Flexible reconfiguration of visual working memory across gaze shifts

When walking down a trail, the location and identity of a fleetingly perceived object (e.g., a bird on a branch) can be remembered robustly, even if our gaze shifts away from it. How visual working memory (VWM) remains stable across gaze shifts and, specifically, the type of reference frame in which VWM content is stored, are poorly understood. VWM is typically maintained in the brain hemisphere contralateral to the memorandum [1,2,3,4], indicating a retinotopic ("gaze-centered") reference frame. Yet, recent work [5] shows that VWM is transferred across hemispheres following a gaze shift, suggesting a spatiotopic ("world-centered") reference frame.

Here, we asked whether VWM is stored in spatiotopic coordinates invariably or can be reconfigured flexibly based on task context. Participants (n=24) performed a VWM-based orientation discrimination task while also making horizontal eye-movements (in either direction) during the retention period (Fig. 1a). Electroencephalography (EEG) recordings were acquired concurrently. We tested: i) a "spatiotopic" context in which the test probe appeared at the same world-centered location as the memorandum and ii) a "retinotopic" context in which the test probe appeared at the same gaze-centered location.

Inter-hemispheric transfer of VWM – a shift in memorandum decoding from contralateral to ipsilateral electrodes – occurred in more robustly the spatiotopic relative to the retinotopic contexts ($p=0.022$) (Fig. 1b). In addition, closely mimicking literature [5], inter-hemispheric transfer evoked strong theta (3-6 Hz) and low-beta (12-15 Hz) coherence in the spatiotopic context (Fig. 2a). Finally, VWM precision – the slope of the psychometric curve [6] (Fig. 2b, left) – was higher on trials with a higher transfer magnitude, in the spatiotopic context alone (Fig. 2b, right).

Our findings show that VWM representations can be flexibly reconfigured either spatiotopically or retinotopically, contingent on task demands. More broadly, we uncover neural mechanisms by which gaze shifts interact with VWM in the brain.

Supporting Information

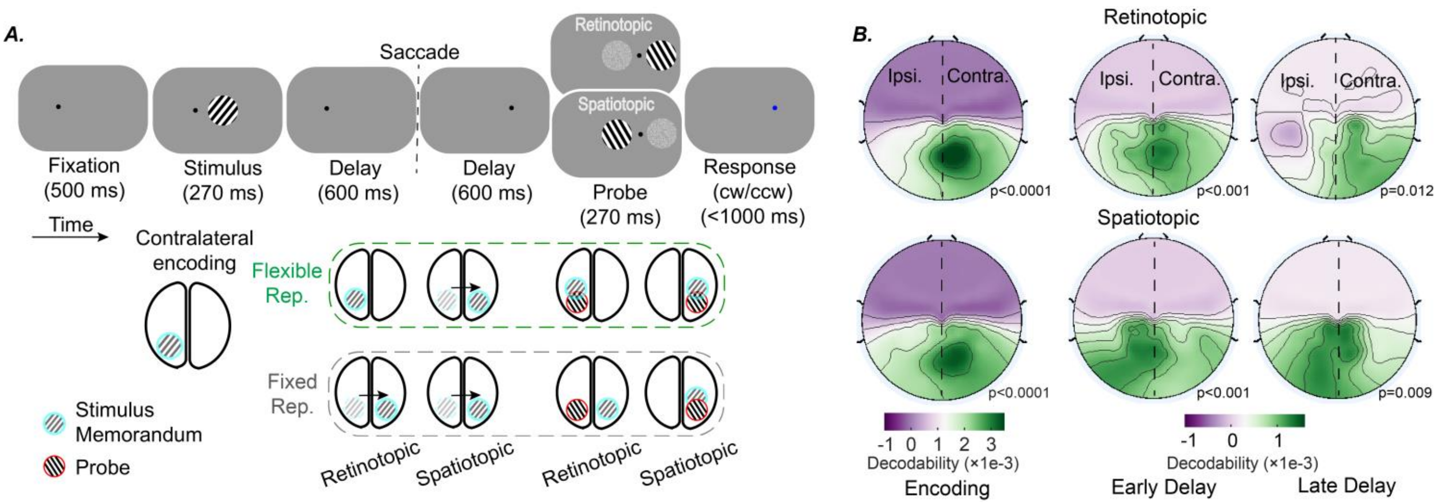

Figure 1. Flexible interhemispheric transfer of visual working memory. A. VWM-based orientation discrimination task. **(Top)** Each trial began with a fixation dot on one side of the screen. After 500 ms, a grating stimulus (memorandum) appeared in the center of the screen (200 ms), followed by a noise mask (70 ms) and a delay period (1200 ms). Midway during the delay, the fixation dot shifted to the other side of the screen, prompting the participant to make a saccade to its new location. Then, a "test" probe grating appeared either at the same retinotopic (gaze-centered) location or at the same spatiotopic (world-centered) location, as that of

initial memorandum. The participant responded with one of two keypresses indicating whether the probe was oriented clockwise or counterclockwise of the memorandum. The order of spatiotopic and retinotopic contexts were blocked (4 x 125 trials), and block order was counterbalanced across trials. **(Bottom)** If VWM was represented invariably, in a spatiotopic reference frame ("fixed rep.", bottom row, gray outline), interhemispheric transfer would occur following a gaze-shift in both the spatiotopic and retinotopic contexts. On the other hand, if VWM was represented in a flexible reference frame ("flexible rep.", top row, green outline) interhemispheric transfer would occur in the spatiotopic context, but not in the retinotopic context. **B.** The memorandum's orientation was decoded from occipital-parietal EEG electrodes, using a Mahalanobis distance-based decoder [6] (average across n=24 participants). (Left) Encoding epoch, (Middle) early VWM delay (soon after memorandum offset) and (Right) late VWM delay (soon before saccade onset). The color-bar indicates the magnitude of decodability. Right and Left sides of each "topoplot" represent contralateral and ipsilateral electrodes with respect to the memorandum, respectively. In the retinotopic condition (top row) the decodability is largely limited to contralateral electrodes across all phases, whereas in the spatiotopic condition (bottom row) the decodability clearly shifts from contralateral to ipsilateral electrodes during early and late delay phases.

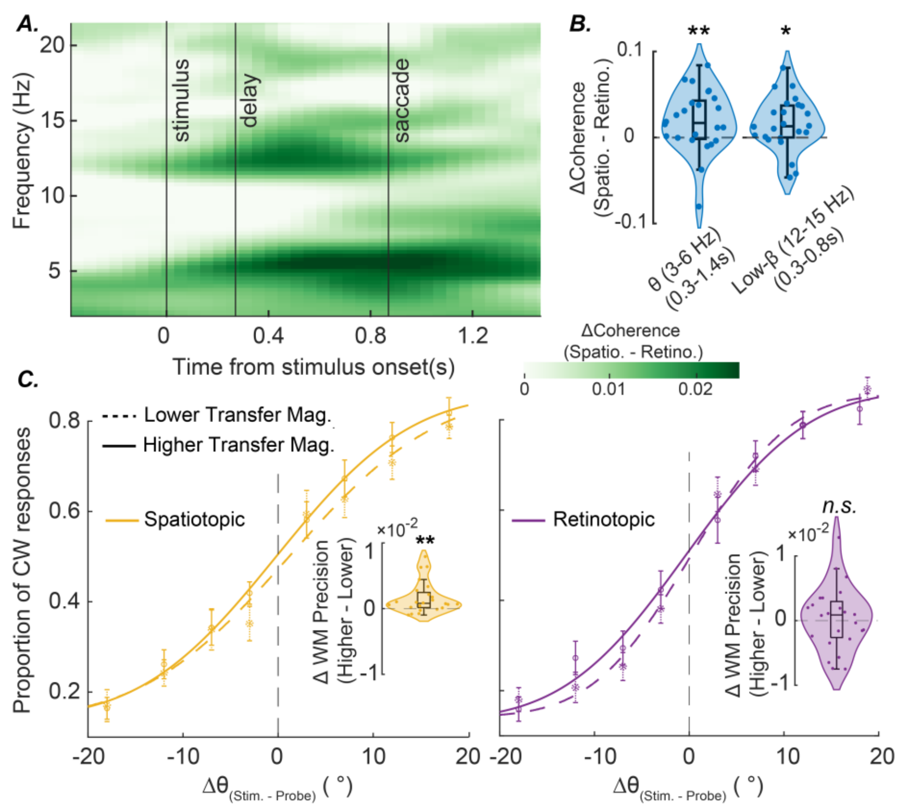

Figure 2. Neural signatures of VWM transfer predict behavior. A. Time-frequency representation of interhemispheric coherence (occipito-parietal electrodes), shown as a difference between the spatiotopic and retinotopic contexts. **B.** Differential coherence in theta and low-beta bands during the delay. Coherence in theta (3-6 Hz) band was significantly higher in the spatiotopic compared to the retinotopic context. **C**. Psychometric function showing the proportion of clockwise (CW) responses plotted against change angle difference between memorandum and probe orientation. Solid and dashed lines: Trials with the highest and lowest magnitude of interhemispheric VWM transfer (Ipsilateral – Contralateral decoding; median split), respectively, in the late VWM delay phase. Inset: Difference in VWM precision quantified from the slope of the respective psychometric function [6]. Left, yellow: spatiotopic context; Right, purple: retinotopic context. (conventions: *: $p<0.05$, ** $p<0.01$, n.s.: not significant)

References

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