Multimodal imaging of auditory working memory for tones

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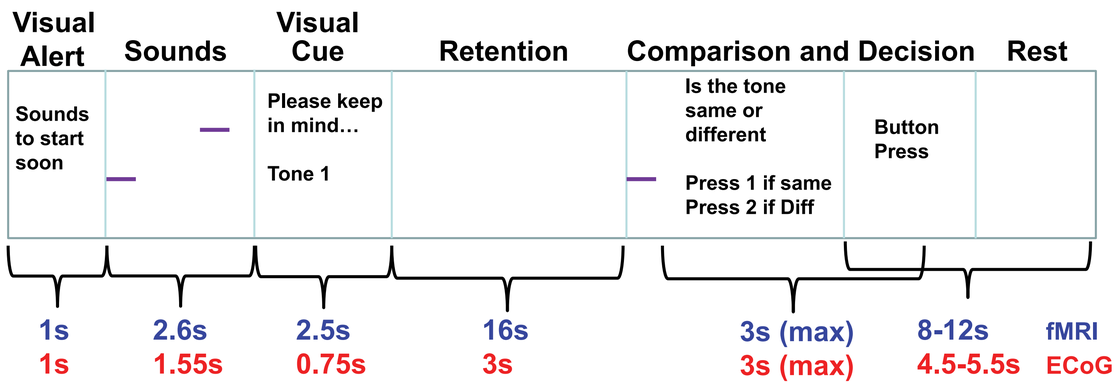
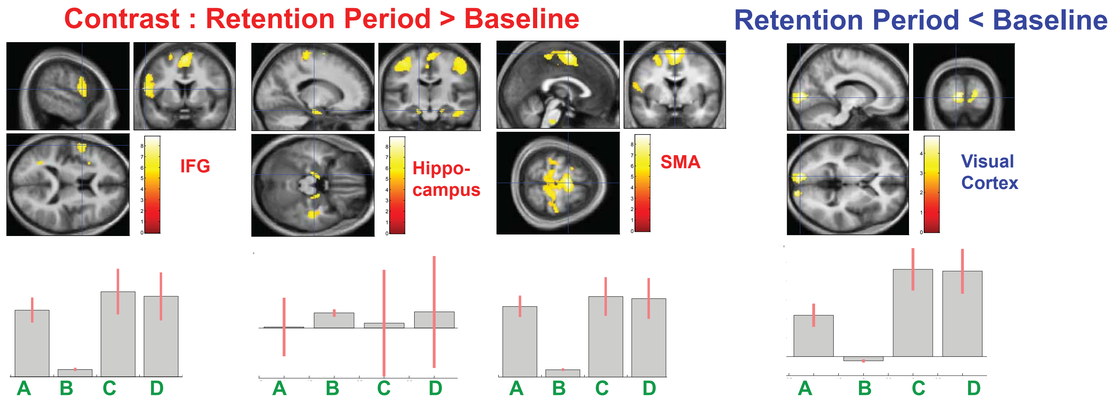
1 Introduction/Methods

- Neural substrates of auditory working memory for auditory stimuli that are not speech or music are not completely understood.
- We measured BOLD signal (17 subjects) and recorded LFPs (ECoG, 3 subjects) during auditory memory for pure tones.

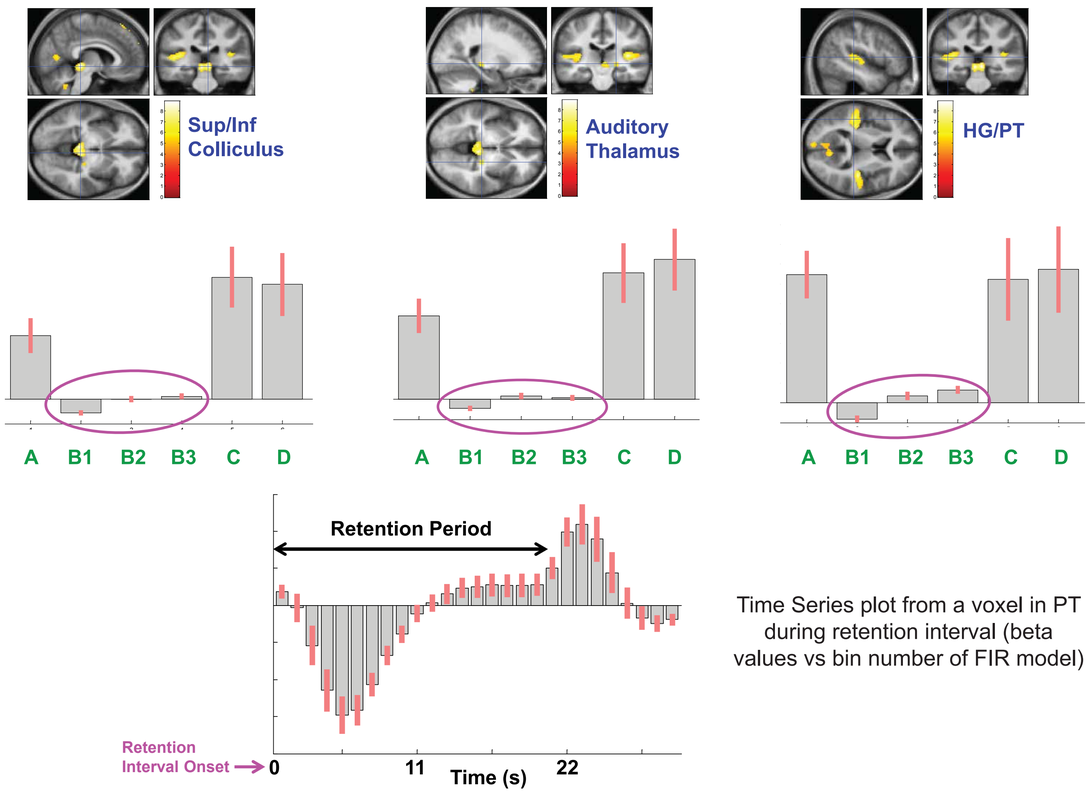


2 GLM Analysis (fMRI)

- All trials together; Modelled the whole retention period (18.5s); Random effects analysis; $p < 0.05$ (FWE, whole brain); Regressors (4):
  SoundEnc (A) Retention (B) LowToneRecall (C) HighToneRecall (D)



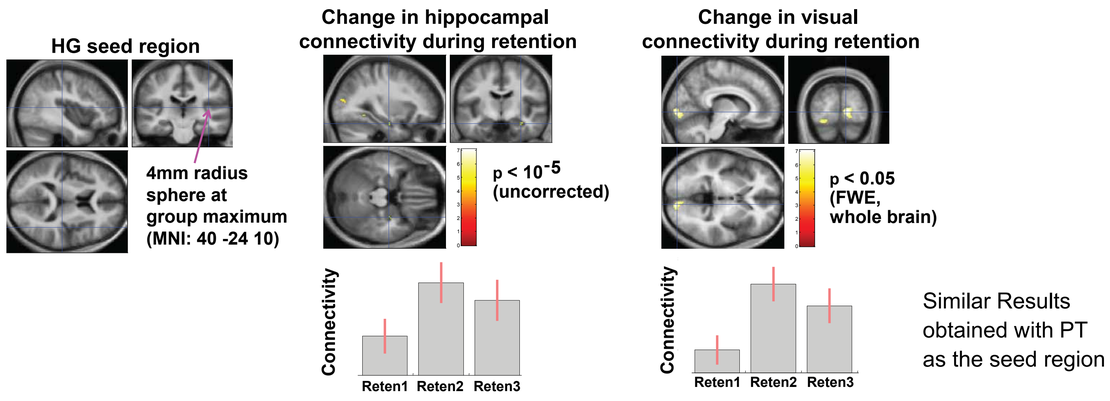
- No auditory cortex activation observed when whole retention period is modelled.
- Retention period broken into three parts (6.17s each): Reten1, 2, 3.
- Auditory cortex (HG and PT) changed from negative to positive from Reten1 to Reten2 and stayed positive for Reten3.



Time Series plot from a voxel in PT during retention interval (beta values vs bin number of FIR model)

3 Psychophysiological Interactions PPI (fMRI)

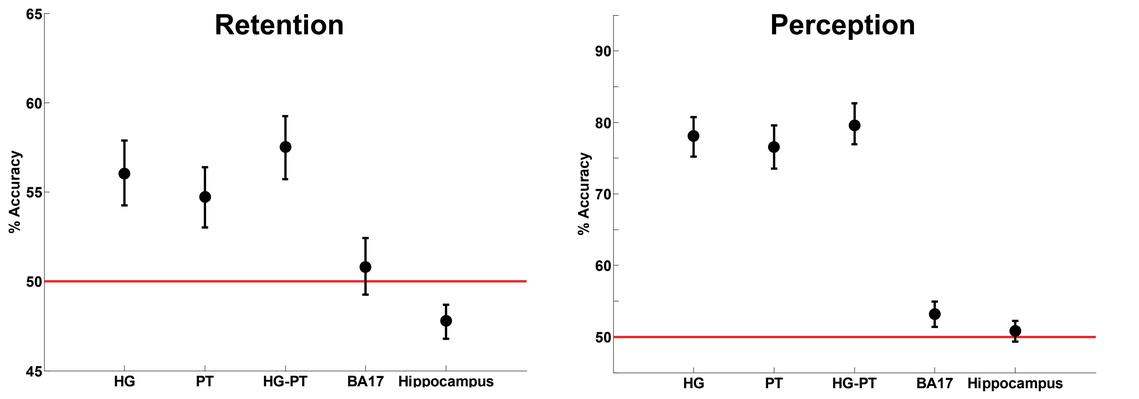
- Using PPI we determined if connectivity of auditory cortex changes from Reten1 to Reten3. In two separate PPI analyses we chose HG and PT as seed regions.



Similar Results obtained with PT as the seed region

4 Multivariate Pattern Analysis (MVPA, fMRI)

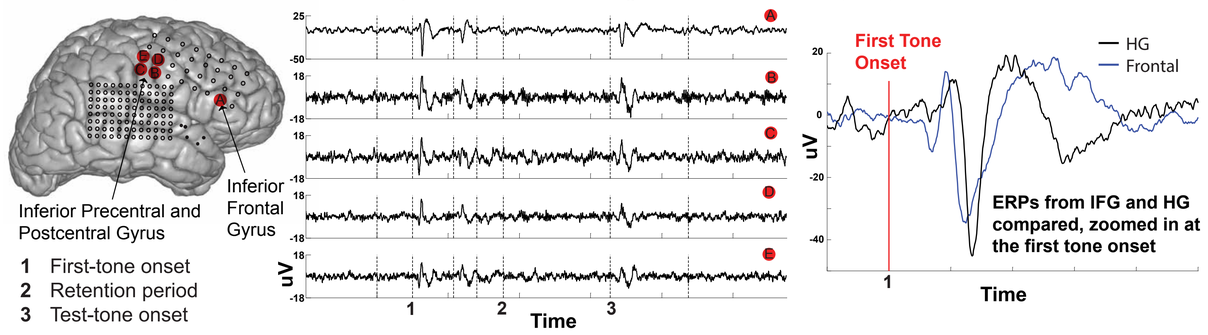
- Using GLM analyses we did not find significant differences in activity in any part of the brain during retention of low and high tones.
- We applied MVPA to check if patterns of BOLD activity could be used to decode which tone (low or high) is held in mind. A separate classifier was also trained and tested during perception of low and high tones (Recall period).
- Linear support vector machine; leave one session out; anatomically defined ROIs; classification based on T-images generated using SPM.
- Significant classifier performance during retention in HG and PT.



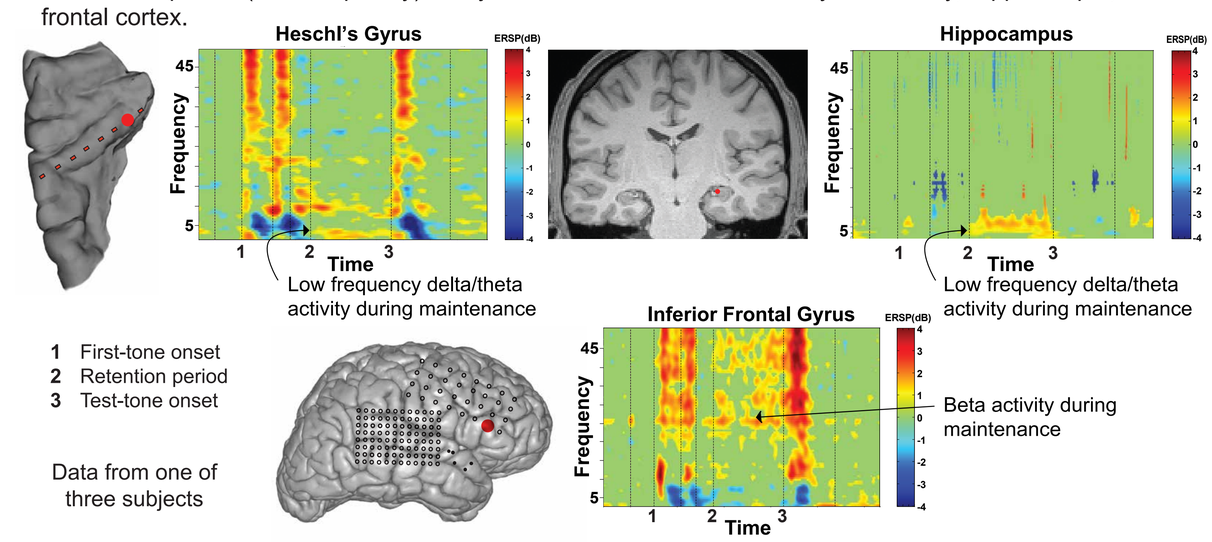
5 Intracranial Recordings (LFPs)

Time-locked (ERP) analysis shows evoked potentials to tones in auditory and frontal cortex.

- We recorded LFPs from three human subjects; paradigm similar to that run using fMRI (see Figure 1). Data for one subject is shown.
- High impedance HG electrodes (70 - 300 kΩ) and low impedance pial electrodes (clinical).
- Recording sites : HG; Temporal grid; Hippocampus; Frontal grid.
- ERP analysis : LFPs downsampled to 500Hz, averaged across all trials (160).



Induced-response (time-frequency) analysis shows maintenance activity in auditory, hippocampal, and frontal cortex.



6 Conclusions

fMRI Study

- Changing BOLD activity was observed in the auditory cortex (HG/PT) during the retention period. This changed from negative to positive during the retention period.
- While the GLM analysis showed no difference in BOLD activity for retention of low and high tones, using multivariate analyses it was possible to decode, from patterns of activity in HG and PT, which tone was held in mind. These structures, therefore, encode specific information about tone identity.
- Sustained BOLD activity occurred throughout the maintenance period in IFG, HC, and SMA. While involvement of IFG (Zatorre et al, 1994) and SMA (Strand et al, 2008) has been shown previously, we are not aware of any prior studies showing a role for hippocampus in auditory WM. The results are in accord with visual studies suggesting a role for HC during WM in the binding of sensory features.
- Connectivity analyses based on BOLD data showed functional connectivity between auditory cortex and hippocampus (and also visual areas).

Intracranial recording Study

- We observed sustained delta and theta band (2-6 Hz) activity in HG during the retention period. The relationship between oscillatory activity and the BOLD signal is not straightforward: low frequencies (up to 20 Hz) correlate negatively; higher frequency bands (above 20 Hz) correlate positively (Mukamel et al, 2005). The theta band activity observed in intracranial recordings is consistent with suppression of BOLD activity during the first part of the maintenance period.
- The involvement of hippocampus in auditory WM is further confirmed by induced LFP activity. Low-frequency sustained theta oscillatory activity (5-8 Hz) during the maintenance period is observed.
- We also observe beta activity during retention in IFG.

Overall Conclusion

- The data support the existence of a system for tone working memory involving auditory cortex, hippocampus and frontal cortex.
- Ongoing systems modelling of both BOLD and electrical data is examining the effective connectivity between these regions in order to define the system.

References

Mukamel et al (2005). Science, 309:951-954.
Strand et al (2008). Brain Research, 1212:48-54.
Zatorre et al (1994). Journal of Neuroscience, 14:1908-1919.

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