fMRI-experiments on syntactic processing

in the human brain

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Overview

1. Introduction

There are different regions with different functions for language processing. The most popular ones might be:

- the Broca area (left frontal cortex)
- the Wernicke (left posterior temporal cortex)

Possibilities to find out how speechproduction is working in the human brain:

- studies on patients with brain lesions, i.e. aphasics

  problem: the matching from brain damage to brain function

- studies on healthy subjects

From studies on healthy subjects comes the evidence, that there are a lot more areas involved in speech production, i.e.:

- primary motor cortex (in both hemispheres)
- supplementary motor area (SMA)
- insula cortex
- cerebellum

- Methods for monitoring brain electrical activity:

  EP (Evoked Potentials),

  MEG (MagnetoEncephaloGraphy),

  EEG (ElectroEncephaloGraphy)

- Methods based on imaging brain blood flow:

  SPECT (Single-Photon-Emission Computed Tomography),

  PET (Positron-Emission Tomography),

  fMRI (Functional Magnetic Resonance Imaging)

2. Technique of fMRI

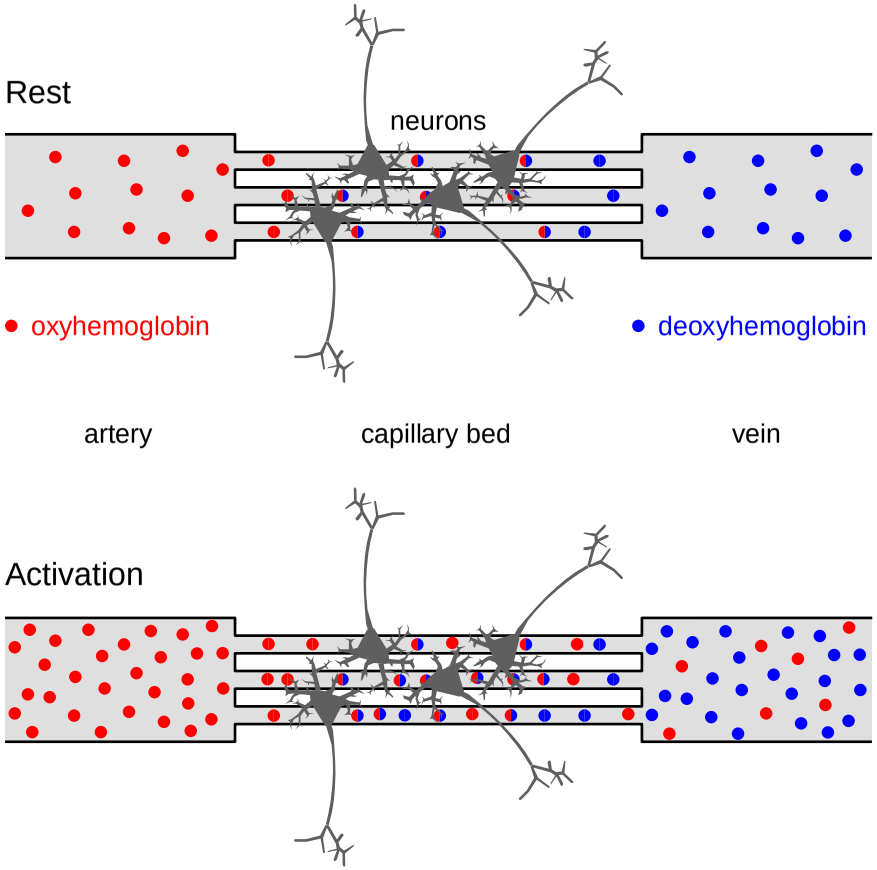
2.1 Presuppositions

- fMRI is a hemodynamic method
- coupling between neuronal activity and its blood supply
- an increase in net activity is associated with an increase in blood supply
- with local blood flow and in correlation with neuronal activity the blood properties change
- with fMRI this hemodynamic changes can be registered

2.2 BOLD-effect

- blood oxygenation level dependent effect
- more oxygen and glucose are made available by increased blood flow
- oxygen consists among others of oxyhemoglobin and deoxyhemoglobin
- in the arteries that supply the active neurons is more oxyhemoglobin while in the veins is more deoxyhemoglobin
- the magnetic susceptibility of deoxyhemoglobin is greater than of oxyhemoglobin, the fMRI detectors measure the ratio of oxygenated to deoxygenated hemoglobin

Blood Oxygenation Level Dependent (BOLD) effect



- the BOLD-effect can be registered up to 12 seconds after the activity has stopped but the hemodynamic signal changes which occur in MR during brain activation are extremely small, from 2 to 5% at moderate magnetic field strengths (1.5 Tesla)

>> With the detection of blood flow changes one can identify the brain regions that are activated during a cognitive task.

2.3 Imaging procedure

- for scanning, the individual is placed within a strong, controlled magnetic field (1.5 Tesla)
- the nuclei in the persons body that have a magnetic moment are lined up in the same orientation as the large, externally applied magnetic field
- radiofrequency pulses tip the atoms off their aligned axis of spin and as they return to their original orientation they give off a resonance which can be detected as a signal
- the scanner takes data from the whole brain volume, often 28 slices of 4 mm thickness and a gap of 1 mm inbetween
- the head is fixed with a foam rubber to minimize head movement
- the subject sees a screen via a mirror for visual tasks or get earphones for an auditive task

2.4 Paired image subtraction

- the image subtraction is a kind of a union between cognitive and imaging science

Task A has n cognitive components and m neural components.

Task B has n+**x** cognitive components and m+**y** neural components.

The subtraction B-A reveals the correlation between the cogntive component **x** and the neural component **y**.

- the subtraction methodology rests on the assumption, that the mapping between a cognitive operation and its neural substrate is invariant
- the experiment contains two states, a task state and a control state
- the images of these states are subtracted from one another to discover, which areas of the brain differ between the two states
- the method is usefull if the task could be split up in different succesive steps, so the two tasks could differ in one of these steps

3. Experiments

3.1 ‚Old‘ Experiment

- Dogil et al. (2000). The Speaking Brain. Journal of Neurolinguistics, 14. (in press)
- purpose: isolation of specific syntactic processing from general cognition
- material: phrasestructures and list generation
- participants: ten right-handed native speakers of German (five female, five male, age med. = 27)
- the subjects lay supine in a MR scanner (1.5 Tesla)
- their heads being secured to minimize movement artifacts
- the stimuli were presented as textlines on a computer screen

3.1.1 Material

Word lists

Hotelführer Museumsführer Kunstreiseführer

Abfallgebühren Parkhausgebühren Leihgebühren

Orangenbäume Haselnußbäume Apfelbäume

Abenteuerroman Liebesroman Kriminalroman

Sentences

Juristen haben sich mit dieser Frage beschäftigt.

Ein Aktivist hat sich an den Gitterzaun gekettet.

Auf einem Dachboden haben sich Marder einquartiert.

Über dem Gebirge haben sich Wolken gebildet.

3.1.2 Tasks

The task was:

- read the sentence silently
- manipulate the word order
- produce the result in overt speech

>> Mit dieser Frage haben sich Juristen beschäftigt

The same with the list:

- read the list silently
- move the second element to the first position
- produce the result in overt speech

>> Museumsführer Hotelführer Kunstreiseführer

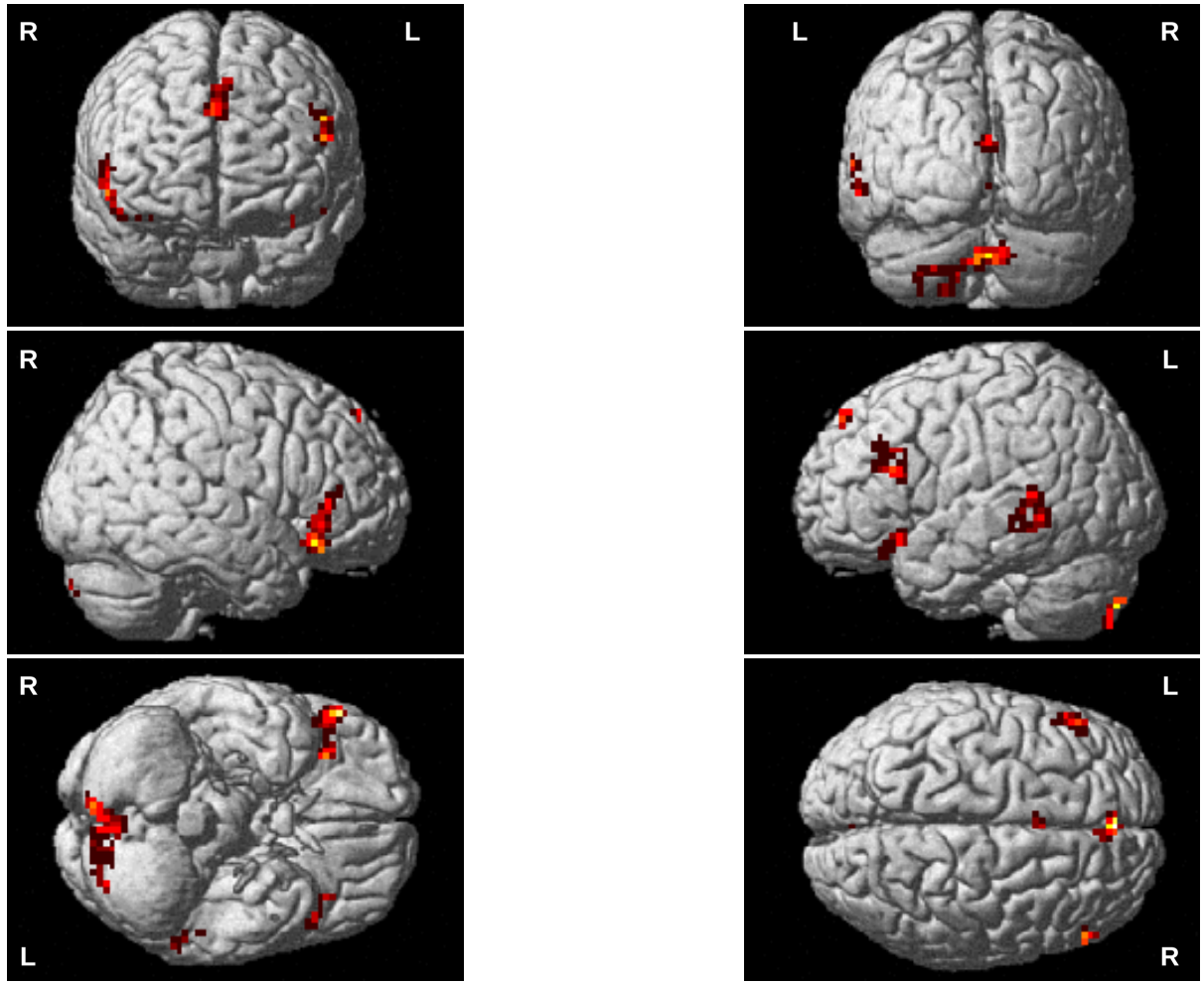
- list reordering as the control task
- sentence reordering as the test task.
- the tasks differ minimal, only the test task is a grammatically geared task
- the visual processing, graphem-phoneme conversion and the speech motor control should be neutralized by subtracting

>> only the syntactic activities should appear

3.1.3 Results

What was found after subtracting the control task from the test task?

- Broca‘s area
- Wernicke‘s area
- Dorso-lateral prefrontal cortex (DPF)
- Anterior cingulate cortex (ACC)
- Cerebellum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- **Broca‘s area** known as a participating area in syntactic processing
- **Wernicke‘s area** interacts with Broca-area through neuronal connections
- **Dorso-lateral prefrontal cortex** is connected to the dorso-caudal region of the Broca-area
- **Anterior cingular cortex** was known to participate in the limbic system for pain and discomfort
- the activation of the **Cerebellum** is surprising

Questions

How can one say that these areas are activated because of language processing and not because of other processes?

Could these area be a network for syntactic processing?

What role plays the working memory?

3.2 New Experiment

- purpose: verify the results from the old experiment
- material: list generation and phrasestructures
- for the word list instead of composita the names of the months as a ‚stored' word list
- is there also an activation in the Cerebellum?

References

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