Sensory modality and information domain modulate behavioral and neural signatures of working memory interference

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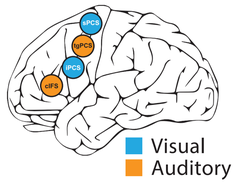
Summary

- Recent fMRI studies have uncovered a series of sensory-biased regions in the lateral frontal cortex (LFC), active during attention and working memory tasks.[1,2]
- LFC regions can be recruited by stimuli in their non-preferred modality depending on task domain:
  - Auditory-*spatial* tasks recruit the visual-biased regions.
  - Visual-*temporal* tasks recruit the auditory-biased regions.



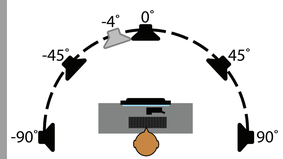
Hypothesis: If new information must be processed during WM retention, the amount that this information interferes wtih the WM trace will depend on both its sensory modality and its domain (spatial vs. temporal).

Approach: Dual-task paradigm, with working memory (WM) and interfering (INT) tasks

Main Findings

- Behavioral performance, pupil dilations, and event-related potential (ERP) amplitudes indicated that WM interference was greatest when the WM and INT tasks matched in both sensory modality and domain.
- Neural oscillations largely reflected whether an INT task was present, rather than specific WM interference patterns.

Methods



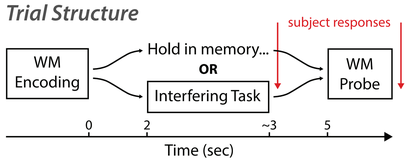
Experimental Setup

- 6 free-field loudspeakers, 1.5m distance
- 27" display for visual stimuli
- EyeLink 100 Pro eyetracker
- 64-channel EEG

Participants

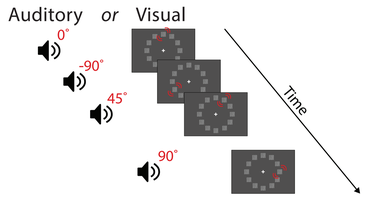
- N = 20 (11F); mean age 20.9 years
- All had clinically normal hearing and vision.

Trial Structure



WM Task

- Derived from fMRI localizers for LFC networks.
- Encoding: Remember *spatial locations (S)* or *timing (T)* of a sequence of 4 stimuli.
- Stimuli could be auditory (A) or visual (V).
- Make a same-different judgment on a Probe sequence in the same sensory modality.



Sample WM Encoding or Probe sequence

Interfering (INT) Task

- Always auditory; could be temporal or spatial.
- 3 stimuli presented from speakers at 0° (right) and -4° (left; reserved for the INT task).
- Played either L-R-L or R-L-R.
- One interstimulus interval was slightly longer, by an average of 90ms.
- Temporal task: Which interval was longer?
- Spatial task: Was middle stimulus to the L or R?

Stimulus and Experiment Details

Auditory WM Task
- 50 ms harmonic tone complexes
- 5 possible locations: ±90°, ±45°, 0°
- 2 possible intervals: 200 or 340 ms

Visual WM Task
- "Noise" patches: white/black pixel assignment re-randomized to generate stimulus
- 12 possible locations in a circle around fixation
- 2 possible intervals: 200 or 580 ms

Experiment Structure
- 40 trials per WM modality * WM domain * INT task
- Blocking: 20 trials of same modality, domain, and INT
- Visual and Auditory WM tasks done on separate days.

Data Analysis

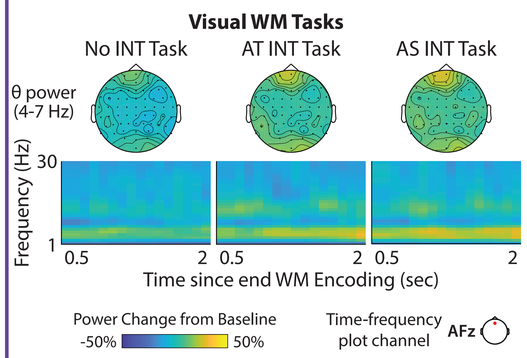
Behavioral Data
- Within-subjects ANOVAs, followed by Bonferroni-corrected Tukey's HSD post-hoc testing

Pupillometry Analysis
- Blinks linearly interpolated; traces Z-scored
- Permutation testing: Shuffle condition labels 2000 times to construct null distribution; p-values reflect position of actual difference within this distribution.

EEG Analysis
- ERP statistics: cluster-based permutation tests
- Time-frequency decomposition with wavelet transform
- Power calculated in frequency bands of interest
- Cluster tests performed on these power time courses

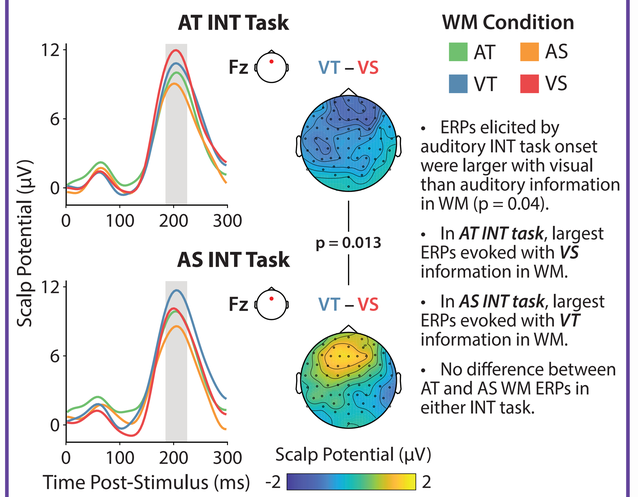
Behavior, Pupillometry, and EEG Results

In visual WM conditions, an upcoming INT task caused increased frontal theta (4-7 Hz) power.



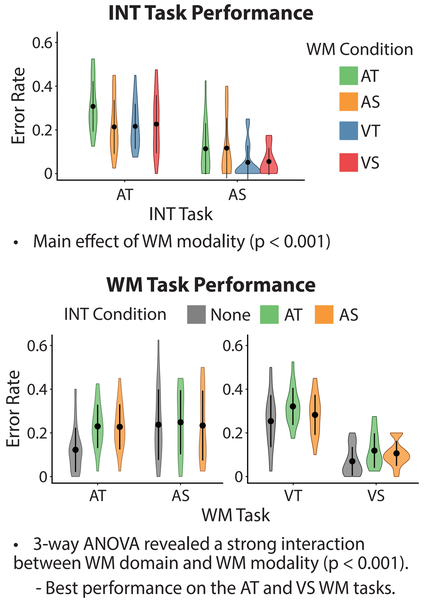
- Data are shown avered across spatial and temporal visual WM (no effect on theta activity).
- Theta elevation was significant for both AT (p = 0.002) and AS (p < 0.001) INT tasks.
- No difference between AT and AS INT tasks.

ERPs elicited by the INT task were largest when dissimilar information was being held in WM.



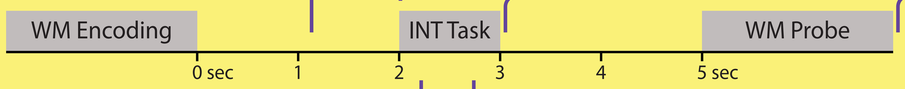
- ERPs elicited by auditory INT task onset were larger with visual than auditory information in WM (p = 0.04).
- In ***AT INT task***, largest ERPs evoked with ***VS*** information in WM.
- In ***AS INT task***, largest ERPs evoked with ***VT*** information in WM.
- No difference between AT and AS WM ERPs in either INT task.

INT task performance was impaired by a modality match with the WM task.

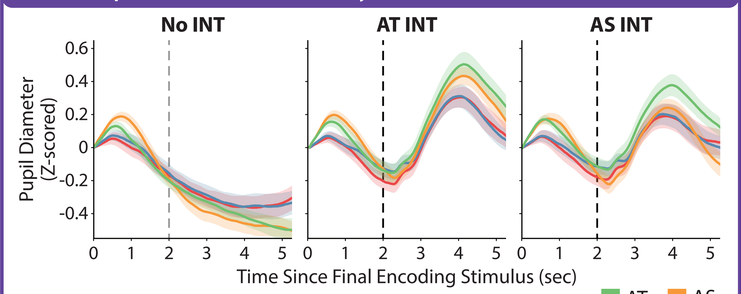


- Main effect of WM modality (p < 0.001)
- 3-way ANOVA revealed a strong interaction between WM domain and WM modality (p < 0.001).
  - Best performance on the AT and VS WM tasks.
- Main effect of INT task (p < 0.001) indicates INT tasks generally impaired WM performance.

Trial Timeline

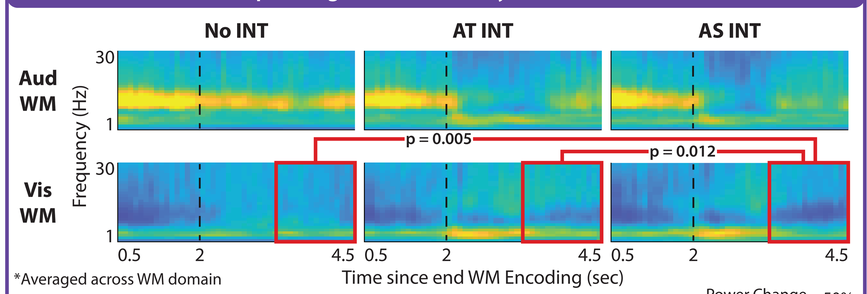


Pupil diameter during memory retention reflected patterns of both modality and domain interference.



- Task-evoked pupil dilations associated with increased cognitive load, effort, or arousal.[3]
- Large dilations in response to both INT tasks.
- INT tasks (auditory) elicited larger dilations in auditory WM conditions than visual (p < 0.001).
- AS INT: Larger dilations with AT WM information than AS WM (p < 0.01).
  - Likely reflects temporal bias of auditory LFC network.

Posterior alpha (8-13 Hz) power during memory retention differed depending on WM modality and INT task.



*Averaged across WM domain

Auditory WM
- Alpha power elevated re. baseline during WM encoding and retention.
- INT tasks immediately halted ongoing alpha oscillations.

Visual WM
- Alpha power initially suppressed, then returned to baseline during WM retention.
- Alpha suppression returns after the AS INT task – possible signature of interference with the visual/spatial-biased LFC network.

References

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[2] Noyce, A.L., Cestero, N., Michalka, S., Shinn-Cunningham, B.G., and Somers, D.C. (2017). Sensory-biased and multiple-demand processing in human lateral frontal cortex. J. Neurosci. *37*(36), 8755-8766.
[3] Sirois, S. and Brisson, J. (2014). Pupillometry. WIREs Cogn. Sci. *5*, 679-692.

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