Semantic memory in the anterior temporal lobes: A new distortion correction method for fMRI

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Introduction

Semantic memory refers to our mental representations of the meanings of words, objects, people and general information about the world. The neural substrate of semantic memory is a topic of considerable debate. Semantic dementia results from bilateral anterior temporal lobe atrophy (ATL) and gives rise to a highly specific impairment of semantic memory, suggesting that this region is the critical neural substrate for semantic processing (see Figure 1) [1, 2]. However, neuroimaging studies have not consistently found ATL activation in semantic tasks [3]. The functional magnetic resonance imaging (fMRI) signal acquired using gradient echo EPI is vulnerable to distortion and drop-out caused by variation in magnetic susceptibility in the brain, especially in areas near bone or air-filled cavities, such as the ATL. This susceptibility artefact was highlighted in [3]; their study repeated a semantic task using fMRI and Positron Emission Tomography (PET). PET is not vulnerable to the susceptibility artefact and revealed ATL activation, whereas, fMRI did not. However, the PET methodology has some important limitations; it is invasive, has less power and poorer spatial resolution than fMRI and is restricted to a blocked design with relative long trial times. It is therefore essential to develop fMRI methods that can overcome the distortion affecting the ATL. We conducted an fMRI study on semantic memory using a new distortion correction method applied to spin echo EPI [4], based on a gradient reversal technique of [5].

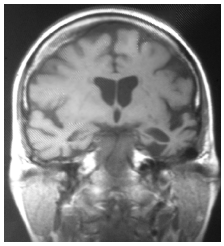

Figure 1: Bilateral atrophy in the anterior temporal lobes in a patient with semantic dementia

Experimental procedure

Twelve participants (right-handed, mean age = 32, SD = 6.8) were tested on the verbal semantic categorization task used by [3]. Two subjects were excluded due to technical problems. Three words drawn from one semantic category were presented every 600ms. Participants indicated with a button press if a fourth word was from the same category or not. In a control task, participants saw three letter strings and then indicated if a fourth letter string was the same letter identity or not. The study used a blocked design, and included 8 semantic blocks and 8 control blocks.

Image acquisition

Functional images were acquired on a 3T Phillips Achieva scanner (Phillips Medical Systems, Best, NL) using an 8 element SENSE head coil with a sense factor of 2.5 and phase encoding in the left-right orientation. A 30 slice, single shot, spin echo EPI sequence was used (TE = 75ms, TR = 3200ms, 112 x 112 matrix, reconstructed resolution 1.875, and slice thickness 4.2mm). The fMRI sequence consisted of a 10 dynamic pre-scan with interleaved reversed direction phase encoding and the subject at rest. An in-house algorithm was used to register image pairs to sub-voxel accuracy in the frequency encoding direction [4]. The images of the pre-scan were corrected and a map of pixel displacement was produced showing the difference between the distorted images and the corrected images. This was followed by the main dynamic sequence of 160 time points with a single phase encoding direction whilst the participants performed the cognitive tasks. The pixel displacement map was than used to correct the distorted data.

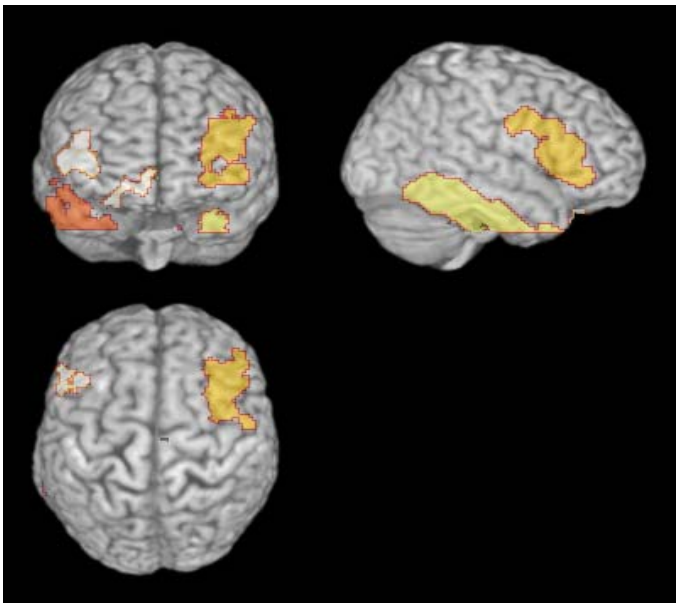

Figure 2: Results of the semantic task contrasted with the control task

Data analyses

Analysis was carried out using FEAT version 5.63 (FMRI Expert Analysis Tool), which is part of the FSL analysis package (www.fmrib.ox.ac.uk/fsl). Pre-processing included motion correction, slice time correction, spatial smoothing (8mm FWHM) and high pass temporal filtering. Multi-subject analysis was carried out using a fixed effects model. Z (Gaussianised T/F) statistic images were thresholded using clusters determined by Z>2.3 and a (corrected) cluster significance threshold of P=0.05 [6]

Results

When the semantic task was contrasted with the control task, the distortion correction revealed bilateral temporal activation extending from the inferior temporal lobe along the fusiform gyrus to anterior temporal regions, bilaterally. There was also bilateral inferior and middle prefrontal activation (see Figure 2).

Discussion

The results indicate that the bilateral ATL is involved in semantic memory, providing convergence with evidence from patients with semantic dementia. The frontal activation that we observed is in line with previous studies which have suggested a role for this region in the executive control of semantic processing [7, 8]. Importantly, the new distortion correction applied to spin echo EPI is able to overcome the susceptibility-induced signal losses and geometric distortions, making it possible to investigate the semantic function of the ATL using fMRI.

References

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