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"Overwriting", not "Competing", Characterizes the Visual Working Memory Consolidation

Huiming Sun[1,2,*], Hubert D. Zimmer[3,*] , and Xiaolan Fu[1,**]

[1] *State Key Laboratory of Brain and Cognitive Science, Institute of Psychology, Chinese Academy of Sciences, Beijing, China*

[2] *Graduate University of Chinese Academy of Sciences, Beijing, China*

[3] *Brain & Cognition Unit, Department of Psychology, Saarland University, Saarbrücken, Germany*

Abstract*—Visual working memory (VWM) consolidation is the process to transfer a fleeting perpetual representation into a durable WM representation that can survive the presentation of new sensory inputs. It is investigated by post-exposure of a mask shortly after offset of memory array (S1). The memory performance increases as stimulus onset asynchrony (SOA) between S1 and mask array increases and finally reaches a asymptote level not influenced by the mask. It is considered that masks interfere the memory items representation into VWM in short SOA and that causes the consolidation phenomenon. Nevertheless, the question leaves open: how do masks interfere with this consolidation process. In this study, we tested whether masks overwrote the perceptual representation of memory items or competed with them for VWM representation. Masks interfered only when they appeared in the same location as memory items. We concluded that "overwriting", not "competing", characterized the VWM consolidation. Using the model "boost and bounce theory of temporal attention"[1], we gave the explanation to that conclusion.

Keywords-visual working memory; consolidtion; boost and bounce theory; attention

I. INTRODUCTION

Visual working memory (VWM) is the memory system responsible for processing and storing visual information for a few seconds so that it can be used for ongoing cognitive tasks [2][3]. It is relevant for the guidance of actions, for visual thinking and also for perception [4]. It has a limited capacity [5][6] which some authors consider as fixed [7] whereas other considers consider it as variable [8] varying with stimulus qualities. However, not only the qualities of items have effects on VWM performance, but also the time that is available for stimulus processing. It seems to be that one need a small amount of time after encoding for the genesis of durable entries in VWM. If another item or a mask is presented shortly after the memory stimulus, memory performances deteriorate, even though the presentation time was long enough to perceive them [9][10][11]. The latter phenomenon is called VWM consolidation and it is this process we investigated in this study.

An elegant method for investigating consolidation is the masked change detection paradigm introduced by Vogel and colleagues [11]. Just as in a standard change detection paradigm, an array of a small number of stimuli is presented (S1) that has to be remembered. After a short delay (900ms) a test array is shown (S2) which is either identical to the memory array or one stimulus has changed. Participants are asked to report whether the two arrays are the same or different. In order to investigate consolidation, S1 is only briefly exposed (about 100 ms) and after a variable empty interval, a mask is presented for 200 ms showing patterns at the locations of each of the stimuli. In the study of Vogel and colleagues [11], the interval between the offset of S1 and the onset of the mask varied from 17 to 484 ms. It is assumed that the mask interrupts the consolidation of items in VWM so that

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[*] These two authors contributed equally to this paper.

[**] Corresponding author. Correspondence concerning this article should be addressed to Xiaolan Fu, State Key Laboratory of Brain and Cognitive Sciences, Institute of Psychology, Chinese Academy of Sciences, 4A Datun Road, Chaoyang District, Beijing 100101, China. E-mail: fuxl@psych.ac.cn

the effective processing time is the stimulus onset asynchrony (SOA) between S1 and the mask. Results showed that when the number of items was near to storage capacity of VWM (about 3 to 4 items), performances were very poor with a SOA of 117 ms and they gradually increased to the asymptotic level reached in the no-mask condition. The number of items stored in VWM – estimated by the k Index, i.e., set size × (proportion of hits – proportion of false alarms) [5] – showed a linear relationship to SOA. This very likely has to do with storage and not with perceptual encoding because neither pre-exposure of the mask did impair consolidation nor visual search was influenced by masking [11]. From these results Vogel and colleagues concluded that consolidation is limited in capacity and that it needs about 50 ms per item if simple colour squares are presented as stimuli [11].

Vogel and his colleague revealed the time course of VWM consolidation, and found that the consolidation process was also capacity-limited. However, the question leaves open: how do masks interfere with consolidation of representations of memory items? Two alternative explanations exist. One possibility is that these representations are low level representation of visual shapes in spatially organized structures. Masks would interrupt consolidation by overwriting these perceptual representations of memory items. Irwin and Yeomans suggested that a "visual analog representation" exists that starts at the offset of a stimulus and persists for 150 to 300 milliseconds and that is mask-able by a pattern presented spatially congruent locations [12]. Another possibility is that the units are represented at a more abstract level that has no retinotipic organization. Masks, for example, could compete with the memory items for deeper visual processing and representation in memory. Support evidence comes from Schmidt, Vogel, Woodman and Luck study [13]. They argued that sudden-onset objects such as masks competed with VWM storage capacity.

In this study, we aimed to test which of the two possibility causes the interference with consolidation. This knowledge will help us to understand the process of consolidation and reveal the mechanism behind it. We realized two masking conditions. In the "same position" condition, we presented masks at the positions of S1 items. In the "different position" condition masks were presented next to the position of S1 items but the memory stimuli and masks were non-overlapping. In case that masks overwrite the perceptual representation of memory items, we should only observe interference in the same position condition. In contrast, we should observe interference in both conditions if consolidation works on higher level representations because masks and stimuli compete for representation.

II. METHOD

A. Participants

22 (6 males, 16 females) undergraduates were recruited from the Saarland University in Germany. One female student's data was excluded due to chance performance. Participants were voluntary and all participants participated for course credit. They were naïve to the experimental hypothesis and have normal or corrected-to-normal vision.

B. Apparatus and stimuli

The experiment was conducted with a Pentinum-IV computer connected to a 17-inch monitor. E-prime 1.2 was used to control the stimuli presentation and response recording. Participants were seated approximately 60 cm from the monitor.

Ten Chinese characters which had similar structural complexity (between three to five) were used as visual stimuli that German participants had no experience with so that they can only remember the characters according to visual information. Masks were constructed by scrambling small portions of a character within its boundary box. Each stimulus subtended approximately 2.3° of visual angle.

Always three stimuli of the same type were presented together on a computer monitor as memory array. Items appeared in a black lines on a white background within a field of 12° × 9°. Within this area, the items were randomly placed with the constraint that every two items in a given array were separated from each other by at least 3.3° (centre to centre). The items of a trial were randomly selected from the stimulus set without replacement.

C. Design and procedure

We manipulated two within-subject factors. SOA (217, 333, 450, 567, 683 ms) and the position of the masks (same position vs. different position). In the same position condition, the masks' positions were identical to the item positions. In the different condition the masks were presented non-overlapping besides of the memory items.

The whole experiment consisted of two sections divided according to the position of masks. Each section consisted of a practice block of 40 trials and 200 experiment trials divided by a short break every 40 trials. SOA varied randomly. The order of the two sections was counterbalanced across participants.

Totally, each participant completed 80 practice and 400 experiment trials lasting 30 minutes.

The trial procedure is illustrated in Fig. 1. A fixation cross appeared in the centre of the screen at the beginning of each trial and lasted for 1000ms. After that, the memory array appeared for 200ms. We presented S1 a bit longer than Vogel et al. did [11] because perceptual encoding of our complex items is more demanding than that of the simple colours used by Vogel and colleagues [11] and we did not want to constrain the quality of encoding. After a variable interval, the mask array was presented for 200ms depicting a mask at each position an item was shown in the preceding memory array. The duration of the empty interval randomly varied from trial to trial in order to change the consolidation time. This variation defined an effective SOA between the memory array and the mask array from 217 to 683 ms, i.e. a mask delay between 17 and 483ms. Between mask offset and test array, an empty interval of different duration was introduced so that the memory duration, i.e. the time between the offset of the memory array and onset of the test array, was always 1000ms, independent of the consolidation time. The test array remained visible for 2000ms, during which time the response was collected. On 50% of the trials, the test array was identical to the memory array and on another 50% of the trials it was non-matching. In the latter case, one of the three items was replaced by a non-studied item from the stimulus set. Participants indicated whether the two displays were the same or different by a key press.

D. *Data analysis*

As dependent variable A’ was calculated, a nonparametric measure of sensitivity that is frequently used in change detection experiments [14][15]. To compute A’, we first quantified the hit rate (H) as the proportion of correct responses for

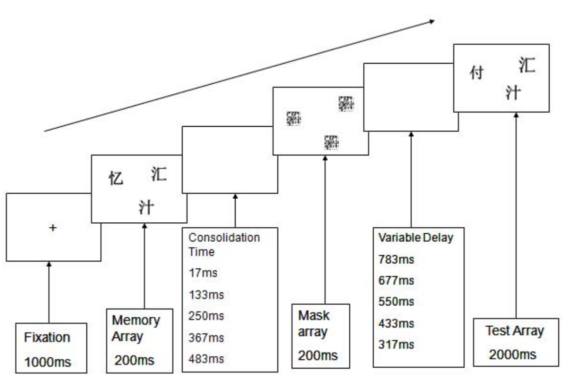

Fig. 1 An illustration of the trial structure of the experiments.

trail in which the sample and test arrays were identical and the false-alarm rate (F) was quantified as the proportion of incorrect responses in which the two test stimuli were different. A’ scores were calculated using the following formulas: A’ = 0.5 + (H－F)(1 + H－F)/4H(1－F), when H ≧ F, and A’ = 0.5－(F－H)(1+F－H)/4F(1－H), when F > H [16]. Chance performance corresponds to an A’ of 0.5 and perfect performance corresponds to 1.0.

III. RESULTS

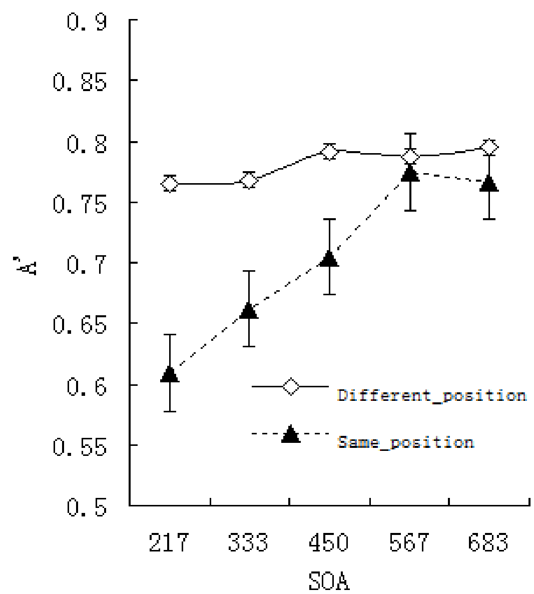

Fig. 2 Performance (A’) as a function of SOA and the mask position compared to memory items position. Error bars denote standard errors of the means.

Fig.2 illustrates A’ performance for same position and different position at different SOA level. In the different position condition, performance was nearly the same across all SOAs, suggesting no mask effect across SOA levels. In the same position, performance changed in a nearly identical pattern to Vogel study [11]. It was poor at the short SOAs and increased monotonically as the SOA increased, finally reaching an asymptote nearly at the level of the different position condition.

A two factor repeated measure of ANOVA confirmed this pattern of results, yielding highly significant main effects of the position of the mask, $F(1, 20) = 24.71$, $p < .001$, $\eta_p^2 = 0.55$, of SOA, $F(4, 80) = 10.19$, $p < .001$, $\eta_p^2 = 0.39$, and a significant interaction between these two factors, $F(4, 80) = 4.49$,

p < .003, η_p^2 = 0.1. Follow-up tests showed that except of the 587 SOA the different position condition was always worse than the same condition (ps < .04) (p > .54). Separate ANOVAs were also conducted for same and different position condition. There was significant mask SOA effect for same position condition, $F(4, 80) = 9.56$, $p < .001$, $\eta_p^2 = 0.32$, but no significant effect of mask SOA for different position condition , $F < 1$. Finally, the linear contrasts analysis revealed a significant linear trend for same position condition, $F(1, 20) = 23.60$, $p < .001$, $\eta_p^2 = 0.54$, but not for different position condition, $F(1, 20) = 1.74$, $p > 0.20$, $\eta_p^2 = 0.08$, which causes a significant interaction of the two factors, $F(1, 20) = 10.65$, $p < .004$, $\eta_p^2 = 0.35$.

IV. DISCUSSION

In present study, we investigated how the masks interfered the memory items in VWM consolidation. Clearly we observed a significant consolidation process when masks were in the same position as memory items in S1. However, this consolidation phenomenon did not happen when masks and memory items were non-overlapping. These results suggested that consolidation happened probably due to overwriting , not competing between memory items and masks.

Someone may argue that why interference observed only in the same position condition means "overwriting", whereas interference observed in both conditions means "competing". Before explaining that, we want to make use of the boost and bounce theory of temporal attention suggested by Olivers and Meeter [1]. In their model, WM is a global workspace in which the rules applying to the task are implemented. Only items that are represented in WM can be reported. Not all items are represented in WM but they are selected according to an input filter which works as a gating process. "Sets of sensory representations that are important for the task are enhanced, or boosted, through excitatory feedback, whereas sets of sensory representations that are irrelevant are tempered, or bounced, through inhibitory feedback" [1]. Accordingly, targets would be boosted and masks bounced.

On the basis of that model, we want to have a closer look at the consolidation process. When the targets , i.e. Chinese characters, are detected, attention is directed to that location (this is the exogenous shift) and it boosts processing of information presented in that location. According to the boost and bounce theory, it is assumed that attention is directed to a specific location in the visual field. If non-target stimuli, i.e. masks, are presented in the same location at the time that processing of targets is still at the first boosted, non-targets will be represented into a widely opened attention gate consequentially, updating the object files [17] that represents the targets, i.e., the mask overwrites the character. However, the first boost of target or the maximum attention is reached about 100 ms after target detection. How could it explain the consolidation process we observed when the masks appear at least 217 ms delay after target onset. Here, another assumption of the model comes into effect. No more than one attentional set is active at the same time. Therefore at the offset of S1, the goal has to be changed from perceiving targets to inhibiting masks presented at the same locations. The offset of S1 signals that masks will appear at the locations of the characters and attention should therefore switch away from the targets' locations (this is the endogenous shift). This endogenous attention switch is slow, it takes time to close the attention gate (around 200 ms after S1 offset according to the model). The more time is available before the mask is presented, the more the attention gate is closed. Therefore, the length of the interval between the offset of S1 and the onset of the mask is relevant.

However, mask Information that is not presented in the target location does not fall into the attention gate and it is not boosted. It is therefore much easier to inhibit it, because it does not match the target category. That is reason why in the different position condition we did not observe consolidation process.

In contrast, competition might happen at a higher level where objects are represented as individual object files that are not spatially defined. If the target and the mask compete at this level with each other, it should be relevant that something is presented, but not where it is presented. If interference is caused at this level, the higher the competition is, the worse the target and mask are separated in time, a main effect of delay should occur in both conditions independent of location.

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