Brain activation modulated by sentence comprehension

by

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One of the challenges of brain science is to relate the dynamics of higher level cognition to the equally dynamic activity of brain-level events.

A possible meeting ground between these two levels is the modulation in the amount of neuronal activity (at the brain level) in a given task, measured as a function of the amount of computational demand that the task places on cognitive resources.
What does it mean to be "thinking harder" in the course of sentence comprehension, in terms of brain activation?

They have examined whether sentences that were more computationally demanding also engender more brain activation.
At the cognitive level
sentence comprehension requires:
syntactic and thematic relations using world knowledge to construct
a representation of the sentence meaning.

At the brain level
sentence comprehension entails:
activation in a network of cortical areas -
Wernicke's area, Broca's area and their right-hemisphere homologs
(the right-hemisphere homologs may be recruited in times of high
demand)

The left and right inferior frontal gyrus

The left and right latero-superior temporal cortex
They manipulated comprehension demand by using 3 types of sentences that differ in:

**structural complexity** but were **superficially similar**, containing two clauses and the same number of words:

**Active conjoined** (no embedded clause)

active clause that is **simply conjoined**:
"The reporter attacked the senator and __ admitted the error."

**Subject relative clause**

a relative clause that **interrupts a main clause**
"The reporter that [ __ attacked the senator] admitted the error."

**Object relative clause**

not only is the main clause interrupted, but **the first noun plays two different roles**, as the subject of the main clause and the object of the relative clause:
"The reporter that [the senator attacked __] admitted the error."
The 3 sentence types increase in complexity from type A to C:

<table>
<thead>
<tr>
<th>Type</th>
<th>Active conjoined</th>
<th>least complex</th>
<th>Type B</th>
<th>Subject relative clause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type C</td>
<td>Object relative clause</td>
<td>most complex</td>
<td></td>
<td>longer reading times</td>
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<td></td>
<td></td>
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<td>higher comprehension error rates</td>
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<td>larger pupillary responses in adults</td>
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</tbody>
</table>
Participants

- 15 participants (10 males and 5 females) right-handed native English speakers, who were college students or graduates, aged 18 to 30.
Methodology

• Used block design
• The participants read sets of 4-5 successive sentences of the same linguistic type.
• after each sentence, answered true or false to a comprehension probe.
• The response terminate the sentence display.
• The stimulus sentences varied in content, all involving concrete, familiar nouns and actions.
• To control for the visual components of the task, another condition (Type D sentences) involved scanning consonant strings such as:
"Pws ntkgqrfm zjkjrng kwtdc sbfght swn mjrdbxq kgt mxbtq". (using the same number of “words”)
The sentence display was viewed on a rear projection screen at 45 cm away.
pseudorandomized order (to balance order effects) of 21 blocks

Type A block – Conjoined sentences (4-5)
Type B block - Subject Relative sentences (4-5)
Type C block - Object Relative sentences (4-5)
Type D block – Consonant strings (4-5)

Rest blocks (control) - asterisk fixation blocks of 24 s (5 instances)

(Successive blocks were separated by 6 s of rest)
The central result is that all four areas - Wernicke's area, Broca's area and their right hemisphere homologs - showed an increase in the amount of brain activation as the demand on the language processing system increased from the simplest to the most complex sentence structures. (Fig.1)
The precise area that was activated within the left temporal region of interest (ROI):

- Superior temporal gyrus - Brodmann’s area 22
- Middle temporal gyrus - Brodmann’s area 21
- Superior temporal sulcus - Brodmann’s area 42

The modulation of the activation volume in the left inferior frontal gyrus (Brodmann's areas 44 and 45) was similar.
The top panels indicate the mean number of voxels activated per condition in the left (Wernicke’s area) and right laterosuperior temporal cortex. The bottom panels indicate the mean number of voxels activated per condition in the left (Broca’s area) and the right inferior frontal cortex.
Number of voxels => size  
Rather than showing  
The signal intensity  

The top panels indicate the mean number of voxels activated per condition in the left (Wernicke’s area) and right laterosuprior temporal cortex.  
The bottom panels indicate the mean number of voxels activated per condition in the left (Broca’s area) and the right inferior frontal cortex.
The top panels indicate the mean number of voxels activated per condition in the left (Wernicke’s area) and right laterosupairior temporal cortex.

The bottom panels indicate the mean number of voxels activated per condition in the left (Broca’s area) and the right inferior frontal cortex.
• The right-hemisphere homologs of Wernicke's and Broca's areas were also activated but at lower levels.

• Both right homologs showed a modulation in activation as a function of demand.
The processing of the three sentence types recruits an increasing number of voxels from overlapping pools.

The additional voxels that became activated only when the sentences were more complex were spatially contiguous or proximal to those voxels activated during the processing of simpler sentences within each area.

Thresholded (п0) fMRI brain activation images (superimposed on structural images) for only the most activated slice from one participant. The number of activated voxels (shown in white) in the left laterosuperior temporal cortex (Wernicke’s area, indicated by white arrows) generally increases with sentence complexity.
The 3 rows of plots depict data from 3 different participants. The 3 dimensional plots depict the t values of the activated and surrounding voxels from an axial slice of the left temporal region (the anterior region is at the left).

The t value is a proxy for the voxel’s activation increase over the rest condition that controls for variance.
Conclusion

Any mapping between brain site and cognitive function is a variable function between two levels of description of a dynamic system, modulated by the demand of the task, and so cannot be a static cartography of brain anatomy.