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LANGUAGE

Event-related fMRI reveals distinct patterns of neural modulation during semantic and syntactic processing of sentences

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Introduction:

Semantics (the meaning of words and sentences) and syntax (how words are combined together to form grammatical sentences) have different rules and representations and are generally acknowledged to be independent of one another [1]. A fundamental question is whether this distinction is respected as language is processed in the brain. Some evidence for such a neurophysiological dissociation comes from electrophysiological studies that have revealed distinct event-related potential (ERP) components to semantic [2] and syntactic [3-5] anomalies in sentences. We have used event-related fMRI to determine which neural networks are modulated during the presentation of normal sentences (e.g. *My parents couldn't sleep because the baby would cry),* pragmatically/semantically-anomalous sentences (e.g. *My parents couldn't sleep because the baby would phone),* and syntactically-anomalous sentences (e.g. *My parents couldn't sleep because the baby would cries),* within the specific time-window corresponding to when the anomaly was presented. In a parallel electrophysiological study, the same linguistic stimuli, presented in the same randomized sequence, in the same subjects revealed distinct ERP effects to semantically-violated verbs (an N400 effect) and syntactically-violated verbs (a P600 effect).

Methods:

During eight four-minute functional runs (T2*-weighted EP images; 24 slice, 4 mm skip 1 mm; TR 3s; TE 70 ms), fourteen healthy right-handed volunteers read sentences, presented word-by-word (300ms, 100ms ISI). At the end of each ten-word (4s) sentence, they judged whether or not the sentence made sense within the remaining 2s of the trial. The three types of sentence and visual fixation trials were presented in a pseudo-random counterbalanced sequence. In all anomalous sentences, the anomaly fell after the fifth word of the sentence, and in 50% cases it fell on the final word. High-resolution (124 slice sagittal, 1.3 mm thickness) structural images provided detailed anatomic information for the reconstruction of each participant's cortical surface [6]. Following signal deconvolution and selective averaging of each subject's functional data [7], the averages and variances for each subject in each condition were resampled in stereotaxic space [8] and in a spherical space derived from each individual's cortical surface [9], and then averaged across subjects in both these spaces.

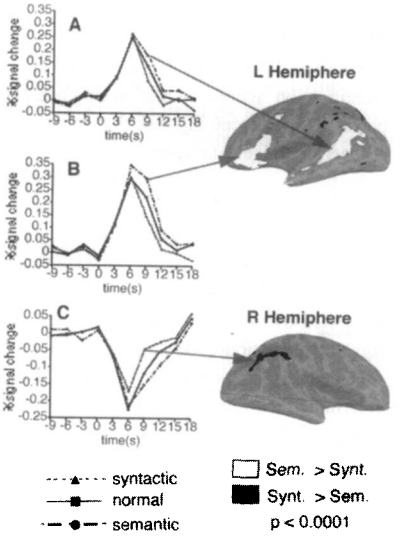

Figure 1

Results:

1. Shown on the right side of Figure 1, is event-related functional activity of all fourteen subjects averaged in spherical space, contrasting semantically- with syntactically-anomalous sentences. The left superior and middle temporal gyri (Wernicke's area: BAs 21 and 22) and the left inferior frontal gyrus (BAs 47,10,11) showed greater activation to semantically- than to syntactically-anomalous sentences. Superior and inferior parietal gyri, particularly on the right, showed greater activation to syntactically- than to semantically-violated sentences.

2. Shown on the left of Figure 1 are the hemodynamic responses for each type of sentence, within selected regions of interest (ROIs). Activity in the left superior/middle temporal regions (Fig.1A) and left inferior frontal regions (Fig.1B) was maximal to semantically-anomalous sentences, less to normal sentences, and least to syntactically-anomalous sentences. In right superior/inferior parietal gyri, all types of sentences were 'deactivated' in comparison with the fixation condition but, within this region, the degree of deactivation was reciprocally modulated according to the type of sentence presented: there was least deactivation to syntactically-anomalous sentences and most deactivation to semantically-anomalous sentences (Fig.1C).

3. In all these hemodynamic time-courses, the percentage signal change diverged after six seconds and thus reflects activation during presentation of the second half of each sentence when the types of sentences differed from each other.

4.Two 'control' ROIs (primary visual areas and pre-motor cortex) showed no modulation of activity in response to the different types of sentence (data not shown).

Conclusions:

We have demonstrated distinct patterns of modulation within a left-sided fronto-temporal network (and a reciprocal pattern of modulation within a right-sided parietal region) to semantic and syntactic violations in sentences. This suggests that activity within the same neural networks is modulated differently when processing semantic versus syntactic information.

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