Chapter 1.
Language Functions in the Brain: From Auditory Input to Sentence Comprehension

A Cognitive Model of Auditory Language Comprehension

Likan Zhan
Beijing Language and Culture University

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https://likan.info
zhanlikan@blcu.edu.cn

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Acoustic-Phonological Processes

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- The language processing model sketched in Figure 7 assumes different processing stages from auditory input up to interpretation.
- At the first stage there are the **acoustic-phonological processes**, which are dealt with by the auditory cortex in both hemispheres.
- The output of this initial process is then further processed by the left hemisphere and the right hemisphere according to their specifications - segmental sounds in the left hemisphere and suprasegmental parameters in the right hemisphere.

Syntactic, Semantic, and Prosodic Processes

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- The first is the processing of sentence melody and intonation, which can signal the beginning or end of a phrase in a sentence, and
- The second is the processing of accentuation relevant for thematic focus.

Different Subprocesses As One System

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- During auditory speech comprehension, the different subsystems within one hemisphere (as well as across the two hemispheres) work together to achieve smooth comprehension.

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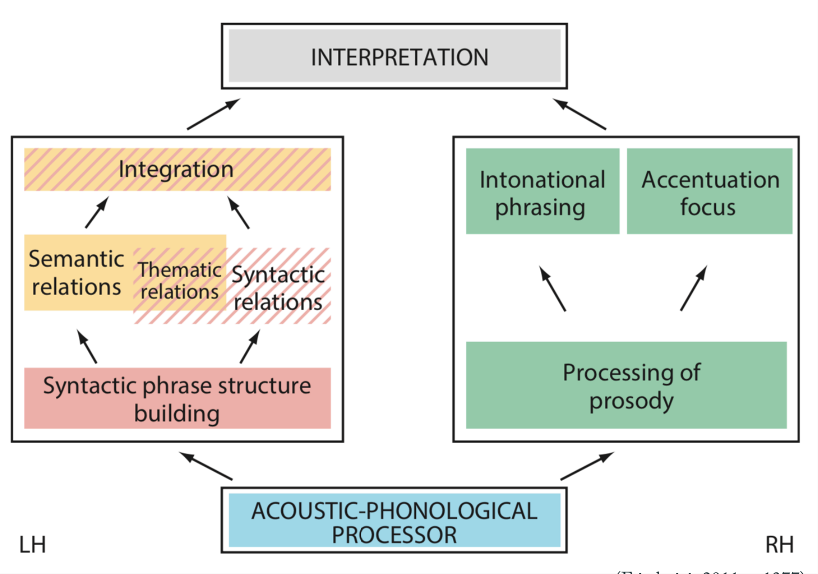
- The processes are assumed to run in a partly parallel, but cascadic manner. That means that each subsystem forwards its output to the next subsystem as soon as possible, thereby causing several subsystems to work in parallel.
- Each of the subsystems corresponds to local cortical networks in specialized brain areas, which together form large-scale dynamic neural networks supporting language comprehension.

A Cognitive Model



(Friederici, 2011, p.1377)

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The challenge of an adequate description

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- The challenge of an adequate description of the neural basis of language is to identify the different processing subsystems in the brain not only with respect to where they are located in the brain but, moreover, how these subsystems interact in time.

Measure the Neural Activity to Language

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- Language-related activation, like any other brain activation, is based on the activation of neurons and neuronal ensembles resulting in electrical activity unfolding in milliseconds that can be measured at the scalp by means of electroencephalography. Since each electrical current has its magnetic field, brain activity can also be measured with magnetoencephalography.

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- Moreover, because neuronal activity is dependent on cerebral blood flow, measurements of changes in the blood flow can be taken as an indicator for brain activity that can be measured by functional magnetic resonance imaging and by near-infrared spectroscopy.

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- Here we will take the following approach: For each of the subprocesses postulated in the functional auditory language comprehension model, we will describe the
- Neurotemporal parameters as reflected by the time-sensitive electroencephalography or magnetoencephalography measures and specify the
- Neurospatial parameters of one or more brain areas as reflected by changes in the blood flow using functional magnetic resonance imaging, by near-infrared spectroscopy, or by calculating the location of the source of a given effect observed in electroencephalography or magnetoencephalography data.

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- We will briefly describe these neuroscientific methods, as they are a necessary part of understanding the data underlying the language-brain relationship and the resulting neurocognitive model of language comprehension.

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- In the late 19th century lesions were diagnosed postmortem, but thanks to the availability of computer tomography in the late 20th century lesions could be identified in vivo.
- The advent of magnetic resonance imaging in the past decades has led to fundamental knowledge about the representation of different aspects of language in the lesioned and intact brain.

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- Due to the fact that brain lesions, in particular vascular lesions caused by a stroke, are not always well circumscribed but rather concern the entire territory of a given blood vessel and are thus often unspecific, we will not cover the entire literature on patient-related language studies.
- However, we will report on patient studies that together with other neuroscientific studies provide essential information for an adequate description of language in the brain.

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Neuroscientific Methods

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- There are two time-sensitive neurophysiological methods, **electroencephalography** and **magnetoencephalography**.

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- In neurocognitive research, electroencephalography is used to measure brain activity time-locked to a particular stimulus, provided to the individual either auditorily or visual, called *event-related brain potentials* (ERP).
- The ERP is a quantification of electrical activity in the cortex in response to a particular type of stimulus event with high temporal resolution in the order of milliseconds.

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- Average electrocortical activity appears as waveforms in which so-called *ERP components* have either positive or negative polarity relative to baseline, have a certain temporal latency in milliseconds after stimulus onset, and have a characteristic but poorly resolved spatial distribution over the scalp.

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- For example: negativity (N) around 400 ms is called N400, and positivity (P) around 600 ms is called P600.

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- These studies often include violations of respective information types in sentences, because the brain reacts most strongly to unexpected events and violations in the input.

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- The fifth is the **P600** (positivity after 600 ms), which is associated with late syntactic integration processes.
- These ERP components are discussed in detail below.

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- Magnetoencephalography provides information about the amplitude, latency, and topography of language-related magnetic components with a temporal resolution comparable to ERPs but with an improved spatial resolution due to a high number of registration channels.

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- It has replaced the partly invasive *positron emission tomography* by a non-invasive, state-of-the-art method for functional-anatomical reconstruction of the language network in the order of submillimeters.
- However, the temporal resolution of magnetic resonance imaging is limited as it measures the hemodynamics of the brain activity taking place in the order of seconds.

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- These neural activity changes are reflected in blood-oxygen-level-dependent (BOLD) signal changes based on the effect of neurovascular coupling.

Near-Infrared Spectroscopy

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- However, the spatial resolution of near-infrared spectroscopy is much lower than that of magnetic resonance imaging whereas its temporal resolution is just as poor.
- For this reason this technique is mainly used with very young participants.

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- **Structural magnetic resonance imaging** provides detailed morphometric and geometric features of the brain's gray and white matter such as its volume, density, thickness, and surface area.
- **Diffusion-weighted magnetic resonance imaging**, especially diffusion tensor imaging, is used to reconstruct the trajectory and quantify tissue probabilities of white matter fiber bundles interconnecting brain areas.

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- Currently, the best approach for gaining reliable knowledge about the brain-function relation is to combine high temporal and spatial resolution.
- Invasive techniques, particularly **intracranial electrophysiology**, overcome this need to combine techniques but are exclusively feasible in clinical settings.

Non-Invasive and Invasive Techniques

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- Based on the available non-invasive techniques such as electroencephalography, magnetoencephalography, near-infrared spectroscopy, and functional magnetic resonance imaging methods, we are able to specify the neural correlates of those regions that support the different subprocesses described in the neurocognitive model, from the acoustic input to the level at which comprehension is achieved.

References i

Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews*, *91*(4), 1357-1392. doi: 10.1152/physrev.00006.2011