Evidence for false memory before deletion in visual short-term memory

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Abstract. Forgetfulness results in interference and/or deletion. Visual short-term memory (VSTM) gradually decays as the retention time elapses, causing forgetfulness. Little is known about forgetfulness in VSTM, while substantial studies on VSTM have focused on the process of memory encoding, often with control of attention. Evidences suggest that the prefrontal cortex may contribute to maintain short-term memory during extended retention periods while the posterior parietal cortex may support the capacity-limited store of visual items. Here we conduct a visual memory experiment to measure the levels and source of memory decay. In particular, multiple retention intervals were used between the presentation of a study array and a cue. The results show that the correct response to cued objects decreased as retention interval increased while that to uncued and novel objects remain unchanged. These data indicate that forgetfulness in VSTM is primarily due to interference rather than memory deletion.

Keywords: Visual short-term memory, forgetfulness, retro-cue, interference

1 Introduction

In delayed matching tasks, such as change blindness, there is more failure in recognition as the retention time increases. Memory of an item to which subjects is exposed to tends to be maintained by employing voluntary attention to the memory itself (recall) during the time of retention and results in a better performance in a later recognition task [2][3]. Although much studies on visual memory have focused on how a better performance in recognition task is achieved, little is known about the nature of this failure. The failure of retrieval accompanying forgetfulness is possibly related to memory deletion or false memory.

Visual short-term memory (VSTM) is known to be memory storage of visual information that has a limited capacity of at least four items, depending on stimulus complexity and the organization of objects in the memory array [4], and lasts approximately from one second to several seconds from the onset of the memory array. Memory before one second from the onset is best understood with iconic or sensory memory which stores a representation with unlimited capacity but decaying more quickly and is more distracted by eye movements and intervening stimuli compared with VSTM. It has been shown that several brain regions are associated with VSTM. The prefrontal cortex is associated with the maintenance of working memory and shows increased activity with memory load [6][7][8]. The inferior intraparietal sulcus (IPS) participates in encoding and maintenance of about four objects at different spatial locations independent of object complexity whereas superior IPS and lateral occipital complex participates in that of variable capacity depending on object complexity [5].

Employing attention to an external visual stimulus [1][9][10] as well as that to an internal representation of a stimulus that is stored in VSTM [2][3] gives rise to a better memory performance. Visual attention to an item in the external world enhances processing of information for that item, whereas suppressing that for unattended items through gating the processing resources on perception [1][3], activating posterior parietal cortex and extrastriate cortex [12]. On the other hand, attention to internal representation is different from the visual attention in respect of targets because the internal representation in VSTM is encoded in the brain in advance, giving a better performance in a later recognition task [2][3]. In addition, attention to internal representation selectively activates several frontal lobe regions, although there is also an overlapping mechanism associated with orienting attention to locations in external and internal representations in parietal, frontal, and occipital areas [11]. A question is whether memory of unattended items that were once encoded in the brain in advance attenuates with or without attention to memory of an item in VSTM. In other words, memory of unattended items, or not recalled items, may be deleted or mistaken with other items.

Griffin and Nobre first described attention directed to internal representations of enhanced object memories in a similar manner to attention directed to external stimuli [3]. In their experiment, an informative cue was presented either before (pre-cue) or after (retro-cue) an array of four coloured crosses followed by a memory probe. Each cue had 80 % validity to targets, consisting of two distinct conditions valid and invalid (in the so-called Posner paradigm [12]) together with a neutral condition that was cued with a non-informative signal. The results showed that, as well as the enhancement of accuracy for valid objects, accuracy for invalid objects was significantly impaired when directing attention to both the external and internal. They did not, however, address contents of memory degradation, namely memory deletion and interference in the invalid condition. In case of retro-cues that prompt attention to the internal representation, differing from pre-cues, the array might be once encoded and stored in VSTM.

Here we investigate these issues by instructing the subjects to direct attention to visual memory of an object after multiple retention intervals. A delayed match paradigm was designed to investigate the effect of retention intervals when attention was oriented to visual memory (internal representation) of an object within VSTM during its retention (Figure 1). Attention was controlled by a predictive symbolic cue which indicates a possible target identity, using the Posner paradigm [12]. In 67 % of total trials, targets appeared with the cued identities. In half of the remaining trials, targets appeared with an identity other than the cued identity. In the other half, targets appeared with a novel identity (But see table 1). Nonsensical figures were used to control subjective familiarity with the stimuli and to minimize the effect of verbal encoding. They were also easily distinguishable and prone to forgetting so as to facilitate investigation of the nature of mere VSTM.

2 Materials and methods

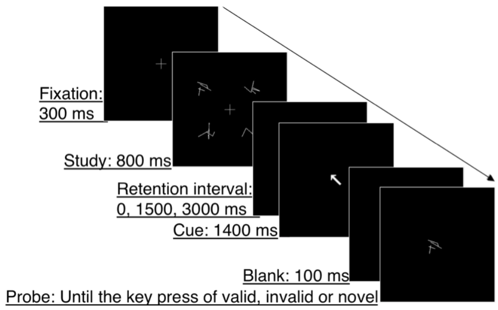

Figure 1. Time course of a trial. A predictive cue indicating a possible probe identity was presented after multiple retention intervals (0, 1500, 3000 ms). Subjects were instructed to answer VALID, INVALID or NOVEL in a three-alternative forced-choice at the probe phase. Four nonsensical figures consisting of 5 lines were randomly generated by the computer.

Trial type \ Retention interval (ms)	0	1500	3000	Total
Valid	51%	5.5%	5.5%	67%
Invalid	5.5%	5.5%	5.5%	16.5%
Novel	5.5%	5.5%	5.5%	16.5%

Table 1. Percentage of numbers of trials in the designed conditions in the experiment.

Subjects: 8 subjects (4 females and 4 males, age 25-32, with an average of 28.1) participated in this experiment. All subjects were right-handed by self-report and had normal or corrected-to-normal vision. The subjects gave written informed consent after being explained about the purpose and nature of the experiments. The stimuli were presented on a computer screen. The subjects responded by key pressing.

Stimuli and apparatus: Nonsensical figures were generated by the following algorithm. 20 invisible vertices were randomly chosen by the computer on a 120 x 120 pixel bitmap with black background, of which 2 vertices were randomly chosen to draw a white line segment between them. The nonsensical figures were composed of 5 line segments each. The 5 segments composition was designed to avoid a resemblance to the letters while minimizing the complexity of the figure. A single vertex may be shared by more than one line segments.

Procedure: the experiment consisted of 18 blocks with 24 trials each. A trial started with a 300 ms fixation followed by the study phase. In the study phase, an array of 4 nonsensical figures was presented in the centre of the screen for 800 ms followed by retention intervals of multiple durations (0, 1500, 3000 ms). After the retention intervals, a cue was presented for 1400 ms. After the presentation of the cue and a 100 ms interval, the probe was displayed in the centre of the screen until the subjects responded with a key press. The cue was an arrow (i.e. top left, top right, left bottom, and right bottom) displayed in the centre of screen predicting one of four identities of a figure that was previously shown in the study phase, whereas the probe was one of four figures displayed at the study phase of the same trial or a novel figure. There were 67 % "valid-trials" (where the correct answer is "valid"), 16.5 % "invalid-trials" (where the correct answer is "invalid") and 16.5 % "novel-trials" (where the correct answer is "novel"). Further details of number of trials are shown in Table 1. One picture was displayed in only a single trial so that all pictures apparently had comparable familiarity level. The inter-trial interval was 2000 ms.

Before the experiment, the subjects were informed that a single block consisted of 24 trials and there would be a total of 18 blocks. They sat comfortably in front of the screen at the distance of 60 cm. They were instructed to look at the crisscross throughout its presentation, to remember the object identity in the study phase and to answer a task question ("valid" "invalid" or "novel" with a key press using right index, middle or third finger, respectively) as accurately and quickly as possible. After the instruction, the subjects practiced the tasks.

3 Results

Hit rate of attended objects (VALID response in the valid trial) decreased significantly when retention intervals were increased (one way ANOVA, $p<0.001$; between 0 and 1500 ms retention interval, Tukey post hoc test, $p<0.05$; between 0 and 3000 ms retention interval, Tukey post hoc test, $p<0.001$) while the hit rate of invalid objects (INVALID response in the invalid trial) and of novel objects (NOVEL response in the novel trial) remained unchanged ($p>0.1$) (Figure 2 (a)). Comparison of trial types on 0 ms retention interval by Tukey post hoc test revealed significant differences between the valid and novel trials ($p<0.001$) and between the invalid and novel trials ($p<0.05$) (Figure 2 (a)). d' in each trial was calculated in a case of three alternative forced choice with chance level 33% (Figure 2 (c)). The statistical significances were the same as the hit rate above.

With an increase in failure in recognition for valid objects after longer retention intervals, wrong answers of invalid and novel objects were increased (one way ANOVA for invalid objects, $p<0.001$; between 0 and 1500 ms retention interval, Tukey post hoc test, $p<0.05$; between 0 and 3000 ms retention interval, Tukey post hoc test, $p<0.05$ and one way ANOVA for novel objects, $p<0.05$; but none of combinations among 0, 1500 and 3000 ms retention interval by Tukey post hoc test revealed significant differences) (Figure 2 (b)). Paired t-tests were performed on two types of the wrong answers for each retention interval. Only with the interval of 1500 ms, the rate of INVALID response was significantly higher than that of NOVEL response ($p<0.05$), indicating that the failure in recognition of a valid object may result in having false memory (i.e. of an unattended object) rather than memory deletion at that retention interval. As hit rate of the invalid trial (INVALID response in the invalid trial) and that of the novel trial (NOVEL response in the novel trial) were not changed with increasing retention interval, neither wrong answers in the invalid trial (i.e. VALID and NOVEL response) or that in the novel trial (i.e. VALID and INVALID response) were changed with increasing retention interval.

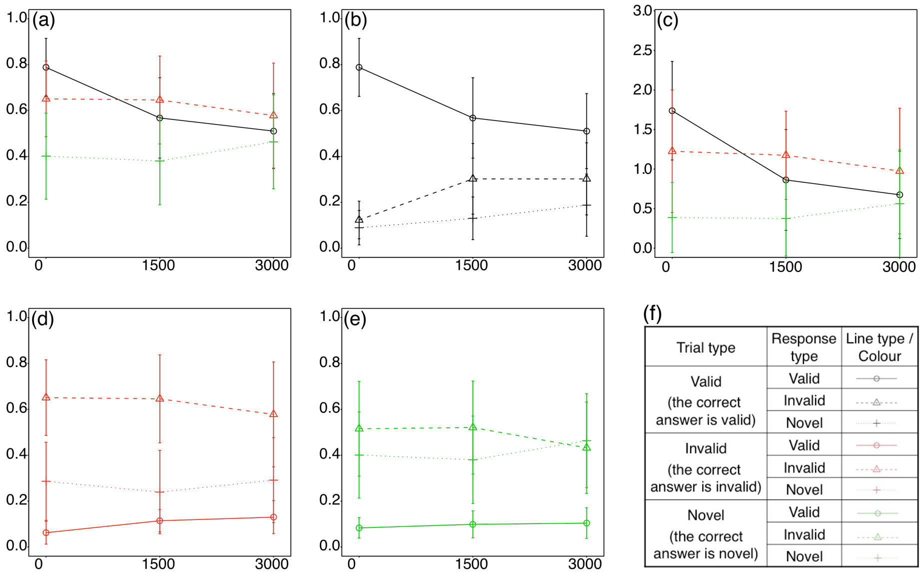

Figure 2. (a) Hit rate in each trial type (the rate of VALID response in valid trial, INVALID response in invalid trial or NOVEL response in novel trial). (c) Values of d' in each trial type. (b),(d),(e) Rate of response types in the valid, invalid, and the novel trials, respectively (see Table 1). (f) Line type and colour. Colours of the line indicate the trial types: black for the valid trials, red for the invalid trials and green for the novel trials. Types of the line indicate the response type: solid lines for valid, long dashed lines for invalid and short dashed lines for novel. The horizontal axis is the retention intervals (ms). The bars give the standard errors.

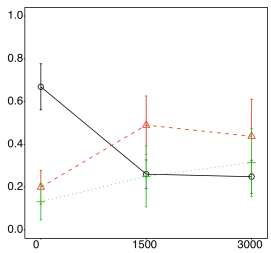

Figure 3. Rate of responses irrespective to the trial types. Colours of the line indicate the response types: black for the VALID response, red for INVALID response and green for NOVEL response. Note that numbers of trials conducted in the experiment are shown in Table 1.

There is also the possibility that the set of data in the valid trial includes false alarms from other trial types. To exclude the mutual effects of trial types, the mere rates of response types (= number of each response / total number (= 432) of trials) were analyzed (Figure 3). Although the numbers of trials were designed asymmetrically to control for the validity of cues (Table 1), the result shows significantly different tendencies (Figure 3). The rate of VALID response decreased (one way ANOVA, $p<0.001$; between 0 and 1500 ms retention interval and 0 and 3000 ms retention interval, Both Tukey post hoc test, $p<0.001$) whereas the rate of both INVALID and NOVEL response increased (both one way ANOVA, $p<0.001$; between 0 and 1500 ms retention interval with NOVEL response. Tukey post hoc test, $p<0.0001$; between 0 and 3000 ms retention interval with NOVEL response. Tukey post hoc test, $p<0.01$; between 0 and 3000 ms retention interval with NOVEL response. Tukey post hoc test, $p<0.05$). When the retention intervals were 1500 ms, the rate of INVALID response was significantly higher than that of both VALID and NOVEL responses (Tukey post hoc test, both $p<0.05$). In post-experimental interview, all subjects reported that they realized that the valid trials were more frequent but did not realize the difference among retention intervals within the valid trial (see Table 1).

4 Discussion

The nature of memory degradation when orienting attention to the internal representation (one of remembered objects) in VSTM was investigated. Unlike previous studies [2][3], our experiments provide the time course effect on retrieval VSTM. As the retention interval between the offset of stimuli and orienting attention increased, only memory of attended objects degenerated while hit rate of unattended objects (i.e. INVALID response in the invalid trial and NOVEL response in the novel trial) did not (Figure 2 (a)). Thus, attention did not simply bring about a better memory performance but rather it seemed to make a gradient on VSTM. Orienting attention to more abstract VSTM with a long retention may lead to a quick decay of VSTM. Further study is necessary to investigate whether orienting attention to internal representation actually causes a quick decay after a long retention interval.

To investigate the nature of forgetfulness in VSTM, we focused on wrong answers in the valid trial. Both INVALID response and NOVEL response increased with increasing retention interval, while the rate of INVALID response and NOVEL response did not make a difference at both 0 and 3000 ms retention interval (Figure 2 (b)). The responses of both INVALID and NOVEL have a similar tendency and these responses in daily life may often appear coincidently. Here we show a separation of INVALID and NOVEL response in wrong answers at the time of 1500 ms retention interval from the offset of memory array. In the valid trial, response of INVALID is interpreted as interference within VSTM. Having a false memory and response of NOVEL is considered to be the deletion of memory. Thus, as forgetfulness increases with a longer retention, there is a tendency to have a false memory more than memory deletion at an early time of retention. And later, the difference in the level of having false memory and memory deletion becomes insignificant. Once the VSTM is established, it would be maintained by recurrent neural activation during short-term period [13] rather than by physical changes on the structure of connectivity such as the long-term potentiation. Such recurrent activation would maintain the VSTM, degrading over time. When the VSTM is retained at a certain level at 1500 ms retention interval, attention that activates neurons in several brain regions may distract the recurrent activation of VSTM, as much as bringing out a mistake for the other remembered objects, but not as much as causing a deletion of VSTM. This may explain why VSTM may be distorted by orienting attention to memory of an object that leads to a new wave of activations on a circuit. Consequently, it is possible that forgetfulness in VSTM is primarily due to interference rather than memory deletion.

The effect of Posner paradigm was analyzed in the mere rates of response types in all of trial types (Figure 3). The experiment was designed in an asymmetrical manner regarding the number of trials (Table 1). Only the number of the valid trial at 0 ms retention interval was large and the subjects actually chose VALID the most often at 0 ms retention interval. If subjects had been successfully biased with this asymmetric number of trials (Posner paradigm), they would have tended to choose VALID the most frequently. However, at 1500 ms and later the rates of VALID response were low and stayed around the chance level of 33 %. Interestingly, the rate of INVALID response at 1500 ms retention interval was significantly higher than that of VALID and NOVEL. There are two possibilities: The subjects were not biased. Or, they were biased but tended to choose INVALID response more. According to the subject's reports, they did not strategically respond to retention intervals, such that they responded equally to three alternatives for the longer intervals. Suppose they did so without being aware, the rate of response cannot be reversed at 1500 ms retention interval. Thus the latter hypothesis may be more appropriate. As discussed above, if there is distractive effect with attention to internal representation at the intermediate retention period, interference of memory may be more often the case than deletion of memory.

5 Conclusion

When the retention intervals increased, success in the recognition of attended (valid) objects decreased while that of unattended or novel objects did not. This failure in recognition of attended objects as early as 1500 ms retention interval from offset of a memory array is possibly due to having a false memory. Further study is necessary to investigate the effect of attention to internal representation stored in VSTM.

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