

Introduction

- Understanding speech in complex and demanding listening environments can require significant effort and attention.
- Functional imaging studies demonstrate anterior and posterior temporal lobe regions that are responsive to intelligible speech (Davis & Johnsrude, 2003; Scott et al. 2006).
- Anterior cingulate (ACC), middle frontal gyrus (MFG), and inferior frontal gyrus (IFG) activation is observed during attention-related tasks, particularly tasks requiring subjects to ignore conflicting information to make an appropriate behavioral response (conflict monitoring and response inhibition) (Fan et al., 2003; Durston et al. 2005).
- The role of attention-related frontal lobe cortex for understanding speech in complex and demanding listening conditions is poorly understood (Boatman, 2006). This study tested the hypothesis that medial frontal cortex is increasingly responsive to increasingly degraded speech and determined the extent to which frontal and temporal systems interact under these conditions.

Methods

Participants

- 12 right-handed adults (5 females, 7 males) with normal hearing.
 - Edinburgh handedness = 93.8 +/- 9.6; Mean age = 34.8 +/- 12.6 years.

Functional Imaging

- Acquired with the MUSC Phillips 3T scanner.
 - Sparse sampling; TR 8000 ms; TE 30 ms; TA 1647 ms, providing 6353 ms of silence for stimulus presentation (2500 ms) and subject response.
 - 36 3.25 mm thick slices with no gap.
- Word recognition experiment
 - 40 monosyllabic CVC nouns with a normal distribution of lexical difficulty (Dirks et al. 2001).
 - Each word was low pass filtered at 3150, 1600, 1000, and 400 Hz to parametrically modulate word intelligibility (Figure 1).
- Words were presented (75 dB SPL) through electrostatic earphones (Sensimetrics Corp) with background noise (65 dB SPL) spectrally shaped to equate audibility.
- In a separate experiment designed to engage frontal attention networks, subjects performed a visual conflict monitoring task requiring them to button press to indicate the direction of the middle arrow head when flanking arrowheads were oriented in consistent (>>>>) or conflicting (>><< <<>>) directions.
 - Performance: consistent = 97%; conflicting = 90%.
 - Reaction time: consistent = 768 ms; conflicting = 927 ms.

Statistical Analyses

- Word Recognition:** first level analyses identified regions parametrically responsive to decreasing word intelligibility in each participant (Figure 2). Second level group t-tests were performed to identify regions across subjects that were responsive to decreasing word intelligibility (peak voxel of $p < .01$ and a cluster extent of $p < .01$) (Figure 3).
- Visual Attention Task:** first level analyses identified regions exhibiting increased activation for conflicting stimuli (><<<) vs. consistent stimuli (>>>>). Second level group analyses similar to the word recognition analysis (Figure 3).
- Functional Connectivity (fcMRI):** the average time series from anterior cingulate and inferior frontal regions were included in a multiple regression to identify brain regions exhibiting coupled activity with the ACC or IFG independently of global changes in gray matter, white matter, and CSF signal (Figures 4 and 5).

Results

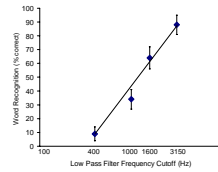


Figure 1. Word recognition varies as a function of frequency cutoff. Subjects repeated the word correctly, produced an incorrect word, or said "nope" if they could not provide a response.

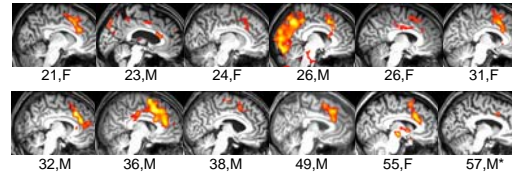


Figure 2. Individual subject results demonstrating increasing ACC and paracaudate activity with decreasing word intelligibility ($p < .05$). *The 57-year-old male's response was best estimated with a quadratic function.

Results (cont.)

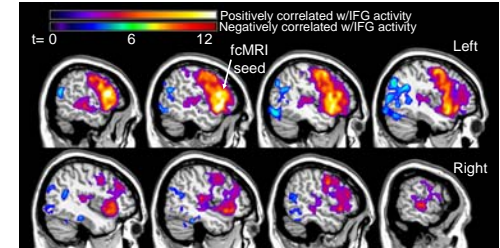


Figure 5. fcMRI results showing regions correlated with the left IFG cluster (Figure 4) during the word recognition experiment.

Positively coupled activity

Left IFG -> ACC; MFG; left and right temporal cortex, including the STS

Negatively coupled activity

Left IFG -> Occipital; occipito-temporal parietal junction; and inferior temporal cortex.

Discussion

- Frontal lobe regions exhibited increased activity when speech was difficult to understand.
- These frontal regions largely overlapped with cortex that was engaged during a visual attention task.
 - Cortex in the cingulate sulcus, right middle frontal gyrus, and right inferior frontal gyrus was particularly engaged during the word recognition and visual attention tasks.
- Cingulate cortex appears to interact with lateral inferior frontal cortex during demanding listening conditions (Figure 4), through which auditory cortex can be engaged (Figure 5).
 - These observations are consistent with evidence that ACC responds to conditions requiring cognitive control and engages MFG and IFG regions to select an appropriate response (Badre and Wagner, 2004).
- Future work will determine whether this frontal-temporal system is affected by age and thereby limits the speech recognition of older adults in complex and demanding listening conditions.

Acknowledgements

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