How repetition hinders priority switching in visual working memory states: An EEG study

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Abstract

Working Memory (WM) prioritizes items as per the requirement of a top-down goal. However, bottom-up attention might interfere with this prioritization as it can act as a distractor to goal-driven tasks. Bottom-up attention induced by saliency and relational account, like the perceptual similarity between items, has been found to facilitate and attentionally prioritize while recalling items during short-term working memory. The top-down goal tries to maintain and selectively recall items in differently prioritized WM states, a hierarchical way beneficial in recalling information. However, there is a genuine knowledge gap about whether repeated items, a relational property of stimuli, can acquire a prioritized WM state by default and act as a distractor that hinders recalling not-repeated items even if a

matching probe prioritizes them. To address this gap, we designed a novel Visual Working Memory based EEG study where a memory array comprising of repeated and non-repeated items was introduced, and a probe item was presented after a delay period; participants responded by matching the probe to items that might be present or absent in the memory array. We found significantly slower reaction times and comparatively poor accuracy for recalling not-repeated items, which suggests that not-repeated items are not prioritized by default. Using EEG-based spectral perturbation-based analysis, we identified specific differences for sensor clusters and increased power of alpha, theta, and the beta band as the neural correlate of probe matching for not-repeated vs. repeated conditions. Comparatively higher mid-frontal theta power for not-repeated probe trials than repeated probe trials indicating stronger WM control for the matching probe. Also, significantly higher parietal alpha power for the not-repeated probe matching condition indicates a role of active inhibition of repeated item representations prioritized by default and hinders recalling accurately deprioritized items. These results imply that despite both items being encoded from the memory array in a limited time, repeated items possibly hold on to the default prioritized WM state. In contrast, not-repeated items acquire a secondary WM state. Higher frontal theta and parietal alpha power, along with behavioural results, demonstrate switching of WM states to prioritize hindered WM state corresponding to not-repeated probe. In summary, this opens up avenues for further investigations of mechanisms of priority switching from default prioritized items to goal-driven relevant items in short-term visual working memory.

Introduction

Visual working memory (VWM) is a limited-capacity cognitive system (Luck & Vogel, 1997, 2013) that can briefly maintain control and provide access to encoded information

(Oberauer, 2002; Olivers et al., 2011). The top-down goal selectively exercises cognitive control over items in VWM to protect the salient information against interference and decay. Thereby allowing the allocation of attention over certain items or sets of items to enhance the accessibility of information to maximize performance in a goal-directed task (Lewis-Peacock et al., 2012; Stokes, 2015). Based on this reasoning, performance in visual working memory tasks can be modulated as per the top-down goal and prioritized representational state for a specific information set over others (Lewis-Peacock et al., 2012; Stokes, 2015). Generally, a cue or probe indicative of attending to specific features or spatial direction can facilitate specific retrieval of items from the working memory (Griffin & Nobre, 2003; Makovski et al., 2008). Hence, attention brings items into either an active response-ready prioritized state or the items dwell into an accessory state which might be required to give a response later or rendered as not of primary importance. Such prioritization influences recall strength and production of required behavior to perform a goal-directed task (Sandry, J., Ricker, T. J., 2020). Therefore, revamping the items in the accessory state and bringing them into an actively prioritized state requires flexibility in prioritizing attention. This further requires top-down executive control and attention to bring less prioritized items to a more prioritized state (Myers et al., 2018).

However, certain perceptual features can facilitate bottom-up attentional selection leading to prioritization for encoding the items in visual working memory. This Default prioritization can be induced due to salient perceptual features (e.g., size, salient hue (color red) (Constant, M., & Liesefeld, H. R., 2021) or relational properties like visual similarity (Hamblin-Frohman et al., 2023). Memory items that are more similar and congruent to each other are recalled better and faster than others (Jiang et al., 2016; Lin & Luck, 2009; Yang & Mo, 2017). Visually similar items can also be attentionally prioritized and are facilitated during memory recall (Hamblin-Frohman et al., 2023). Such preferential recall for items

sharing similarity was also observed for other visual feature domains, including line orientation and length (Sims et al., 2012), unfamiliar characters (Mate & Baqués, 2009), and more complex stimuli (Jiang et al., 2016; Yang & Mo, 2017). This bottom-up attentional prioritization might limit the recall of cued/probed items or features in the deprioritized working memory state. One reason could be that any priority established by bottom-up features must interfere with the flexibility in priority switching. Although interference is reduced while participants are performing the goal-directed attention and working memory task (Peters, J. C., Goebel, R., & Roelfsema, P. R., 2009), such hindrance in flexible priority switching must be reflected in the change in properties of brain oscillations in the EEG data and may shed crucial insight about their possible neural correlates.

Extant literature further suggests that the priority switching (de Vries et al., 2018) is reflected in the changes in the power of the theta and alpha frequency bands. Previous studies have related Theta power (4-7Hz) oscillatory changes related to top-down control over items (Sauseng, P., Griesmayr, B., Freunberger, 2010; Sauseng & Liesefeld, 2020). Complex behavioral tasks require a higher need for cognitive control (Cavanagh & Frank, 2014; Cavanagh & Shackman, 2015; Cavanagh et al., 2012) and have been shown to exhibit an increase in neural power when switching the focus of attention between the working memory representations of two sequential tasks (de Vries et al., 2018). More importantly, Fronto-medial theta (FMT) is affected by changes in Working memory load (Klimesch, W, 1999; Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W., 2010), cognitive load and cognitive effort. It has been reported that synchronization in the posterior parietal cortex during attention (Paneri, S., & Gregoriou, G. G., 2017) and VWM tasks (Van Driel, J., Gunseli, E., Meeter, M., & Olivers, 2017) is seen to be mediated by activity in frontal cortices. Frontal theta Field controls the endogenous attentional selection of task-relevant

items (Johnson, et.al., 2017; Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W., 2010).

While alpha plays for sensory information-specific attention requirements. Moreover, changes in relative priority of stored maintained representations are reflected in modulation of posterior alpha power oscillations (8–14 Hz). Role of visual attention is reflected in alpha lateralization for selection of task-relevant information for both external selection of relevant stimuli (Sauseng, et.al., 2005), and for internal selection of information maintained within VWM (van Ede, F., Niklaus, M., & Nobre, A. C., 2017). Attentional shift happens in accordance to what needs to be inhibited. Generally, alpha desynchronisation causes active inhibition of items which need to be inhibited and it works in accordance with frontal theta. The attentional selection of certain working memory content could be the result of linking a sensory representation to such a representation of a to-be-executed action (Olivers & Roelfsema,2020).

Our experiment utilises a memory array which contains equal number of unique items which are repeated and not repeated. However, each repeated item is repeated twice. This memory array facilitated encoding of items of both the category however there is equal chances of appearance of probe from either of the category. This is to gain empirical evidences for our question on how these items takes up different Working memory states and behaviourally how this affects prioritisation as indicated by behavioural analysis. Next, we test our hypothesis that band specific spectral power differences in different frequency bands in particular theta and alpha power across two conditions can be associated with underlying causes for task specific behavioural differences elicited by the participants. Next, we demonstrate that the observed differences of recalling items of either of the probe of repeated (Rep) and not repeated (NRep) condition is strongly linked with mid frontal Theta and Parietal-Occipital Alpha oscillations. Finally, we test our hypothesis that during probe

matching for items in the two conditions (rep vs NRep), whether we get any signatures of top down attentional I*is-a-vis* through EEG Alpha oscillations that reveals attentional facilitation of certain items interfered with items in assumed deprioritised state. Taking together our results imply that despite both types of items being encoded from the memory array in a limited time duration, repeated items possibly hold on to the default prioritised WM state whereas not-repeated items acquire secondary WM state. Higher frontal theta and parietal alpha power show switching of WM states to prioritise hindered WM state corresponding to not-repeated probe, also confirmed by behavioural results. This study opens up avenue for understanding the role of priority switching and attentional control in working memory.

2.Material and Methods

2.1 Participants

Twenty-five participants (12 females; M(age) = 25.04 years, SD = 2.52 years, range: 21- 32 years) were recruited for the study. All participants had University degrees or higher; were right-handed (indexed by laterality score according to the Edinburgh handedness questionnaire); reported normal or corrected-to-normal vision; and declared no history of neurological or psychiatric disorders. The participants were requested to avoid the intake of any stimulant or medication (e.g., coffee, sedatives, etc.) before coming for the experiment. Two participants' data was rejected for analyses as one did not follow the proper instructions, and the other performed below the chance level in behavioural analysis of accuracy. Therefore, data for 23 participants (11 females; M(age) = 24.82 years, SD =2.12 years, range: 21-28 years) was included in the study for further analysis.

2.2 Ethics statement

The study was carried out following the ethical guidelines and prior approval of the Institutional Human Ethics Committee (IHEC) of the National Brain Research center, India.

Written informed consent was obtained from all participants before the commencement of the experiment, and they were remunerated for the time of their participation.

2.3 Stimuli and Procedure

The working memory task for the study was designed and presented using Presentation® software (Version 23.0, Neurobehavioral Systems, Inc., Berkeley, CA) and displayed on a 22-inch LED monitor screen (60 Hz; 1024 x 768 pixels) at a viewing distance of 75 cm.

Participants were first acquainted with the experiment using 15 practice trials. In both the main experiment and practice trials, visual working memory was tested using a probe matching task **(see Fig.1),** where participants were subjected to 280 trials in 6 blocks, with each block lasting 7-8 minutes. Participants responded in a two alternate forced choice (2-AFC) er.

2.4 Memory array

The memory array comprises of stimuli set where nine number digits were shown in each memory array, out of which three items were repeated twice and arranged in a jumbled fashion, along with three items that were not repeated; in total, nine items were presented in each memory array arranged in a circle. To remove biases in encoding, sets of numbers used in a particular array were controlled to avoid forming commonly used chunks (e.g., numerical order, odd or even set, etc.). Numbers were shown within the foveal area (dva < 2.5 degrees), and each item subtends an angle of 0.76 degrees. Hence, all memory arrays were presented as stimuli images during the trials and were pseudo-randomized. Memory arrays were shown for 2000 msec on average.

2.5 Trial structure

After presenting a fixation cross for 1000 msec, a memory array appears for 2000 msec, which participants were instructed to register carefully. After the presentation of the memory array, a delay screen appears with a cross in the center followed by the onset of the probe on which participants have to respond using the left and right arrow keys for whether the probe item was present in the memory array or not. Participants were instructed to give responses as fast and as accurately as possible. Reaction time and Accuracy were analyzed. The interstimulus interval (ISI) appears as a black screen after a response window of 1600 msec. Out of the total 280 trials, 140 were 'No' trials in which participants had to respond to a probe for which item was not present in the memory array. The remaining 140 'Yes' trials were for probes having a corresponding item in the memory arrays. Out of all the 'Yes' trials, half had a probe for Rep items, and the other half had a probe for NRep items.

2.6 EEG data acquisition

Behavioral and EEG data were acquired in the EEG recording room, where ambient noise, lights and other interferences were strictly controlled during the experiment to the same levels for all recording sessions. A Neuroscan EEG recording and acquisition system (Scan 4.3.3 & Presentation), which included an elastic cap (EasyCap) with 64 Ag/AgCl sintered electrodes and an amplifier (SynAmps2), was used. The 64-channel EEG signals were recorded using the International 10–20 electrode placement system. The reference electrode was positioned on the z line between Cz and CPz (closer to Cz), grounded to AFz, and all 'hannels' impedances were monitored to be below 25 kΩ. The data were acquired at a sampling rate of 1000 Hz.

2.7 Pre-processing for EEG spectral analyses

Analysis was conducted using MATLAB® and the EEGLAB toolbox(Delorme & Makeig, 2004). Data of one participant were discarded at this step due to very noisy recordings (jitters with very large amplitudes). EEG data was down-sampled to 256 Hz, and High-pass (0.5 Hz) and low-pass filters (30 Hz, respectively) were applied before the data were re-referenced to the linked mastoid (TP9 and TP10). Noisy channels were removed after visualization of spectral power over those channels and removing bad temporal segments. Next, we applied Infomax independent component analysis (ICA) algorithm to detect artefactual ICAs (eye blinks, ocular, muscular, and electrocardiograph artifacts) and subsequently, these components were removed manually after visual inspection. Epochs of 0 msec to 1600 msec were extracted from the probe display onset till the end of the response window. They were sorted for the Rep, NRep two probe conditions and used for the Event-related spectral perturbation (ERSP) analysis. Trial-by-trial detrending of each epoch category was performed to remove linear trends from the signal.

2.8 Behavioural analysis

For response time and accuracy analysis, we used data from all the "Yes" trials of the Repeated and Not-Repeated categories, where response time and accuracy were calculated for the response window starting from probe onset. Data from two subjects were not used in data analysis as one subject had poor accuracy (38%), and the other did not follow the instructions well. Outlier trials were removed using the Inter-Quartile range (IQR) method, where any data point lesser than 1.5 times of IQR below the quartile (Q1) or greater than 1.5 times of IQR above the quartile (Q3) is removed. For Response time analysis, only trials with correct responses for probe matching in Rep and NRep conditions were used for analysis. After removing outliers' trials, accuracy was analyzed.

2.9 Event related spectral perturbation analyses

Event-related spectral perturbation (ERSP) was computed by convolving three-cycle complex Morlet wavelets with each epoch of the EEG data. These analyses were based on 200 time points from −1000 to 1600 msec, cantered on the appearance of the probe till the end of the response time window, and frequencies ranging from 3 to 30 Hz with '0.8' number of cycles in the wavelets used for higher frequencies which will continue to expand slowly. The number of cycles instantiated in the wavelets from 3 cycles at 3 Hz. Baseline normalization was based on the time window (-1000 to 0 msec) prior to the presentation of the probe. Only trials where participants responded correctly to the probe were included in these analyses.

3.1 Behavioral response

We only used data for trials with correct responses for probe matching in Rep and NRep conditions for reaction time analysis. The violin plots (Fig.2a) (generated using ggplot 2(Wickham, 2011) in R software) for both conditions depict that the reaction times of participant responses show Rep < NRep. The Reaction time distribution of Rep condition is skewed and visually asymmetric. Hence, we employed a non-parametric Wilcoxon rank-sum test to compute the statistical significance of differences between the medians of reaction times (RTs) of any two categories. We rejected the null hypothesis as we found using the Wilcoxon Signed-Rank test that the median of the two conditions was significantly large Z= 5.1666, p = .384e-7, r = 1.0773. Comparatively shorter reaction time in the Rep condition might be due to attentional facilitation of repeated items. In contrast, the larger rT for NRep condition might be due to the default prioritization of repeated item representations as they are not facilitated and may be hindered by them.

For accuracy analysis, percentage accuracy was calculated, and mean percentage accuracy is plotted (Fig.2b) with distinguishable differences in distribution and median values showing Mean Percentage Accuracy (MPA) as higher for repeated items median = 95.3 in comparison to that of Not Repeated items (Median = 79.4) with -5.1666 p = 2.384e-7, r = -1.0773. Higher accuracy for Repeated items shows better recalling strength and a more prioritized state of repeated items compared to Not-repeated items in accessory states.

Longer reaction times and relatively poor accuracy for Not repeated items reflect the role of attention and cognitive control over Working memory items, which are required to be recalled and matched for provided probe. The facilitation of Repeated items in Working memory is reflected in shorter reaction time and better accuracy leading to attentional prioritization of these items in behavior, which might interfere with recall and probe matching for not-repeated items. Hence, it is important to characterize whether the neural dynamics corresponding to Event-related spectral perturbation will reflect changes in the power of different frequency bands for these differences in reaction time and accuracy for the two probe-matching conditions.

3.2 Event related spectral perturbations in Rep vs NRep probe conditions

Event related spectral perturbations (ERSP) of EEG signals was computed for trials with the correct response for the two categories of probe recall i.e. (Repeated items Vs Not-Repeated items). The ERSPs are computed for the epoch from probe onset till end of the response window at 1600 msec. Using permutation-based statistics with 2000 iterations of trial randomizations to generate permutation distribution and plotting values for frequencies from 3Hz to 30 Hz and period of -100 to 1100 msec for ERSP plots where 0 msec represents the onset of the probe **(Fig.3)**, Significant clusters with a threshold of 0.05 were found prominent

for theta band, alpha band, and beta band after multiple comparisons by False discovery rate (FDR) correction.

These clusters showed an increase in the power of alpha, theta, and beta band, which was further investigated by plotting ERSP plots and scalp maps and using cluster-based permutation statistics to find statistical differences in event related spectral differences in the power of theta and alpha oscillatory bands.

3.3 Role of Mid-Frontal Theta band oscillations during deprioritized item recall

Frontal medial electrodes were chosen to examine the difference in theta power for the two probe conditions as it is sensitive to changes in cognitive load and cognitive effort. C1 and C2 were used instead of Cz as it was used for referencing. Using cluster-based permutation with 800 iterations of trials randomizations, we found significant cluster at around 5Hz – 7Hz and 600 to 900 msec even after FDR correction, reflecting significantly higher theta power with a threshold of 0.05 for recalling items using the probe for NRep category in ERSP plot **(Fig.4.1)**. This also holds for average topography **(Fig.4.2)**, and topographical distribution of voltage **(Fig 4.3)** over frontal-medial electrodes (Ferreira et.al., 2019) involving multiple sensors F1, Fz, FCz, FC1, FC2, C1, and C2. The cluster of these sensors was depicted using permutation-based statistics with 800 iterations with a threshold of 0.05 and FDR correction for 5Hz to 7Hz and a period of 600 msec to 900 msec. Supplementary **Fig.S1** shows a significant enhancement in power in ERSP plots for most sensors in the NRep condition compared with the Rep condition, especially for frontal electrodes. This further elucidates the role of frontal-medial theta power in recalling deprioritized items in this task which is indicative of cognitive control required as other factors like the number of items in the two categories are controlled, and only repetition is the factor. Next, we test whether this top-

down control and interference might affect frontoparietal alpha power as it is sensitive to suppressing task-irrelevant items.

3.4 Topographical difference in frontal-parietal Alpha power for Rep vs. NRep probes

Alpha power changes are sensitive to attention demands and reflect active inhibition required to inhibit interference by distractors or task-irrelevant items, especially posterior parietal alpha. Hence, Cluster based permutation statistics with 800 iterations of trials randomizations with a threshold of 0.05 were used to generate data and plot alpha power distributions which showed significant clusters of PO7, PO8, PO3, PO4, POz, P1, P2, P3, P4, P5, P6, P7, P8 (Erickson et.al., 2019) at around 400 msec to 800 msec and 9 Hz – 12 Hz as displayed in ERSP plots **(Fig.5 A, B. C)**. Alpha power tends to increase for most of the electrodes for the NRep probe condition (**see Fig 3A and B**) While the topoplots **(Figs.5 D, E, F and G, H, I)** using permutation statistics in the relevant temporal response window of 400 msec to 800 msec after epoch onset and 9 Hz to 12 Hz frequency reveals significant involvement of parietal electrodes. Moreover, there is an increase in frontal alpha **(Fig 6 G, H, I)** and the involvement of a significant set of electrodes comprising **(FCz and FC1).** Further, **Fig.6** displays increased alpha power for the right parietal and a subset of frontal electrodes. This shows the role of Alpha power in mediating internal attention and suppressing irrelevant items during memory recall. However, the cluster of significant sensors that displayed increased frontal alpha topographical differences might indicate the perceptual gain required to respond to probe matching.

Discussion

The present study investigated effect of hinderance in switching between different WM states brought due to simultaneous maintenance before probe appearance and to respond

selectively. This requires actively recalling the probe from either the item from the repeated set or a not-repeated set of working memory. Recalling by matching probes for the items in either of the two types of item sets requires control over these items and attentional selection differently as designed in the current study in a memory array.

Behavioural results show that compared to responding to NRep items, the repeated items are recalled faster and more accurately. Our results are comparable to the prioritization of visual similarity in the working memory paradigm (Hamblin-Frohman et al., 2023) but by using the repetition of numbers as a relational account. Our experimental results demonstrate that the repetition of digits is attentionally facilitated, leading to default prioritization. This default prioritization can be attributed to faster response time for the Rep items. The repetition effect is perhaps leading to attaining a prioritized WM state.

Previously reported findings based on the bottom-up saliency view (Theeuwes, 1992; Wolfe, 1994) suggests that non-redundant dissimilar item should have gained prioritized access to VWM. However, repeated items are gaining prioritized access in WM due to repetition enhancement-like effect. This further suggests that the visual system deploys a top-down attentional prioritization to encode repeated items dominating over bottom-up saliency signals to ensure an enhanced representation of similar items in VWM (e.g., (Emrich et al., 2017). One probable reason for such attentional facilitation might be implementing some form of chunking strategy in the presence of repeated items (Oberauer, Klaus (2019). This finding implies that similar or repeated items escape the WM limits or capacity. However, an active WM state is achieved even if WM items exceed the average limit of magic numbers with n = 3+/-2 items in WM. Thus, repetition might lead to a default prioritized state due to occupying comparatively more imagined visual space.

Interestingly, attentional prioritization of Rep items does not directly explain poor accuracy and longer RT for the NRep items. The longer RT may indicate a role of interference by

repeated item's internal representation on probe matching task for the NRep items. This requirement in a shift of attention and cognitive control is crucial for suppressing distraction by repeated item representations during priority switching from the default prioritized Rep items to the probe matching for NRep items. However, for probe matching of Rep items, there must be no interference as repeated item representations are already attentionally prioritized, leading to the faster and more accurate recall of items from short-term working memory.

In this study, we have investigated the interference mechanism during switching from the default prioritized WM state using EEG analysis and examining relevant brain oscillations associated with behaviour. ERSP results revealed the role of different frequency bands in differential attentional selection mechanisms and cognitive control required for recalling items in WM states and confirming the probes of either of the two categories.

While repeated items achieve an active state due to default prioritization as elicited by behavioural results, they compromise probe matching of not repeated items. Our findings suggest that revamping the accessory state of not-repeated items requires more top-down control, which was indexed by the change in theta power from frontal-medial sensors. Comparatively increased theta power for recalling and responding to the NRep items implies more cognitive control required for recalling these items. This is in line with previous research showing the crucial role of theta in prioritizing task-relevant information and potentially in suppressing information that is no longer relevant to successfully guide behaviour (de Vries et al., 2018; Riddle et al., 2020). Contrary to that, repeated items do not require much cognitive control and utilize a chunking-like strategy. Theta power is comparatively lower due to the repetition enhancement-like effect as default prioritization of repeated items reduces the effort. Here, we fixed the number of items so that cognitive load or varying working memory capacity does not affect the theta power. Instead, the difference

in theta power during NRep items probe matching appears due to interference of repeated item representations, similar to frontal-medial theta power effects of cognitive interference as suggested by previous finding (Nigbur et al., 2011).

The cognitive control over WM items as reflected in the frontal–medial theta power also drives the alpha oscillations in sensors of posterior parietal cortices. Alpha power mediates attention for selection of relevant information and in this study, difference in frontal alpha power changes as well as right posterior parietal alpha power changes is observed. Active inhibition of non-relevant but distracting representations of repeated item requires its suppression while matching probe for not-repeated condition. This is reflected in increase in alpha power for NRep items in comparison to recalling for repeated items. Along with theta power this indicated more cognitive control in recalling the deprioritised items. Switching of priority from default prioritised items to deprioritised but relevant matching probe for not - repeated items requires increases in alpha power in right parietal cortex. Such increase in Right alpha power was shown by (Benedek et.al., 2014) where they concluded that deactivation of right temporo-parietal junction causing inhibition of ventral attention network which helps in inhibition of orientation of attention towards irrelevant items or information as is required for cognitively demanding task (e.g., mental imagery and idea generation). Interestingly, in our experiment this change in alpha power is possibly present for actively shielding the items from irrelevant representations.

We also noticed significant differences in frontal alpha power while comparing the epochs for probe matching of Rep and NRep items. Frontal alpha oscillations might reflect the origin of top-down control of parietal alpha. As frontal alpha is also related to the perceptual gains (Misselhorn et.al., 2019), its role might be crucial for enhancing the representation of not-repeated items which need to become prioritized while also suppressing irrelevant but attentionally facilitated and prioritized representation of repeated items. This requirement of

perceptual gain might explain the revamping of not-repeated items in the accessory WM state.

Our findings suggest that default prioritization of repeated items can be seen in behavior and their relevant neural correlates. The default prioritization in WM state requires lesser effort due to their attentional facilitation. However, comparative hindrance in matching probes for not-repeated items is explained by increased frontal-medial theta power and alpha power from both frontal and parietal sensors providing substantial evidence for priority switching from default prioritized items to relevant items facing interference by non-relevant representations.

Conflicts of interests

The authors declare no conflicts of interest.

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Figure captions

Figure 1. Each trial begins with the presentation of one of the pseudorandomised memory arrays comprising of total 9 digits out of which three are repeated twice while remaining three are not repeated. After this a delay period occurs followed by probe matching task. 50% times probe matches item in memory array, with equal number of trials with probe of repeated items (Rep) and not repeated items (NRep) while 50 % times probe is for item not present in the array.

Figure 2. Behavioural Results. Panel(a) Each Violin plot shows responses time distribution for each condition (NRep Vs Rep). Each dot represents average response time for one participant. Panel (b) shows Mean percentage accuracy distribution for each condition (NRep Vs Rep) where dot represents average accuracy for one participant.

Figure 3. Fig 3A, B. shows the scalp maps for all averaged over frequency from 8 Hz to 13 Hz separately for each condition for a period of -100 msec to 1000 msec: repeated Probe condition (left), Not-Repeated probe condition (right). Alpha power is relatively higher in the Not repeated probe condition, Figures D, E, and F display ERSP results for all 63 electrodes averaged over frequency ranges from 3Hz to 30 Hz separately for each condition for the temporal window of -100 msec to 1000 msec. Repeated (Rep) Probe condition (left), Not-Repeated (NRep) probe condition (middle), and plot of FDR corrected clusters with the threshold of 0.05 after cluster-based permutation test (right) showing significant difference in ERSP of two conditions.

Figure 4. Frontal–medial theta (FMT) power. Figure (4.1) ERSP plot for Frontal-medial electrodes averaged over frequency from 4 Hz to 7 Hz separately for each condition for a period of -100 msec to 1000 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle), and plot of FDR corrected clusters with threshold over the range reflected on the vertical bar after cluster-based permutation (right) showing significant difference in ERSP of two conditions. Figure (4.2) Scalp maps for all the electrodes averaged over frequency from 5 Hz to 7 Hz separately for each condition for a period of 600 msec to 900 msec: Repeated Probe condition (left), Not-Repeated probe condition (right). Figure (4.3) ERSP plot for Frontal-medial electrodes averaged over frequency from 4 Hz to 7 Hz separately for each condition for 600 msec to 900 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle), and plot of FDR corrected clusters with the threshold of 0.05 after cluster-based permutation (right) showing significant difference in ERSP of two conditions.

Figure 5. Alpha power. Figure (A, B, C) ERSP plot for parietal electrodes averaged over frequency from 8 Hz to 13 Hz separately for each condition for a period of -100 msec to 1000 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle) and plot of FDR corrected clusters with threshold over the range reflected on the vertical bar after cluster-based permutation (right) showing significant difference in ERSP of two conditions.

Figure (D, E) Scalp maps for all the electrodes averaged over frequency from 9 Hz to 13 Hz separately for each condition for 400 msec to 800 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle) and (F) shows plot of FDR corrected clusters with threshold of 0.05 reflected on the vertical bar after cluster-based permutation (right) showing significant difference in ERSP of two conditions.

Figure 6. A, B, and C display ERSP maps for FC1, and (G, H, I) display FCz electrodes averaged over frequency from 8 Hz to 13 Hz separately for each condition from -100 msec to 1000 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle), and plot of FDR corrected clusters with the threshold of 0.05 after cluster-based permutation (right) showing significant difference in ERSP of two conditions. D, E, and F depict topographic maps for parietal and parieto-occipital electrodes averaged over Alpha band frequency ranges from 9 Hz to 13 Hz separately for each condition for 400 msec to 800 msec. Repeated Probe condition (left), Not-Repeated probe condition (middle), and plot of FDR corrected clusters with the threshold of 0.05 after cluster-based permutation (right) showing significant difference in ERSP of two conditions.

Figure 1

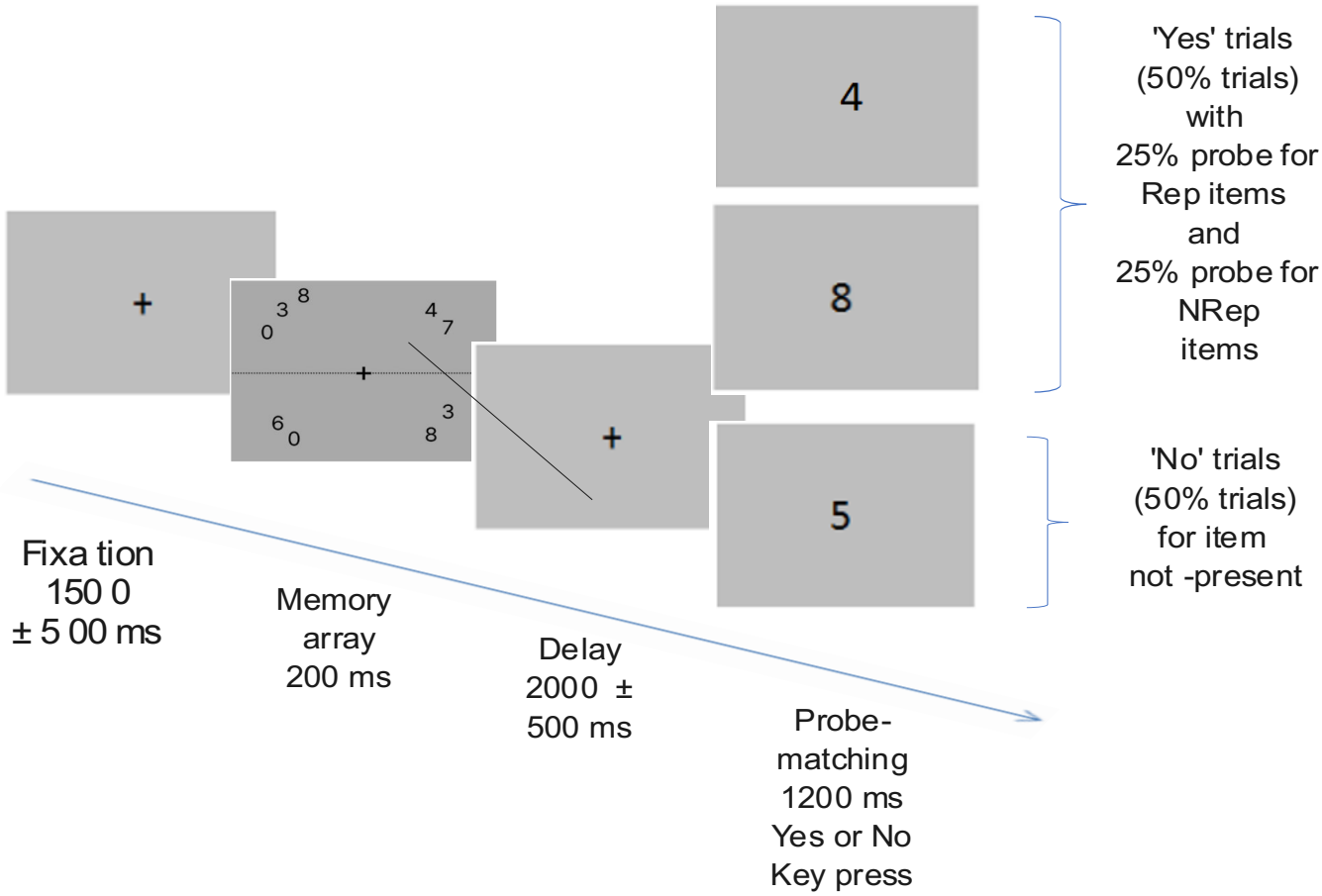


Figure 2A and B

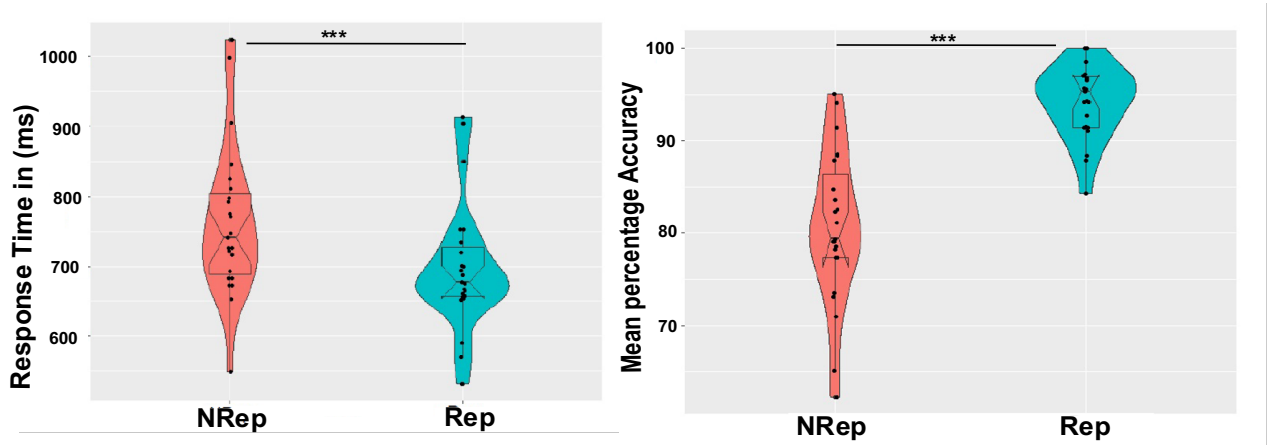
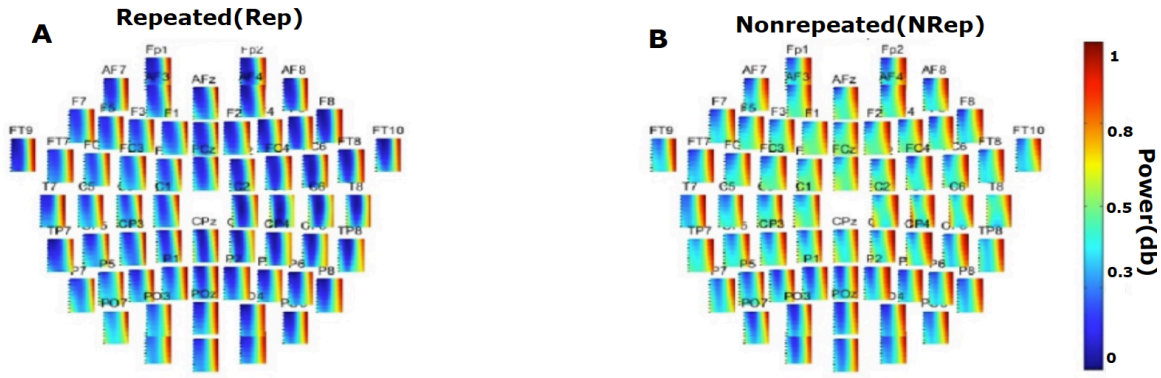


Figure 3.



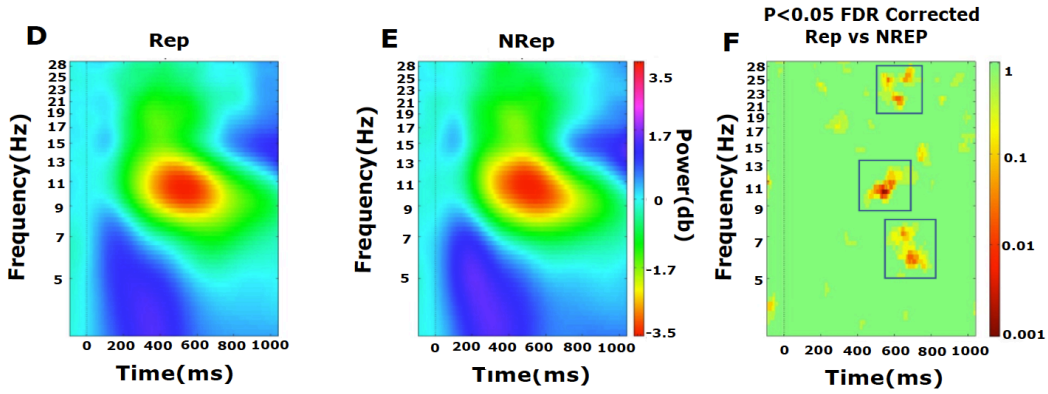


Figure 4

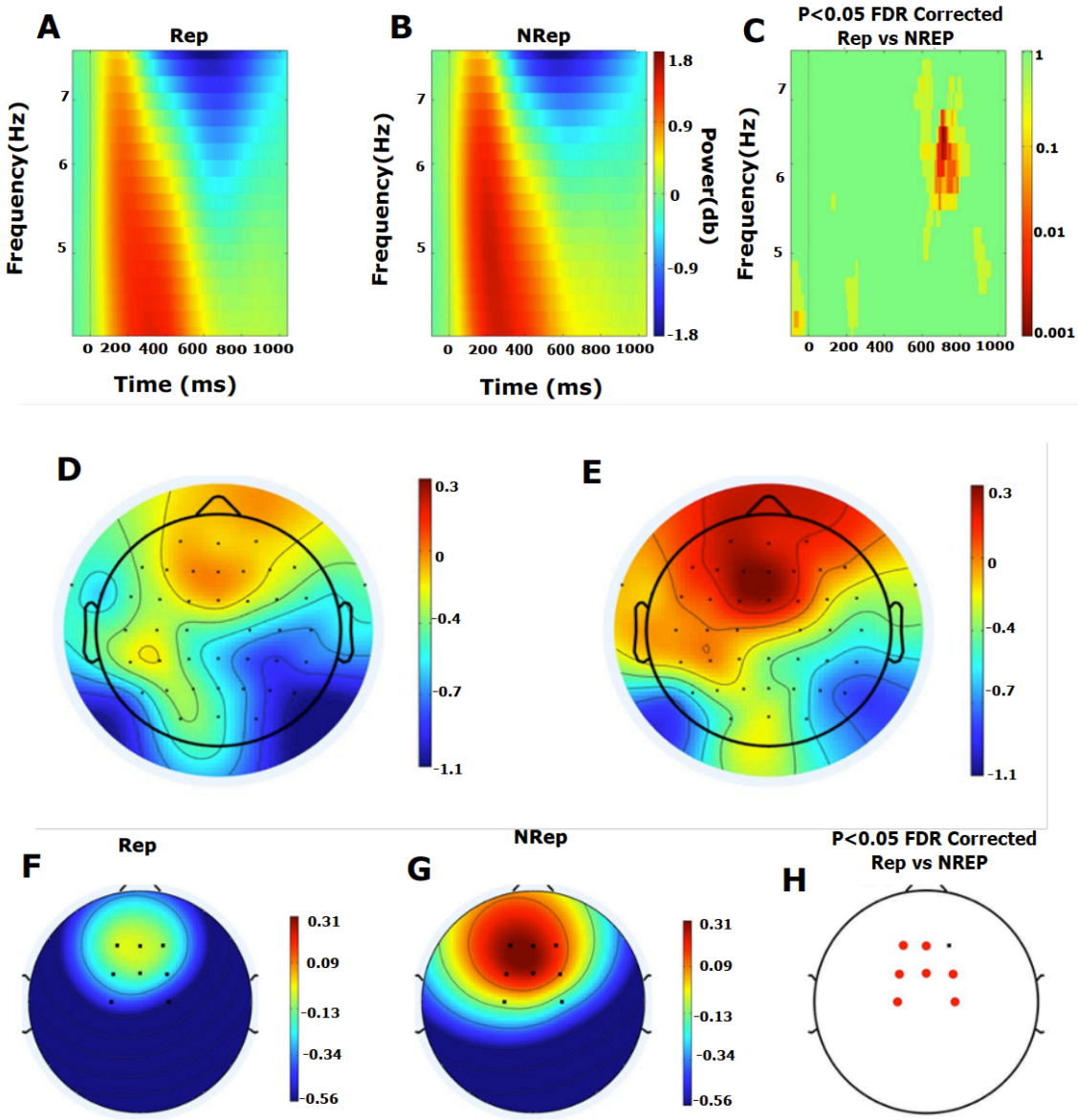

A
Rep
Frequency(Hz)
7
6
5
0 200 400 600 800 1000
Time (ms)
B
NRep
Frequency(Hz)
7
6
5
0 200 400 600 800 1000
Time (ms)
1.8
0.9
0
-0.9
-1.8
Power(db)
C
P<0.05 FDR Corrected
Rep vs NREP
Frequency(Hz)
7
6
5
0 200 400 600 800 1000
1
0.1
0.01
0.001
D
0.3
0
-0.4
-0.7
-1.1
E
0.3
0
-0.4
-0.7
-1.1
F
Rep
0.31
0.09
-0.13
-0.34
-0.56
G
NRep
0.31
0.09
-0.13
-0.34
-0.56
H
P<0.05 FDR Corrected
Rep vs NREP

Figure 5

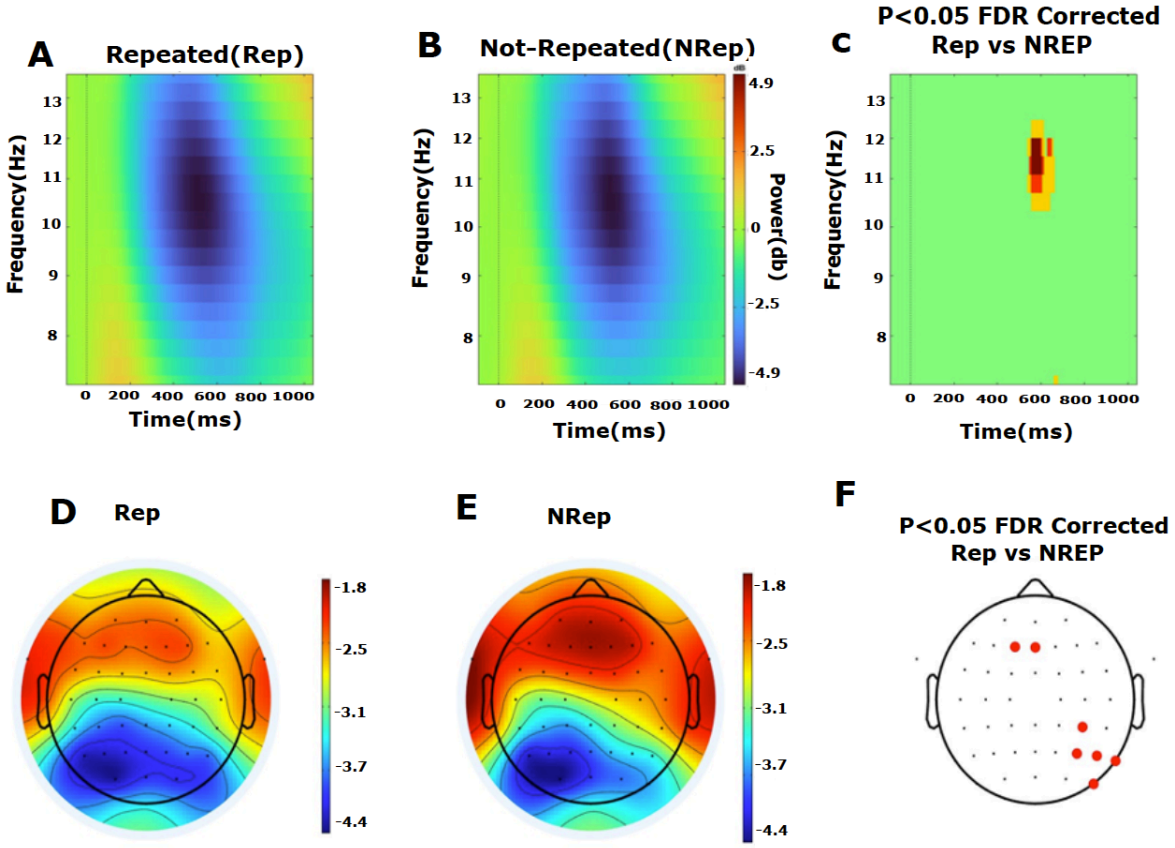
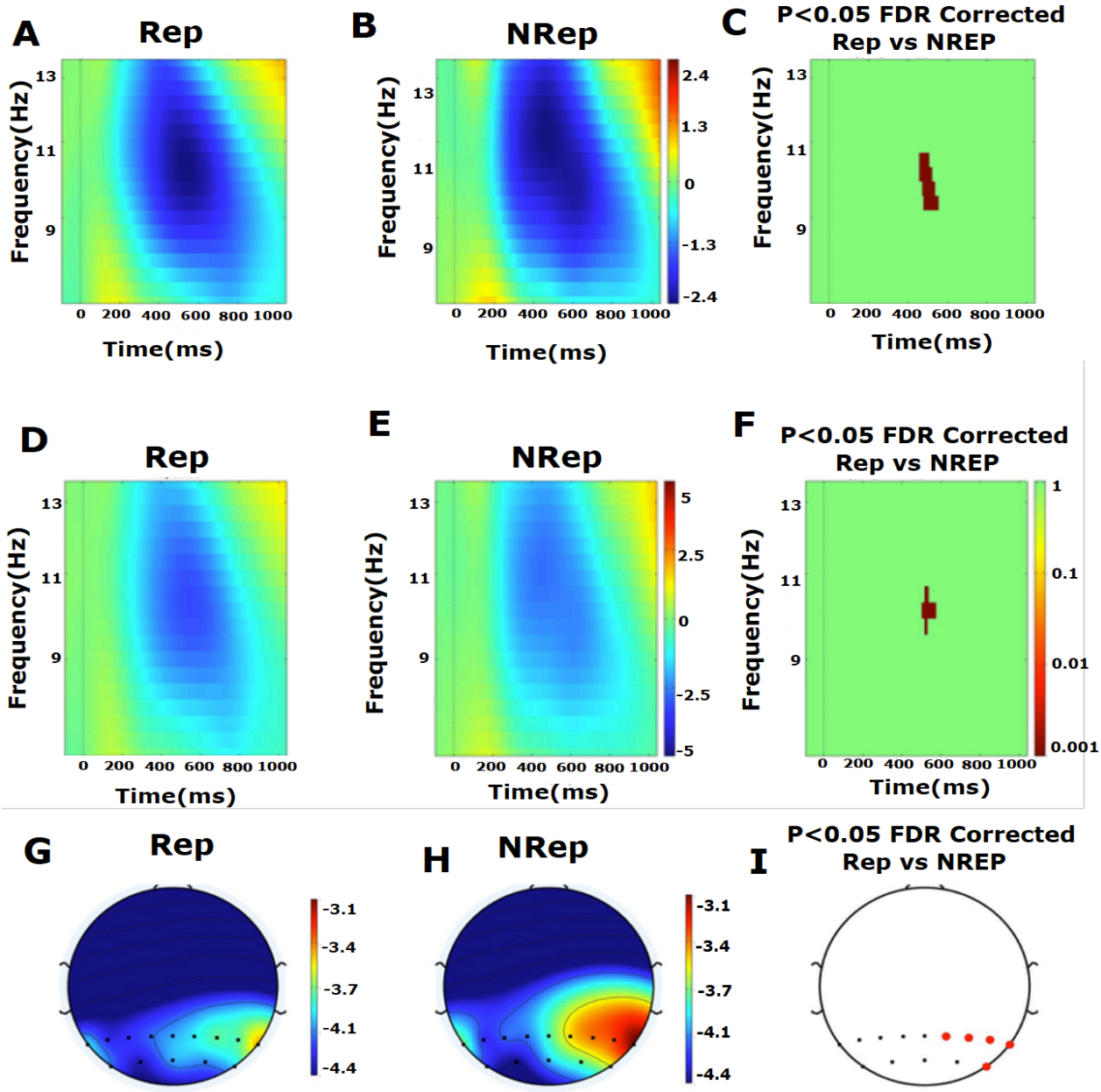

A
Repeated(Rep)
Frequency(Hz)
13
12
11
10
9
8
0 200 400 600 800 1000
Time(ms)
B
Not-Repeated(NRep)
Frequency(Hz)
13
12
11
10
9
8
0 200 400 600 800 1000
Time(ms)
4.9
2.5
0
-2.5
-4.9
Power(db)
C
P<0.05 FDR Corrected
Rep vs NREP
Frequency(Hz)
13
12
11
10
9
8
0 200 400 600 800 1000
Time(ms)
D
Rep
-1.8
-2.5
-3.1
-3.7
-4.4
E
NRep
-1.8
-2.5
-3.1
-3.7
-4.4
F
P<0.05 FDR Corrected
Rep vs NREP

Figure 6



References

1. Benedek et.al. (2014). Alpha power increases in right parietal cortex reflects focused internal attention. *Neuropsychologia*, *56*, 393–400.
2. Constant, M., & Liesefeld, H. R. (2021). Massive effects of saliency on information processing in visual working memory. *Psychological Science4*, *32*(5), 682-691.

3. de Vries, I. E., van Driel, J., Karacaoglu, M., & Olivers, C. N. (2018). Priority switches in visual working memory are supported by frontal delta and posterior alpha interactions. *Cerebral Cortex*, *28*(11), 4090–4104.

4. Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21.

5. Emrich, S. M., Lockhart, H. A., & Al-Aidroos, N. (2017). Attention mediates the flexible allocation of visual working memory resources. *Journal of Experimental Psychology: Human Perception and Performance*, *43*(7), 1454.

6. Erickson et.al. (2019). Alpha-band desynchronization reflects memory-specific processes during visual change detection. *Psychophysiology*, *56*(11), e13442.

7. Ferreira et.al. (2019). Theta oscillations show impaired interference detection inolder adults during selective memory retrieval. *ScientificReports*, *9*(1), 1–11.

8. Griffin, I. C., & Nobre, A. C. (2003). Orienting attention to locations in internal representations. *Journal of Cognitive Neuroscience*, *15*(8), 1176–1194.

9. Hamblin-Frohman, Z., Low, J. X., & Becker, S. I. (2023). Attentional prioritisation and facilitation for similar stimuli in visual working memory. *Psychological Research*, 1–8.

10. Jiang, Y. V., Lee, H. J., Asaad, A., & Remington, R. (2016). Similarity effects in visual working memory. *Psychonomic Bulletin & Review*, *23*, 476–482.

11. Johnson, et.al. (2017). Bidirectional frontoparietal oscillatory systems support working memory. Current Biology, 27(12), 1829-1835. *Current Biology*, *27*(12), 1829–1835.

12. Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, *29*(2), 169–195.

13. Lewis-Peacock, J. A., Drysdale, A. T., Oberauer, K., & Postle, B. R. (2012). Neural evidence for a distinction between short-term memory and the focus of attention. *Journal of Cognitive Neuroscience*, *24*(1), 61–79.

14. Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279–281.

15. Luck, S. J., & Vogel, E. K. (2013). Visual working memory capacity: From psychophysics and neurobiology to individual differences. *Trends in Cognitive Sciences*, *17*(8), 391–400.

16. Makovski, T., Sussman, R., & Jiang, Y. V. (2008). Orienting attention in visual working memory reduces interference from memory probes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(2), 369.

17. Mate, J., & Baqués, J. (2009). Short article: Visual similarity at encoding and retrieval in an item recognition task. *Quarterly Journal of Experimental Psychology*, *62*(7), 1277–1284.

18. McFerren, A. (n.d.). Causal role of frontal-midline theta in cognitive effort: A pilot study. Journal of Neurophysiology, 126(4), 1221-1233. *Journal of Neurophysiology, 126*(4), 1221–1233.

19. Misselhorn et.al. (2019). Frontal and parietal alpha oscillations reflect attentional modulation of cross-modal matching. *Scientific Reports*, *9*(1), 5030.

20. Myers et.al. (2018). Benefits of flexible prioritization in working memory can arise without costs. Journal of Experimental Psychology: Human Perception and Performance, 44(3), 398. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(3), 398.

21. Nigbur, R., Ivanova, G., & Stürmer, B. (2011). Theta power as a marker for cognitive interference. *Clinical Neurophysiology*, *122*(11), 2185–2194.

22. Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(3), 411.

23. Olivers, C. N., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*(7), 327–334.

24. Paneri, S., & Gregoriou, G. G. (2017). *Top-down control of visual attention by the prefrontal cortex. Functional specialization and long-range interactions. Frontiers in neuroscience. 11*, 545.

25. Peters, J. C., Goebel, R., & Roelfsema, P. R. (2009). Remembered but unused: The accessory items in working memory that do not guide attention. *Journal of Cognitive Neuroscience*, *21*(6), 1081–1091.

26. R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

27. Riddle, J., Scimeca, J. M., Cellier, D., Dhanani, S., & D'Esposito, M. (2020). Causal evidence for a role of theta and alpha oscillations in the control of working memory. *Current Biology*, *30*(9), 1748–1754.

28. Sandry, J., Ricker, T. J. (2020). Prioritization within visual working memory reflects a flexible focus of attention. *Attention, Perception, & Psychophysics*, *82*, 2985–3004.

29. Sauseng, et.al. (2005). A shift of visual spatial attention is selectively associated with human EEG alpha activity. *European Journal of Neuroscience*, *22*(11), 2917–2926.

30. Sauseng, P., Griesmayr, B., Freunberger, R., & Klimesch, W. (2010). Control mechanisms in working memory: A possible function of EEG theta oscillations. *Neuroscience & Biobehavioral Reviews*, *34*(7), 1015–1022.

31. Sauseng, P., & Liesefeld, H. R. (2020). Cognitive control: Brain oscillations coordinate human working memory. *Current Biology*, *30*(9), R405–R407.

32. Sims, C. R., Jacobs, R. A., & Knill, D. C. (2012). An ideal observer analysis of visual working memory. *Psychological Review*, *119*(4), 807.

33. Stokes, M. G. (2015). 'Activity-silent'working memory in prefrontal cortex: A dynamic coding framework. *Trends in Cognitive Sciences*, *19*(7), 394–405.

34. The MathWorks Inc. (2022). MATLAB version: 9.13.0 (R2022b), Natick, Massachusetts: The MathWorks Inc. https://www.mathworks.com

35. Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*(6), 599–606.

36. Van Driel, J., Gunseli, E., Meeter, M., & Olivers,. (2017). C. N. Local and interregional alpha EEG dynamics dissociate between memory for search and memory for recognition. , 149, 114-128. *Neuroimage*, *149*, 114–128.

37. van Ede, F., Niklaus, M., & Nobre, A. C. (2017). Temporal expectations guide dynamic prioritization in visual working memory through attenuated α oscillations. *Journal of Neuroscience*, *37*(2), 437–445.

38. Wickham, H. (2011). Ggplot2. *Wiley Interdisciplinary Reviews: Computational Statistics*, *3*(2), 180–185.

39. Wolfe, J. M. (1994). Guided search 2.0 a revised model of visual search. *Psychonomic Bulletin & Review*, *1*, 202–238.

40. Yang, L., & Mo, L. (2017). The effects of similarity on high-level visual working memory processing. *Advances in Cognitive Psychology*, *13*(4), 296.