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# Does attribute amnesia occur with the presentation of complex, meaningful stimuli? The answer is, "it depends"

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## Abstract

Attribute amnesia (AA) is a recently reported phenomenon whereby participants are unable to report a salient attribute of a stimulus (e.g., the color or identity of a target letter) on which their attention has just been focused during a prior task. This counterintuitive effect has been repeatedly replicated with various simple stimuli such as digits and letters. The current study sought to explore boundaries of AA by investigating whether the phenomenon persists when participants encounter complex, meaningful stimuli (e.g., pictures) that have been shown to hold an advantage in cognitive processing and memory. In Experiments 1a–d, we examined whether AA was observed with different types of complex stimuli. In Experiments 2a–b and 3a–b, we linked the type of stimuli (simple vs. complex and meaningful stimuli) to the other two potential boundary factors of AA (i.e., repetitiveness of target stimulus and set effects of *Einstellung*) to see whether there were interactions between stimuli type and these two boundary factors. The results demonstrated that the AA effect was still consistently observed for complex stimuli in a typical AA paradigm wherein participants encountered many trials and the targets were repeated across trials. However, this effect only appeared for simple stimuli, but not for complex stimuli in two special cases: when target stimuli were never repeated through the experiment, or when the surprise test was placed on the first trial of the experiment. These findings have crucial implications in understanding the boundaries of the AA phenomenon.

**Keywords** Attribute amnesia · Working memory · Complex stimuli · Expectation

It is commonly believed that information can be remembered and reported in an immediate test if it has been the focus of attention (e.g., Lamme, 2004; Simons & Chabris, 2011). However, a series of recent studies have challenged this common-sense belief (H. Chen & Wyble, 2015a, 2015b; Eitam, Yeshurun, & Hassan, 2013). For example, in a study conducted by Eitam et al. (2013), participants occasionally failed to report the task-irrelevant features of a unitary attended object. In addition, a recent study provided stronger evidence showing that participants often even fail to report salient, task-relevant attributes of stimuli (e.g., the color or identity of a letter) on which their attention has just been focused during a prior task (H. Chen & Wyble, 2015a). This counterintuitive phenomenon was called attribute amnesia (AA) by H. Chen and Wyble (2015a).

In a typical AA experiment, participants perform numerous trials in which they are required to report one attribute (e.g., the location) of a target presented with three distractors, and then are unexpectedly asked to report another task-relevant attribute (i.e., a target-defining attribute) on which their attention has been focused in the trials. For instance, in the first experiment of a study conducted by H. Chen and Wyble (2015a), participants were presented with a colored target letter and three colored distractor digits and asked to indicate the location of the target letter in 155 trials. Thereafter, in a surprise trial, participants were unexpectedly asked to report the identity (i.e., a target-defining attribute) and color (i.e., a task-irrelevant attribute) of the target letter before reporting its location, and completed the final four control trials in the format used for the surprise trial. The results showed that most participants were unable to report the identity or color of the target letter accurately in the surprise test, even though they had located the target letter accurately in previous trials.

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Moreover, this failure to report attended attributes (i.e., identity and color) was not caused by limitations in perception or working memory capacity, as the levels of accuracy observed in control trials (in which participants expected to report these attributes for the same target letters) were very high. Instead, this finding suggests that expectation plays a crucial role in determining memory for attended information.

This counterintuitive AA effect has been replicated repeatedly and extended in various experiments conducted by H. Chen and Wyble (2015a). That is, their follow-up experiments demonstrated that this effect persisted even under the following conditions: (1) the target was a pop-out stimulus (i.e., a colored target letter presented with three black letters); (2) the stimulus presentation duration increased from 150 ms (in the original experiment) to 250 ms, and, meanwhile, the stimuli masks were removed; (3) there were only 11 presurprise trials; and (4) the target and distractor stimuli belonged to the same category (e.g., an even target digit presented with three odd distractor digits or vice versa).

A follow-up study by H. Chen and Wyble (2016) investigated the mechanism underlying this phenomenon and demonstrated that the AA effect was likely to have been driven by the absence of memory consolidation for attended attributes that had been processed to a certain extent, rather than forgetting induced by the surprise test per se. Specifically, participants were required to remember and hold the color of a fixation cross for a brief period at the beginning of each trial, and then search for a target letter of the same color. In presurprise trials, participants were asked to report the location of the target letter, whereas in the surprise trial, they were unexpectedly asked to report the color of the target letter (which always matched the color of the fixation cross in the trial). The results showed that participants were able to report the color of the target letter accurately, even in the surprise test, indicating that once a stimulus attribute had been consolidated into memory, it could survive a surprise test.

In another line of research, Chen and collaborators adopted AA as a tool to study other memory-related questions. For example, in a study conducted by H. Chen, Carlson, and Wyble (2018), using the AA paradigm, source memory failure, which was traditionally believed to occur only in long-term memory, was observed in working memory or short-term memory. In another study, McCormick-Huhn, Chen, Wyble, and Dennis (2018) adopted the AA paradigm to test two competing accounts of associative binding in older adults during working memory—the associative-deficit hypothesis (Naveh-Benjamin, 2000) and the hyper-binding account (Campbell et al., 2010)—and found that older adults, like younger adults, do not spontaneously bind information in working memory when there is no expectation to use the bound representation, and thus argued against the hyper-binding account.

It should be noted that most previous AA studies used simple, low-level stimuli such as letters, digits, and colors (Chen, Swan, & Wyble, 2016; Chen & Wyble, 2015a, 2016; Jiang, Shupe, Swallow, & Tan, 2016; Swan, Wyble, & Chen, 2017; the only exception was Chen & Howe, 2017, which will be described in detail below), which raises the question as to whether AA persists with the presentation of complex, meaningful stimuli (e.g., Chinese characters or sentences) that require high-level processing. It is likely that AA might be eliminated or reduced when using complex, meaningful stimuli, because many previous studies showed that participants exhibited an aptitude for processing and/or remembering complex, meaningful stimuli (e.g., Brady, Konkle, Alvarez, & Oliva, 2008; Brady, Stormer, & Alvarez, 2016; Christianson, Loftus, Hoffman, & Loftus, 1991; Dolan, 2002; Esteves, Parra, Dimberg, & Ohman, 1994; Li, VanRullen, Koch, & Perona, 2002; Nickerson, 1965; Potter, Nieuwenstein, & Strohminger, 2008; Shepard, 1967). For instance, some previous studies showed that participants could categorize images of nature at high speeds (Delorme, Richard, & Fabre-Thorpe, 2010) and in the near absence of attention (Li et al., 2002). Esteves et al.'s (1994) study also revealed that emotional items were more likely to be detected in studies of attentional blink, a phenomenon showing a failure to detect the second of two masked visual targets presented at temporal separations of 100 ms to 400 ms (e.g., Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; Wyble, Bowman, & Nieuwenstein, 2009), as compared with other neutral items. Besides the advantage of processing, some other studies have provided evidence that these complex and meaningful stimuli could also be better remembered both in long-term memory and in working memory (Bankó, Gál, & Vidnyánszky, 2009; Brady et al., 2016; Shepard, 1967). Shepard (1967) adopted complex, meaningful stimuli (e.g., English words, short sentences, colored pictures) and found that human memory capacity considerably exceeded previous estimates based on stimuli such as monosyllabic words. Bankó et al. (2009) found that emotional expressions of both familiar and novel faces could be stored well in short-term memory, with the memory traces not decaying even after a delay of 6 seconds. Brady et al. (2016) reported working memory capacity advantage for natural objects relative to simple stimuli. More importantly, two previous AA studies (Chen & Wyble, 2016; Chen & Howe, 2017) provided stronger and more direct evidence implying that the AA effect might differ when using complex, meaningful stimuli as compared with using simple stimuli. Chen and Howe (2017) adopted animal pictures as target stimuli and found that AA almost disappeared when the target stimuli of animal pictures were not repeated in the whole experiment (Experiments 3 and 4 in Chen & Howe, 2017). In contrast, H. Chen and Wyble (2016, Experiment 2) employed colored letters as target stimuli and observed that AA persisted even when the target stimuli were never repeated through the experiment. Apart from the different type of stimuli (simple letters vs. complex animal pictures), there were several other

methodological differences between W. Chen and Howe (2017) and H. Chen and Wyble's (2016) studies (e.g., stimuli display time and number of presurprise trials), which might also have contributed to the different results. Thus, further work is needed to test whether the difference of AA between these two studies is indeed due to the different type of stimuli by controlling all the methodological differences.

The abovementioned findings inspired us to test whether AA, a phenomenon revealing failure to report information that has just been the focus of attention, persisted with the presentation of complex, meaningful stimuli. Answering this question is necessary and crucial, because not only could it allow us to explore the boundaries of the AA effect but it could also enable us to investigate whether there are potential constraints on the advantage of processing and remembering complex, meaningful stimuli.

To address this issue directly, in Experiments 1a–d we used different types of complex stimuli (pictures of objects, Chinese characters and poems, and emotional faces) to systematically test whether AA could still persist with these complex stimuli. Then, in Experiments 2a–b and 3a–b we sought to link the type of stimuli (simple stimuli vs. complex and meaningful stimuli) to the other two potential boundary factors of AA (i.e., repetitiveness of target stimulus and set effects of *Einstellung*/mechanized states of mind; Luchins, 1942). To preview the results, in a typical attribute amnesia paradigm in which the target stimuli were repeated across trials and participants were repeatedly asked to perform a task before a surprise test, the AA effect was still consistently observed for all four types of complex stimuli in Experiments 1a–d. However, in two atypical versions of attribute amnesia paradigm, in which either the target stimuli were never repeated through the experiment (Experiments 2a–b), or the surprise test was placed on the first trial of the experiment so that participants no longer suffered from *Einstellung* (Experiments 3a–b), the AA effect no longer appeared for complex and meaningful stimuli, despite it still appeared for simple stimuli.

## Experiments 1a–d: Exploring AA boundaries with different types of complex and meaningful stimuli

In Experiments 1a–d we tried to test whether AA would persist when participants paid attention to different kinds of complex, meaningful stimuli, including picture stimuli, Chinese character stimuli, Chinese poem stimuli, and emotional face stimuli.

### Method

**Sample size** Each experiment included predetermined sample size of 20 participants based on the original study that demonstrated robust AA (H. Chen & Wyble, 2015a). All participants were naïve to the experiments, and none participated in more than one experiment or was excluded from the analysis.

**Participants** In each of the four experiments, 20 undergraduate students from Nanjing Normal University were recruited. Participants were instructed in Chinese, and all reported normal or corrected-to-normal visual acuity. Upon completion of the experiment, each participant received 5 RMB. All experimental procedures were approved by the local review board for the ethical treatment of human participants.

**Apparatus** The experiments were presented on a 19.5-inch computer with a resolution of 1,440 × 900 pixels and a refresh rate of 75 Hz. Participants sat at a viewing distance of about 50 cm and provided their responses using a computer keyboard. The experiment was programmed using MATLAB with the Psychophysics Toolbox extension (Brainard & Vision, 1997; Pelli, 1997).

**Stimuli** The fixation display consisted of a black central fixation cross (radius = 0.57° [degrees of visual angle]) and four black placeholder circles (0.69°) located in the four corners of an invisible square (6.53° × 6.53°). Each stimulus display contained one target and three distractors.

In Experiment 1a, there were 16 pictures (i.e., line drawings in black and white), taken from a picture database developed by Szekely et al. (2005) and other researchers (Abbate & LaChappelle, 1979; Snodgrass & Vandaerwart, 1980). Four pictures of furniture (e.g., a bed) were used as target stimuli, and the remaining 12 pictures of common items encountered in daily life (e.g., a boat) were used as distractor stimuli. Each stimulus subtended visual angles of approximately 2.52° horizontally and 2.52° vertically. The mask (2.86° × 2.86°) consisted of black and white interlaced lines (see Fig. 1). All stimuli were presented against a white background (RGB: 255, 255, 255).

In Experiment 1b, the stimuli consisted of 16 Chinese characters, and the meaning of each of the characters matched the corresponding picture presented in Experiment 1a (see the Appendix). All stimuli were common Chinese characters with a mean word frequency of 91.31 (*SD* = 116.31), a mean number of strokes of 9.00 (*SD* = 3.35), and a mean familiarity score of 6.61 (*SD* = 0.38) according to the Chinese Single-Character Word Database (Liu, Shu, & Li, 2007; http://blclab.org/pyscholinguistic-norms-database). Each character subtended visual angles of 1.15° horizontally and 1.15° vertically. The stimuli mask consisted of a black "@" and a hash pattern consisting of four lines (1.26° × 1.26°). All the black stimuli were presented against a gray background (RGB: 150, 150, 150).

In Experiment 1c, 16 Chinese poem sentences were used as stimuli, which were chosen based on a pretest in which an

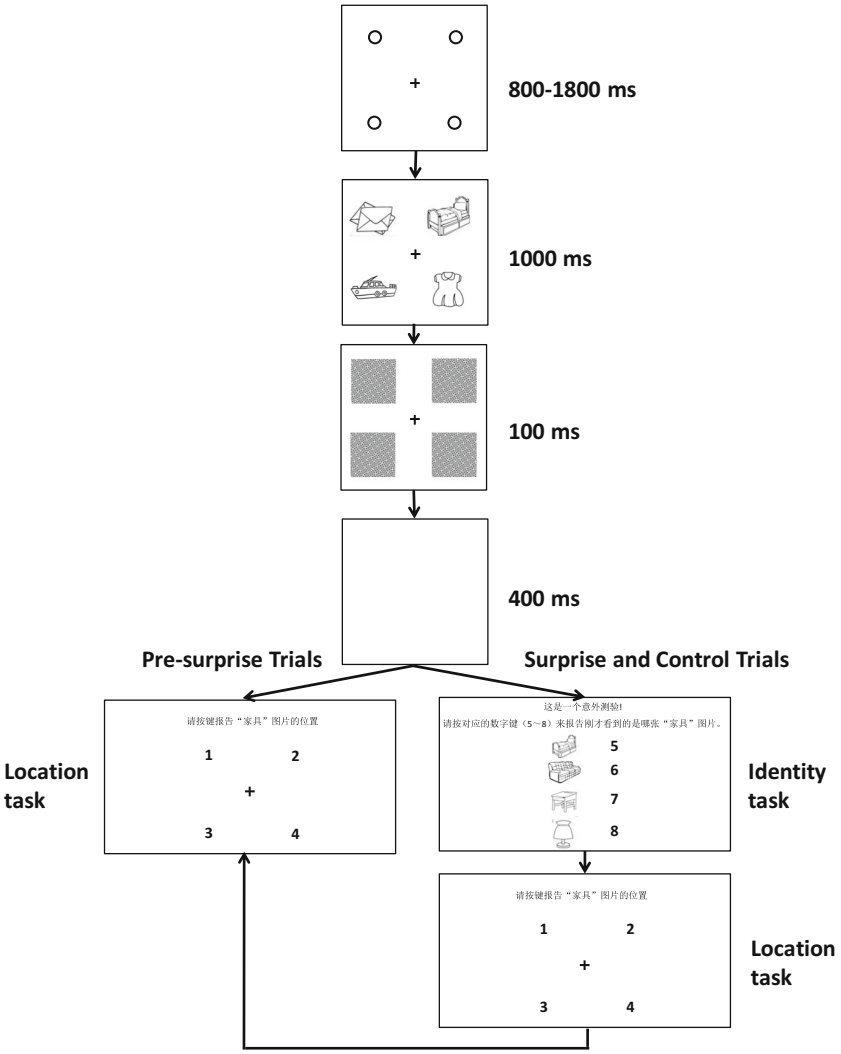


**Fig. 1** Sample trial sequences in Experiment 1a. Note that the picture stimuli are not the actual picture stimuli used in the experiment because of permission for reprint issues

additional 30 participants were recruited and asked to rate the familiarity of 30 Chinese poem sentences, using a scale ranging from 1 (*totally unfamiliar*) to 5 (*very familiar*), and indicate the theme of each poem, using a four-alternative forced-choice test. Ultimately, we selected 16 poems for which participants' performance levels were high for both familiarity ratings and theme judgment tasks. The mean familiarity score was 4.43 ($SD$ = 0.62), and the average accuracy score for theme judgment was 0.98 ($SD$ = 0.03). The 16 poems consisted of four themes/topics: the topic of the four target poems was patriotism, whereas those of the remaining 12 distractor poems were love, homesickness, and philosophy (i.e., four poems to each topic). Each poem consisted of 14 Chinese characters (approximately 0.69° × 0.92°), which were presented on two lines (6.75° length × 1.83° height; see Fig. 2c). We used a different type of stimulus mask (6.87° × 1.83°) for the Chinese poem sentences, in accordance with previous research (Luo et al., 2014). All stimuli were presented against a white background (RGB: 255, 255, 255).

In Experiment 1d, the stimuli were 20 different pictures of emotional faces from the NimStim Set of Facial Expressions (Tottenham et al., 2009), divided equally into five kinds of expressions: happiness, anger, disgust, fear, and sadness, with each expression enacted by four actresses. Among these emotional faces, the four happy faces were distractor stimuli, whereas the other 16 negative ones were target stimuli. In each trial, there was one target negative face and three distractor happy faces, with all four faces enacted by four different actresses in each trial. Each face stimulus subtended visual angles of 3.21° horizontally and 3.44° vertically. We employed the same masks as in Experiment1a, and all stimuli were presented against a white background (RGB: 255, 255, 255).

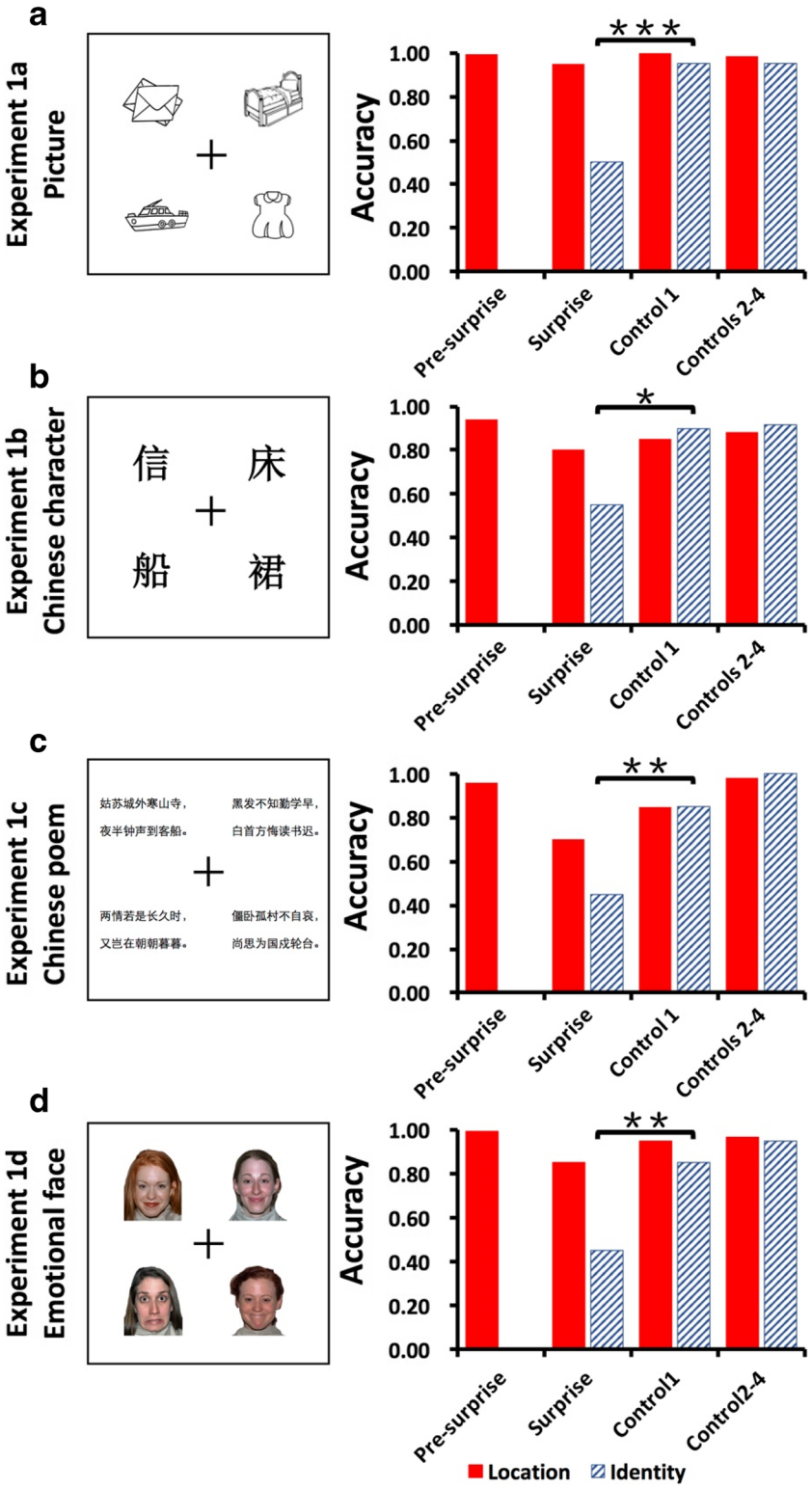


**Fig. 2** Sample stimuli displays and results of Experiments 1a–d. Note that the picture stimuli of Experiment 1a were not actual picture stimuli used in the experiment because of permission for reprint issues. The sizes of all stimuli were not the actual sizes shown in the experiments. *$p < .05$. **$p < .01$. ***$p < .001$

**Procedure** The experimental procedure is essentially similar among Experiments 1a–d, which followed that of H. Chen and Wyble (2015a), as shown in Fig. 1. At the beginning of each trial, the fixation cross appeared for 800 ms to 1,800 ms. Thereafter, the stimulus display appeared on the screen for 1,000 ms in Experiments1a–b and for 2,000 ms in

Experiments1c–d (note that the stimulus duration varied depending on the complexity of stimuli in order to counterbalance the difficulty of task among experiments) and was then masked for 100 ms. The mask was followed by a blank screen for 400 ms. Finally, four numbers (i.e., 1, 2, 3, and 4) appeared at the locations of the four placeholders until participants provided a response.

The design of Experiments 1a–d was identical. There were 32 trials in each experiment. In the first 27 trials (i.e., presurprise trials), participants were asked to indicate the location of the target stimulus (Experiment 1a: picture of an item of furniture; Experiment 1b: Chinese character of an item of furniture; Experiment 1c: the poem sentence of patriotism; and Experiment 1d: the face with negative expression) among three distractors by pressing one of four number keys (i.e., 1, 2, 3, or 4). However, in the 28th trial (i.e., the surprise trial), they were unexpectedly presented with a recognition test, in which they were asked to select the target item (out of four alternatives) that they had just seen in the trial, by pressing one of four number keys (i.e., 5, 6, 7, or 8). The four possible choices on the surprise test were all four target stimuli in that experiment, which were presented in random order. Following the surprise memory test, participants were required to report the location of the target, as in the presurprise trials. After the surprise trial, the participants completed four additional control trials (Trials 29, 30, 31, and 32) in the format used for the surprise trial.

### Results and discussion

The results of Experiments 1a–d are depicted in Fig. 2. As depicted in this figure, the participants' performance in locating the target in presurprise trials was almost perfect in all these experiments (99%, 94%, 96%, and 99% correct in Experiments 1a–d, respectively), which indicated that it is easy for participants to locate the target and report their locations. Crucially, the results of surprise trial showed that the AA effect was consistently obtained in all experiments. In Experiment 1a, only 10 of the 20 (50%) participants selected the target picture that they had just seen in the surprise trial, and their performance improved significantly in the first control trial, 50% versus 95%, $\chi^2(1, N = 40) = 10.16$, $p = .001$, $\varphi = .50$. In Experiment 1b, only 11 of the 20 (55%) participants reported the identity of the target Chinese characters correctly in the surprise trial, and their performance improved significantly in the first control trial, 55% versus 90%, $\chi^2(1, N = 40) = 6.14$, $p = .013$, $\varphi = .39$. In Experiment 1c, only nine of the 20 (45%) were able to identify the target poem in the surprise trial, and their performance improved significantly in the first control trial, 45% versus 85%, $\chi^2(1, N = 40) = 7.03$, $p = .008$, $\varphi = .42$. In Experiment 1d, only nine of the 20 (45%) correctly reported the emotion they had seen in the surprise trial, and their performance improved significantly in the first control trial, 45% versus 85%, $\chi^2(1, N = 40) = 7.03$, $p = .008$, $\varphi = .42$. The accuracies of the other three control trials are all very high, as revealed in Fig. 2.

These results showed that AA persisted with the presentation of complex, meaningful stimuli, suggesting that it could occur not only for simple stimuli (e.g., the color and identity of a letter), as reported in previous studies (Chen et al., 2016; H. Chen & Wyble, 2015a, 2016; Jiang et al., 2016; Swan et al., 2017), but could also be generalized to experiments using complex, meaningful stimuli, including pictures of common objects in daily life (Experiment 1a), Chinese characters (Experiment 1b), Chinese poems (Experiment 1c), and emotional faces (Experiment 1d). These findings seem to indicate that, although the participants exhibited an aptitude for processing and/or remembering complex, meaningful stimuli in many previous studies (e.g., Brady et al., 2008; Christianson, et al., 1991; Dolan, 2002; Esteves et al., 1994; Li et al., 2002; Nickerson, 1965; Potter et al., 2008; Shepard, 1967), they did not have robust memory traces for these just-attended complex stimuli if they had no expectation of reporting them.

## Experiments 2a–b: Exploring AA boundaries by linking the stimuli type to repetitiveness of target stimulus

Although Experiments 1a–d provided converging evidence showing a similar AA with complex, meaningful stimuli in comparison with those using simple stimuli, as noted before, the different results between W. Chen and Howe (2017) and H. Chen and Wyble (2016) appear to imply that the AA effect might differ when using complex, meaningful stimuli as compared with using simple stimuli. However, apart from the different type of stimuli (simple letters vs. complex animal pictures), there were several other methodological differences between W. Chen and Howe (2017) and H. Chen and Wyble's (2016) studies (e.g., stimuli display time: 150 ms vs. 250 ms, number of presurprise trials: 155 trials vs. 11 trials), which might also have contributed to the different results. In Experiments 2a–b, we sought to exclude all methodological differences between W. Chen and Howe (2017) and H. Chen and Wyble's (2016) studies, and investigate whether different results in these two studies were indeed due to the different type of stimuli used.

### Method

Experiments 2a–b were identical to Experiment 1a, except for the following differences. A new group of 40 participants from Zhejiang University participated in Experiments 2a–b (20 participants for each experiment). The most crucial manipulation was that as in W. Chen and Howe (2017) and H. Chen and Wyble (2016), the target stimuli were never

repeated through the experiment. For Experiment 2a, the target stimuli were English letters that were randomly chosen from a set of 26 letters (A–Z), whereas the distractor stimuli were digits (2–9). Each of the letter and digit stimuli subtended visual angles of approximately 1.15° horizontally and 1.15° vertically. In 11 presurprise trials, participants were asked to report the location of a target letter among three distractor digits. Then, in the surprise trial, prior to the location task, they were unexpectedly presented with four letters (one was the target letter on that trial and the other three were novel letters that never appeared in previous trials), and asked to indicate which one was the target letter that they had just seen in that trial. Subsequently, participants received four more control trials identical to the surprise trial. Experiment 2b was identical to Experiment 2a, except that the target stimuli were 31 animal pictures,[1] and the distractor stimuli were 12 pictures of common things. Each of the picture stimuli subtended visual angles of approximately 2.52° horizontally and 2.52° vertically. Examples of stimuli displays of these experiments as well as Experiments 3a–b are depicted in Fig. 3.

### Results and discussion

The results of Experiments 2a–b are depicted in Fig. 3a. Experiment 2a replicated H. Chen and Wyble's (2016) results, showing that AA was still observed even when the target stimuli (i.e., letters) were never repeated through the experiment. That is, only 11 of the 20 (55%) participants reported the identity of the target letter correctly in the surprise trial, and their performance improved significantly in the first control trial, 55% versus 90%, $\chi^2(1, N = 40) = 6.14$, $p = .013$, $\varphi = .39$. However, consistent with W. Chen and Howe (2017), the results of Experiment 2b revealed that AA nearly disappeared, with 17 of 20 (85%) participants being correct in reporting the target animal in the surprise trial, which was identical to the performance in the first control trial (85% correct). Furthermore, the comparison of the performance of surprise trials between Experiments 2a and 2b showed that participants' performance in Experiment 2a was significantly worse than that in Experiment 2b, 55% versus 85%, $\chi^2(1, N = 40) = 4.29$, $p = .038$, $\varphi = .33$.

The only difference between Experiments 2a and 2b was the type of stimuli—that is, Experiment 2a used simple stimuli whereas Experiment 2b adopted complex, meaningful stimuli. Thus, these results suggest that when target stimuli were never repeated through the experiment, AA differed between simple stimuli (e.g., letters) and complex, meaningful stimuli (e.g., animal pictures), with AA appearing in the former but not in the latter case. These findings suggest that the different results between W. Chen and Howe (2017) and H. Chen and Wyble (2016) were indeed caused by the different type of stimuli used in these two studies.

[1] There were 31 animal pictures in Experiment 2b, which ensured that the target stimuli in all 16 trials and the four stimulus choices in the test phase of the surprise and four control trials were never repeated. As there were only 26 English letters, all target stimuli in 16 trials as well as the stimulus choices in the surprise and first control trial of Experiment 2a were not repeated, whereas some stimulus choices in the second through fourth control trials might not have been novel stimuli and could have been presented in previous trials. Nonetheless, this would not affect our conclusions since the AA effect relies on the difference between the surprise and first control trial, wherein both the target and stimulus choices in the test phase were never repeated.

## Experiments 3a–b: Exploring AA boundaries by linking the stimuli type to set effects of Einstellung

Experiments 2a–b linked the type of stimuli (simple vs. complex) to another boundary factor of AA (i.e., repetitiveness of target stimulus) and showed that AA differed between simple and complex stimuli when the target stimuli were never repeated through the experiment. Here, we attempted to link the type of stimuli to another potential boundary factor of AA (i.e., *Einstellung*; Chen, Swan, & Wyble, 2016; Luchins, 1942) through testing whether AA differed between simple and complex stimuli when the surprise test was placed on the first trial of the experiment wherein participants no longer suffered from *Einstellung*.

### Method

Experiments 3a–b were identical to Experiments 2a–b, except as follows. Another 40 participants from Zhejiang University were recruited for Experiments 3a–b (20 participants for each experiment). In Experiments 3a–b, the surprise test was placed on the first trial of the experiment, which was followed by four control trials, resulting in a total of five trials through the experiment. For Experiment 3a, participants were instructed to report the location of a target letter (A, B, D, or E) presented among three distractor digits (2–9), but were unexpectedly asked to report the identity of the target letter on the very first trial, prior to the location report task. Experiment 3b was identical to Experiment 3a, except that, as in Experiment 2b, the target stimuli were animal pictures whereas the distractor stimuli were pictures of common things. There were four possible target animal pictures and 12 distractor pictures in the whole experiment.

### Results and discussion

The results of Experiments 3a–b are depicted in Fig. 3b. AA was observed in Experiment 3a. That is, 14 of the 20 (70%) participants correctly reported the identity of the target letter in the surprise trial (first trial), and their performance improved significantly in the first control trial, 70% versus 95%, $\chi^2(1, N$

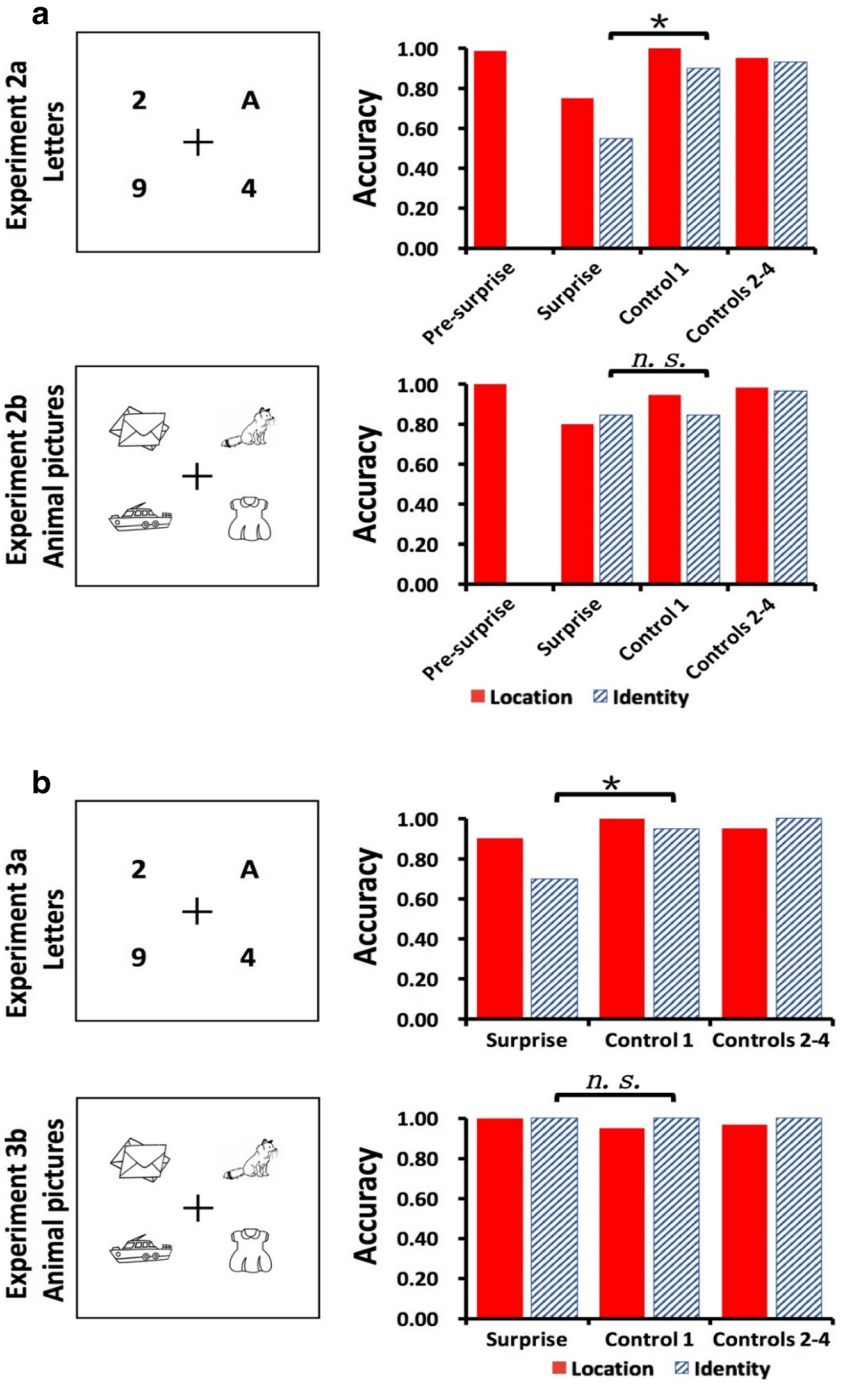


**Fig. 3** Sample stimuli displays and results of Experiments 2a–b, and 3a–b. Note that the picture stimuli of Experiments 2b and 3b were not the actual picture stimuli shown in the experiment because of permission for reprint issues. The sizes of all stimuli were not the actual sizes shown in the experiments. *$p < .05$. **$p < .01$. *** $p < .001$

= 40) = 4.33, $p = .037$, $\varphi = .33$. However, in Experiment 3b, the performance was perfect in the surprise trial (100% correct), which was identical to that of the first surprise trial. Furthermore, we compared the performance of the surprise trial between Experiments 3a and 3b and found that participants' performance in Experiment 3a was significantly worse than that of Experiment 3b, 70% versus 100%, $\chi^2(1, N = 40) = 7.06$, $p = .008$, $\varphi = .42$.

As in Experiments 2a–b, Experiments 3a–b provided another case showing the effect of stimuli type on AA. That is, when the surprise test was placed on the first trial of the experiment, AA differed between simple stimuli (e.g., letters)

and complex, meaningful stimuli (e.g., animal pictures), with AA appearing in the former but not in the latter case.

## General discussion

The aim of this study was to explore the boundaries of AA, a recently reported counterintuitive phenomenon (H. Chen & Wyble, 2015a) by investigating whether AA would persist when participants encountered complex, meaningful stimuli (Experiments 1a–d). Furthermore, we linked the type of stimuli (simple vs. complex and meaningful) to the other two boundary factors of AA (i.e., repetitiveness of target stimulus and *Einstellung*) to see whether there were interaction effects between stimuli type and these two boundary factors (Experiments 2a–b and 3a–b). The results of Experiments 1a–d indicated that AA persisted even for different types of complex, meaningful stimuli in a typical version of attribute amnesia paradigm. However, the results of Experiments 2a–b and 3a–b showed that in some special situations, AA did differ between simple stimuli and complex, meaningful stimuli. To be specific, Experiments 2a–b revealed that when *the target stimuli were not repeated across trials*, AA was only obtained when using simple stimuli (letters among digits), but not when using complex stimuli (animal pictures among common thing pictures). Similarly, Experiments 3a–b showed that when the surprise test was on the first trial of the experiment, AA only appeared with simple stimuli, but not complex stimuli.

These results are important for multiple reasons. First, they have implications in understanding the boundaries of AA. For instance, the results of Experiments 2a–b showed that there was an interaction between the type of stimuli and repetitiveness of target stimuli. That is, the type of stimuli could be a boundary factor of AA, and this is true only when the target stimuli were not repeated across trials. Moreover, the repetitiveness of target stimuli could also be the boundary factor of AA, which is true only when the targets were complex, meaningful stimuli (e.g., animal pictures; W. Chen & Howe, 2017), but not when the targets were simple stimuli (e.g., letters; H. Chen & Wyble, 2016). This could explain why there were seemingly conflict findings regarding the effect of target repetitiveness on AA between W. Chen and Howe (2017) and H. Chen and Wyble (2016), who used different types of stimuli. Experiments 3a–b revealed that there was also an interaction between the stimuli type and set effects of *Einstellung*. This indicates that despite *Einstellung* or mechanization partially explaining AA, it could not fully explain this effect, in particular when the targets were simple stimuli like letters. Apart from the abovementioned boundary factors, there were also some other boundaries that need to be discussed. For example, Jiang et al. (2016) reported that AA was not found in an implicit memory task, because they found that despite participants failing to report the identity of a target, this unreportable information could still produce an intertrial priming effect. This finding is consistent with the expectancy-based binding hypothesis proposed by H. Chen et al. (2016). That is, information that participants attended to but did not expect to report would have been stored as an activated trace in long-term memory (e.g., familiarity; Oberauer, 2002) or stimulated state (Eitam & Higgins, 2010), without being consolidated, so as to produce robust memory traces that can survive a surprise test.

The results of the current study also support and significantly extend the view that participants have an aptitude for processing and/or remembering complex, meaningful stimuli as compared with simple stimuli (e.g., Brady et al., 2008; Brady et al., 2016; Christianson et al., 1991; Dolan, 2002; Esteves et al., 1994; Li et al., 2002; Nickerson, 1965; Potter et al., 2008; Shepard, 1967). Experiments 2a–b and 3a–b showed that AA disappeared when using complex, meaningful stimuli, such as animal pictures, but it still appeared when using simple stimuli, like letters. This finding has significant contributions beyond previous findings that also showed the advantage of processing/remembering complex stimuli, because in most of these previous studies, participants typically expected to remember the to-be-reported information, whereas in the current study, participants did not expect to be required to remember certain information (i.e., meaning), even though they had to process that information to locate the target. In other words, the current study suggests that participants not only could remember complex stimuli better if required, they were also more likely to automatically remember information of complex, meaningful stimuli relative to simple stimuli. However, Experiments 1a–d showed that the advantage of remembering complex stimuli over simple stimuli disappeared when the stimuli were repeated across trials. It seems reasonable to conjecture that the degree of interitem similarity might play a role in yielding the above results. Specifically, in Experiments 2a–b and 3a–b, AA occurred for simple letters rather than for complex pictures, because the complex pictures were less similar with each other in comparison with simple letters and digits that were repeatedly shown in daily life, and thus caused weaker proactive interference (W. Chen & Howe, 2017). However, in Experiments 1a–d, AA appeared even for complex, meaningful items, because these stimuli became more similar with each other when they were repeatedly shown across trials in these experiments. This interpretation was similar to what Nickerson (1965) mentioned when he explained the larger capacity of short-term memory for complex, meaningful photographs in comparison with simpler stimuli, such as three-digit numbers. Christianson et al. (1991) also speculated that the better memory for the emotional event stimuli than for the neutral stimuli was because the former stimuli were more distinctive than the latter ones. Nonetheless, it has to be mentioned that the interitem similarity account is only one possible explanation for the advantage effect of processing and remembering complex, meaningful

stimuli; another popular explanation is that there might be an evolutionary advantage in processing or retaining some special complex, meaningful stimuli, such as animal pictures and emotional events (e.g., Brady et al., 2008; Brady et al., 2016; Christianson et al., 1991; Dolan, 2002; Li et al., 2002). Future work is needed to further clarify the mechanism(s) underlying this advantage effect.

Finally, these findings also have some important implications in understanding how an attended object is represented in visual working memory, which has been heatedly discussed recently. Object-based theory assumes that all features of an object are automatically encoded regardless of its relevance (e.g., Gao, Gao, Li, Sun, & Shen, 2011; Luria & Vogel, 2011; Marshall & Bays, 2013; Xu, 2010). By contrast, opposite evidence was found that features were separately encoded and maintained, and could be forgotten independently (e.g., Bays, Catalao, and Husain, 2009; Bays, Wu, & Husain, 2011; Fougnie & Alvarez, 2011; Fougnie, Asplund, & Marois, 2010; Pertzov, Dong, Peich, & Husain, 2012; Serences, Ester, Vogel, & Awh, 2009). The current findings suggest that these two hypotheses might not necessarily be mutually exclusive, since both of them received supporting evidence from the current study. Instead, as suggested by previous studies (e.g., Xu, 2010), these two hypotheses might be reconciled if considering modulation factors such as working memory load and stimuli type.

## Conclusion

This study demonstrated that AA persisted with the presentation of complex, meaningful stimuli in a typical AA paradigm wherein participants encountered many trials and the targets were repeated across trials. In contrast, when the target stimuli were not repeated across trials, or the surprise test occurred on the first trial of the experiment, AA occurred only for simple stimuli (e.g., letters), but not for complex and meaningful stimuli (e.g., animal pictures).

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## Appendix

The stimuli used in Experiments 1b–d are listed below, while the picture stimuli used in Experiments 1a, 2b, and 3b were not listed here because of permission for reprint issues.

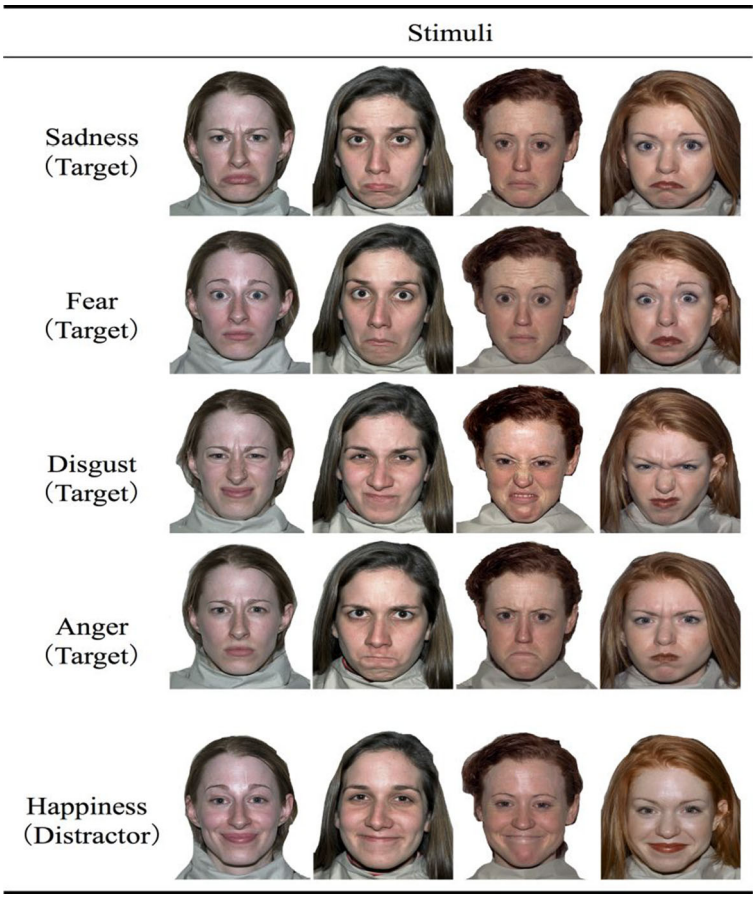
All Chinese character stimuli in Experiment 1b

| | Stimuli | Translations |
|---|---|---|
| Furniture (target) | 床、椅、桌、灯 | bed/ chair/ table/ lamp |
| Other common items (distractor) | 船、箭、车、桥、裙、信、火、鬼、叶、塔、梯、针 | boat/ dart/ car/ bridge/ dress/ letter/ fire/ ghost/ leaf/ tower/ ladder/ needle |

All Chinese poem stimuli in Experiment 1c

| | Stimuli |
|---|---|
| Patriotism (target) | 僵卧孤村不自哀,尚思为国戍轮台。 |
| | 王师北定中原日,家祭无忘告乃翁。 |
| | 商女不知亡国恨,隔江犹唱后庭花。 |
| | 但使龙城飞将在,不教胡马度阴山。 |
| Love (distractor) | 两情若是久长时,又岂在朝朝暮暮。 |
| | 此情可待成追忆,只是当时已惘然。 |
| | 在天愿作比翼鸟,在地愿为连理枝。 |
| | 相见时难别亦难,东风无力百花残。 |
| Homesickness (distractor) | 姑苏城外寒山寺,夜半钟声到客船。 |
| | 此夜曲中闻折柳,何人不起故园情。 |
| | 今夜月明人尽望,不知秋思落谁家。 |
| | 少小离家老大回,乡音无改鬓毛衰。 |
| Philosophy (distractor) | 黑发不知勤学早,白首方悔读书迟。 |
| | 劝君莫惜金缕衣,劝君惜取少年时。 |
| | 少年易老学难成,一寸光阴不可轻。 |
| | 古人学问无遗力,少壮工夫老始成。 |

All emotional face stimuli in Experiment 1d

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