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Research Report

The effect of occlusion on the visual working memory pointer-system

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ABSTRACT

To access its online representations, visual working memory (VWM) relies on a pointer-system that creates correspondence between objects in the environment with their memory representations. This pointer-system allows VWM to modify its representations using a process called updating. When the pointer is invalidated, however, VWM triggers a process called resetting in which the no longer relevant representation and pointer are replaced. Past studies used the contralateral delay activity (CDA) to differentiate between updating and resetting and found that resetting is followed by a drop in the CDA amplitude. The current study aimed to investigate the effects of occlusion on VWM representations and the resetting process across four experiments. Experiment 1 examined whether resetting occurs with occluded changes and compared the CDA of occluded versus visible objects. The results indicated a decline in CDA amplitude during occlusion, but it was unclear if resetting occurred when the change was occluded due to the lack of time-locked changes. To better isolate the resetting process, Experiment 2 used a brief occluder appearances (100 ms) and observed a CDA drop likely due to an ERP response to the sudden stimulus appearance. This drop occurred earlier than the resetting CDA drop and appeared even in conditions that did not trigger resetting, which indicates that it might be an ERP response to the short and sudden appearance of a stimulus. Experiment 3 further isolated this ERP response, confirming the early CDA drop as a reaction to the occluder's onset and offset. Experiment 4, which included occluders that did not flash to avoid ERP responses, found a CDA drop indicating that resetting can occur with inferred changes. These findings suggest that VWM maintains representations of occluded objects, and can update or reset these representations based on inferred changes, with brief stimuli eliciting ERP responses that affect CDA amplitude.

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1. Introduction

The world we perceive is full of objects that constantly move and interact with each other. Our visual system is capable of tracking, maintaining, and representing these objects, even when they become occluded (Scholl & Pylyshyn, 1999; Yantis, 1995). The current research investigated how our visual system can monitor changes in the object status that occur behind an occluder.

Visual working memory (VWM) is the mechanism responsible for holding online representations of relevant objects in the world and constantly manipulating them to match the changing environment (Kahneman et al., 1992; Luck & Vogel, 2013). The process of tracking and manipulating VWM representations is enabled by relying on a pointer system, such that each VWM representation has correspondence with a specific object in the world. This correspondence, which is metaphorically labeled as a 'pointer', is unique to this representation and it enables VWM to detect and access the specific representation that needs to be modified in case of an object's change taking place in the environment (Pylyshyn, 2000). There are two processes by which VWM can modify a representation; updating and resetting. During an updating process, the current representation is maintained and the information stored within this representation is modified. The resetting process, on the other hand, includes deleting the current representation and replacing it with a new representation, forming a new pointer. This resetting process takes place when the object changes in a way that invalidates the correspondence between the actual object and its VWM representation, such that the representation can no longer be accessed (Balaban, Drew, & Luria, 2018a). In addition, resetting can also be triggered strategically, when the context or task demands require VWM to perform resetting significantly more than updating (Friedman, Drew, & Luria, 2024).

A previous study has shown evidence for resetting when the object being tracked was split into two halves or when its shape dramatically changed resembling the appearance of a new object. A split of an object invalidates the object's pointer since after the split, the old pointer loses its correspondence with any of the new object's parts. Consequently, the old representation and the old pointer have to be replaced by two new representations and pointers to reflect the novel situation (Balaban & Luria, 2017). Evidence for resetting after observing a dramatic change has been demonstrated in different studies (Balaban & Luria, 2017; Balaban, Luria & Drew, 2018a, 2018b; Balaban, Drew, & Luria, 2019).

Resetting and updating can be distinguished using the contralateral delay activity (CDA). The CDA is an ERP component whose amplitude indexes the number of objects stored in VWM. The CDA amplitude becomes more negative as more objects are stored in VWM, reaching a plateau when the number of objects reaches VWM capacity (Vogel & Machizawa, 2004; for a review see Luria et al., 2016). Balaban and Luria (2017) have shown a sharp decline in the CDA amplitude after participants observed a split of an object or a sudden change in its shape (see Fig. 1). The same split did not result in a CDA drop when the two object halves were assigned two separate pointers by presenting the two halves in different colors, allowing VWM to individuate them before they split. Namely, as long as the object halves were represented as two objects with two pointers, and thus the split did not invalidate any pointer, no drop in the CDA was found. As a result, Balaban et al. (2018) argued that this CDA drop is a marker of the resetting process. Furthermore, this drop was not present in conditions in which another object was added to the memoranda without interfering with the mapping of the old object that was already present in the array. Instead, there was an increase in the CDA amplitude, representing the addition of a new representation to VWM in an updating process.

In previous research, the resetting and updating processes were triggered by visual manipulations that were visible to the observer (e.g., an object that split into its parts). However, objects in a dynamic environment often temporarily occlude other objects or are occluded by other objects, and this does not seem to jeopardize the perceived stability of the visual environment. If a change occurs while an object is temporarily occluded, one can therefore hypothesize that the pointer system infers an object's change when the object becomes visible again, either by updating or resetting a VWM representation, depending on the type of change inferred following the temporary occlusion. The influence of the visibility of these changes in object status on the resetting process has not yet been tested. The current study investigated whether the processes of updating and resetting occur when the changes in the objects are occluded. In such a situation, participants can't see that a change occurs in real time and only infer the change when the object becomes visible again. In the following experiments, we tested whether the occlusion of changes in the object affects the processes of updating and resetting. One option is that updating and resetting occur similarly regardless of the visibility of the change. The other option is that these processes do not occur when the change is occluded. Answering this question will help us understand how allocating, maintaining, and discarding the pointers is affected when the change in the object has to be inferred because the change was occluded, compared to a condition in which the change is visible.

A second question this study addressed was whether occluded objects are represented in VWM in the same way as objects that are not occluded and simply disappear out of sight. Very little work has been done on the influence of occlusion on the VWM representation, especially one that measures the influence of occlusion on the CDA. One example is Chen et al. (2018) who compared the behavioral and EEG measurements in a change detection task in which the critical conditions included partially occluded objects that were either interpreted as complete objects that were partially occluded or as partial objects that were positioned next to the occluder (mosaic). The main result showed better accuracy and higher CDA amplitude when these objects were interpreted as complete objects compared to partial objects (mosaic), showing an effect of the additional load of object completion on the CDA. However, as stated above, the current study aims to investigate whether occlusion affects the pointer system of the occluded object. To test this question, we need to measure the CDA under conditions in which the tracked object is not in view for a portion of the memory array,

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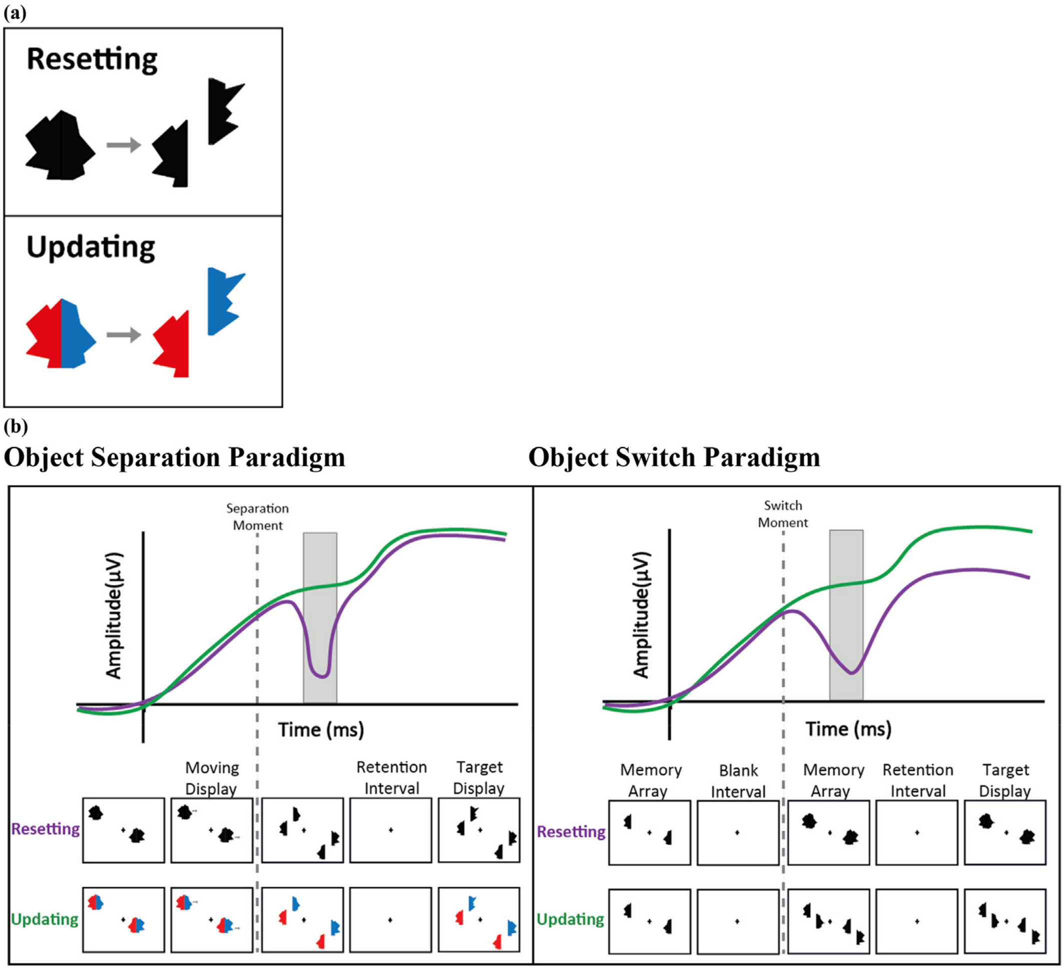

Fig. 1 – Examples of resetting and updating patterns from previous studies. (b) The left side of the figure shows an example of a paradigm in which the object (a polygon) splits into two halves. When a black polygon is split, the original representation of the integrated polygon is no longer relevant and needs to be replaced by new representations of the two halves. Therefore, a resetting process is being triggered and the integrated polygon representation is being deleted and replaced. This resetting process is followed by a CDA drop. However, if the original object is presented in a way that enables each half to be encoded separately (with a unique pointer to each half), the same split does not trigger resetting, since the representations of the two halves can still be maintained after the split. In this case, there is no CDA drop. (2) a similar pattern has been shown in a paradigm in which the change that triggers resetting is not a split, but a sudden switch in the object's shape. In this paradigm, a single polygon half appears on the screen and then another polygon half is added to the display after a very short blank interval (50 ms long). When this new polygon half completes the original half to an integrated polygon shape, it is perceived as a new object just replacing the old one. This change triggers resetting and results in a CDA drop. However, when the second polygon half appears in a different location, not completing the first half, the original representation is maintained and added by another representation. There is no resetting in this case and no CDA drop.

for example, when they are temporarily moving behind another object (an occluder) and compare the CDA in this condition to a similar condition in which the object is visible during the memory array. This question is interesting in light of previous work comparing VWM performance when the objects disappeared during the retention interval as compared to a condition in which the objects stayed visible (Tsubomi et al., 2013). Surprisingly, both behavior and the CDA showed similar patterns across these two conditions in this previous study, indicating that VWM performance was identical when comparing visible to represented (no longer visible) objects. In this study, we investigated whether the CDA response for occluded objects is similar to objects that disappear. Since in both cases the object is no longer in view, it is important to find out whether occlusion interferes with the ability to maintain the pointer, or that it does not have any effect on it (as Tsubomi et al., 2013 have shown).

In the following experiments, we tested the two research questions described above. In Experiment 1 we used a change detection paradigm that has been used in previous studies and compared identical conditions that differ if the change was visible or whether an occluder covered a change in the object or a part of its trajectory. We then moved on based on one caveat we encountered while interpreting Experiment 1.

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We tried to solve this caveat in Experiment 2 using a different paradigm in which changes in the objects occur at a narrower point in time. The results showed an unexpected CDA drop after presenting an occluder for 100 ms. This drop was hypothesized to be a result of the sudden onset and offset of the occluder, and not of the resetting process. Experiment 3 then confirmed this hypothesis. Finally, Experiment 4, in which all the solutions to the diverse caveats were incorporated, showed clear-cut evidence for resetting when the change was occluded. When collectively taken, the results support a new phenomenon in which the CDA of an occluded object declines, presumably as a result of a change in the representation's status when the object is occluded.

2. Experiment 1

Experiment 1 was designed to address the two questions raised above. First, Experiment 1 investigated whether resetting occurs in cases in which the change is occluded. To test this question, we tracked the CDA while an object split into two halves behind an occluder and compared this condition to a condition in which the same change was presented without being occluded, a manipulation that is known to trigger resetting (Balaban & Luria, 2017; Balaban et al., 2018). The second goal of Experiment 1 was to test whether objects are represented in VWM in the same way when they are temporarily occluded compared to when they are visible. Previous studies have shown that the CDA amplitude during the retention interval (when the objects disappear) is not different when the objects remain present during this time. On the other hand, no study investigated what happens to the CDA (and the VWM representation) when an object is occluded. To address this question, we measured the CDA while an object moved and then passed behind an occluder (without changing) and compared this condition to a condition in which the object stayed visible throughout its movement phase.

Previous studies that investigated the occluder effect on the object representation have shown that a representation can persist when the object moves behind an occluder and emerges from the other side in a suitable time frame, a phenomenon called ‘The Tunnel Effect’ (Burke, 1952). Flombaum and Scholl (2006) used a paradigm in which participants tracked objects moving behind an occluder and then emerged from the other side while participants were asked to remember these objects, creating a paradigm that used the tunnel effect combined with change detection. They found a decline in accuracy in detecting changes in the objects when the time or location in which these objects emerged behind the occluder violated a smooth movement pattern as compared to when they didn't violate it, suggesting that a disruption in the continuity of the object interferes with the persistence of its representation.

We combined Flombaum and Scholl's (2006) paradigm with Balaban and Luria (2017) shape change-detection task and compared conditions that trigger resetting or updating, with or without an occluder. We used the split of a moving object as a change that triggered resetting and compared two resetting conditions, with the only difference between them being whether the split was masked or visible. Namely, participants observed a single polygon moving on the screen and, in half of the trials, the polygon split into two polygon halves in the middle of its trajectory. Importantly, in half of the trials, the polygon passed behind an occluder, masking the exact moment at which the object might split (see Fig. 2).

When the polygon was not occluded, we expected to replicate previous results, such that the polygon spit should trigger a resetting process, evidenced by a drop in CDA

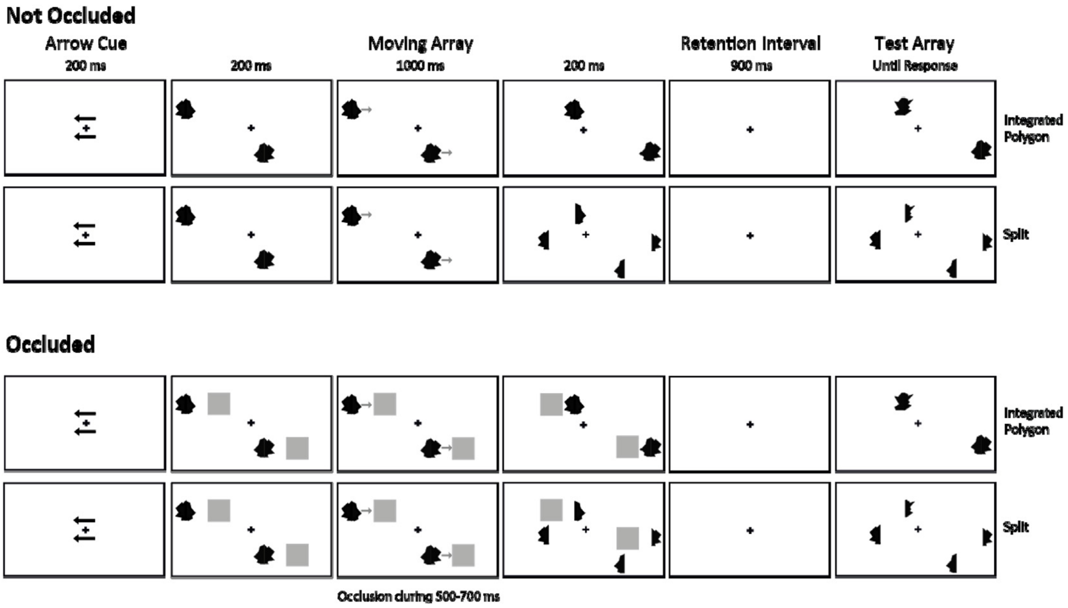

Fig. 2 – Example of trials from Experiment 1. Half of the trials were “Occluded” trials and the other half were “Not Occluded”. The four conditions are presented from top to bottom; occluded Integrated polygon, occluded split, Not Occluded integrated polygon, and Not Occluded split.

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amplitude (Balaban & Luria, 2017). If the occluder does not affect the pointer system, we expect to find similar results also when the polygon was occluded. If such were the case, the results would indicate that the occluded change could still be inferred, and therefore the pointer could be invalidated in the same way as it is invalidated by a visible change. On the other hand, if there were no evidence for resetting when the change is occluded, it might indicate that an occluded change does not invalidate the pointer. At stake here, therefore, is whether the pointer system can update the existing representation instead of resetting it when the change is occluded.

3. Methods

To select a sample size, we performed a power analysis based on Experiment 2 of Balaban & Luria, 2017 who used a similar paradigm with the same number of conditions. We calculated the effect size based on the reported F value and sample size ($F(1, 11) = 20.73$). The sample required for showing a main effect of condition with 80% statistical power and an alpha level of 5% was 10 participants.

3.1. *Participants*

20 Tel-Aviv University students participated in this experiment (15 females and 5 men, ages: 19–25). All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants were informed according to a protocol vetted by the local ethics committee. Participants received course credit for participation. Subjects with more than a 25% rejection rate due to eye blinks or eye movements (none) or less than 60% accuracy (one participant) were replaced.

3.2. *Procedure and stimuli*

Stimuli were presented in black and white colors on a grey background. Each trial consisted of a moving array and a 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 white 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 ignore the other half. After the arrow disappeared, the fixation cross remained on the screen for 300, 400, or 500 ms (randomly determined). Two polygons appeared on the screen, one on each side of the screen, for 200 ms. Each block contained only trials of the Occluded condition or the Not-Occluded condition with an equal number of blocks for the two conditions. In the Occluded condition, a dark grey square appeared to the left or the right of the polygon, randomly assigned. During the moving array, the polygons moved for 1000 ms towards the square and behind it and then emerged from the other side of it. In half of the trials of this condition, the polygon that emerged from the other side of the occluder looked the same as before it was occluded (Integrated Polygon, Occluded condition). In the other half of the trials, the polygon split into two halves behind the occluder and the two polygon halves continued to move independently after emerging out of the occluder and until the end of the trace (Split, Occluded condition). The exact time in which the polygon or polygon halves were partially or fully occluded was 500–700 ms after the stimulus onset. During the rest of the time (onset to 500 ms and 700–1000 ms), the polygon or polygon halves were visible. The Not Occluded condition was similar to the Occluded conditions, but without the gray square, such that the polygon did not move behind any other stimulus and remained visible throughout the movement period. In half of the trials, the polygon moved on the screen without any change (Integrated Polygon, Not Occluded condition). In the other half of the trials, the polygon split into two halves, and the two halves continued to move independently on the screen (Split, Not Occluded condition).

After the moving array, the polygons disappeared for a retention interval of 900 ms. Finally, the target display appeared. In the Integrated Polygon conditions, the target was a single polygon that was identical to the polygon presented in half of the trials and different in the other half. In the Split conditions, the target was two polygon halves. After the movement ended, the polygon or polygon halves stayed static for another 200 ms at the end of the trajectory. 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. Ten percent of the trials were catch trials, in which instead of the moving array, the objects appeared and remained static for 200 ms, which was followed by the retention interval. The purpose of the catch trials was to make sure participants attended to the objects right from the beginning of the moving array. Participants were instructed to indicate if the target was the same or different from the second stimulus in the moving array by pressing "/" or "z" keys of a computer keyboard, respectively. Each subject completed 18 blocks of 60 trials.

3.3. *EEG recording and analysis*

EEG was recorded using BioSemi Active-Two system, 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 (0 in Experiment 1, 2 in Experiment 2, 0 in Experiment 3 and 1 in Experiment 4). Only trials with a correct response were included in the analysis.

For illustration purposes, the epoched data displayed in the results figures were low-pass filtered using a noncausal

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Butterworth filter (12 dB/oct) with a half-amplitude cutoff point at 30 Hz. All statistical analyses were performed on the filtered 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. *Behavior*

We analyzed accuracy in the change detection task using two-way repeated measures analysis of variance (ANOVA), with Condition (One polygon and Split) and Visibility (Not Occluded and Occluded) as within-subject variables. This analysis showed no significant effect for Visibility ($F(1, 19) = 3.128$, $p = .09$, $\eta_p^2 = .14$) but a significant effect of condition ($F(1, 19) = 173.98$, $p < .05$, $\eta_p^2 = .90$). This effect was a result of lower accuracy in the Split condition compared to the Integrated Polygon condition, which indicated a set size effect, such that accuracy was higher when encoding one object compared to two. In addition, there was a significant interaction ($F(1, 19) = 5.44$, $p < .05$, $\eta_p^2 = .22$). This interaction was a result of a larger set size effect in the Not Occluded condition compared to the Occluded condition.

4.2. *ERP*

We used the CDA as an electrophysiological marker of working memory capacity. To test whether occlusion affects the resetting process, we analyzed mean CDA amplitude between 900 and 1000 ms after stimulus onset, which is 200 ms after the split (Balaban & Luria, 2017), as a dependent measure using a two-way repeated measures ANOVA, with Condition (One polygon and Split) and Visibility (Not Occluded and Occluded) as within-subject variables. Both main effects were not significant (Condition, $F(1, 19) = 1.52$, $p = .23$, $\eta_p^2 = .07$; and Visibility $F < 1$), but we found a significant interaction between Condition and Visibility ($F(1, 19) = 8.68$, $p < .05$, $\eta_p^2 = .31$). To check whether the current results replicate the CDA drop when resetting occurs, we performed planned comparisons (contrasts) between the One polygon condition and the Split condition. In the Not Occluded condition, we found a significant difference between the One polygon and the Split conditions ($F(1, 19) = 7.36$, $p = .01$, $\eta_p^2 = .28$), indicating a resetting process, replicating previous findings. However, in the Occluded conditions, there was no difference between the One polygon and the Split conditions ($F(1, 19) = 1.65$, $p = .21$, $\eta_p^2 = .08$), indicating no significant resetting process.

Next, we tested the question of whether the occlusion of an object affects the way in which this object is represented in VWM. To test this question, we used the One polygon condition, that is, when the polygon moved behind the occluder without changing. Indeed, a visual inspection of the results shows a long decline in the CDA amplitude between 800 and 1100 ms after stimulus onset in the Occluded conditions. To test whether this decline was statistically significant, we compared the CDA amplitude in the Integrated Polygon conditions (i.e., when the polygon did not change along its trajectory) between the Occluded and the Not Occluded condition, within this time period. The CDA amplitude was lower in the Occluded Integrated Polygon condition relative to the Not-Occluded Integrated Polygon condition ($F(1, 19) = 5.23$, $p < .05$ $\eta_p^2 = .21$). Thus, we found evidence that passing behind an occluder affected VWM relative to a condition in which the object stayed visible.

5. Discussion

Experiment 1 had two main goals. One was to investigate whether the processes of updating and resetting are affected by a change that occurred behind an occluder. In other words, whether visibility affects the pointer allocation. The second goal was to provide an answer to the question of whether occlusion affects the way in which occluded objects are represented in VWM in relation to visible objects.

We replicated the drop in the Not Occluded split condition (Balaban & Luria, 2017; cf., Balaban, Drew & Luria, 2018; Balaban, Drew, & Luria, 2019; 2023), such that the split of the polygon invalidated its pointer and triggered a resetting process. However, we didn't observe a significant drop when the split was masked behind the occluder.

There are two possible explanations for the lack of evidence for resetting in the Split Occluded condition. One explanation is that there is no resetting when the change is not visible, implying that a change invalidates the pointer only when the change is visible. A different explanation is that there is resetting in the Occluded condition, but the moment of resetting is not locked to a specific punctual point in time, causing the CDA drop to smear when averaged across different trials, resulting in a long and shallow decline in the CDA amplitude relative to the sudden and sharp CDA drop that characterizes resetting. In the Not Occluded condition, the split occurred at a specific moment, making the latency of the resetting process time-locked to this point in time. In the Occluded condition, on the other hand, the split needs to be inferred after watching the polygon halves that gradually emerged behind the occluder. This gradual emergence is not as sudden as the visual split and as a result, the latency of the resetting process might vary from trial to trial or between participants and the drop might be averaged out. A visual inspection of Fig. 3 reveals in fact a long drop in the CDA amplitude that is compatible with the view resetting was not time locked. To test this hypothesis, in Experiment 2 we used a paradigm in which the occluded change was still not visible, but was time-locked to a specific event similar to a visible change.

Regarding our second question, whether objects are represented in the same way in VWM when they are visible or occluded, we found that when the object moved behind an occluder there was a shallow but significant decline in the CDA amplitude, following the time interval in which the object was behind the occluder. Importantly, this decline was present even if the polygon did not split behind the occluder,

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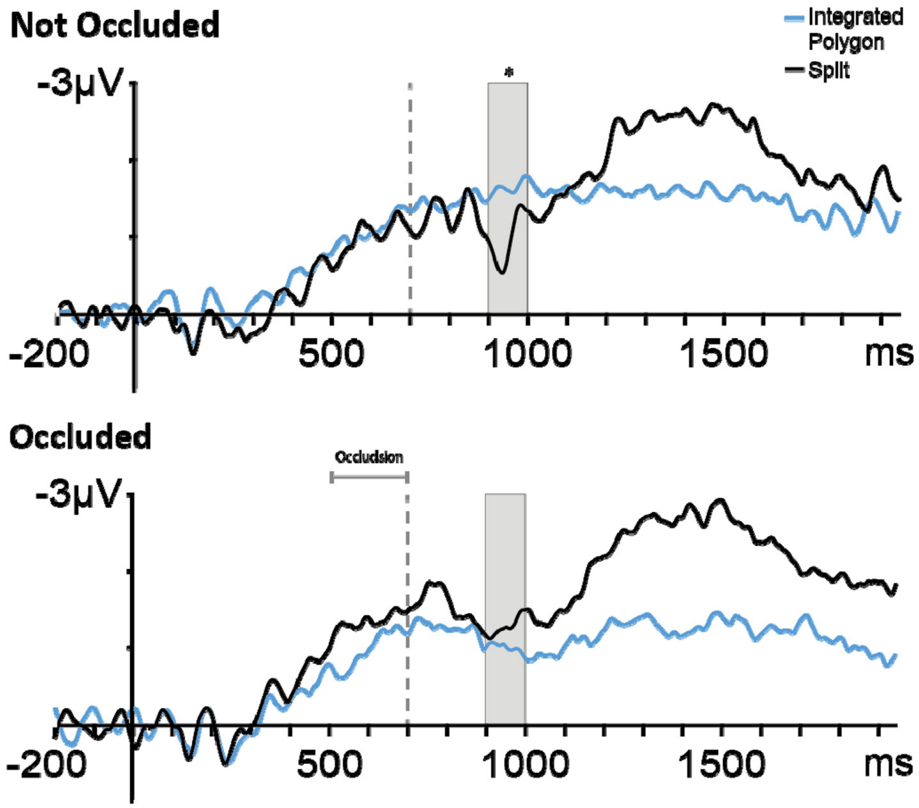

Fig. 3 – Results of experiment 1. Data were averaged across the P7/8, PO3/4, and PO7/8 electrodes. The x-axis describes the time in milliseconds from stimulus onset. The y-axis describes the voltage in millivolts. The vertical dashed line depicts the time at which the polygon split into two halves in the split conditions. The analyzed time window (900 ms–1000 ms) is depicted by the grey rectangle. The time in which the polygon was occluded or partially occluded (500 ms–700 ms) is depicted by the grey horizontal line.

which means that the decline was not related to the resetting process. To reiterate a finding that is particularly important in the present context, it has previously shown that the CDA did not change when the to-be-remembered objects disappeared relative to when they stayed visible (Tsubomi et al., 2013). With this finding in mind, it is thus surprising that occlusion creates a decline in the CDA, since in both cases (occlusion and disappearance), the objects are not in view. The CDA decline in the current experiment might be a result of degradation of the representation or it may reflect instances in which the representation was lost, but it can also be a result of interference that is created when the occluder covers the object. We will discuss these options in more detail in the General Discussion.

6. Experiment 2

The results of Experiment 1 showed that the pointer system behaved differently when processing a visible compared to a non-visible change. As mentioned above, one of the explanations we proposed is that there is resetting for non-visible (occluded) changes, but we can't see the evidence for it (i.e., the CDA drop) because the moment resetting occurred was not time-locked to the moment of the change, likely because the change in the object status was likely to be inferred while the two polygons' halves gradually emerged from the occluder. As a result, there was a larger variation in the latency of the resetting in the Occluded Split condition, and since the drop is averaged across trials, it resulted in a long but shallow decline in the CDA amplitude.

In Experiment 2, we aimed to test this issue by using a paradigm in which the change in the object was occluded but the resetting latency was still time-locked. This should help us understand if non-visible changes trigger resetting like visible changes do, or whether resetting only occurs when the change is visible.

To this end, we replicated Balaban and Luria's (2017) object switch paradigm in which the change that triggers resetting is a polygon half that is suddenly switched by an integrated polygon (see Fig. 4). Participants performed a shape change-detection task with polygons' shapes. In the Not Occluded condition, on each trial, a single polygon half appeared on the screen for 500 ms, then disappeared for 100 ms (the blank interval), and then it either reappeared (the One polygon half condition), was switched by an integrated polygon (the Switch condition which triggered resetting in a previous study) or the same polygon half reappeared

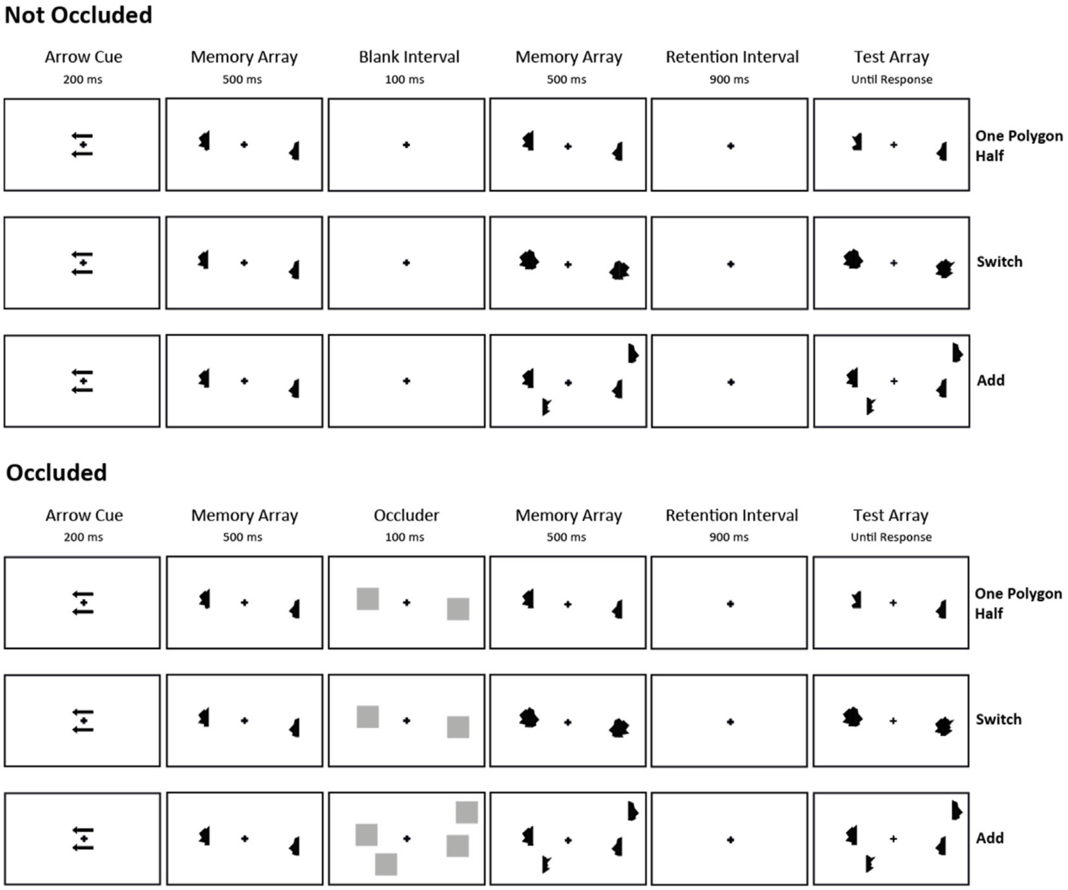

Fig. 4 – Example of trials from Experiment 2. One group of participants performed the "Not Occluded" condition and another group performed the "Occluded" condition. The three conditions are presented from top to bottom; One polygon-half, Switch, and Add.

together with another polygon half occupying a different location (the Add condition). Participants were asked to remember the shape of the polygon(s) appearing in the second array (500 ms).

The Occluded condition was identical except that instead of the 100 ms blank interval, an occluder appeared on the same location of the object, masking the change in shape in the Switch condition. As mentioned above, this task is a replication of Experiment 3 from Balaban & Luria, 2017, except that in their task, the blank interval appeared for 50 ms, while we used a 100 ms as in the current study. The reason is that the occluder was barely visible when it appeared for only 50 ms. As a result, we extended it to 100 ms, and to equate all conditions (occluded and visible), we extended the blank interval in the Not Occluded condition as well, so objects in this condition disappeared for 100 ms.

To avoid using six experimental conditions for each participant, we used a between-subject design with regard to the occlusion manipulation. Each group performed three conditions (One polygon half, Switch and Add), but in the Occluded group, the occluder always appeared and in the Not Occluded group, the Occluder never appeared and was replaced by the blank interval (a replication to Balaban & Luria, 2017). Similar to Experiment 1, these conditions allowed us to investigate how the occluder affects VWM representation. While Experiment 1 compared an occluded object to a visible object, in Experiment 2 we compared an occluded objects to a disappearing object. This comparison is interesting because in both conditions the object remained out of sight.

7. Methods

7.1. *Participants*

40 Tel-Aviv University students participated in this experiment (29 females and 11 men, ages: 18–35). 20 of the participants performed the Occluded condition and 20 performed the Not Occluded condition. All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants 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 received course credit for participation. Subjects with more

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than a 25% rejection rate due to eye blinks or eye movements (two participants) or less than 60% accuracy (one participant) were replaced.

7.2. *Procedure and stimuli*

Stimuli were presented in black and white colors 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 white 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). Each trial consisted of two memory arrays and a test array. In the Not Occluded condition, the first memory array was presented for 500 ms and consisted of two polygon-halves polygon halves (one on each side of the screen). The locations of the polygons were randomly sampled from a 4.5°*3.5° rectangle (one on each side of the screen). This array was followed by a 100 ms blank interval. 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). 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). The Occluded condition was identical to the Not Occluded condition, but instead of the blank interval, two gray squares appeared on the screen (one on each side of the screen) for 100 ms. The location of the squares was identical to the location of the polygon halves in the first memory array. In the Add condition, there were four squares (two on each side of the screen), located in the same place as the polygon halves in the second memory array. Finally, the target display appeared; In the One Polygon-Half, the target display consisted of two polygon-halves (one on each side of the screen), in the Add condition the target display consisted of four polygon-halves (two on each side of the screen), and in the Switch condition the target display consisted of two complete polygons (one on each side of the screen). The stimuli in the target display were identical to the stimuli in the second memory array in half of the trials and different in the other half. 10% percent of the trials were catch trials, in which the retention interval appeared right after the first memory array. The purpose of the catch trials was to make sure that participants attended to the objects in the first memory array.

Participants were instructed to indicate (by pressing "/" or "z") if the target is the same or different from the second memory array. They were also instructed to ignore the occluders (the gray squares) and only focus on remembering the polygon shapes. Each subject completed 18 blocks of 60 trials. One group of 20 participants performed the Occluded condition and another group of 20 participants performed the Not Occluded condition.

7.3. *EEG recording and analysis*

EEG recording and analysis were identical to Experiment 1.

8. Results

8.1. *Behavioral Results*

We analyzed the accuracy in the change detection task using a mixed-design ANOVA with Visibility (Not Occluded and Occluded) as the between-subject variable and Condition (One polygon-half, Add and Switch) as the within-subject variable. This analysis showed no significant effect for Visibility ($F < 1$), a significant effect of Condition ($F(2, 76) = 280.35$, $p < .05$, $\eta_p^2 = .88$), and no interaction ($F < 1$). The main effect for Condition was a result of higher accuracy in the One polygon-half condition compared to the Add condition ($F(1, 38) = 470.13$, $p < .05$, $\eta_p^2 = .92$) and lower accuracy in the Switch condition compared to the One polygon-half condition ($F(1, 38) = 457.56$, $p < .05$, $\eta_p^2 = .92$) and compared to the Add condition ($F(1, 38) = 13.21$, $p < .05$, $\eta_p^2 = .26$). This result is in line with Flombaum and Scholl (2006).

The higher accuracy in the One polygon-half condition compared to the Add condition is a result of a set size effect; Accuracy was higher when encoding one object compared to two. The lower accuracy in the Switch condition compared to the other two conditions is assumed to be a result of less encoding time to the integrated polygon shape; participants had more time to encode the stimuli in the One polygon-half condition compared to the Switch and the Add conditions since the first polygon-half in the One polygon-half and the Add conditions 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 had a new polygon shape. Hence, participants had only 500 ms to encode it.

8.2. *ERP Results*

To test whether our paradigm replicated the drop in the Not Occluded Switch condition found in Balaban & Luria, 2017, we first analyzed the mean CDA amplitude between 850 and 950 ms after stimulus onset, which is 50 ms later than the time window used by Balaban & Luria, 2017 in a similar paradigm. The reason is that the blank interval was 50 ms longer in the current study (100 ms relative to 50 ms in the original study). The ANOVA included the variables Visibility (Not Occluded and Occluded) as the between-subject variable and Condition (One polygon-half, Add and Switch) as the within-subject variable. We found no main effect for Visibility ($F(1, 38) = 2.66$, $p = .11$, $\eta_p^2 = .06$) and no interaction ($F(2, 76) = 2.13$, $p = .13$, $\eta_p^2 = .05$), but a main effect for Condition ($F(2, 76) = 17.18$, $p < .05$, $\eta_p^2 = .30$). Even though the interaction was not significant, we further analyzed the results to test whether we replicated the former results of the Not Occluded condition which is equivalent to Experiment 3 of Balaban & Luria, 2017. In the Not Occluded group, we found a difference in CDA amplitude between the One polygon-half and the Switch conditions ($F(1, 38) = 15.85$, $p < .05$, $\eta_p^2 = .29$), which means that we replicated the CDA-drop

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in the Switch condition and found evidence for resetting when the polygon's shape dramatically changed.

We analyzed the same time window in the Occluded group to find out if there was a drop in the resetting time window, indicating a resetting process. We found no difference between the One polygon-half and the Switch conditions ($F(1, 38) = 2.87$, $p = .09$, $\eta_p^2 = .07$) and between the One polygon-half and the Add conditions ($F(1, 38) = 1.42$, $p = .24$, $\eta_p^2 = .04$), meaning that we found no evidence for resetting in this group.

8.3. *ERP post hoc analysis*

A visual inspection of Fig. 5 reveals a strong ERP effect just after the appearance of the occluder, such that the CDA amplitude declines for about 200 ms in all conditions, right after the occluder offset. We now turn to statistically analyze this effect and then we replicate this occluder-related activity in Experiment 3. To analyze this drop, we analyzed the time window of 600–800 ms just after the appearance and disappearance of the occluder (500–600 ms) and compared the mean CDA amplitude in this time window to the mean CDA amplitude during the appearance of the occluder (500–600 ms after stimulus onset). We performed a two-way repeated measures ANOVA with Time (Occluder Response and Pre-Occluder Response) and Condition (One polygon-half, Add and Switch) as dependent variables and found a main effect for Time found a main effect ($F(1, 19) = 40.99$, $p < .05$, $\eta_p^2 = .68$) which caused by a decline in the CDA amplitude compared to the pre-drop time window. Planned comparisons revealed that this decline was significant in all conditions: Switch ($F(1, 19) = 45.32$, $p < .05$, $\eta_p^2 = .70$), Add ($F(1, 19) = 22.01$, $p < .05$, $\eta_p^2 = .53$) and the One Polygon-Half ($F(1, 19) = 51.42$, $p < .05$, $\eta_p^2 = .73$). Interestingly, this CDA drop seems to last longer for the Switch condition when resetting should occur, a trend that we replicated in Experiment 4.

A further visual inspection of Fig. 5 revealed that the Not Occluded group showed a drop in all conditions 700–800 ms after the second array appeared, which is before the resetting time window. This drop might be the ERP response to the abrupt offset and onset of the polygon. To test if this drop is significant, we compared the mean amplitude in the time window of the drop (700–800 ms) to the pre-drop time window (600–700 ms). We performed a Two-way Repeated Measures ANOVA with Time (Onset and Pre-Onset) and Condition (One

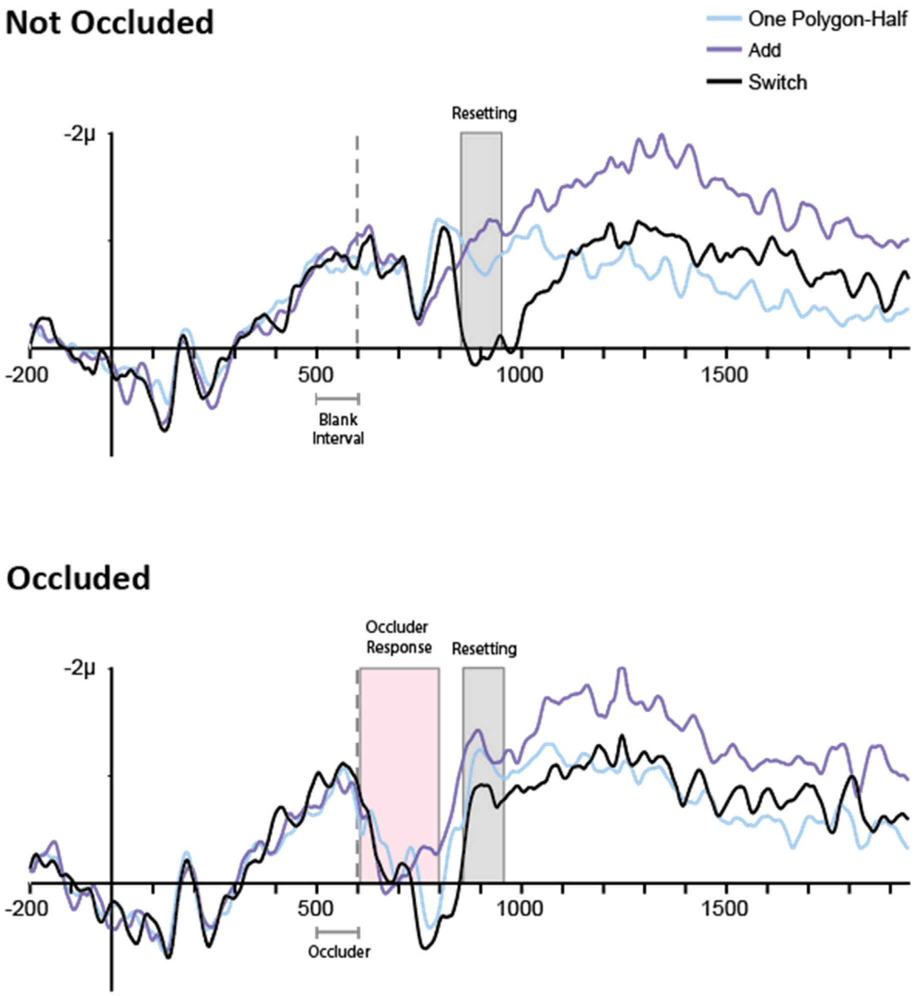

Fig. 5 – Results of experiment 2. Data were averaged across the P7/8, PO3/4, and PO7/8 electrodes. The *x*-axis describes the time in milliseconds from stimulus onset. The *y*-axis describes the voltage in millivolts. The vertical dashed line depicts the time of the second memory array. The grey rectangle depicts the analyzed time window (900 ms–1000 ms). The time in which the occluder appeared on the screen (500 ms–600 ms) is depicted by the grey horizontal line.

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polygon-half, Add and Switch) as dependent variables. We found no main effect for Condition ($F < 1$), but we did find a main effect for Time ($F(1, 19) = 26.29$, $p < .05$, $\eta_p^2 = .58$), indicating that the CDA response to the onset and offset of the polygon is significant for all conditions. This effect might indicate a P1N1-like effect (Hillyard & Münte, 1984; Eason et al., 1969) in response to the offset and onset of the stimulus.

The next experiment will try to replicate the two post hoc results to further understand their meaning.

9. Discussion

The current experiment replicated Balaban and Luria's (2017) object-switch paradigm, but in one group we replaced the blank interval with an occluder. In the Not-Occluder condition (the replication) the resetting resulted in the predicted CDA drop. Notably, all conditions in the Not-Occluder group also showed a P1N1-like effect just after the abrupt offset and onset of the polygon (700–800 ms after stimulus onset). This effect will be replicated in Experiment 3.

The occluder group showed a decrease in the CDA amplitude in all conditions, presumably as a response to the flashing occluder. Interestingly, the decline was longer for the Switch condition, which might indicate that there was a resetting CDA drop on top of the P1N1 response. This pattern was unexpected, and it demonstrates the difficulty of isolating the resetting process when the occluder is flashing. We now turn to explain our rationale for identifying the resetting process in an occluder setting, based on the results of Experiment 2.

9.1. *Distinguishing between resetting and occluder-induced ERP responses*

To understand the results of the current experiment, it is important to differentiate between the resetting process ERP response, and the occluder-induced ERP response. While both show a reduction in the CDA amplitude, based on the results of Experiment 2, we argue that they can be differentiated based on their timing. Resetting is marked by a drop in the CDA amplitude appearing 200 ms after the change that invalidated the object's pointer and triggered the resetting process. Conversely, in the current experiment, we likely see another type of CDA drop induced by the onset and offset of the occluder. This drop appears immediately after the occluder, in a much earlier time window compared to the resetting drop. Moreover, we could see the occluder ERP response in all three Occluder conditions (1-half, Switch, and Add), even without invalidating the object pointer that triggers a resetting process. Thus, we argue that this drop is a perceptual response to the sudden appearance and disappearance of the occluder; in this experiment, the occluder abruptly appeared and disappeared, unlike the first experiment in which the occluder stayed on the screen throughout the trial.

This early CDA drop in the occluder group showed an interesting pattern: It took longer for the CDA to recover in the Switch condition relative to the One polygon half condition. The Add condition, which involved an updating process was somewhere in between. This pattern of result suggests that the resetting and updating processes might override the occluder ERPs, such that we could only see the end of the resetting and updating CDA drop. In Experiment 4 we replicated the longer drop for the resetting condition when the polygon changed behind an occluder.

To test these assumptions, Experiment 3 was designed to directly investigate the effect of the appearance and disappearance of the occluder and the effect of the appearance and disappearance of the polygon on the ERPs in an experiment without resetting.

10. Experiment 3

The purpose of Experiment 3 was to investigate the early CDA drop in the Occluded and Not-Occluded conditions. Specifically, based on the results of Experiment 2, we reasoned that this early drop is an ERP response (i.e., p1n1) to the sudden appearance and disappearance of the occluder or the polygon. To test this, we used an identical design to Experiment 2, but this time the occluder appeared during the first memory array and importantly appeared next to the polygon, without occluding it (see Fig. 6). This way we isolated the effect of the abrupt onset and offset from the occlusion effect, such that any drop in the CDA appearing immediately after the occluder could be attributed to its ERP response rather than to a resetting process. Next, the polygon disappeared and reappeared with similar timing as in Experiment 2, isolating any ERP response that is related to its offset and onset. Overall, this setup enabled us to observe both an early occluder ERP response (only in the conditions with occluder) and the later polygon response (in all conditions).

Experiment 3 included only the One Poly-Half condition and the Add condition, without any resetting condition. Thus, any drop in the CDA could not be attributed to the resetting process. We expected to see the occluder response in the same time window as in Experiment 2, relative to the appearance of the occluder, which is from the moment the occluder disappeared until 200 ms later. Since in the new experiment the occluder appeared between 300 and 400 ms after stimulus onset, the occluder response is expected to occur at 400–600 ms after stimulus onset. In addition, if this experiment replicates the polygon-induced drop, we expect to see it in the same time window as in experiment 2, since the offset and onset of the polygon appears at the same time in both experiments (500–600 ms after stimulus onset).

11. Methods

11.1. *Participants*

We performed a power analysis based on Experiment 2. We calculated the effect size based on the reported F value and sample size ($F(1, 38) = 9.60$). The sample required for showing a main effect of Visibility with 95% statistical power and an alpha level of 5% was 12 participants.

14 Tel-Aviv University students (8 females and 6 men, ages: 18–31) participated in this experiment. All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants agreed to participate in the experiment

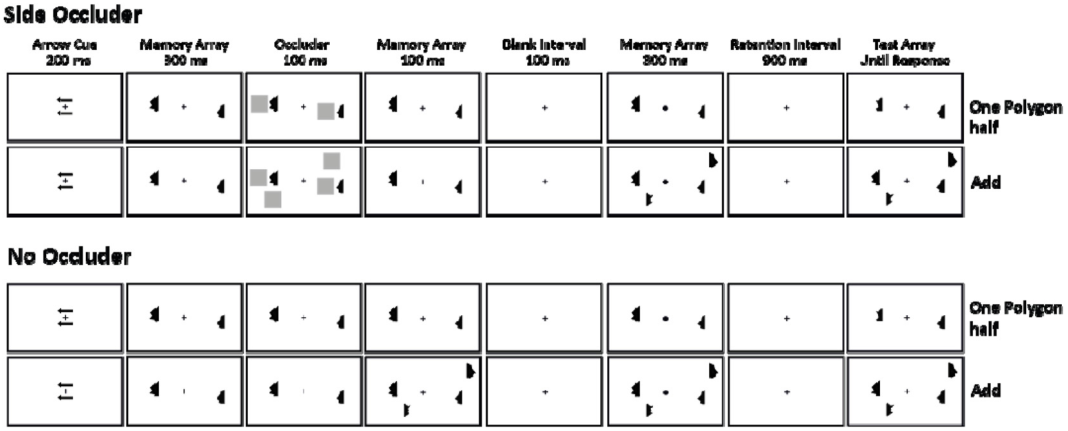

Fig. 6 – Example of trials from Experiment 3. The four conditions are presented from top to bottom; One polygon-half with occluder, Add with occluder, One polygon-half without occluder, and Add without occluder. The No Occluder condition is similar to the same condition in Experiment 2, except that the current experiment included only the One Polygon Half and the Add conditions (no Switch condition). The Side Occluder condition was identical to the No Occluder condition, except that a grey square (occluder) appeared next to the polygon-half during 300–400 ms after stimulus onset.

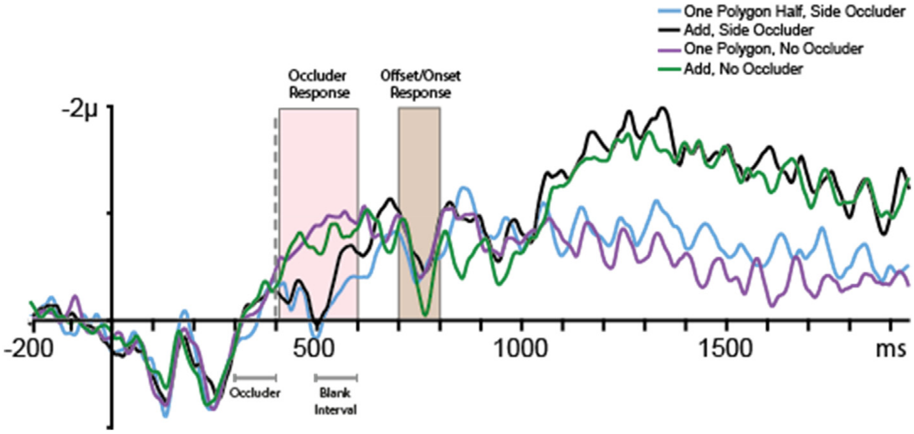

Fig. 7 – Results of experiment 3. Data were averaged across the P7/8, PO3/4, and PO7/8 electrodes. The *x*-axis describes the time in milliseconds from stimulus onset. The *y*-axis describes the voltage in millivolts. The vertical dashed line depicts the time in which the occluder disappeared. The grey rectangle depicts the analyzed time window (450 ms–550 ms). The time in which the occluder appeared on the screen (400 ms–500 ms) is depicted by the grey horizontal line.

were informed following the procedures of a protocol approved by the local ethics committee. Participants received course credit or 40NIS (~10USD) per hour for participation.

11.2. *Procedure and stimuli*

Stimuli and procedure were identical to the Occluded condition from Experiment 2 with the following differences; we used only the One Polygon-Half and the Add condition. Importantly, the squares appeared next to the location on the polygons (and not in the same location as in experiment 2).

11.3. *EEG recording and analysis*

EEG recording and analysis were identical to Experiments 1 and 2.

12. Results

12.1. *Behavioral Results*

We analyzed the accuracy in the change detection task using ANOVA with Occluder (No Occluder and Side Occluder) and Condition (One polygon-half and Add) as the within-subject variables. This analysis showed no significant effect of Occluder ($F < 1$) but a significant effect of Condition ($F(1, 13) = 160.90$, $p < .05$, $\eta_p^2 = .92$). The main effect of the Condition was a result of higher accuracy in the One polygon-half condition compared to the Add condition. This higher accuracy is a result of a set size effect; Accuracy was higher when encoding one object compared to two.

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12.2. *Occluder ERP response*

We analyzed the mean CDA amplitude between 400 and 600 ms after stimulus onset as a dependent measure. As mentioned above, we used this time window since it's the same time window used in experiment 2; the window started at the moment the occluder disappeared and lasted for 200 ms. We performed an ANOVA with Occluder (No Occluder and Side Occluder) and Condition (One polygon-half and Add) as the within-subject variables. This analysis showed a main effect for Occluder ($F(1,13) = 15.05$, $p = .001$, $\eta_p^2 = .54$) which shows that the CDA amplitude was lower when the occluder appeared next to the stimulus compared to the condition without an occluder. This result showed direct evidence for an occluder-induced ERP response, such that the CDA amplitude was lower after the onset and offset of the occluder. There was no main effect for Condition ($F < 1$) and no interaction ($F(1,13) = 2.03$, $p = .18$, $\eta_p^2 = .13$).

12.3. *Polygon onset/offset ERP response*

As in Experiment 2, looking at the ERP, we see a drop in all conditions in the time window of 700–800 ms after stimulus onset. We compared the mean amplitude in the time window of the drop (700–800 ms) to the mean amplitude during the pre-drop time window (600–700 ms). We used the pre-drop time window as a control since all conditions show a CDA drop, so we cannot use the One Polygon-Half as a control condition. We performed a Three-Way Repeated Measures ANOVA with Time (Drop and Pre-Drop), Occluder (Side Occluder and No Occluder), and Condition (One polygon-half and Add) as dependent variables. We found no main effect of Condition ($F(1, 13) = 1.52$, $p = .23$, $\eta_p^2 = .10$), and no main effect of Occluder ($F < 1$). However, as in Experiment 2, we found a main effect for Time ($F(1, 13) = 18.28$, $p < .05$, $\eta_p^2 = .28$), which shows that there is a drop within 800–700 ms after stimulus onset. This drop is a response of the offset and onset of the polygon and it appears in all four conditions since the blank interval is in all conditions. In addition, we found an interaction between Time and Condition ($F(1, 13) = 7.09$, $p = .01$, $\eta_p^2 = .35$), no interaction between Time and Occluder ($F(1, 13) = 1.62$, $p = .22$, $\eta_p^2 = .11$), and between Condition and Occluder ($F(1, 13) = 1.98$, $p = .18$, $\eta_p^2 = .13$), and no three-way interaction ($F < 1$).

13. Discussion

The purpose of the current experiment was to investigate whether the occluder and the polygon onset and offset produce a drop in the CDA amplitude. The results showed that the abrupt offset and onset of both the occluder and the polygon resulted in a P1/N1 like ERP drop. The occluder drop appeared right after the disappearance of the occluder and lasted for 200 ms, which is an earlier time window compared to the resetting drop. Importantly, since the ‘occluder’ appeared next to the stimulus without occluding the stimuli, we were able to isolate its brief onset and offset the ERP signature from occluding the target stimulus (see Fig. 7).

As in experiment 2, we also found a drop in all conditions in the time window of 700–800 after stimulus onset which we argue is a result of the 100 ms offset and onset of the polygon. Presumably, due to their timing and because no resetting process was involved in Experiment 3, these ERP responses are P1/N1-like effects and could be differentiated from the later resetting CDA drop.

To sum up, we replicated the results of Experiment 2 by showing that both the occluder and the offset and onset of the stimulus produce an early ERP drop, and now we can move to isolate any resetting CDA drop, over and above this activity.

14. Experiment 4

The goal of this study was to investigate the resetting process when the change that triggers resetting is not visible. While the results of Experiments 2 and 3 clearly demonstrated a CDA drop that is related to the onset and offset of the occluder and the polygon, it is still unclear how the resetting process is affected by the visibility of the change in the object's status, after controlling for the onset/offset ERP response.

Experiment 1 showed that the object change needs to be relatively time-locked to test this question. Experiments 2 and 3 have shown that a sudden and short appearance and disappearance of the occluder and the polygons could be problematic when trying to isolate the resetting CDA drop because they also triggered a CDA drop. Importantly, the results of Experiments 2 and 3 demonstrated that the onset/offset of the occluder and polygon resulted in a P1N1 response which is earlier than the resetting CDA drop which occurs 200–300 after the change. In Experiment 4, we aimed to test the main question of this study; does resetting occur when the change in the object's status is occluded? However, we considered the limitations described above.

We utilized a paradigm in which the change that triggered resetting was relatively time-locked, while at the same time, the occluder was presented on the screen throughout the trial (similar to Experiment 1) thus eliminating its ERP response. This new paradigm involved the movement of the occluder instead of the movement of the object (see Fig. 8).

In this task, participants were initially presented with a polygon half and a grey square (occluder). In the Occluder condition, the grey square appeared directly above or below the polygon half. After a static phase of 500 ms, the occluder started to move towards the polygon half, passing over the polygon, occluding it along its trajectory. The occluder stopped when it reached the same distance from the polygon as at the beginning of the trial. This movement period lasted 300 ms and was followed by another static period of 500 ms in which the polygon half and the occluder remained stationary on the screen. The Not Occluded condition was identical, but the grey square appeared beside the polygon (slightly above or below) and it moved next to the polygon without occluding it. This condition enabled us to isolate any occluder-related ERP response.

The experiment included three conditions (see Fig. 8). All conditions involved a movement of the occluder, either on top or besides the polygon. In the One Polygon Half condition, the occluder moved over the polygon half, but the polygon half did not change. In the Switch condition, the polygon half was replaced by an integrated polygon when reappearing after the

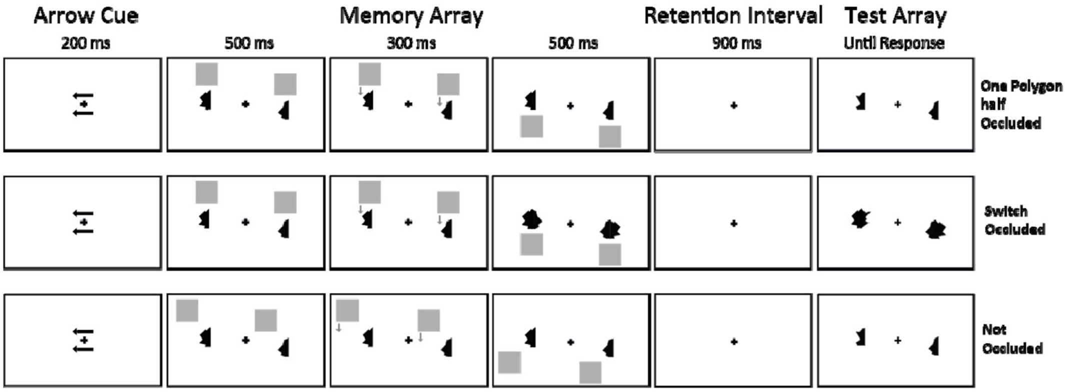

Fig. 8 — Example of trials from Experiment 4. The three conditions are presented from top to bottom; One polygon-half occluded, Switch with Not Occluded.

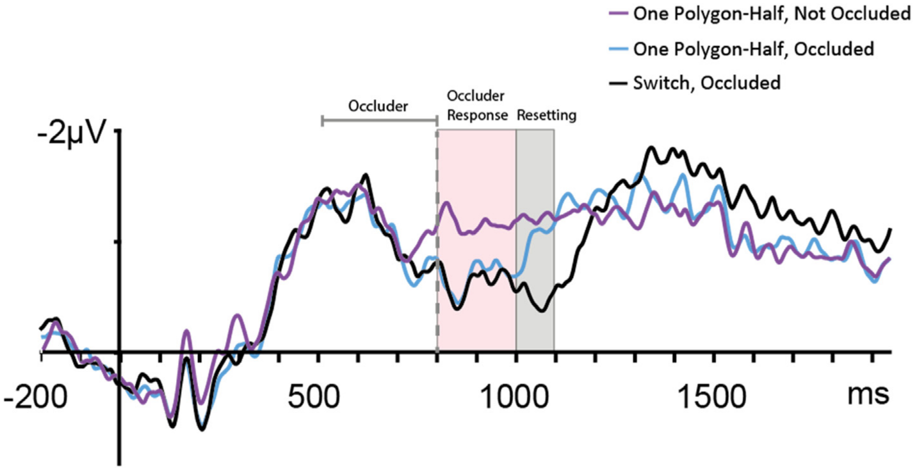

Fig. 9 — Results of experiment 4. Data were averaged across the P7/8, PO3/4, and PO7/8 electrodes. The x-axis describes the time in milliseconds from stimulus onset. The y-axis describes the voltage in millivolts. The vertical dashed line depicts the time in which the polygon was fully not occluded. The grey rectangle depicts the analyzed time window (1000–1100 ms after stimulus onset). The time in which the polygon was occluded or partially occluded (500 ms–800 ms) is depicted by the grey horizontal line.

occlusion. This condition should trigger a resetting process. In the Not Occluded condition, the grey square performed the same trajectory adjacent to the polygon, such that the polygon was never occluded.

If resetting occurs even when the change in the object is not directly visible, we expect to see a CDA drop in the Switch condition. A resetting-related CDA drop should occur 200 ms after the object becomes visible again, namely 1000–1100 ms from the trial onset. The other conditions, namely the One Polygon half and the Not Occluded conditions do not invalidate the object pointer, hence any CDA drop should only be related to the moving occluder. Following the results of Experiments 2 and 3, we expect to see the ERP response (the decrease in the CDA amplitude) following the occluder movement in both the One Polygon half and the Not Occluded conditions. Importantly, the decline in the CDA should be evident immediately following the occluder movement (700–1000 ms after stimulus onset).

Moreover, if occluding the object disrupts the representation or the object pointer we expect to see a difference in the CDA drop between the Not Occluded condition (involving only a movement of the grey square without occluding) and the One Poly-half condition (involving an occlusion of the object without invalidating the pointer).

15. Methods

15.1. *Participants*

20 Tel-Aviv University students participated in this experiment (15 females and 5 men, ages: 20–31). All participants had normal or corrected-to-normal visual acuity and normal color vision. Participants agreed to participate in the experiment were informed following the procedures of a protocol approved by the local ethics committee. Participants received

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course credit or 40NIS (~10USD) per hour for participation. Subjects with more than a 25% rejection rate due to eye blinks or eye movements (one participant) or less than 60% accuracy (none) were replaced.

15.2. *Procedure and stimuli*

Stimuli were presented in black and white colors on a grey background. Each trial consisted of a memory array, a retention interval, and a display. 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 white 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). The experiment consisted of one memory array and a test array. The memory array was presented for 1300 ms and consisted of two static arrays and one moving array. In the polygon-half (one on each side of the screen) and two squares in a dark gray color (the occluders, one on each side of the screen) above or below each one of the polygon-halves polygon halves (randomly). Stimuli were presented for 500 ms. The locations of the polygon halves were randomly sampled from a 4.5°*3.5° rectangle (one on each side of the screen) and the location of the occluders was always .3° above or below each polygon half, or .3° above and .6° to the right or left of the polygon-half. Then, each occluder moved for 300 ms towards the other side of the polygon-half, covering the polygon during the trajectory. The overall time in which each polygon was occluded or partially occluded was 300 ms (during 500–900 ms after stimulus onset). After the movement period, the polygon halves and the occluders remain static for another 500 ms.

This experiment consists of three conditions. In the Not Occluded condition, the occluder appeared on the top right or left side of the polygon half and did not occlude the polygon half during its trajectory, but moved next to it. In both the One polygon Half and the Switch conditions, the occluder did cover the polygon-half during the trajectory. In the One polygon half condition, the polygon-half did not change during the display. In the Switch condition, the shape that reappeared after the polygon-half was covered was of an integrated polygon. After the memory array was over, a retention interval of 900 ms started, followed by the target array. 10% percent of the trials were catch trials, in which instead of the memory array, the object and the occluder appeared and remained static for 200 ms, which was followed by the retention interval. The purpose of the catch trials was to make sure that participants attended to the objects right from the beginning of the memory array.

Participants were instructed to indicate (by pressing "/" or "z") if the target is the same or different from the second memory array.

15.3. *EEG recording and analysis*

EEG recording and analysis were identical to Experiments 1 and 2.

16. Results

16.1. *Behavioral Results*

We analyzed the accuracy in the change detection task using a one-way ANOVA with Condition (One Polygon-half Occluder, Switch Occluder, and Not Occluded) as a within-subject variable. This analysis showed a main effect of Condition (F(2, 38) = 143.93, $p < .05$, $\eta_p^2 = .88$). Planned comparisons (contrasts) revealed that this main effect is a result of a lower accuracy in the Switch condition compared to the two other conditions (F(1, 19) = 163.27, $p < .05$, $\eta_p^2 = .89$), the same pattern found in Experiment 2.

16.2. *ERP Results*

To test our first research question of whether resetting occurs when the change is occluded, we analyzed the mean CDA amplitude between 1000 and 1100 ms after stimulus onset as a dependent measure. We have chosen this time window to match the typical time in which the resetting CDA drop appears (which is 200–300 ms after the change); Here, we used 200–300 ms after the integrated polygon in the Switch Occluder condition fully appeared. We performed a one-way repeated measures ANOVA, with Condition (One Polygon-half Occluder, Switch Occluder, and Not Occluded) as a within-subject variable. We found a main effect of Condition (F(2, 38) = 13.89, $p < .05$, $\eta_p^2 = .42$). To calculate the drop in CDA in the Switch Occluded condition, we performed planned comparisons (contrasts); We compared the One polygon half condition and the Switch condition and found a significant difference (F(1, 19) = 12.03, $p < .05$, $\eta_p^2 = .39$), meaning that there is a CDA-drop in the Switch Occluder condition. This drop shows evidence for resetting in the Switch condition, which means that even when the change in the polygon's shape was occluded, it triggered a resetting process.

Our second question was whether occluded objects are represented in the same manner when they are occluded compared to when they are visible. Similar to Experiment 1, there was an early decline in the CDA amplitude in both Occluded conditions compared to the Visible condition, and this decline might be a result of the occlusion. Importantly, this decline started before the time window of the resetting. To test whether this decline is significant, we analyzed the CDA amplitude in the time window of 800–1100 ms after stimulus onset, which is the same time window we analyzed in Experiment 1. This analysis showed a main effect for condition (F(1,19) = 11.02, $p < .05$, $\eta_p^2 = .36$). We calculated planned comparisons between the three conditions and found a higher amplitude in the Not Occluded condition compared to the One Polygon-half Occluder condition (F(1,19) = 10.34, $p < .05$, $\eta_p^2 = .35$) and compared to the Switch Occluder condition (F(1,19) = 15.98, $p < .05$, $\eta_p^2 = .45$). These results show that there was a decline in the CDA amplitude in both Occluder conditions, even when the object did not change behind the occluder. This result shows that the occlusion of an object creates a decline in the CDA amplitude.

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17. Discussion

The purpose of experiment 4 was to test whether a dramatic change in the object's status triggered a resetting process even when this change was not visible to the observer. The design of Experiment 4 took into account that the change needs to be relatively sudden (switch instead of split), reducing the chance for a high variance in the latency of the resetting drop. Looking at the resetting time window, the results of experiment 4 showed a CDA drop in the resetting time window only in the Switch condition, the only condition in which the object changed behind the occluder. In other words, we have found a drop in the Switch condition in the time window that matches the time window of the resetting in previous studies (see Fig. 9).

This result suggests that changes in the object's status triggered resetting even though the change was not visible in real-time and needed to be inferred later when it became visible. The pointers are still maintained when objects are occluded and resetting occurs when a dramatic change is detected even if this change is processed after the moment it occurred.

Another purpose of this experiment was to directly compare a condition in which the object was temporarily occluded to a condition in which the object was not occluded. The results of this experiment showed a longer decline in the CDA amplitude that occurred only in conditions in which the object was occluded, compared to the Visible condition. This result indicated that the status of the representation in VWM declined when the object was occluded. This result is interesting because Tsubomi et al. (2013) has shown that the CDA amplitude looked the same when the objects disappeared or remained in view. In this experiment, we see a difference in CDA response when objects are covered by the occluder. This pattern implies that occluding objects is a different process in VWM then the disappearing objects. It is possible that the occluder can erase or degrade the VWM representation (at least on some trials), but more direct evidence is needed to firmly conclude to the potential process triggered by an occluder relative to disappearance.

18. General Discussion

The purpose of this study was to investigate how VWM tracks and manipulates representations that are temporarily not in view, to further understand how the VWM pointer system tracks represented objects. Our first goal was to find out whether the resetting process occurs when a change in the object's properties is not visible at the moment of the change or only afterward, namely, when the object becomes visible again. Another goal was to investigate what happens to a VWM representation when the object is temporarily occluded. Does the occluder affect or interfere with the representation in any way?

Experiment 1 showed that the CDA sharp drop that marked the resetting process was present only when the change was visible (in the Not Occluded Split condition) and there was no drop when the change was occluded (in the Occluded Split condition). Instead, there was a long decline in the CDA when the object was occluded. In the Occluded Split condition when a resetting process was expected, this decline can be a result of the moment of change not being time-locked, and therefore the drop was averaged out. However, this decline appeared also in all Occluded conditions, even when the polygon did not change, which might suggest that it is a result of decline in the quality of the representation when the object was occluded.

To test whether the long decline in the CDA amplitude in the Occluded Split condition resulted from the moment of processing the change not being time locked, we designed Experiment 2. In Experiment 2 we aimed to create a situation in which the change is occluded, but also time locked. Importantly, in this experiment, the occluder appeared for a very short time on each trial, unlike Experiment 1, in which it was present on the screen for the entire trial. Experiment 2 has shown that a sudden and short-term appearance of the occluder resulted in a CDA drop. This drop was earlier than the typical resetting drop and recovered after a longer duration. It was also present in all the conditions in which the occluder was present, even those in which there was no resetting-inducing change. Therefore, we assumed that this drop was not a result of resetting, but a response to the fast onset and offset of the occluder. Experiment 3 has shown that a similar drop was present even if a stimulus physically identical to the previously used occluder appeared next to the object without occluding it. Importantly, there was no resetting condition in this experiment. This result supports our assumption that this peculiar CDA amplitude reduction indexes a substantially different phenomenon than resetting. This drop is assumed to be a result of a perceptual response to the abrupt onset of a stimulus, presumably akin to P1/N1 ERP. Interestingly, we can see a similar response to short offset and onset of the polygon in experiments 2 and 3. We will discuss this issue further later on.

In Experiment 4, we used a modified paradigm that better isolated the moment of the resetting compared to Experiment 1, but this time we used a design in which the occluder remained on the screen for the entire trial to prevent the CDA response to its onset and offset. The results showed evidence for resetting when the change is occluded. Interestingly, this experiment also showed a long decline during the time that the object was occluded, even when it did not change behind the occluder, as in Experiment 1. This result is particularly interesting because a previous study by Tsubomi et al. (2013) found that the CDA amplitude was similar when the objects in the task disappeared compared to when they remained on the screen. During occlusion, the occluded object is temporarily not in view. Based on Tsubomi et al. (2013) we would expect the CDA to not be affected by the occlusion. However, the current study has shown that occlusion (which also makes the object temporarily out of view) resulted in a CDA decline. This result suggests that occluding an object creates a difference in their representations, perhaps due to a degradation in the representation's quality, interference of the correspondence between the object and the representation, or deletion of the representation (at least in some of the trials).

Another study has shown a difference between oscillatory EEG activity (between 20 and 50 Hz) in infants when they

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observed an object that was gradually occluded or changed in a way that resembled occlusion, compared to when the object was disintegrated (Kaufman et al., 2005). Arguably, disintegration should invalidate the pointer, and indeed their results indicated different EEG activity for occluded compared to disintegrated objects. Note that they did not observe any difference between occluded and visible objects, although a close inspection of their Fig. 2, certainly suggests such a difference. While this oscillatory activity doesn't necessarily reflect VWM activity or activity of the pointer system, these results appear to converge nicely with the present results is suggesting a functional distinction between maintaining and losing a pointer.

Experiment 4 also showed that during the resetting time window, there was a CDA-drop when the object changed behind the occluder, and this drop was not present in this time window in the other conditions. This result suggests that the resetting process is not affected by the occlusion. This means that when an object is changing in a way that breaks the correspondence between the object and the representation, the resetting process is triggered the moment VWM can infer it and process the change. Experiment 4 also suggests that the CDA-drop was simply averaged out in Experiment 1. This is an important limitation that needs to be taken into account in future studies.

Another new interesting phenomenon was observer in Experiments 2 and 3. Although our visible condition in experiment 2 was a replication of Balaban & Luria, 2017, we made a small change that resulted in a different CDA pattern. Balaban & Luria, 2017 used a similar task with a blank interval of 50 ms. They have shown a resetting drop that was wider compared to other paradigms. In the current study, we prolonged the blank interval to 100 ms. We replicated the resetting drop, but in a 50 ms delay (compared to the original study).

In addition, the CDA results also showed another drop in all three conditions between 100 and 200 ms after the blank interval. Importantly, the fact that this drop appeared in all three conditions suggests that it is also not a result of resetting. Interestingly, this drop appeared in experiment 3 too, in the same time window (100–200 ms after the blank interval) and in all conditions. Since experiment 3 has the same blank interval as experiment 2, this might suggest that this drop is a result of the longer blank interval. Prolonging the blank interval to 100 ms might create an interference in the continuity of the representation that either did not happen when the interval was 50 ms, or it happened but was not distinguishable from the resetting drop in the CDA.

To summarize, this study investigated how visual changes, specifically changes that triggered resetting, are processed in visual working memory when the change is not visible. We have provided a few interesting and novel results regarding the process of resetting and the effect of occlusion of VWM representations. First, resetting occurred also when the pointer invalidation moment was occluded: Experiment 4 showed that after controlling for different artifacts, there was evidence for resetting even when the object change was occluded. Second, this study showed that the CDA amplitude declined while an object was occluded. This decline might be a result of interference in representing the object in VWM, created by the occluder. The last novel result is that briefly presenting a stimulus (for 100 ms), resulted in a CDA drop. This drop is not assumed to be a result of resetting since it occurs in all conditions, even in those in which the object does not change at all. Interestingly, this drop occurs even if the abrupt stimulus was presented next to the relevant object, presumably reflecting the onset and offset of the stimulus.

CRediT authorship contribution statement

Shani Friedman: Writing – original draft, Project administration, Formal analysis, Data curation, Conceptualization. **Roberto Dell'Acqua:** Writing – review & editing. **Paola Sessa:** Writing – review & editing. **Roy Luria:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

Open practices

Materials and data for the study are available at https://osf.io/b8h3p/

No part of the study's procedures or analyses was pre-registered before the research was conducted.

The study in this article has earned Open Data, and Open Materials badges for transparent practices. The data, and materials are available at: https://osf.io/b8h3p/

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Scientific transparency statement

DATA: All raw and processed data supporting this research are publicly available: https://osf.io/b8h3p/.

CODE: All analysis code supporting this research is publicly available: https://osf.io/b8h3p/.

MATERIALS: All study materials supporting this research are publicly available: https://osf.io/b8h3p/.

DESIGN: This article reports, for all studies, how the author(s) determined all sample sizes, all data exclusions, all data inclusion and exclusion criteria, and whether inclusion and exclusion criteria were established prior to data analysis.

PRE-REGISTRATION: No part of the study procedures was pre-registered in a time-stamped, institutional registry prior to the research being conducted. No part of the analysis plans was pre-registered in a time-stamped, institutional registry prior to the research being conducted.

For full details, see the *Scientific Transparency Report* in the supplementary data to the online version of this article.

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