The Influence of Identical Objects on Visual Working Memory Capacity: Electrophysiological Evidence

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ABSTRACT

Identical memory items have the potential to reduce cognitive demands on visual working memory (VWM) and enhance its precision. Previous studies have investigated this question preliminarily. However, there is still some controversy surrounding this question, as we cannot confirm whether the benefits from identical items can be generalized to complex stimuli. This study aimed to explore it further. We investigated whether individuals compress the identical items within their memory range to reduce VWM capacity consumption. Participants performed a change detection task, memorizing the orientations of the memory array, which included three conditions: 1) four-same orientations, 2) two pairs of same orientations, and 3) four-different orientations. Using the contralateral delay activity (CDA), an event-related potential component that is sensitive to the number of items stored in VWM, we found that the CDA amplitude in late-time window was significantly lower for the all-same condition compared to the partial same and all-different conditions, with no significant difference between the latter two conditions. Our findings suggest that participants compress identical information, reducing VWM capacity consumption and increasing the number of items that can be remembered. However, this compression is conditional and occurs only when the strategy is most efficient, as in the all-same condition.

Keywords: Visual working memory; Identical object; Capacity; Contralateral delay activity

Introduction

Visual Working Memory (VWM) is an important cognitive system tasked with the temporary storage and processing of visual information, ensuring that visual stimuli remain active in the brain even after their disappearance from the environment. VWM plays a central role in cognitive functioning, able to predict individual differences in fluid intelligence[4,10,29] and performance on general cognitive tasks[6,30]. However, the capacity of VWM is pretty limited, with research indicating that individuals can only maintain approximately 3-4 independent items in their VWM at any given time[16,17,32], which seems to impose constraints on our cognitive abilities.

Fortunately, in real-life, we do not always need to remember different items; rather, we often need to remember several items that share common information. For instance, we might observe some flowers of the same color along a roadside or numerous identical buildings in a residential area. Common sense and experience tell us that we find it easier and remember more items when we are trying to recall items with identical information. A key question is whether the presence of identical objects reduce the consumption of VWM capacity. If so, how do these identical objects help us alleviate the memory burden? And under what situations does this effect occur? This question dives into the exploration of the interrelationships between memory items, a topic that has rarely been addressed in traditional VWM research.

Traditionally, VWM research has tended to focus on the storage of discrete memory items[3,5,20,39], but researchers have gradually shifted their attention to the interrelationships between objects within VWM recently[7,14,21,23]. Particularly, the similarity relationships between objects have induced significant interest. Lin and Luck (2009) were among the first to investigate the impact of similar colors, which are close in color coordinates, on VWM[14]. Their findings revealed that compared to dissimilar colors, the accuracy of recalling similar colors was higher, confirming the positive influence of similar items on VWM. Building upon this discovery, researchers have further explored whether the principle of similarity can also enhance VWM performance in terms of orientation and shape features, with results consistently demonstrating a positive effect, suggesting that the similarity effect across different feature dimensions is stable within VWM[31,38]. These studies have provided crucial insights into whether items containing identical information can enhance memory performance. Given that identical items represent the extreme case of similarity, one area of interest has been to test whether VWM performance benefits observed in similarity extend to identical.

Because of the advantage of on-line tracking the information processing, ERP studies could provide particular important evidence on the above issues. An ERP component contralateral delay activity (CDA), representing a sustained negative potential that reflects the information currently held in VWM. Previous studies have widely utilized CDA to examine VWM processes[19,34]. Generally, as the number of items represented in VWM increases, the amplitude of the CDA also increases; however, once an individual reaches the limit of their VWM capacity, the amplitude of the CDA no longer increases with the number of items to be remembered9[,30]. Compare to the traditional behavior index, like accuracy (ACC), CDA provides a real-time tracking of the number of items stored in VWM, occurring before the participant's response and not influenced by the probe stimuli or the matching decision stage. But the behavior results not only reflect the influence of VWM maintenance but also the impact of memory decisions, such as the difficulty of detecting changes in the probe array. Moreover, previous studies have shown that CDA primarily tracks the number of VWM representations, rather than being modulated by factors such as the information load[12,14,37] or the current focus of spatial attention[14]. Therefore, the amplitude of the CDA better be serve as an index of the number of items stored in VWM and provide insights into the allocation of VWM capacity to storage representations than ACC[19].

Previous research has used the CDA to investigate whether the presence of identical colors can reduce the consumption of VWM capacity[11,22]. Gao et al. set up three different memory array conditions: 1 color, 4 identical colors and 4 different colors, they found that the CDA amplitude was no difference between the 1 color and 4 identical color condition, but those two conditions are both significantly lower than 4 different colors condition. These results suggest that when all the items within the participant's attentional focus are identical, the consumption of VWM capacity is greatly reduced. Subsequent research by Peterson et al. further addressed the question of whether similar benefits would be observed if only some of the stimuli within the memory array were identical. In this study, researchers arranged three different memory arrays: three differently colored squares (high load, all different condition); two differently colored squares (low load, all different condition); and three squares with two of the same color (high load, partial same condition). The results suggest that identical colors can alleviate the representation load of VWM， and this benefit is not limited to situations where all colors within the visual field are the same. However, a limitation of these studies is that they used simple color materials as stimuli. Furthermore, the experimental results obtained from color stimuli may not be directly generalized to other visual materials without further testing[13]. For instance, previous research has demonstrated that the mechanisms of memory consolidation for color stimuli differ from those for orientational stimuli. Color stimuli occupy a smaller bandwidth in VWM consolidation, whereas orientational stimuli and other complex stimulus require a larger bandwidth. Consequently, color stimuli are often parallel consolidated in VWM, while orientational and other complex stimuli are consolidated in a serial way. The unique consolidation mechanism of color stimuli may be a key factor contributing to the observed results in prior studies.

Therefore, in our study, we explored further this issue by using orientation stimuli. We designed an experiment that included three conditions, each requiring participants to remember four items. However, we controlled the content of the items at three different levels: four different stimuli, four same stimuli, or two pairs of stimuli that were same to each other. Additionally, we used the CDA as an indicator to track the representation numbers in VWM, examining the quantity of representations stored in VWM under different conditions. Our experimental design imposed a higher memory load than previous studies[22], where participants were required to remember a maximum of three items. This relatively low-level load may not have compelled them to actively seek to reduce the memory load. Despite this, previous studies still revealed the fact that participants reduce memory consumption under the partial same condition. However, to investigate whether participants would employ a strategy to handle identical stimuli in VWM and alleviate memory load when dealing with more complex stimuli, we needed to increase the memory load by setting four items. This created a situation where participants were acutely aware of the need to reduce memory difficulty.

Furthermore, based on two previous studies[11,22], this research concurrently set conditions for complete all same condition and partial same condition. Considering the distinct consolidation mechanisms of color and orientation stimuli, we could not directly infer that orientation stimuli could reduce VWM capacity consumption under the all and partial same conditions. Therefore, we required the all same condition for comparison with the partial same condition to confirm whether the reduction in VWM capacity consumption was due to the unique consolidation pattern of color stimuli or whether it occurred whenever there was partial same in the stimuli during memory processing. This allowed us to confirm whether the reduction in VWM capacity consumption observed in previous studies was specific to color stimuli or a general phenomenon occurring with partially same stimuli during memory processing.

We hypothesize that our experimental findings may align with one of three possibilities. Firstly, the "Not Absolute Identical Benefit Effect" hypothesis, which same as the previous research findings, suggests that the presence of partial identical objects within the memory range can reduce the consumption of VWM capacity, thereby increasing the number of items that can be remembered. The expected result would be that the CDA amplitude in the all different condition is higher than in the partial same condition, which is in turn higher than in the all same condition. Secondly, the "Absolute Identical Benefit Effect" hypothesis believes that, unlike color stimuli, same orientational or other complex stimulus cannot easily trigger a reduction in VWM capacity consumption. According to this hypothesis, all same stimulus within the visual field is required. The anticipated result would be that the CDA amplitude in the all different condition is higher than in the all same condition, with no difference between the all different and partial same conditions. Lastly, the "No Identical Benefit" hypothesis believes that identical orientation or other complex stimuli do not lead to a reduction in VWM capacity consumption. In this case, the expected result would be that the CDA amplitude in the all same condition is no difference from that in the all different and partial same conditions.

To better confirm the effectiveness of the experimental task control, we conducted a behavioral pilot study prior to the formal experiment, with specific details available in the Supplementary Materials.

Methods

Beyond the experimental setup described in the preceding text, we controlled different change angles to avoid participants developing a fixed expectation regarding the range of the changes in the probe array. We expected that participants would find it more challenging to detect changes with smaller angles, leading to poorer performance. However, if the effects of the three memory conditions extend beyond working memory processing and also influence the decision-making and judgment stages, we would anticipate an interaction between the memory conditions and the angle change range. In the pilot study, we found that when the change angle was either too small (15°), there was no significant difference in memory performance between the all different condition and the partial same condition, contrary to the patterns observed at other angles (30° and 45°). In these cases, the all different condition's performance was worse than that of the partial same condition and the all same condition (see supplementary materials for details). This suggests that the change angle influences the effects of the three memory conditions. To maintain consistency with the pilot study and prevent participants from forming fixed expectations about the change angle, we further explored the effects using 15°, 30°, and 60° change angles in the current experiment.

Participants

In this Experiment, one participant was excluded due to lack of attention, which led to the termination of the experiment. Another participant was excluded because the program crashed during data collection, resulting in the termination of the experiment. Therefore, a total of 23 participants were included in the analysis. The sample size of participants was determined by a priori effect size analysis for single-factor repeated measures ANOVA8 (α=0.05 and β=0.95, as set in the reference to previous literature[22], with an effect size of $\eta^2 p$ = 0.26~0.31. This analysis indicated that a sample size of 20 to 25 could provide sufficient power to detect the predetermined effect size. Before the experiment, their basic conditions were confirmed, including normal or corrected vision, mental alertness, no color blindness, and no other mental illnesses. After confirming that the participants met the basic requirements, all participants signed an informed consent form and received a monetary reward upon completion of the experiment. Our study was conducted under the Declaration of Helsinki and approved by the Ethics Committee of the Institute of Brain and Psychological Sciences, Sichuan Normal University (Protocol ID: SCNU-221114).

Stimuli

The procedure of this experiment was programmed using E-Prime. The experimental stimuli were presented on a 23.8-inch LCD display with a resolution of 1280x768 and a refresh rate of 60Hz. The screen background color during the experiment was black (RGB: 0, 0, 0). Each participant was seated approximately 60 centimeters from the screen. Throughout the experiment, a cross-fixation point remained centered on the screen. Memory stimuli and probe stimuli consisted of white (RGB:225, 225, 225) bars. In the memory array, 8 bars were presented, arranged in a circle around the central cross fixation point with a radius of. The bars were symmetrically distributed to the left and right of the fixation point. The size of each bar was 1.4° x 0.2°, with an inter-bar spacing of 2.9° and a distance of 3.3° from the fixation point. In the test array, one bar appeared at a random position on each side, matching the location of a bar from the memory array. In the probe array, the angles of the bars presented in the memory array were randomly changed by 15°, 30°, or 60° under different conditions.

Procedure

The experimental procedure is illustrated in Figure 1. Throughout the experiment, a cross-fixation point is present to maintain the participants' attention. Each trial begins with a cue phase that lasts for 200ms, during which an arrow appears above the fixation point, pointing either left or right, each orientation being presented half the time. In this phase, participants are cued to remember the orientation of the bars on the corresponding side. Following the cue phase, a 100ms interval is set to allow participants time to process the arrow information and prepare for the memory array, with the fixation point displayed in the center of the screen. Next, a memory array phase lasts for 500ms and presents a total of 8 bars, 4 on each side, symmetrically arranged. There are three conditions for the memory array: all bars on each side have the same orientation (all same condition), the orientations of the 2 bars on each side are the same (partial same condition), and the angles of all bars are different (all different condition). After the memory array phase, a maintenance phase lasts for 1000ms, with the fixation point displayed in the center of the blank screen. Participants are required to maintain their memory of the items during this phase. In the probe phase, a random probe stimulus appears on each side, matching the angle of a remembered item or not. Participants must judge whether the probe stimulus matches their memory. If it does, they press the "f" key; if not, they press the "j" key. The trial ends after the participant's response or after 2000ms of screen presentation. Finally, a feedback phase lasts for 500ms, displaying "correct" or "incorrect" depending on the participant's response.

Before the formal experiment begins, participants undergo 18 practice trials. The total number of trials is 648, with each condition appearing 216 trials (randomly). The entire experiment takes approximately 1 hour, with 17 breaks to prevent fatigue from interfering with the results. To prevent the observed CDA result patterns from being influenced by eye movements, participants were instructed to focus on the central fixation point throughout the experiment, with a restricted range of eye movements.

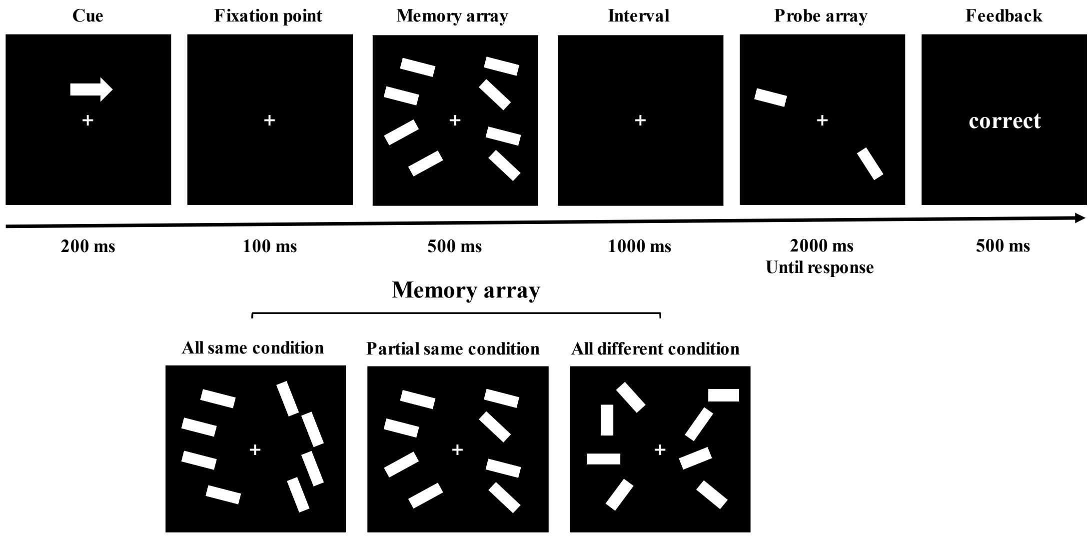

Figure 1: (A) Flowchart of the experimental task. (B) Three conditions of the memory array: all same condition; partial same condition; all different condition.

Data analysis

Electroencephalogram recording and analysis

During the task, we continuously recorded electroencephalogram (EEG) activity using a 62-channel active Ag/AgCl electrode system (Brain Products ACTi Champ) positioned on an elastic cap, according to the International 10-10 system. The ground electrode was placed at FPz. The online reference for the data was set to the vertex (Cz). For the post-recording analyses, the data were re-referenced offline to the average of the bilateral mastoids(TP9、TP10). A horizontal electrooculogram (IO) was recorded by using a referenced electrode pair positioned approximately 1 cm laterally to the outer canthi of right eyes. The impedance at each electrode site was kept below 5 kΩ. The EEG and EOG signals were digitized at a sampling rate of 500 Hz.

The data were processed offline by using MATLAB (2019). The EEG signals were segmented into epochs of 1000-ms duration, starting from 200 ms before the onset of the memory array. A low-pass filter with a cutoff frequency of 30 Hz was applied to the data. Baseline correction was performed by subtracting the average amplitude of the 200-ms peristimulus interval. Trials containing horizontal eye movements, identified by IO amplitudes exceeding ±60 μV, were excluded from the analysis. Additionally, trials with remaining artifacts exceeding ±80 μV in amplitude were rejected. Participants with a trial rejection rate higher than 45% were excluded from further analysis. The EEG data from the remaining trials were averaged for each participant and condition, and the averages were time-locked to the onset of the memory array.

We selected one pair of posterior electrode sites (PO7/PO8 and P7/P8) for our analysis. In each block and for each stimulus condition, the contralateral amplitudes were calculated for each participant by averaging the activity recorded at the left hemisphere electrode sites when the participants were cued to memorize the right side of the memory array. For the opposite condition, the activity recorded at the right hemisphere electrode sites was averaged when participants were cued to memorize the left side. The ipsilateral amplitudes were computed by averaging the activity from both the left and right hemisphere sites when participants were cued to memorize the left and right sides of the memory array, respectively. The whole CDA amplitude was determined by subtracting the ipsilateral activity from the contralateral activity within a measurement window of 500–850 ms after the onset of the memory array.

The CDA amplitude is an ERP component that real-time reflects the number of items stored in VWM. Therefore, when analyzing CDA results, it is not sufficient to merely focus on whether there are differences in mean amplitude during the overall time window. This way could lead to a failure to track the process of changes in the number of stored items. Moreover, in this study, even though we may observe the effect of identical information on reducing VWM capacity consumption, we still need to further investigate whether the processing of identical information effect occurs during the early or late consolidation phases of VWM. Therefore, when analyzing CDA data, we selected the 500-650 ms (early time window) and 700-850 ms (late time window) to analyze the CDA results for the three different memory array conditions. We also analyzed the CDA across the whole time window (500–850 ms), and found that the pattern of results was identical to that observed in the late time window (700-850 ms). Thus, we attribute the whole-time window effects primarily to the contributions from the late time window. For a detailed report and analysis of the CDA results over the whole time window, please read the Supplementary Materials.

Statistical analysis

The purpose of this experiment was to examine whether identical information would alleviate the consumption of VWM capacity. To achieve this, a one-factor repeated measures was employed to compare the three memory array conditions (all same condition vs. partial same condition vs. all different condition), with ACC and mean CDA amplitudes as the dependent variables under different memory array conditions. The effect size for ANOVAs was estimated using the partial eta-squared (η^2_p) value. Paired samples t-tests were conducted for the planned pairwise comparison among the three memory array conditions. JASP (version 0.19) was used to provide Cohen' s d, estimating the effect size for the t-tests, and Bayes factors, showing whether the t-test results supported the alternative hypothesis[26], thereby providing an odds ratio for the alternative/null hypotheses (values <0.3 provide evidence for the null hypothesis and values >3 provide evidence for the alternative hypothesis.).

Results

ACC

The mean ACC for each memory condition (all same condition vs. partial same condition vs. all different condition) is presented in Figure 2A. The analysis of variance (ANOVA) revealed a significant main effect of the memory array (mean ACC for the all same condition, partial same condition, and all different condition: 0.842 ± 0.008, 0.712 ± 0.011, 0.647 ± 0.01, respectively), $F(2,44) = 186.735, p < 0.001, \eta^2 = 0.895$.

Planned pairwise comparisons revealed that the ACC were significantly lower for the all different condition than for the all same condition, $t(22) = 21.434, p < 0.001$, *Cohen's* $d = 4.469, BF_{10} > 1000$. Additionally, the ACC showed a significant difference between the partial same condition and the all same condition, $t(22) = 11.136, p < 0.001$, *Cohen's* $d = 2.322, BF_{10} > 1000$, and significant differences were observed between the partial same condition and the all different condition, $t(22) = 6.607, p < 0.001$, *Cohen's* $d = 1.378, BF_{10} > 1000$. These ACC results suggest that the performance of VWM improved with the number of identical orientations increases.

As the change angle increased, participants' performance on the change detection task improved (see Figure 2B). The significant main effect of change angle supported this observation (average ACC were 0.615±0.011, 0.746±0.074, and 0.838±0.053) for the 15°, 30°, and 60° conditions, respectively; $F(2,44) = 310.995, p < 0.001, \eta^2_p = 0.934$). Participants' memory performance was better in the all same condition than in the partial same condition and the all different condition, which was supported by the significant main effect of memory array condition on ACC, $F(2,44) = 179.352, p < 0.001, \eta^2_p = 0.891$. We also found an interaction between the memory array and change angle, $F(4,88) = 9.690, p < 0.001, \eta^2_p = 0.306$.

Planned pairwise comparisons revealed that when the change angle was 15°, the ACC were significantly lower for the all different condition than for the all same condition, $t(22) = 8.617, p < 0.001$, *Cohen's* $d = 1.797, BF_{10} > 1000$. Additionally, the ACC showed a significant difference between the partial same condition and the all same condition, $t(22) = 5.585, p < 0.001$, *Cohen's* $d = 1.165, BF_{10} > 1000$, but only marginal differences were observed between the partial same condition and the all different condition, $t(22) = 2.065, p = 0.051$, *Cohen's* $d = 0.431, BF_{10} = 1.302$. When the change angle was 30°, the ACC were significantly lower for the all different condition than for the all same condition, $t(22) = 15.433, p < 0.001$, *Cohen's* $d = 3.218, BF_{10} > 1000$. Additionally, the ACC showed a significant difference between the partial same condition and the all same condition, $t(22) = 8.841, p < 0.001$, *Cohen's* $d = 1.843, BF_{10} > 1000$, and significant differences were observed between the partial same condition and the all different condition, $t(22) = 5.118, p < 0.001$, *Cohen's* $d = 1.067, BF_{10} = 626.354$. When the change angle was 60°, the ACC were significantly lower for the all different condition than for the all same condition, $t(22) = 13.221, p < 0.001$, *Cohen's* $d = 2.757, BF_{10} > 1000$. Additionally, the ACC showed a significant difference between the partial same condition and the all same condition, $t(22) = 10.953, p < 0.001$, *Cohen's* $d = 2.284, BF_{10} > 1000$, and significant differences were observed between the partial same condition and the all different condition, $t(22) = 5.888, p < 0.001$, *Cohen's* $d = 1.228, BF_{10} > 1000$. These ACC results suggest that the change angle impacted the identical effect, the difference between partial same and all different was absent when the change angle was too small.

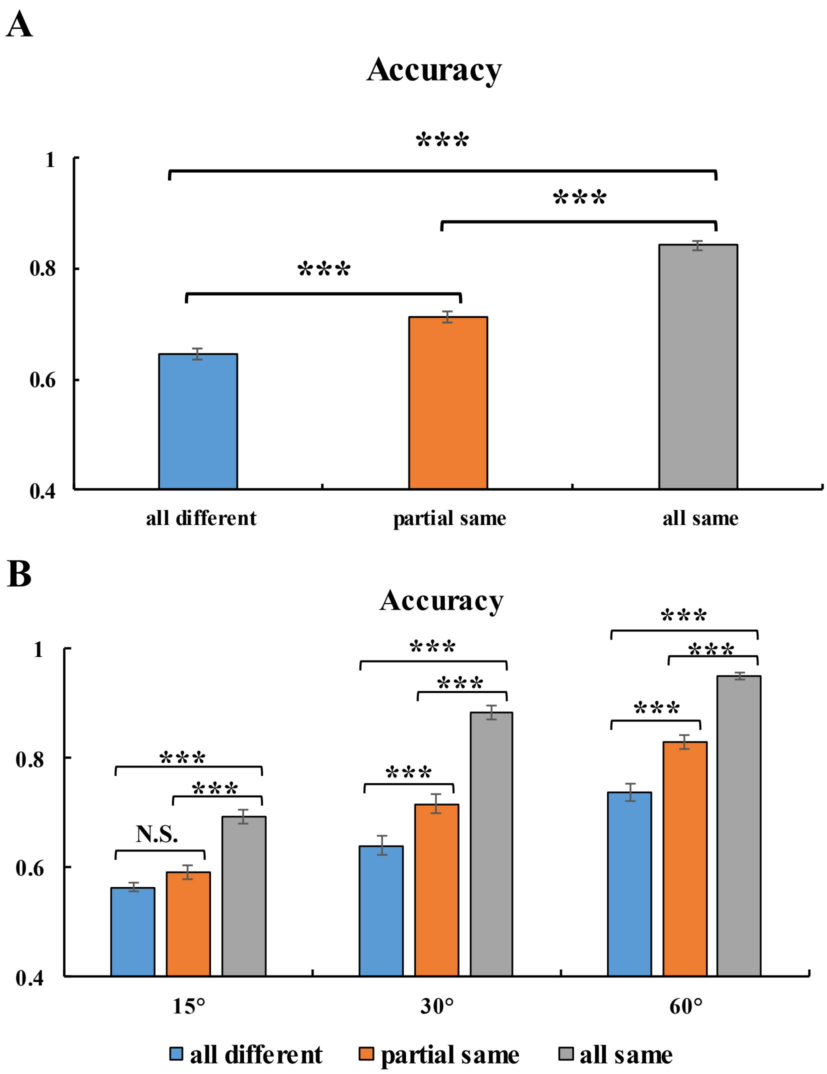

Figure 2 Accuracy results for each condition. (A): Mean and standard error of the mean for the ACC under different memory array conditions (all same condition, partial same condition, and all different condition). Error bars indicate SE. ***= p <0.001. (B) ACC results for the three memory arrays under three different conditions of angle change.

CDA result

The CDA amplitudes for each condition are depicted in Figure 3. Figure 4 and 5 illustrate the early CDA amplitudes (500–650 ms) and late CDA amplitudes (700–850 ms) for all memory conditions. The two-way repeated measures ANOVA revealed a significant interaction between the time window, memory condition, $F(2, 44) = 4.385$, $p = 0.018$, $\eta^2_p = 0.166$, a significant main effect of the time window, $F(1, 22) = 4.378$, $p = 0.048$, $\eta^2_p = 0.166$, and a significant main effect of the memory condition, $F(2,44) = 4.568$, $p = 0.016$, $\eta^2_p = 0.172$.

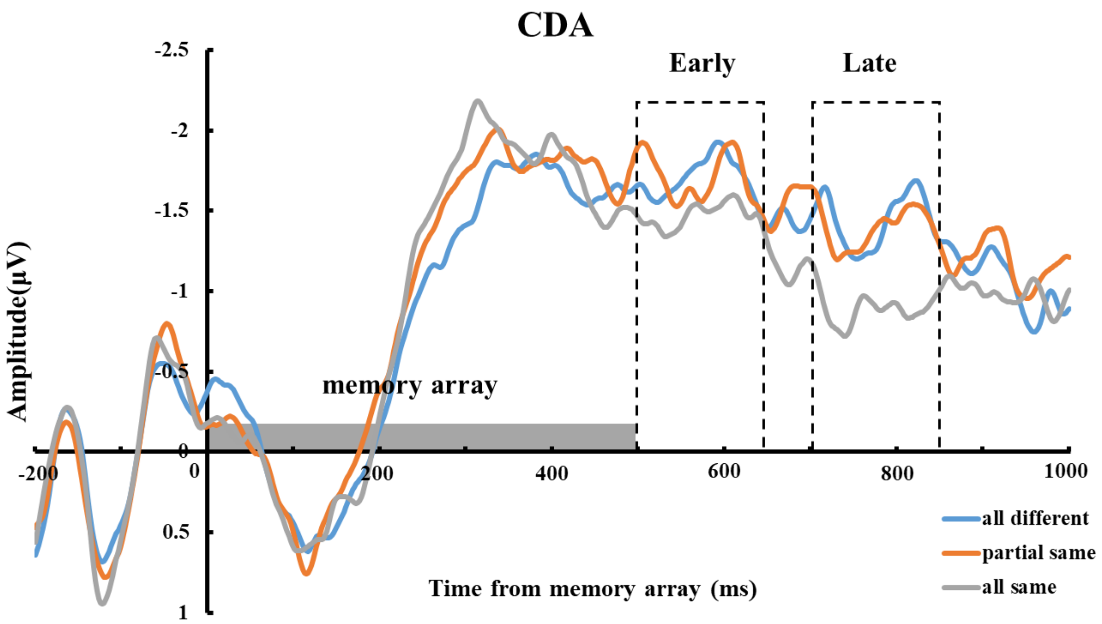

Figure 3 Mean waveforms of the average ERP for different memory array conditions: all same condition (gray), partial same condition (orange), and all different condition (blue), showing the difference waveform (contralateral minus ipsilateral). The waveforms are time-locked to the onset of the memory array (y-axis at time zero). The shaded grey box represents the time window of the memory array presentation. The two dashed rectangles denote the time windows for the early CDA and the late CDA, respectively.)

Early CDA result(500-650ms)

The averaged difference early CDA amplitudes for all same condition, partial same condition, and all different condition are presented in Figure 4. The ANOVA revealed no significant main effect of the size condition, $F\ (2,44) = 1.921,\ p = 0.159,\ \eta^2_p = 0.08$.

Planned pairwise comparisons revealed that the early CDA amplitudes were no difference between the all different condition (-1.695 ± 0.192) and the all same condition (-1.466 ± 0.24), $t\ (22) = 1.635,\ p = 0.116$, *Cohen's* $d = 0.341,\ BF_{10} = 0.694$. Additionally, the early CDA amplitudes showed no significant difference between the partial same condition (-1.691 ± 0.246) and the all same condition, $t\ (22) = 1.796,\ p = 0.086$, *Cohen's* $d = 0.375,\ BF_{10} = 0.867$. As well as, no significant differences were observed between the partial same condition and the all different condition, $t\ (22) = 0.03,\ p = 0.976$, *Cohen's* $d = 0.006,\ BF_{10} = 0.219$. The results of early CDA amplitudes suggest participants didn't reduce VWM capacity consumption when the identical orientation is existed during the early phase of VWM consolidate.

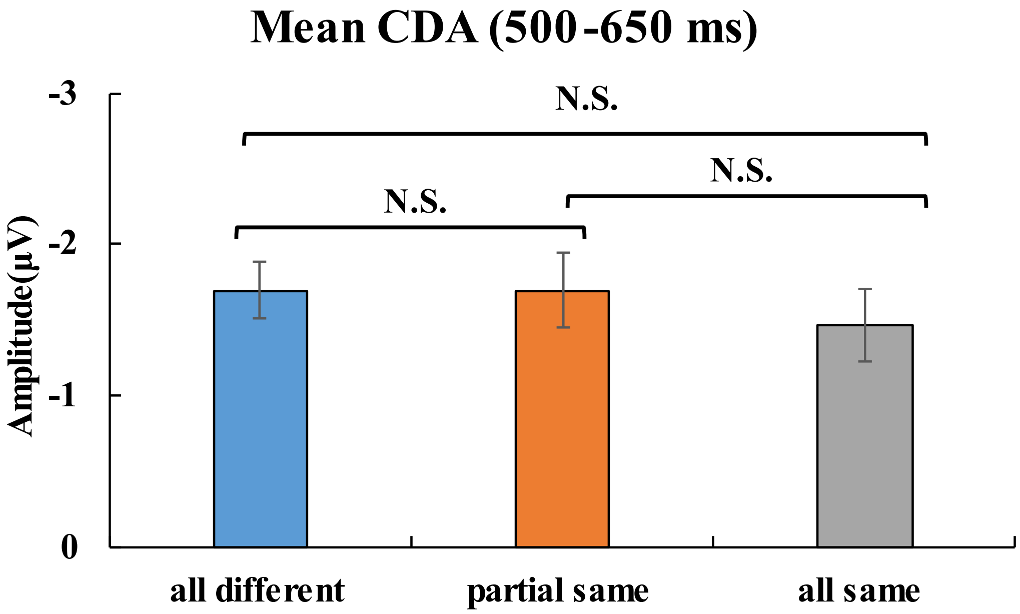

Figure 4 Early CDA results for each condition. Mean and standard error of the mean for the CDA (500-650 ms) under different memory array conditions (all same condition, partial same condition, and all different condition). Error bars indicate SE. N.S. = p > 0.050.

Late CDA result(700-850ms)

The averaged difference late CDA amplitudes for all same condition, partial same condition, and all different condition are presented in Figure 5. The ANOVA revealed no significant main effect of the size condition, $F\ (2,44) = 6.08,\ p = 0.005,\ \eta^2_p = 0.217$.

Planned pairwise comparisons revealed that the late CDA amplitudes were significantly lager for the all different condition (-1.442 ± 0.289) than the all same condition (-0.894 ± 0.319), $t\ (22) = 2.813,\ p = 0.01$, *Cohen's d* $=0.587,\ BF_{10} = 4.858$. Additionally, the CDA amplitudes showed significant difference between the partial same condition (-1.691 ± 0.246) and the all same condition, $t\ (22) = 2.681,\ p = 0.014$, *Cohen's d* $= 0.559,\ BF_{10} = 3.783$. However, no significant differences were observed between the partial same condition and the all different condition, $t\ (22) = 0.331,\ p = 0.744$, *Cohen's d* $= 0.069,\ BF_{10} = 0.23$. The results of late CDA amplitudes suggest that participants only reduce VWM capacity consumption when the all orientation were identical during the late phase of VWM consolidate.

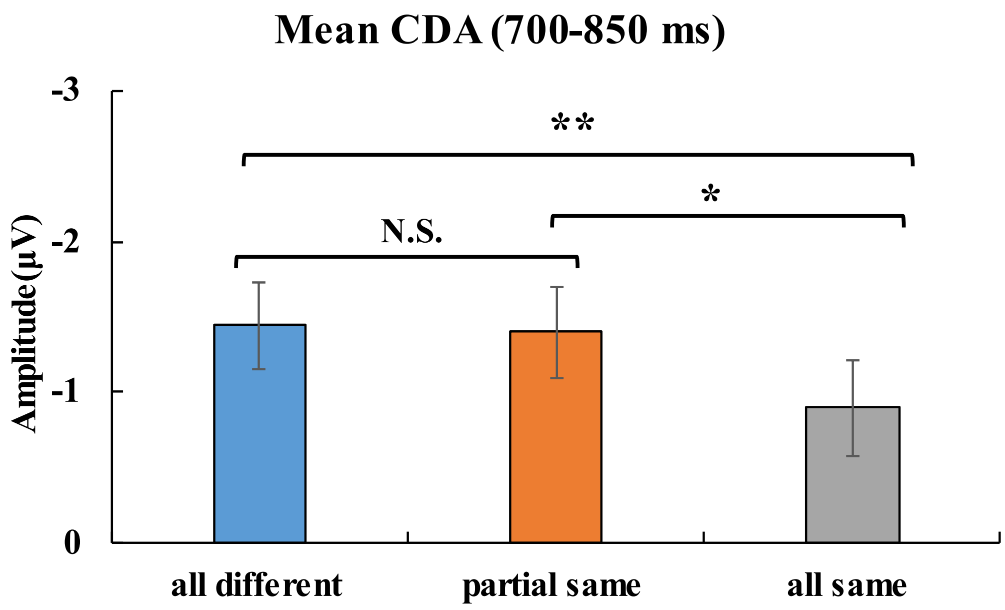

Figure 5 Late CDA results for each condition. Mean and standard error of the mean for the CDA (700-850 ms) under different memory array conditions (all same condition, partial same condition, and all different condition). Error bars indicate SE. ** = $p < 0.01$, * = $p < 0.05$, N.S. = $p > 0.050$.

Discussion

The aim of this study was to investigate whether identical orientation stimuli can reduce the consumption of VWM capacity. Additionally, we sought to identify the specific conditions and temporal windows in which this effect might emerge. Through CDA analysis, we examined the differences in CDA amplitudes among different memory groups (all items identical, partial items identical, and all items different).

In our study, participants were required to remember the orientation of four bar stimuli, which were divided into three conditions: all four bars facing the same orientation, two pairs of bars facing the same orientation, and all four bars facing different orientations. Behavioral results showed that participants had higher accuracy in recalling identical items than in recalling partially identical or completely different items, and recalling partially identical items was more accurate than recalling completely different items. This suggests that memory accuracy improves with the number of identical items recalled, aligning with findings from the similarity research domain and previous studies on the precision of recalling identical color [22,25]. Even with discrete items within the memory range, some visual information connection (similarity or identity) can aid individuals in automatic binding, simplifying the memory array and thus reducing the memory load for all items within the memory range[1,2,17,21,24,28,36]. Furthermore, through the analysis of the orientational differences between the probe array and the memory array, we found that similar patterns of results were observed at change angles of 30° or 60°. However, when the change angle was 15°, there was only a marginal difference between the all different and partial same conditions. This indicates that ACC results are susceptible to the influence of the decision-making stage. In change trials, when the orientational difference between the probe array and the memory array is small, participants may not be able to discern the difference during decision-making, thereby affecting the behavioral outcomes.

The differences in CDA results revealed a more complex memory process. Intriguingly, we noted an inconsistent pattern between early and late CDA amplitudes: in the early window, there were no significant differences between the all same, partial same, and all different conditions. However, in the late window, the CDA amplitude for the all same condition was significantly lower than that of the other two conditions. This indicates that under all same conditions, participants initially store all same orientations information in VWM but efficiently reduce the consumption of capacity by using certain strategies during the later maintenance phase. In contrast, under the conditions where partial items were identical and all items were different, CDA amplitudes did not differ whenever there are during early or late time window, suggesting that participants remembered all orientation information in partial same condition, which means partial same condition can’t induce the impact of identical object on VWM capacity.

Our results align with the "Absolute Identical Benefit Effect" hypothesis. For handling complex stimuli that are identical, the benefit of reducing VWM capacity consumption is only triggered when all stimuli within the visual field are identical. This differs from previous studies that used color stimuli, which found that participants could process identical colors even when only a partial of the stimuli within the visual field were the same, leading to a reduction in VWM capacity consumption. They suggested that this is because the salience of identical color stimuli within the visual field allows them to be easily integrated into a single representation. This conclusion can be inferred from Peterson's (2015) experiment, which demonstrated that identical color stimuli can be integrated regardless of whether they are adjacent or not. In other words, this suggests that colors naturally facilitate participants' ability to quickly find the identical color, even when identical colors are separated by other colors. However, we believe that for complex stimuli, participants may not be able to search for identical stimuli within a short time when other different stimuli are present within the visual field. For instance, in Ren's (2023) study, identical orientations were associated with higher memory precision compared to unidentical objects when the identical items were presented horizontally and vertically, demonstrating a facilitating effect. Importantly, this facilitating effect was absent when the identical items were presented in a diagonal manner. This indicates that when the conditions that help with the integration of orientational stimuli are lost, participants find it difficult to actively integrate identical orientational stimuli. This is likely the reason for the different result patterns observed when using complex stimuli compared to color stimuli. This result also reinforces the idea that conclusions from simple color stimuli cannot be directly generalized to other stimuli.

Analysis of CDA data across different time windows also supports the conclusion that orientational stimuli are more challenging to integrate. There were no differences in the early window among the three conditions, but a significant decrease in the CDA amplitude for the all same condition in the late window, compared to the other two conditions. This suggests that even when all stimuli within the visual field are of the same orientation, participants require a brief period for discernment and integration of the identical orientational stimuli. As for why partial same stimuli cannot trigger integration, we hypothesize that when presented with partially identical orientations, participants may have automatically judged that directly remembering four items was more efficient than separately compressing the information, thus opting for the more efficient memory strategy. This suggests that humans tend to automatically choose the most effort-saving memory strategy during VWM, even if we have not consciously made a choice.

In addition to this, we also provided another possibility for why the CDA amplitude in the late window for the all same condition significantly decreased, while the partial same condition did not. Firstly, another interpretation of the results is that the all same condition requires no active processes in memory since in that condition there is no competition of resources and no distracting information. In all different and partial same conditions, different orientations either compete with or distract each other, leading to an increase in cognitive load. Since three memory array conditions all have 4 memory items, the results suggest that CDA is only sensitive to active memory processing, but not to the number of information/orientations in memory array. This implies that CDA is a sensitive measure of whether information is actively being processed in VWM, rather than a measure of the quantity of information being held in VWM. Therefore, the absence of a difference in CDA amplitude between the all different and partial same conditions suggests that the active processing of the orientations in memory is similar in both conditions, despite the presence of more orientations in the all different condition. As for the lack of significant differences in CDA amplitude in the early window among the three conditions, we believe that participants require a brief period of active processing for all information before making judgments, regardless of the memory array condition.

According to previous research, we understand that the spatial arrangement of items also affects the memory effect of identical objects[25]. For example, when identical items are horizontally or vertically aligned, they have a facilitative effect on memory; however, when they are diagonally aligned, the facilitative effect disappears. This indicates that the memory effect of identical objects is constrained by the spatial environment and cannot be simply extended to identical objects presented at any random location. In our speculation, either horizontal or vertical placement of two identical items can meet the condition for participants to quickly extract identical information. Diagonal placement, however, requires further processing and analysis to confirm identical information. In this experiment, the memory items were always placed on one side, which falls under the category of horizontally aligned identical items. In the case of two items being identical, there might be different items in between, preventing individuals from making a quick judgment about the identical information. This phenomenon can perhaps be explained by the principle of proximity in Gestalt psychology, which suggests that when two or more visual elements are close to each other in space, people tend to perceive them as a single unit or chunk[35]. Diagonal placement of two identical items or different items in between them breaks the "proximity principle," leading to the failure of extracting and processing identical information. Therefore, we speculate that in VWM, individuals can reduce CDA amplitude when they can immediately extract identical information, either by quickly compressing the information (explanation 1), or by not engaging in active memory (explanation 2). However, due to the lack of distinction between the two cases of partial same in this study, the average CDA amplitude for partial same increased. This speculation can be further explored in future research.

In summary, our research findings indicate that that individuals can only reduce their consumption of VWM capacity and alleviate memory load when all objects within the memory range are identical. This finding appears to contradict our daily experience, as we instinctively believe that the presence of identical information can alleviate our memory burden regardless the number of same objects. Despite the possibility that participants might actively or passively choose to remember all four items under the condition of partial item consistency, the memory accuracy of this condition is still superior to that of remembering four items with different orientations. This indicates that, although not compressing identical information, or actively engaging in memory processing may lead to an increased consumption of VWM capacity. Within the limits of VWM capacity, it does not affect our memory performance. The presence of identical information simply under all same condition reduces the individual's occupation of capacity, thereby promoting the storage of more memory items. Our study provides valuable insights into the potential mechanisms of VWM and how individuals process and store identical visual information.

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Author contributions

Lijing Guo: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Software, Validation, Visualization, Writing – Original Draft Preparation. Ruyi Liu: Data Curation, Formal Analysis, Writing – Review & Editing. **Dan Nie:** Writing – Review & Editing. **Chaoxiong Ye:** Conceptualization, Formal Analysis, Funding Acquisition, Methodology, Supervision, Visualization, Project Administration, Resources, Writing – Review & Editing.

Competing interests

The authors declare no competing interests.

Data availability

The datasets generated during and/or analysed during the current study are available in the the Open Science Framework at https://osf.io/j6yse/.

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