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Research Report

The effect of context on pointer allocation in visual working memory

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ARTICLE INFO

Article history:
Received 26 December 2023
Reviewed 15 February 2024
Revised 21 March 2024
Accepted 30 April 2024
Action editor Asaf Gilboa
Published online 28 May 2024

Keywords:
Working memory
Visual working memory
CDA
Resetting
Objects perception
Pointer system

ABSTRACT

Visual working memory (VWM) can hold a limited amount of visual information and manipulate it. It encodes this information and forms representations of each one of the relevant objects. When an object changes, VWM can either update or reset its representation to account for this change. To access a specific representation VWM relies on a pointer system associating each representation with the corresponding object in the environment. While previous studies described these processes as reacting to a change in the object status, this study investigated the adaptability of the pointer system to the task context. We measured the contralateral delay activity (CDA; an electrophysiological marker of VWM) as a marker of updating and resetting. In two experiments we used a shape change detection task (similar to Balaban & Luria, 2017) and manipulated the proportion of the resetting and updating trials to create different task contexts. Experiment 1 indicated that VWM can adapt to a resetting mode in which it performs resetting in conditions that triggered updating in previous studies. However, Experiment 2 revealed that the pointer system cannot adapt to an updating mode and perform updating in conditions that trigger resetting. These results suggest that VWM can strategically perform resetting, but once a pointer is lost, it's impossible to update the representation and a resetting process is mandatory triggered regardless of the context.

1. Introduction

Task context was shown to influence visual perception (Harel, Kravitz, & Baker, 2014; Bracci, Daniels, & Op deBeeck, 2017), attention (Chun & Jiang, 1998; Torralba, Castelhano, & Henderson, 2006), object identification (DeGraef, De Troy, & d'Ydewalle, 1992) and objects representation in visual working-memory (VWM; cf., Balaban & Luria, 2016). The current study investigated how the task context affected VWM

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https://doi.org/10.1016/j.cortex.2024.04.019

pointer system, specifically the processes of updating and resetting the representations within the VWM workspace.

VWM is the mechanism that enables us to perceive a stable and consistent world despite the frequent changes in the visual input. It can hold a limited amount of information in an online state and manipulate it (Luck & Vogel, 2013). It stores representations of objects in the world and modifies them according to changes in the environment. This constant modification creates the experience of consistency, allowing us to perceive a coherent environment.

The process of accessing and modifying representations in VWN is based on a pointer system; each representation has a unique mapping (pointer) that associates it with a specific object in the world (Pylyshyn, 2000). The correspondence between the representation and the object, enabled by this pointer, is essential for accessing and modifying the relevant representation when needed. Namely, when VWM has to update a specific representation, it relies on the pointer system to access and then to modify only the relevant representation.

1.1. *Resetting and updating*

Most of previous research focused on the updating process: whenever an object in the environment changes, VWM modifies the corresponding representation to match the recent state of the object (e.g., Balaban & Luria, 2016; Kahneman, Treisman, & Gibbs, 1992). However, in some cases, the change is too dramatic and the correspondence (the pointer) between the representation and the object can no longer be maintained. In these situations, the change invalidates the pointer that associates the object and the representation, such that this pointer cannot be used to access the representation. Consequentially, this representation cannot be accessed and therefore cannot be updated. In this case, a "resetting process" is triggered, in which VWM discards the existing representation and establishes a new representation and a new pointer (Balaban & Luria, 2017).

To track the resetting and updating processes, previous studies used an electrophysiological marker of object representation in VWM; the contralateral delay activity (CDA), which is a negative slow wave whose amplitude rises as more items are held in VWM (Vogel & Machizawa, 2004; for a review., Balaban & Luria, 2016). Recently, the CDA has been used as a marker for resetting and updating processes. Balaban and Luria (2017) used a shape change detection task in which participants memorized the shape of a moving random polygon. In one condition (the Separating Polygon condition), the polygon shapes split into two halves during the movement (see Fig. 1a). Interestingly, 200 ms after the polygon split into two, the CDA amplitude sharply dropped, only in this condition. After the drop, the amplitude recovered reaching an amplitude similar to a control condition in which participants had to track two independently moving polygons (see Fig. 1b). In a series of control experiments, this study demonstrated that this CDA drop is a marker of the loss of a pointer and the following resetting process. These results suggest that this split triggered the resetting process, presumably because neither of the two polygon-halves matched the original full-polygon representation after the split. As a result, the pointer of the full polygon was no longer relevant. This object split triggered a resetting process in which VWM deleted the no longer relevant representation and then created novel representations with novel mappings (pointers) that corresponded to the two polygon halves.

More support for the CDA drop as a marker of the resetting process came from a study by Balaban, Drew, and Luria (2018), which showed that when the parts of an integrated object are encoded as separate objects with a unique pointer to each part, there was no drop when this object split. For example, when presenting the two polygon halves moving independently before uniting to an integrated polygon, or presenting an integrated polygon with a different color for each half, there was no drop when the polygon split. Since the polygon split was identical to conditions in which only one pointer was allocated to this polygon (which resulted in a resetting process), these results indicate that the drop appears only when the change invalidates the object's pointer, and therefore they support the drop as a marker for pointer invalidation (i.e., resetting).

In the same study by Balaban and Luria (2017), the CDA-drop was also evident in a condition in which a stimulus was suddenly replaced by a different one, known as a Switch condition (see Fig. 1d). In this task, subjects observe two consecutive memory arrays that are separated by a 50 ms blank interval, followed by a retention interval and a target display. They were asked to remember the second memory array and later compare it to the target. In all conditions, the first memory array contained a single polygon-half. In the Add condition, another polygon-half was added in the second memory array in a different location. Importantly, in the Switch condition, this additional polygon-half that was added in the second memory array appears next to the original polygon-half, creating a full polygon shape. This transition from a polygon-half to an integrated polygon was perceived as a sudden switch in the object's shape and resulted in a CDA drop which indicated that this change triggered resetting. Presumably, the abrupt item replacement invalidated the original pointer, creating the impression that the novel item appears. Similar to the separation condition, this drop appeared around 200 ms after the change in the object (the switch in the object's shape).

Noticeably, there was a difference between the shape of the drop and the latency in which it reaches its peak under these two types of changes (split and switch, see Fig. 1b and d). Namely, the drop when abruptly switching objects extended over a larger time period and reached its peak later than when an object split into two parts.

1.2. *The current study*

As outlined above, previous findings have shown that changes in the object status triggered a resetting process when these changes invalidated the pointer that associates the object and its VWM representation. However, when the correspondence could be maintained, VWM used an updating process to access and modify its representations (Balaban et al., 2018). Importantly, past studies on resetting and updating have focused mainly on investigating how different visual changes in the object triggered resetting and updating. Namely, VWM

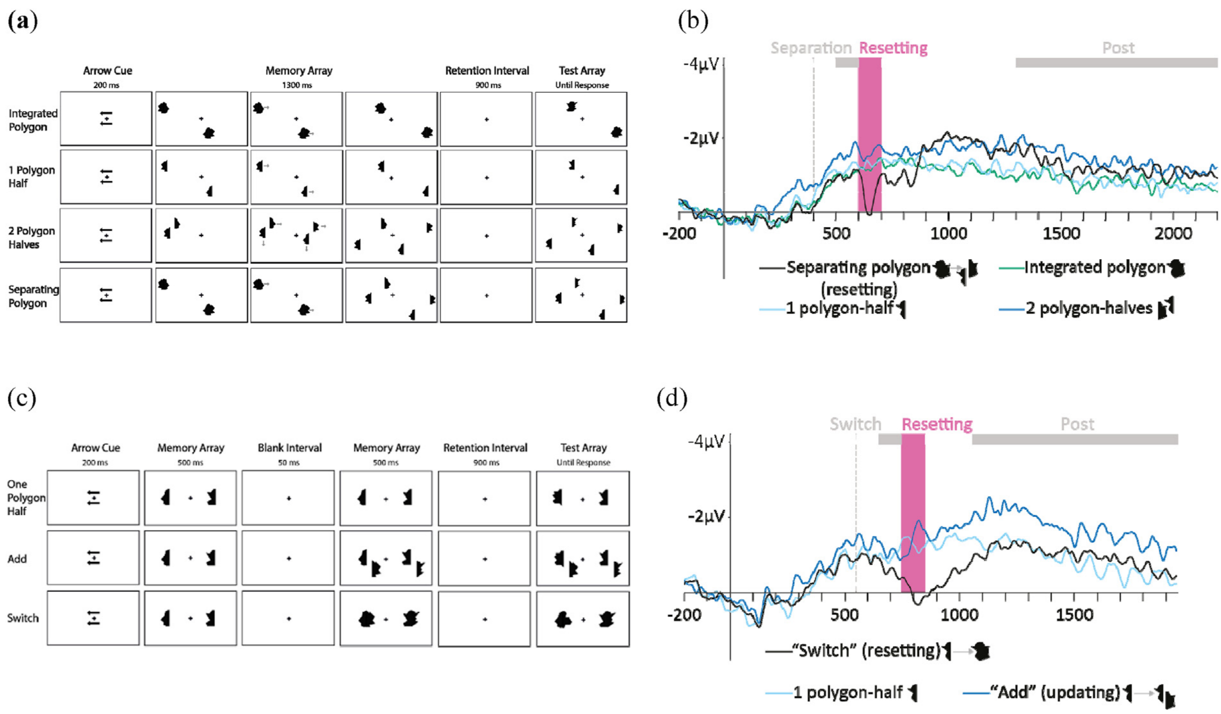

Fig. 1 – A scheme of the tasks from Balaban and Luria (2017) experiments 2 and 3. (a) A description of the "separation paradigm". The four conditions of the Separation paradigm; Integrated polygon, 1 polygon-half, 2 polygon-halves and Separating polygon, are presented from top to bottom. At the beginning of each trial, participants observed an arrow cue indicating to which side they needed to allocate their attention. They were asked to track polygon shapes that moved on the relevant side of the screen during the memory array and remember their shapes during the retention interval. Finally, they were asked to determine whether the object presented in the test array was the same or different from the object (or objects) that appeared during the memory array. Importantly, in the Separating polygon condition, the polygon split into two halves, and subjects were asked to remember the two polygon-halves after the split. (b) ERP results of the separation paradigm described above. The results are time-locked to the beginning of the memory array. The dashed line represents the time of separation in the separation condition. (c) A description of the "switch paradigm". The current study used a similar paradigm, but the only difference was the frequencies of the conditions. The three conditions of the Switch paradigm; One Polygon-Half, Add and Switch are presented from top to bottom. At the beginning of each trial, participants observed an arrow cue indicating to which side they needed to allocate their attention. All conditions started with a single polygon-half presented on the screen. In the One Polygon-Half condition, this polygon-half was repeated in the second display. In the Add condition, the polygon-half was joined by another half that appeared in a different location in the second display. In the Switch, condition the single polygon-half was replaced by an integrated polygon in the second display. (d) ERP results of the Switch paradigm described above. The results are time-locked to the first memory array. The dashed line represents the appearance of the integrated polygon in the switch condition (i.e., the second memory array).

reacted to a change in the object status. However, these studies have not tested whether these processes can be triggered by factors other than changes in the objects themselves. This question is important in order to learn about the nature of the pointer system: Whether it is a low-level mechanism that only reacts to perceptual properties (Kahneman et al., 1992), perhaps it simply follows the number of perceived objects (Balaban & Luria, 2016), or possibly the pointer system may be a high-level mechanism that can be affected by environmental factors that are not necessarily related to the visual properties of the objects.

We aimed to answer this question by investigating whether resetting and updating can be triggered by environmental changes, without changing the object's properties. If the pointer system is in a low-level mechanism, resetting and updating would be triggered only by changes in the object's properties, regardless of the task context. However, if the pointer system is more of a high-level mechanism, it might be able to adjust to different contexts and demands, and therefore resetting and updating might be triggered not only by changes in the objects but also by the context.

The paradigm used in the current study is based on a paradigm used in Experiment 3 by Balaban and Luria (2017). Balaban and Luria (2017) have found a CDA drop in the Switch condition that reflects the resetting process that resulted from the sudden switch in the object's shape in this condition. Experiment 1 and 2 in the current study used the same paradigm, but the only change was the proportion of trials of each condition. In Balaban and Luria (2017), all conditions had a similar probability to appear in the upcoming trial. In the current study, on the other hand, we manipulated the proportion of the trials to create different contexts.

In the next two experiments, we investigated the question of whether the pointer system and specifically the resetting and updating processes could be affected by environmental and contextual properties, without changing the stimuli. Experiment 1 investigated whether the pointer system can adapt to a situation in which resetting is more common than updating and Experiment 2 tested whether the pointer system can adapt to a situation in which updating is more common. In both experiments, we used the same paradigm (Experiment 3 of Balaban and Luria, described above), when the only difference between the experiments is the proportion of the conditions triggering updating and resetting.

2. Experiment 1

The current experiment aimed to investigate whether resetting can be triggered by a specific context. To answer this question, we tested whether resetting can be triggered when we present the stimuli in a different context, even though the object changes in a way we know from previous studies, does not trigger resetting. Thus, we were interested in a condition that did not invalidate the pointer as was evident by a slow rise in the CDA without a drop (Balaban & Luria, 2017; Balaban et al., 2018).

To test that, we created a resetting context such that a condition known to invalidate the pointer and result in a resetting process occurred on most trials. While we certainly expected resetting in this condition, the important outcome was what would happen to the ‘updating’ condition. If VWM adapts a ‘resetting mode’ it should interpret every change as a change that triggers resetting. In such a case, VWM should perform resetting in a situation that in other cases triggers updating. Namely, we investigated whether a resetting context would trigger a resetting process in a condition that previously triggered updating.

The current paradigm was based on the shape change-detection task used by Balaban and Luria (2017), in which participants were asked to detect a change in the object's shape while their CDA was monitored. The paradigm we used was identical to Experiment 3 of Balaban and Luria (2017) and consisted of the same conditions (Fig. 1c). The only difference is that we manipulated the proportion of each condition, which will be described below.

The encoding phase included two sequential memory arrays, and participants were asked to remember the shape(s) in the second display and compare it to the target appearing in the test display. This experiment included three conditions; One polygon-half, Add, and Switch conditions (see Fig. 1c). As mentioned above, Balaban and Luria (2017) found no evidence for resetting in the Add and the One polygon-half conditions (see Fig. 1d), because in these conditions, the mappings could be maintained throughout the trial. They have found an increase in the CDA amplitude after the addition of the second polygon-half in the Add condition, which provides evidence for updating. The Switch condition is the only condition that triggered resetting, since the replacement of the first polygon-half with the integrated polygon was perceived as the appearance of a novel object, thus invalidating the original mapping.

In contrast to Balaban and Luria (2017), the three conditions in the current experiment were not equally distributed, but the majority of the trials were Switch trials. The purpose of this manipulation was to investigate whether a situation in which VWM constantly performs resetting would cause it to perform resetting in the Add condition, that did not trigger resetting in previous research. Namely, if this context can affect VWM to adopt a “resetting-mode”, we should also see evidence for resetting (a CDA-drop) in the Add condition, in which a separate polygon-half is added to the array. While Balaban and Luria (2017) observed an updating process in the Add condition, we argue that an overall resetting strategy should cause resetting in this condition.

3. Method

In the following sections, we report how we determined our sample size, all data exclusions, all inclusion and exclusion criteria, whether inclusion and exclusion criteria were established before data analysis, all manipulations, and all measures in the study.

To select a sample size, we performed a power analysis based on experiment 3 of Balaban and Luria (2017), which used a similar paradigm. We calculated the effect size based on the reported F value and sample size ($F(1, 11) = 14.37$). The sample required for showing a main effect of condition with 95% statistical power and an alpha level of 5% was 6 participants. Since Balaban and Luria's (2017) effect size is related to finding a drop in the expected (Switch) condition and the goal of the current experiment was to find a drop in an unexpected condition (Add) we decided to use 20 participants. Participants with more than 25% rejected trials or less than 60% accuracy were excluded from the analysis. These criteria were established before data analysis, but no participants were excluded in this experiment.

3.1. *Participants*

20 Tel-Aviv University students participated in this experiment (16 females and 4 males, ages: 18–27). All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants who agreed to participate in the experiment were informed following the procedures of a protocol approved by the local ethics committee. Participants received course credit or 40NIS (~10 USD) per hour for participation.

3.2. *Procedure and stimuli*

The paradigm and task in the present study was identical to Experiment 3 of Balaban and Luria (2017) and the only difference was the probability of each condition to appear in the next trial. Stimuli were presented in black color on a grey background. Each trial consisted of two memory arrays and one target array. At the beginning of each trial a black fixation plus, .4°*.4° of visual angle from a viewing distance of ~60 cm, was presented in the middle of the screen and stayed there during the entire trial. After 600 ms, two black arrows (1.9°*.4°) were presented above and below the fixation for 200 ms, and participants were instructed to attend only to the half of the screen to which the arrows were pointed and to ignore the other side. After the arrow disappeared, only the fixation cross remained visible for 300, 400, or 500 ms (randomly determined with an equal probability). Then, the first memory array was presented and consisted of two polygon halves (one on each side of the screen). Each polygon-half was presented on one side of the screen for 500 ms. The locations of the polygons were randomly sampled from 4.5°*3.5° rectangle (one on each side of the screen). This array was followed by a blank of 50 ms. Then, in the second memory array; the polygon-halves either reappeared (the One-Polygon Half condition), reappeared with another polygon-half presented in a different place (the Add condition), or were replaced by a complete polygon (the Switch condition, see Fig. 1c). In the Switch condition, the complete polygon was composed of the original half together with a corresponding half, creating a complete polygon. The polygons stayed on the screen for 500 ms and then disappeared for 900 ms (retention interval). Finally, the target display appeared; In the One-Polygon Half and the Switch conditions, the target was a single polygon or polygon-half which was identical to the polygon presented in the second memory array in half of the trials and different in the other half. In the Add condition, the target was two polygon halves. In half of the trials, both polygons were identical to the polygons that appeared in the last memory array, and in the other trials, one of the polygons changed. Participants were instructed to indicate (by pressing "/" or “z") if the target is the same or different from the second memory array. Each subject completed 12 practice trials followed by 20 blocks of 60 trials each (overall, 1200 trials). Importantly, 15% of the trials (180 trials) were One-Polygon-Half condition, another 15% were Add condition and 70% of the trials (840 trials) were Switch condition.

3.3. *EEG recording and analysis*

The experiment took place inside a shielded Faraday cage. EEG was recorded using BioSemi Active-Two system. EEG was recorded from 32 scalp electrodes: Fp1, Fp2, AF3, AF4, F3, F4, F7, F8, Fz, FCz, C3, C4, Cz, T7, T8, P1, P2, P3, P4, P5, P6, P7, P8, Pz, PO3, PO4, PO7, PO8, POz, O1, O2, and Oz. In addition to the scalp electrodes, data were recorded from two electrodes placed on the mastoids. EOG was recorded from two electrodes placed 1 cm from the external canthi and from an electrode beneath the left eye. Data were digitized at 256 Hz. EEG processing was performed using the EEGLAB Toolbox, the ERPLAB Toolbox and MATLAB (MathWorks) scripts. During the analysis, all electrodes were referenced to the average of the mastoids. The continuous EEG data were segmented into epochs from 200 before the onset of the first memory array to 2000 ms after the onset of the first memory array. Artifact detection was performed using a moving window peak-to-peak analysis, with a threshold of 80 μV for the EOG electrodes and 100 μV for the analyzed CDA electrodes (P7, P8, PO3, PO4, PO7, and PO8). Subjects with more than 25% rejected trials were excluded from the analysis. Only trials with a correct response were included in the analysis. For illustration purposes, the epoched data displayed in the results figures were lowpass filtered using a noncausal Butterworth filter (12 dB/oct) with a half-amplitude cutoff point at 30 Hz. All statistical analyses were performed on the unfiltered data. CDA difference wave was calculated by subtracting the average activity at electrodes ipsilateral to the attended side from the average activity at electrodes contralateral to the attended side. We present only the results from the average of 3 electrode pairs (P7/8, PO3/4, and PO7/8).

4. Results

4.1. *Behavioral results*

We analyzed the accuracy in the change detection task using analysis of variance (ANOVA) with Condition (One polygon-half, Add and Switch) as the within-subject variable. This analysis showed a significant effect of condition ($F(2, 19) = 218.80$, $p < .005$, $\eta_p^2 = .92$). This effect was a result of higher accuracy in the One polygon-half condition (.87, SD: .05) compared to the Add condition (.72, SD: .05), ($F(1, 19) = 300.97$, $p < .0000005$, $\eta_p^2 = .94$), and the Switch condition (.71, SD: .05), ($F(1, 19) = 205.96$, $p < .0000005$, $\eta_p^2 = .91$). The difference between the One polygon-half and the Add conditions is a result of a set size effect; Accuracy was higher when encoding one object compared to two.

A possible explanation for the difference between the One polygon-half and the Switch conditions could be that participants had more time to encode the stimuli in the One polygon-half condition compared to the Switch condition. Since the polygon-half appeared for 500 ms and then reappeared for another 500 ms, the overall time participants observed this stimulus was 1000 ms, but in the Switch condition the second display is different from the first one. Hence, participants had only 500 ms to encode it.

4.2. *Drop related ERP results*

We used the CDA to track the resetting and updating processes. As mentioned, the CDA-drop might vary in shape and latency between different conditions. Balaban and Luria (2017) found a wider and later drop in the Switch condition but also showed a narrow drop in a condition in which a single polygon split into two halves (Split condition). A visual inspection of Fig. 1b, d and Fig. 2a, indicates that in the current experiment, the drop in the Switch condition was similar in shape to the drop in the Switch condition in Balaban and Luria (2017), but the drop in the Add condition was similar to their Separating Polygon condition (a narrower drop). To test whether the drop in the Switch condition in our experiment was indeed later than the drop in the Add condition, we measured the time at which the CDA reached 50% of its maximum amplitude after the drop using a jackknife procedure and tested the

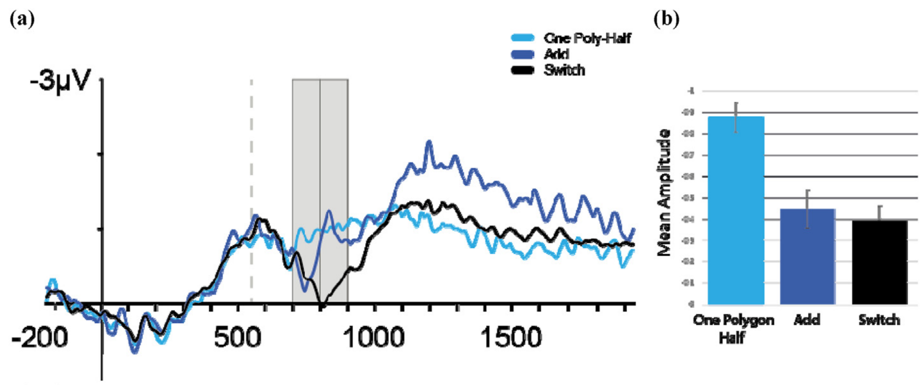

Fig. 2 – (a) Results of experiment 1. The data was collected from 20 subjects. Grand-average CDA time-locked to the first memory array presentation. Averaged across the P7/8, PO3/4, and PO7/8 electrodes. The vertical dashed line depicts the time of the presentation of the second memory array. The analyzed time window (700 ms–800 ms and 800 ms to 900 ms after the first memory array onset) is depicted by the grey rectangle. (b) Mean CDA amplitude of each condition in the time window of 700–800 ms after stimulus onset. Error bars showing the standard error.

differences between the conditions (Miller, Patterson, & Ulrich, 1998). We found that the CDA amplitude reached 50% of its maximum amplitude significantly later in the Switch condition compared to the Add condition ($t(1, 19) = -10.55$, $p < .05$), indicating that the drop in the switch condition is indeed wider than the drop in the Add condition. Hence, we used a wider time window that can include both drops. We analyzed the mean CDA amplitude within the time window of 700–900 ms after stimulus onset as a dependent measure using a one-way analysis of variance (ANOVA), with Condition (One polygon-half, Add and Switch) as the within-subject variable. This analysis resulted in a main effect for condition ($F(2, 19) = 12.52$, $p < .05$, $\eta_p^2 = .39$). To calculate the CDA-drop, we used the One polygon-half condition as a baseline and performed planned comparisons (contrasts) between the One polygon-half and the Switch conditions and between the One polygon-half and the Add conditions. The difference between the One polygon-half and Switch conditions was significant ($F(1, 19) = 34.27$, $p < .05$, $\eta_p^2 = .64$) but the difference between One polygon-half and Add conditions was only marginally significant ($F(1, 19) = 3.42$, $p = .08$, $\eta_p^2 = .15$). We concluded that the reason for this marginal significance is that the timing to evaluate this resetting effect was shorter (similar to Balaban & Luria, 2017). Therefore, we analyzed the mean CDA amplitude within the 700–800 ms time window and compared the One polygon-half and the Add condition. This analysis showed a significant difference between conditions ($F(1, 19) = 8.54$, $p < .05$, $\eta_p^2 = .31$). In the later time window (700–800 ms), the difference between the One polygon-half and the Add condition was not significant ($F(1, 19) = .05$, $p = .82$, $\eta_p^2 = .002$).

5. Discussion

The results showed evidence for resetting (CDA-drop) in both the Switch and Add conditions. Importantly, while the drop in the Switch condition replicated former results, the drop in the Add condition is a novel finding since the Add condition did not trigger resetting in previous research. In the Add condition, the first polygon-half is displayed again together with a novel one, and the pointer of the first polygon can still be maintained when the second polygon is added. Therefore, this addition did not trigger resetting in previous research. In the current experiment, we used the same paradigm and stimuli, and the only difference was that most of the trials were switch trials, meaning that the majority of the trials triggered resetting. The results showed that this contextual change affected the allocation of the pointers such that now the addition of a new object in the Add condition triggered resetting even though nothing had changed in the stimuli. This means that instead of keeping the representation of the first polygon-half and adding another representation, the representation of the first polygon-half was deleted and replaced by the two representations of the two polygon-halves. This result suggests that the pointer system can adapt to different contextual demands. In this case, it adopted a resetting mode and performed resetting in a situation that triggered updating in a different setting. It implies that pointer allocation is not solely affected by visual properties in a bottom-up manner, but it might be adaptively controlled by VWM.

It is important to mention that this result shows that the resetting mode applies only to situations in which the memoranda has changed and needs to be updated. The One polygon-half condition did not show a drop, which supports that not every condition triggers resetting under this context, but only situations in which updating the memoranda is required.

As mentioned before, the drop in the Switch condition in Balaban and Luria (2017) was spread over a larger time window compared to the drop in the Separating Polygon (split) condition and appeared later compared to the Separating Polygon condition (see Fig. 1b and d). The drop in the Switch condition started at 650 ms and ended around 1100 ms after stimulus onset, while the drop in the Split condition started at 600 ms and ended at 700 ms after stimulus onset. A similar pattern was demonstrated in this experiment as well; The drop in the Add condition was narrow and reached its peak earlier compared to the Switch condition. The drop in the Add condition is similar to the Separating Polygon condition in Balaban and Luria (2017). This difference between the shape and latency of the drop in these conditions might reflect a difference in the resetting process performed in each one of the conditions. These differences will be discussed in the General Discussion.

6. Experiment 2

This experiment investigated whether VWM can also adopt an "updating-mode", in which it performs updating in conditions that previously triggered resetting. The paradigm was identical to Experiment 1, but now the majority of trials were Add trials. Thus, in most trials, VWM was performing an updating process. If VWM can adapt to such an updating-mode, we should not see a drop in the Switch condition.

The question of whether VWM can adapt to an updating-mode is particularly important because it might help us better understand how the pointer system works. If VWN can adapt to an updating-mode, it means that it can update representations even when the correspondence with the object is invalidated. Such a finding would indicate that VWM can overcome the loss of a pointer. On the other hand, if VWM can't adapt to an updating-mode, it will indicate that some visual changes mandatorily trigger resetting when they invalidate the pointer (Balaban, Drew & Luria; 2018; 2019).

7. Method

7.1. *Participants*

20 Tel-Aviv University students participated in this experiment (17 females and 3 males, ages: 20–31). All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants who agreed to participate in the experiment were informed following the procedures of a protocol approved by the local ethics committee. Participants received course credit or 40NIS (~10 USD) per hour for participation. Participants with more than 25% rejected trials (one female) or less than 60% (none) accuracy were excluded from the analysis. These criteria were established before data analysis.

7.2. *Procedure and stimuli*

The stimuli and procedure were identical to the first experiment, except for the following; here 70% of the trials were of the Add condition. The One-polygon and the Switch conditions were 15% of the trials each.

7.3. *EEG recording and analysis*

All EEG recordings and analysis were identical to Experiment 1.

8. Results

8.1. *Behavioral results*

Analysis of the accuracy showed an effect of condition (One polygon-half, Add and Switch), ($F(2, 19) = 133.59$, $p < .005$, $\eta_p^2 = .87$). This effect resulted from higher accuracy in the One polygon-half condition (.87, SD: .04) compared to the Add condition (.72, SD: .05), ($F(1, 19) = 300.98$, $p < .0000005$, $\eta_p^2 = .94$), and the Switch condition (.71, SD: .06), ($F(1, 19) = 24.92$, $p < .0005$, $\eta_p^2 = .56$). Similar to experiment 1, this is a result of set size effect. We also found the same benefit of the One polygon-half condition compared to the Switch condition presumably due to more encoding time.

8.2. *Drop Related ERP*

ERP results of experiment 2 are presented in Fig. 3a. We performed the same analysis as Experiment 1, using the amplitude in the time window of 700–900 ms after stimulus onset as a dependent variable and using the One polygon-half as a baseline. There was a main effect of Condition ($F(2, 19) = 11.75$, $p < 005$, $\eta_p^2 = .38$). To calculate the CDA-drop, we performed planned comparisons between the One polygon-half and the Switch conditions, and between the One polygon-half and the Add conditions. There was no difference between the One polygon-half and Add conditions ($F(1, 19) = .03$, $p = .85$, $\eta_p^2 = .002$). However, there was a difference between One polygon-half and Switch conditions ($F(1, 19) = 10.04$, $p < .05$, $\eta_p^2 = .34$), indicating a drop in the Switch condition. This means that unlike Experiment 1, there was no drop in the Add condition while the drop in the Switch condition remained.

9. Discussion

As in Experiment 1, this experiment used the same stimuli and design as Balaban and Luria (2017) with the only difference being the proportion of the trials. In Experiment 2, most of the trials were Add condition that does not invalidate the pointer and hence triggered updating in Balaban and Luria (2017), and this pattern was replicated here as well. We aimed to find whether this contextual change would affect the way VWM's pointers allocation, this time whether it could perform updating instead of resetting, as should be indicated by the disappearance of the drop in the Switch condition. However, the apparent drop in the Switch condition indicates that VWM performed resetting in this condition and did not adapt to an updating-mode. The meaning of this result is that in the Switch condition, the transition from a polygon-half to an integrated polygon still triggered a resetting process; The pointer system did not maintain the polygon-half representation and updated the integrated polygon shape into the same representation (an updating process), but deleted the polygon-half representation and replaced it by a new representation of the integrated polygon (a resetting process).

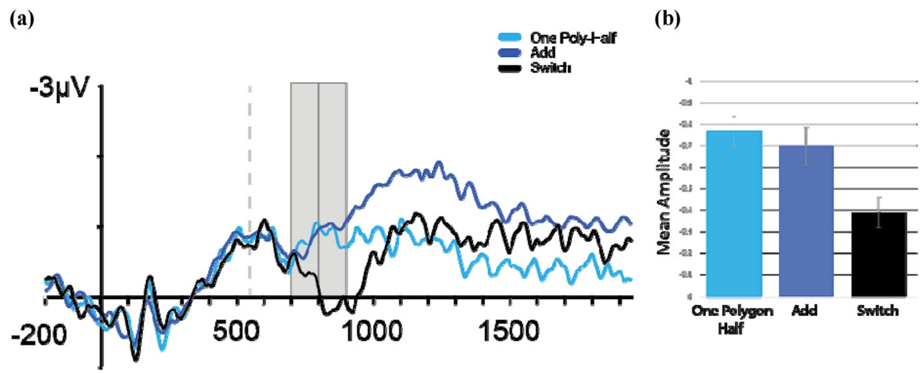

Fig. 3 – Results of experiment 2. The data was collected from 20 subjects. Grand-average CDA time-locked to the first memory array presentation. Averaged across the P7/8, PO3/4, and PO7/8 electrodes. The vertical dashed line depicts the time of the presentation of the second memory array. The analyzed time window (700 ms–800 ms and 800 ms to 900 ms after the first memory array onset) is depicted by the grey rectangle. (b) Mean CDA amplitude of each condition in the time window of 700–900 ms after stimulus onset. Error bars showing the standard error.

This result indicated that when a change in the object invalidates the pointer associates this object and its representation, VWM must delete the old representation, which means it cannot perform updating instead of resetting. Once a dramatic change invalidates the pointer, resetting becomes mandatory.

Even though the grand average showed a CDA drop in the Switch condition, we looked at the individual participant's CDA to find out whether all participants or most of them showed a CDA drop in the Switch condition. 17 out of 20 participants showed a clear CDA drop in this condition. The left three participants showed a very small drop or no drop at all.

10. General Discussion

The main purpose of the current study was to investigate the nature of the pointer system. One possibility is that the pointer allocation process is a low-level mechanism that automatically reacts to changes in the world. Under this assumption, resetting and updating are initiated as a result of whether the change invalidates the pointer or not. On the other hand, the pointer system might be a flexible mechanism that can adapt to different situations and react strategically. To learn more about VWM's control over its pointer system, we investigated whether the experimental context could affect the processes of updating and resetting regardless of the visual changes.

While previous research manipulated the object's visual properties to create resetting and updating conditions, the current manipulations used contextual changes only, while maintaining the same paradigm and stimuli as the previous study. In the two experiments, we showed that VWM can strategically perform resetting over updating. Conversely, VWM couldn't perform updating strategically. That is, VWM can delete representations even when the pointer is not invalidated. However, when the pointer is invalidated, VWM performs resetting in a mandatory way. The reason for that might be the inability of the pointer system to update an existing representation when the change invalidates the pointer. These results show that VWM's pointer system is not solely reacting to the visual input and the same input can trigger different processes under different contexts. However, it is also not solely affected by the context since VWM cannot perform updating, but only resetting when a pointer is invalidated. It is important to mention that the resetting mode did not affect the One polygon-half condition, in which the same object repeated without changing. It means that the resetting mode only affects situations in which the object has changed and requires an updating process.

In addition, this study might point to an important issue regarding the CDA-drop as a marker of resetting (Balaban & Luria, 2017; Balaban et al., 2018, 2019). Interestingly, the switch and add manipulation resulted in two different drop types. Both drops seem to represent resetting, but they differ in their shape and latency; the drop in the Switch condition is similar to the drop that Balaban and Luria (2017) showed in the same condition and the drop in the Add condition is similar to the drop in their Separation condition. Balaban and Luria (2017) found these two types of drops in different paradigms, but in this study, they appeared in the same experiment, ruling out the possibility that the different drops resulted from different tasks. The difference between the two types of drops might stem from the ability of VWM to process the two changes (switch and addition); when an object is suddenly replaced by another one (as in the Switch condition), the new representation interferes with the old one. This interference might be harder to process and therefore might increase the variance in the latencies of the resetting process along the experiment. This higher variance can explain the wider drop in this condition. This is not the case with an addition; when we observe an addition (as in the Add condition), the new representation does not interfere with the old one since it's still in view.

Even though the Add condition showed a different pattern in Experiments 1 and 2 (resetting in one and updating in the other), we did not observe a difference in the behavioral results between the two experiments. Such a difference is expected because in the first experiment, the resetting process makes the encoding time of the first polygon-half shorter because its representation resets by the second memory array. As a result, there is a shorter encoding time to this object which might lead to a lower accuracy. However, the accuracy in the Add condition in both experiments was the same. A reason for this might be that the 500 ms encoding time of the second memory array is long enough to compensate for the resetting process. Indeed, previous studies demonstrated that 500 ms is ample time for VWM to fully encode stimuli in the memory array (Alvarez & Cavanagh, 2004).

Studies on VWM have shown that participants can willfully enhance the precision of VWM representations in specific conditions (Machizawa, Goh, & Driver, 2012). The current study has shown that VWM can adapt to a resetting mode strategically, but not to an updating mode. When a pointer was invalidated, VWM performed resetting. These results provide some evidence that the pointer system can be affected by top-down processes, at least under certain conditions. Future study can focus on the question whether participants can willfully control the processes of updating and resetting.

The current paradigm has a strong relation to selective attention paradigms used in different studies about selective attention and working memory (Hillyard & Anllo-Vento, 1998; Fockert, Rees, Frith, & Lavie, 2001; Machizawa & Driver, 2011; Günseli et al., 2019). Looking at this study alone, it might look plausible that the CDA drop represents the allocation of attention to a salient change, rather than the process of resetting. However, there is a strong support from previous studies that the CDA drop represents the loss of a pointer (resetting). For example, previous studies have shown that when a polygon moved on screen and separated into two halves during the trajectory period, this split triggered resetting. However, when the two polygon halves had different colors, even though that color was task irrelevant, no resetting was found (no CDA drop) since the two halves had different pointers and therefore the split did not invalidate any pointer (Balaban, Drew, & Luria, 2018). These results support the assumption that the CDA drop represent violation of a pointer and not attention allocation.

In conclusion, this research provides the first evidence of the ability for long-term adaptability of VWM's pointer system. This study shows that the pointer system can adapt to environmental demands, but also points to the limitations of this ability.

This study has focused on the effect of environmental and contextual change on the pointer system. We created a contextual change by changing the probability of the experimental conditions. This is only one way to manipulate the task context. Future studies can investigate the effect of other kinds of contextual and environmental changes.

Open practices

The study in this article has earned Open Data and Open Materials badges for transparent practices. The data and materials studies are available at: https://osf.io/ajvk6/.

CRediT authorship contribution statement

Shani Friedman: Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Trafton Drew:** Conceptualization. **Roy Luria:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Acknowledgment

This research was supported by the Israel Science Foundation (grant number 1589/23) to R.L.

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