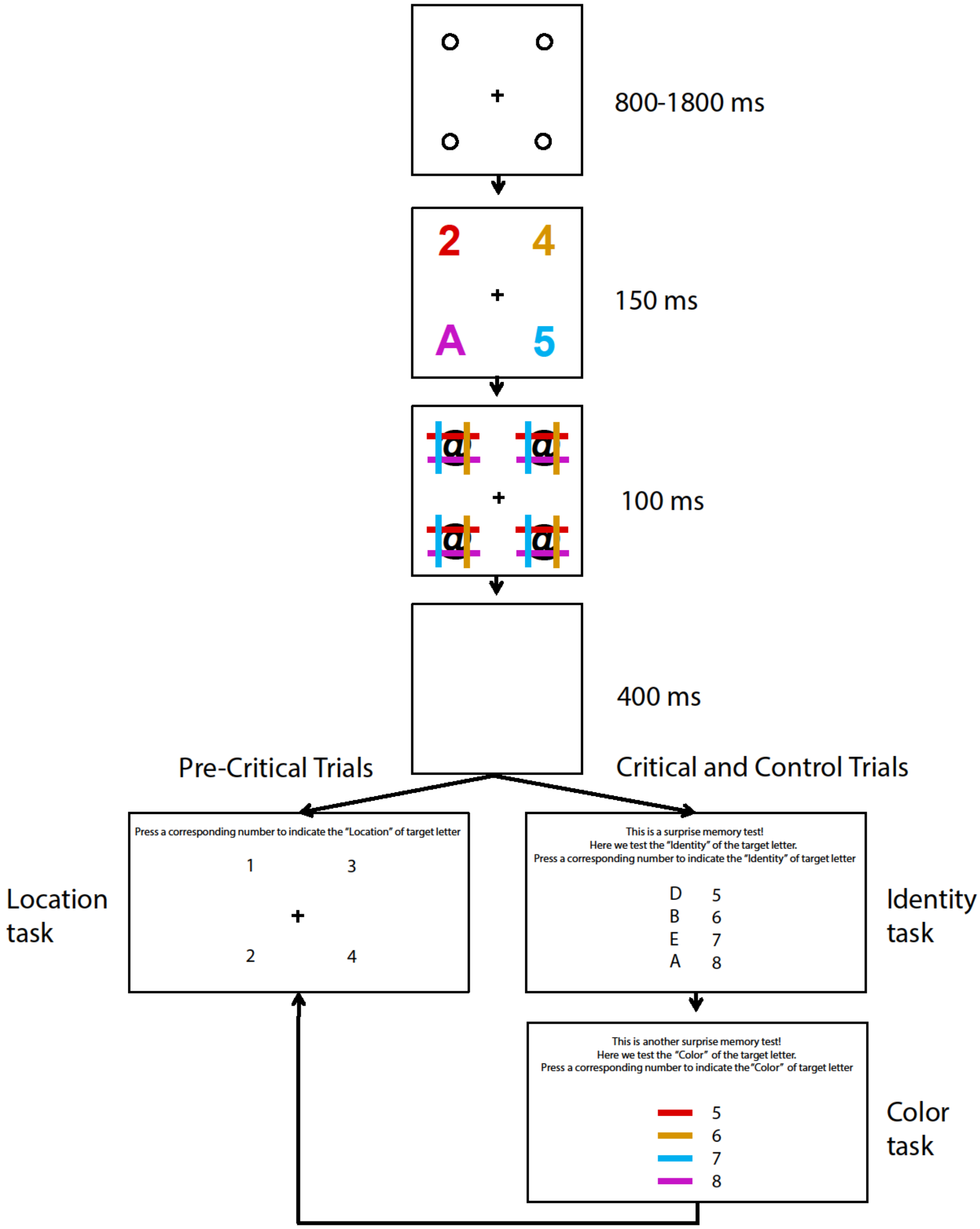

Figure 1: Sample trial sequence of different types of trials in Experiment 1. Note that stimuli are depicted larger than their true scale for the purpose of illustration. The target localization question on the screen read "*Press a*

corresponding number to indicate the "Location" of target letter". The surprise questions of identity and color on the screen were "*This is a surprise memory test! Here we test the "Identity" of the target letter. Press a corresponding number to indicate the "Identity" of target letter"* and "*This is another surprise memory test! Here we test the "Color" of the target letter. Press a corresponding number to indicate the "Color" of target letter"* respectively. The order of these two surprise tests was counterbalanced across participants.

Results

Before the critical trial, 89% of responses were correct on the target localization task, indicating that it is easy for participants to locate the target by using the critical attribute.

On the critical trial, we first separately analyzed the data from the two groups based on the order of the surprise tasks (identity report first vs. color report first) and found the result was almost the same in these two groups in all of the experiments. Accordingly, these two groups of trials were collapsed in the present study. Only 6 of 20 (30%) participants correctly reported the color of the target letter, which is not much better than chance level of 25% (since there were four choices). More surprisingly, the performance on the identity report task (25% correct) was exactly at chance level. These results demonstrate that in this task, people are not capable of reporting a task-relevant attribute of a stimulus that had reached awareness less than one second ago, an effect that is referred to here as *attribute amnesia*. Moreover, unlike the color and identity tasks, participants' performance of the localization task on the critical trial (80% correct) was approximately as good as that in pre-critical trials (89% correct), indicating that the poor performance of the color and identity report on the critical trial was not induced by the surprise test itself, but more likely reflects participants' failure to remember these attributes.

Participants exhibited a dramatic increment of the accuracy of reporting the color (70% correct) and identity (75% correct) of the target letter on the first control trial (the trial right after the critical trial) and the improvement in each case was significant (color: 70% vs. 30%, χ^2 (1, N = 40) = 6.40, p = .011, □ = .40; identity: 75% vs. 25%, χ^2 (1, N = 40) = 10.00, $p < .005$, □ = .50). Performance on these two tasks remained constant on the following three control trials (color: 75%, 70%, and 80% correct; identity: 75%, 80%, and 75% correct). Notably, participants performed almost equally well on the localization task on the critical trial (80% correct) and the control trials (80%, 85%, 80%, and 70% correct). These results indicate a crucial role of expectation on participants' ability to report the attributes of a consciously perceived object. Therefore, Experiment 1 showed that participants were incapable of reporting the attributes of an attended object that they had no expectation to report, even when that attribute had reached awareness immediately prior to the test.

Experiment 1b

To extend these results, we replicated this design with longer durations and without post-stimulus masks.

Method

This experiment was identical to Experiment 1 with the following exceptions. Another twenty undergraduates participated in this experiment. The duration of the stimulus array increased from 150 ms (in Experiment 1) to 250 ms and the masks were removed.

Results

The results of this experiment were essentially the same as those of Experiment 1. Participants were poor at reporting both color (30% correct) and identity (30% correct) on the critical trial, but the performance dramatically increased in the control trials (color: 75%, 100%, 100%, and 100%; identity: 80%, 90%, 90%, and 95%). As in Experiment 1, the improvements of the color and identity report were highly significant on the first control trial relative to the critical trial (color: 75% vs. 30%, χ^2 (1, N = 40) = 8.120, p = .004, □ = .45; identity: 80% vs. 30%, χ^2 (1, N = 40) = 10.101, p = .001, □ = .50). The localization task performance was high on both the pre-critical trials (96% correct) and control trials (65%, 85%, 95%, and 85% correct). However, unlike in previous experiments, the localization performance, which was assessed after the surprise question on the critical trial dropped (50% correct) compared to the pre-critical trials. These findings essentially replicate Experiment 1 and demonstrate that the failure to report the task-relevant attribute can even hold after extending stimuli duration to 250 ms and removing the masks.

Experiment 2

It could be argued that participants might locate the target by the category, without resolving its identity. We think that this is highly unlikely given the lengthy display duration of the easily discriminated stimuli used in this study.

However, to increase our confidence that participants were momentarily aware of the identity of the target, we now asked participants to detect either an odd number among evens or vice versa. It has been well documented that adult participants automatically access meaning (i.e., identity) of numbers during the parity task (e.g., Dehaene, Bossini, & Giraux, 1993; Fias, Brysbaert, Geypens, & d'Ydewalle, 1996; Reynvoet & Brysbaert, 1999).

Method

This experiment was identical to Experiment 1 with the following exceptions. Another twenty undergraduates participated in this experiment. Half of them were required to localize a colored even number (12, 14, 16, or 18) presented among three different colored odd numbers (13, 15, 17, or 19) and the other half of them were asked to localize an odd number among even numbers. In addition, because a pilot experiment showed that this target localization task was much more difficult than that in Experiment 1, the duration of the stimulus array increased from 150 ms (in Experiment 1) to 250 ms in order to ensure participants could become aware of the target and then correctly localize it.

Results

The results of this experiment were essentially the same as those of Experiment 1. Participants were poor at both color (40% correct) and identity report (30% correct) on the critical trial, but the performance dramatically increased by the second control trial (color: 30%, 80%, 90%, and 80%; identity: 65%, 75%, 90%, and 80%). The localization task performance was high on pre-critical trials (80% correct) and the critical trial (70%) as well as control trials (70%, 85%, 100%, and 85%). As in Experiment 1, performance on the identity question improved significantly on the first control trial relative to the critical trial, 65% vs. 30%, χ^2 (1, N = 40) =4.912, p = .027, □ = .35. However, the elevation of color report accuracy only started from the second control trial, 80% vs. 40%, χ^2 (1, N = 40) =6.667, p < .01, □ = .41. This experiment replicated the findings of Experiment 1 and provided an even stronger demonstration of attribute amnesia for an identified stimulus.

Experiment 3

The present experiment explored the boundary conditions of this amnesia effect by determining whether it holds for a highly salient feature such as a popout color.

Method

Twenty new undergraduate participants completed an experiment similar to Experiment 1, with the following changes. There were 15 possible target letters (A,B,C,D,F,H,J,K,L,N,P,R,T,V,X), presented in one of four colors that was randomly chosen on each trial (red, blue, yellow, or purple). The distractors were chosen from the same set of letters as the targets except that all of them were black and there were no repetitions of any letter within a trial. On each trial there was always one colored and three black letters and the participants were asked to localize the popout colored target letter on the first 155 trials, and then on the critical trial they were required to report the color of the target letter in a surprise test, prior to the localization task. As in previous experiments, color was also queried in four subsequent control trials. The order of the four possible choices in the question of color report was constant on surprise and all control trials.

Results

We replicated the findings of Experiment 1. Participants were generally unable to report the color of target letter on the critical trial (35% correct), even though being colored rather than black was a highly salient popout feature that defined the target. As in Experiment 1, the color report performance increased dramatically on the first post-critical trial (95% correct), which was significantly greater than on the critical trial, 95% vs. 35%, χ^2 (1, N = 40) =15.824, $p < .001$, □ = .63, and performance remained stable on the following three control trials (95%, 100%, and 100% correct).

The accuracy of the target localization was close to ceiling (98% correct) on the pre-critical trials, indicating that the color is highly salient and it was very easy for participants to use the popout feature to localize the target. More importantly, and consistent with the results of Experiment 1, the localization accuracy on the critical trial (80% correct) was also quite high, suggesting that the surprise test itself did not result in a clearing of the contents of working memory. The accuracy of the localization on the four control trials was also high (100%, 95%, 95%, and 95% correct). The results of this experiment thus demonstrate that attribute amnesia can hold even for a highly salient popout feature that is task relevant. Note that subjects might have located the popout stimulus using a feature gradient; however we view this as unlikely given the presentation conditions.

Experiment 4

Participants performed a large number of trials before the critical trial in the preceding experiments. Here we explored whether attribute amnesia occurs without such a long sequence of trials prior to the critical trial.

Method

Twenty new undergraduate participants completed the experiment which was identical to Experiment 1, but this time they had only 11 trials before the critical trial, which was again followed by four control trials for a total of 16 trials.

Results

The results were similar to those of Experiment 1. On the critical trial, attribute amnesia appeared in both color (25% correct) and identity tasks (35% correct). Furthermore, the performance of the color and identity tasks considerably increased in control trials (color: 60%, 65%, 75%, and 85% correct; identity: 65%, 60%, 80%, and 85% correct). The increment of color report performance was significant on the first control trial, 60% vs. 25%, χ^2 (1, N = 40) = 5.013, $p = .025$, □ = .35; while the improvement of identity report was marginally significant on the first two control trials and was highly significant by the third control trial, 80% vs. 35%, χ^2 (1, N = 40) = 8.286, $p < .005$, □ = .46. Consistent with previous experiments, the localization performance was similar among the pre-critical trials (76% correct), critical trial (70% correct), and control trials (60%, 70%, 90%, and 70% correct).The results of this experiment demonstrated that attribute amnesia, like inattentional blindness, does not require a prolonged series of trials in advance of the critical trial, although it remains an open question as to whether this would occur on the very first trial.

Discussion

These experiments provided converging evidence that participants could not report attributes of an attended object when they did not expect to report them, even when the attribute had reached awareness shortly before. Furthermore, these participants could accurately report these same attributes once they had an expectation to do so.

Are awareness and attention sufficient for immediate report?

Existing studies show that attention to an object is not sufficient to detect changes to that object (Levin & Simons, 1997; Simons &Levin, 1998) or report its irrelevant attributes (Eitam, Yeshurun, & Hassan, 2013). However, these findings leave open the question of whether awareness of an attended attribute is sufficient to remember it for immediate report. The sufficiency of awareness for report is the core question addressed by the amnesia hypothesis, which argued that people's inability to report a stimulus does not necessarily mean they have not consciously perceived that stimulus (Moore, 2001; Moore & Egeth, 1997; Wolfe, 1999). There is, however, only indirect support for such amnesia. For example, Moore and Egeth (1997) found that unreportable stimuli in the background could influence participants' performance on the primary task (e.g., line length report), but this study does not address whether the unreportable stimuli were consciously perceived. Another type of evidence favoring amnesia was a finding that repeating a search display exhibited no improvement in search efficiency (Wolfe, 1999; Wolfe, Klempen, & Dahlen, 2000; Wolfe, Reinecke & Brawn, 2006). However, when participants were asked to list the stimuli in the repeated display, they could do so. Thus, this study could be interpreted as evidence that participants remembered the repeated items, but could not use the memory to improve their visual search.

The present study provides the first direct evidence, to our knowledge, of the amnesia hypothesis by showing a failure to report an attended attribute that had reached a full level of awareness right before the test. Several lines of evidence indicate that the unreportable attribute had reached awareness. First, the attribute was attended and participants could use it to discriminate between target and distractors to produce highly accurate location judgments. This agrees with two popular definitions of awareness by Lamme (2004) and Holender (2001), respectively. Second, the stimulus appears on the screen for 150-250ms, which is much longer than the suggested threshold for awareness (50 ms, see in Del Cul, Baillet & Dehaene, 2007). Note that our arguments here are intended to demonstrate that the attended attributes had reached awareness in our particular paradigm, but not to argue that an attended attribute must reach awareness in all cases.

Thus, our results suggest that directing attention towards a stimulus attribute and being aware of it are not sufficient to ensure its reportability immediately afterwards. This implies that some demonstrations (but certainly not at all) of inattentional blindness might not necessarily reflect a failure of conscious perception.

How is attentional set defined by a task?

The study of attentional set has a rich history showing that the expectations of a participant affect how well information will be reported (e.g., Gross,1959; Haber,1966; Long, Toppino, & Mondin, 1992).The attentional set in visual attention studies can be described as having two components: *key and response attributes* (Botella, Barriopedro, & Suero, 2001, or as termed elsewhere *defining* vs *response*, Remington & Folk, 2001). A *key attribute* refers to target defining information and *response attribute* refers to information that should be reported. For instance, participants searching black letters for a colored letter to report would have a key attribute of color, and a response attribute of letter identity. Presumably, when an object has been selected by a key attribute, its response attribute is stored in a relatively durable memory trace that persists across multiple cognitive events while the key attribute is not well encoded. Importantly, the response attribute is sampled only at the moment when attention is engaged. Importantly, the studies reported here demonstrate this distinction by showing that key attributes are poorly reported by participants.

One possible explanation is that the key attribute in our experiments was encoded in a fragile form of memory (Sligte, Scholte, & Lamme, 2008). Such information could have been momentarily encoded and then forgotten during the process of reading the surprise question. However, it is also true that the location memory typically did persist through the surprise trial, demonstrating a difference in the durability of the memory for key and response attributes. More sensitive measures (Hoffman, Bein, & Maril, 2011) could be useful for exploring in greater detail the extent to which key attributes are stored in memory.

In conclusion, these results show that attending to a specific piece of information is insufficient to produce a memory trace. We suggest that attentional sets can be configured separately for attributes that define which stimuli are targets and attributes that define what information needs to be remembered. Moreover, these results suggest that the processes governing access to working memory are extremely careful to exclude information that is not expected to be relevant to the participants' goals.

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Author Contributions

Hui Chen and Brad Wyble developed the study concept. Hui Chen performed the programming, data collection, analysis and most of the writing. Brad Wyble contributed writing and editing. Both authors approved the final version of the manuscript for submission.

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