LANGUAGE IN OUR BRAIN

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Spring, 2020 Brain Algorithms Reading Group

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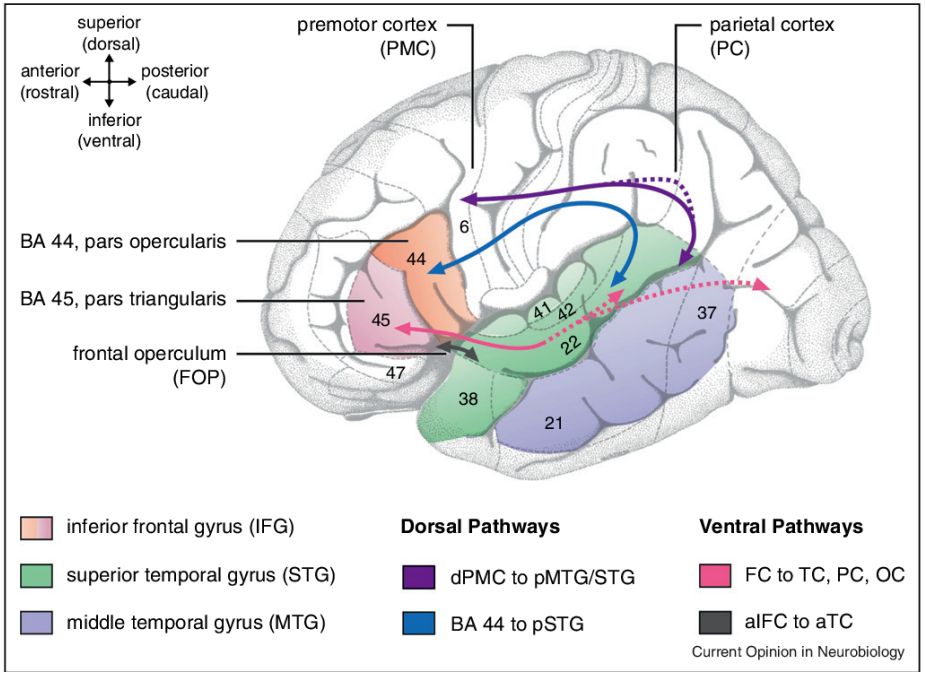


Language in our Brain

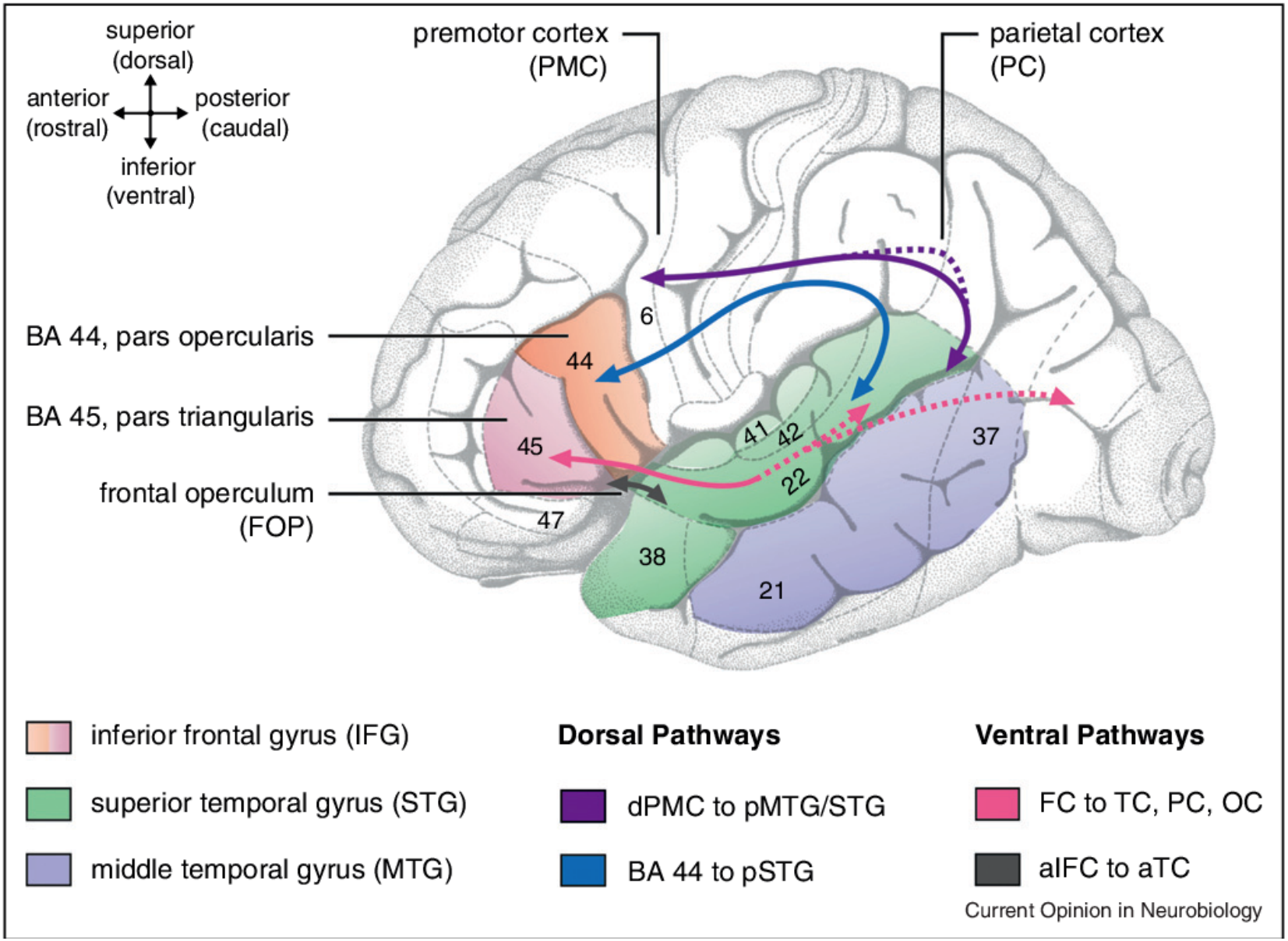
Angela D. Friederici, MIT Press, 2017

Introduction Nancy

1. Language Functions in the Brain: From Auditory Input to Sentence Comprehension Nancy
2. Excursions Nancy
3. The Structural Language Network Shankha
4. The Functional Language Network Shankha
5. The Brain's Critical Period for Language Acquisition Frederik
6. Ontogeny of the Neural Language Network Frederik
7. Evolution of Language
8. The Neural Basis of Language

Overview

- Book is comprehensive, describes everything that is known about how language is processed in the brain.
- Breaks down the language recognition task into many interacting sub-tasks (for auditory processing, syntax processing, semantic understanding),
- Says which regions of the brain carry out the various sub-tasks, and how they communicate.
- All accomplished in milliseconds.
- Describes imaging, experiments used to determine all this.
- Noam Chomsky:
  - Most striking conclusions concern Broca's area (BA 44 and BA 45) and the white matter dorsal fiber tract that connects BA 44 to the posterior temporal cortex.
  - Can be seen as the missing link that has to evolve in order to make full language capacity possible.

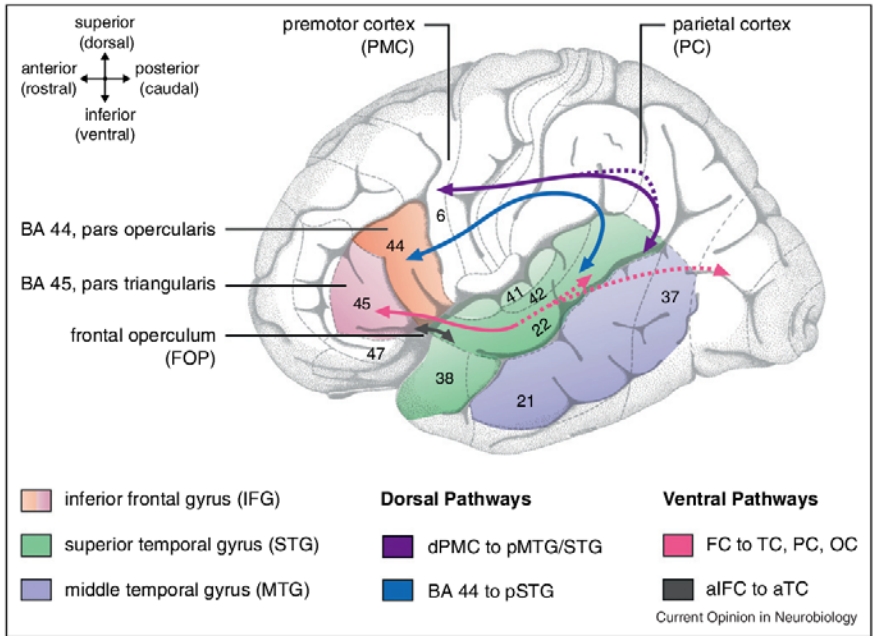

superior
(dorsal)
anterior
(rostral)
posterior
(caudal)
inferior
(ventral)
premotor cortex
(PMC)
parietal cortex
(PC)
BA 44, pars opercularis
BA 45, pars triangularis
frontal operculum
(FOP)
6
44
45
47
41
42
22
37
38
21
inferior frontal gyrus (IFG)
superior temporal gyrus (STG)
middle temporal gyrus (MTG)
Dorsal Pathways
dPMC to pMTG/STG
BA 44 to pSTG
Ventral Pathways
FC to TC, PC, OC
aIFC to aTC
Current Opinion in Neurobiology

Introduction

- Language as a uniquely human trait:
  - Language processing system is an evolved biological system, though specifics of a particular language and environment are, of course, learned.
  - Capabilities partly present in other animals: Attention, memory, associative learning, learning and recognizing sequences.
  - But not: Syntax
  - Q: What is different in human vs. animal brain structure?
- Language as a cognitive system:
  - Used in communication, but differs from other forms of communication by use of syntax---rules for combining words into larger structures.
  - Key building block for syntax: the Merge operation.
  - Language is a system that support the mapping of structured sequences of words into meaning; requires identifying both the syntactic relationships of words and their meanings.

Introduction

- Language as a brain system:
  - Broca's region (BA 44 and BA 45), supports language production and comprehension, particularly grammatical processes.
  - Wernicke's region (BA 42 and BA 22) support lexical-semantic processes.



- Experiments on these were the first indication that different components of language, such as grammar vs. the lexicon, are handled in different locations in the brain.
- Language system now known to consist of a number of cortical regions in both the left and right hemisphere.
- Interact with each other and with other regions such as auditory and motor cortex.

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

- Language areas work together in a partly cascadic, partly parallel manner.
- Core language system: Phonological, syntactic, and semantic information.
- Other parts deal with situational and emotional aspects.
- Chapter 1 focuses on the core language system in the mature brain.

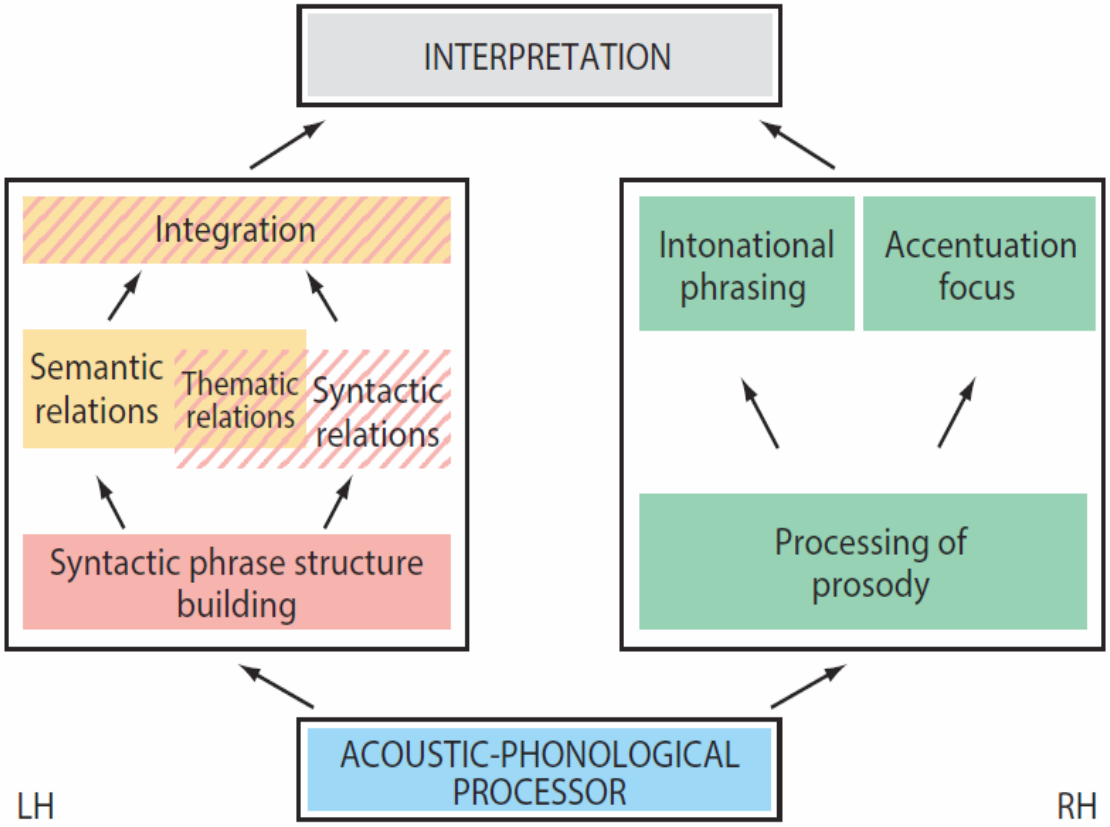


Figure 1.1

Cognitive model of auditory language comprehension. The model represents the different subprocesses during comprehension from auditory input to interpretation. Different color-coded boxes represent subprocesses assumed to take place in the left hemisphere (LH) and right hemisphere (RH). For the details of these subprocesses see text. Adapted from Friederici (2011). The brain basis of language processing: From structure to function. *Physiological Reviews*, 91 (4): 1357–1392.

1.1. A cognitive model of auditory language comprehension

- Her full cognitive model of auditory language comprehension, with functional processing components and processing steps
- First stage: Acoustic-phonological processor, in auditory cortex
- Then processing splits into the two hemispheres.
- Left: Builds syntactic phrase structure
  - Components for discovering syntactic, thematic, and semantic relations
  - Integrates of all of this into existing world knowledge
- Right: Processing of prosody (rhythm, sound, stress)
  - Uses sentence melody and intonation to demarcate phrases.
  - Uses accentuation to understand thematic aspects.
- Final stage: Interpretation

1.2. Acoustic-phonological processes

- Acoustic-phonological analysis of speech, during a few msec after input.
- Detects phonemes = units of sound that distinguish one word from another; language-specific.
- Facilitates access to the word form stored in the lexicon.
- Lexicon: Inventory of words and associated attributes, like syntactic category and meaning.
- Processing in auditory cortex + Heschl's gyrus, planum polare, planum temporale.
- Planum temporale is proposed as the general auditory computational hub from which information is gated to higher-order cortical areas for further processing.
- Two brain regions involved in auditory language processing: One processes auditory information in general, second categorizes it as speech or non-speech.
- Both left and right hemispheres are involved: left reacts to speech, right to tonal pitch.

1.3. From word form to syntactic and lexical-semantic information

- After acoustic-phonological processes have identified phonemes, start trying to find an appropriate word in the lexicon.
- First determine if the phonemes form an actual word, else error signal is produced.
- Find the word, get other information: syntactic word category, and semantic information.
- Build conceptual-semantic structure, suitable for further processing at a subsequent level, where semantic, and thematic relations are also considered.
- Anterior temporal lobe has been called the semantic hub in a general memory system.
- Accommodates multiple modalities (picture, hearing a name).
- How can these modalities be combined?
- Needs more information, models.

1.4. Initial phrase structure building

- Word category information is used for phrase building.
- Phrase: Group of words that functions as a constituent in a sentence: Noun Phrase, Verb Phrase, Prepositional Phrase, Adjective Phrase
- Word category information becomes available quickly, in every language, in spite of different ordering rules in different languages.
- Quickly detect phrase structure violation = impossibility of building a phrase structure from the given input.
- Leads to error signal, in the left frontal cortex.
- If no error, then phrase building proceeds using Merge.
- Involves several regions:
  - The anterior superior temporal gyrus and the frontal operculum support the combination of two elements independent of the underlying syntactic structure.
  - BA 44 supports initial phrase structure building using grammar rules.
  - These regions appear to constitute a functional neural network supporting initial phrase structure building.

1.5. Syntactic relations during sentence processing

- Building complex sentences from phrases involves BA 44, plus posterior superior temporal gyrus and superior temporal sulcus; left temporo-parietal cortex is also involved when working memory is required during sentence processing.
- Areas work together as a functional network to achieve comprehension of the syntax of complex sentences.
- Build a syntactic skeleton (stripping away semantics).
- BA 44 is active during any kind of syntactic hierarchy building.
- Merge is the basis of all syntactic processing; recursive application of Merge allows building complex syntactic structure.
- Merge is realized in the ventral anterior part of BA 44.
- The more complex and non-standard the grammatical structure, the more activation observed in BA 44.
- Posterior superior temporal gyrus and superior temporal sulcus also involved in building the syntactic skeleton, handle both syntactic and semantic information.

1.6. Processing semantic relations

- This section considers neurobiological basis of semantic processes and relations, based on imaging studies.
- Many brain regions involved: anterior temporal lobe, posterior temporal and middle temporal gyrus, angular gyrus,...
- Anterior temporal region supports basic semantic composition, angular gyrus involved in combinatorial semantics, BA 47/45 comes into play for controlled executive semantic processes.
- Models are needed that take the differences between semantic composition, combinational processes, and controlled executive processes into account.

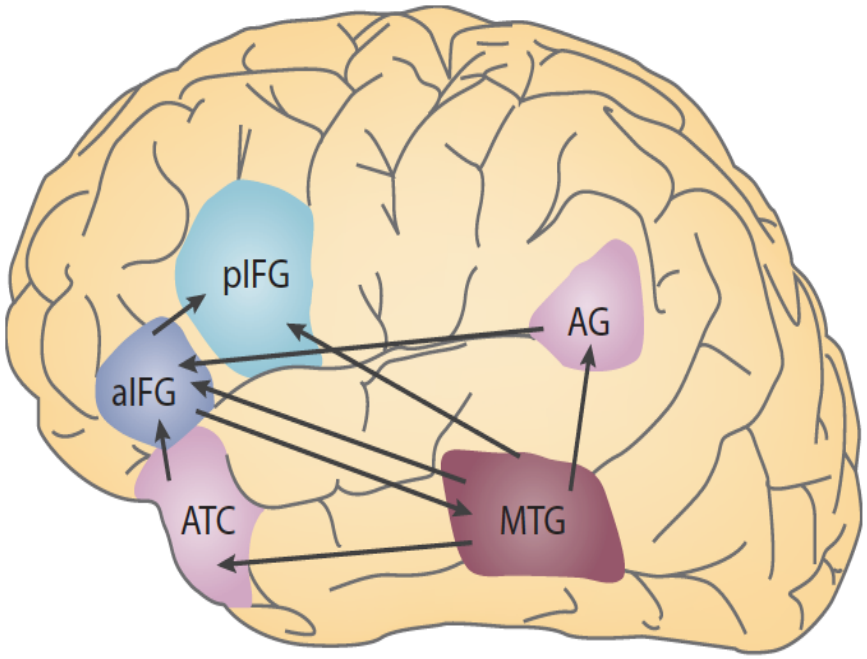
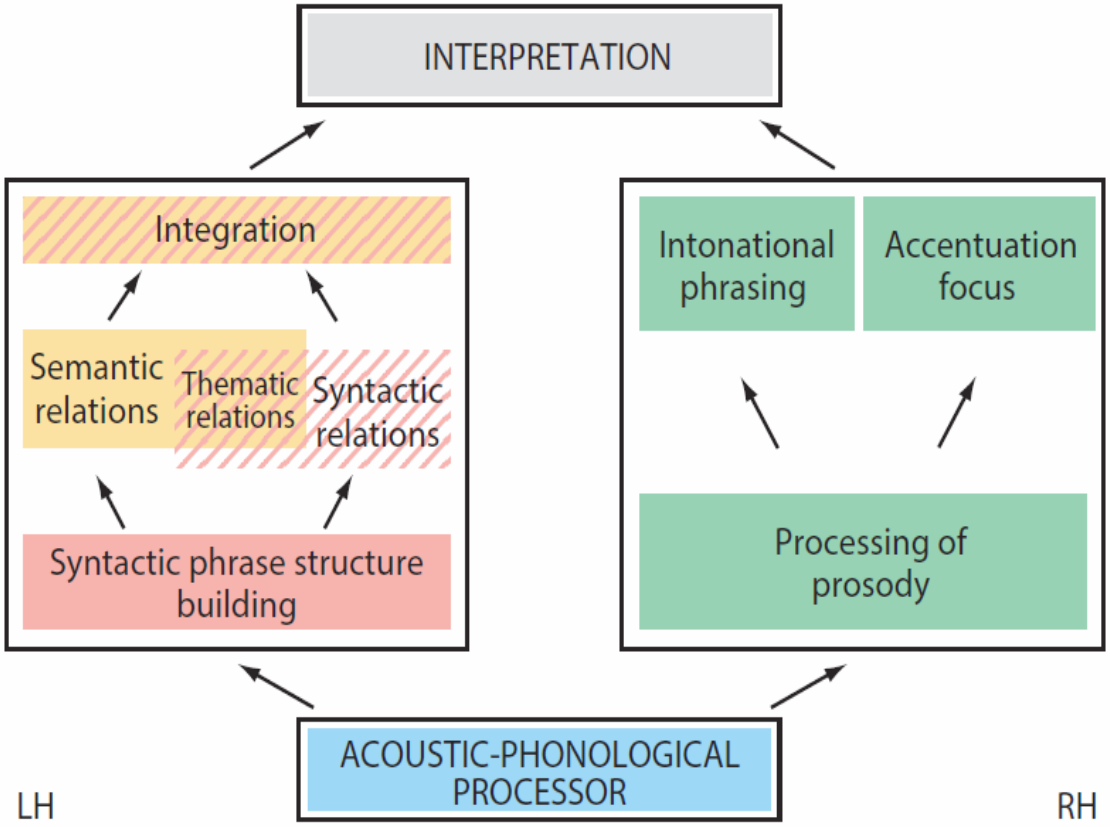


Figure 1.13
A neurofunctional model for semantic processing of words in context. According to the model, lexical representations are stored and activated in the middle temporal gyrus (MTG) and in the nearby superior temporal sulcus and inferior temporal cortex, and are accessed by other parts of the semantic network. The anterior temporal cortex (ATC) and angular gyrus (AG) are involved in integrating incoming information into current contextual and syntactic representations. The anterior inferior frontal gyrus (aIFG) mediates controlled retrieval of lexical representations based on top-down information, and the posterior IFG (pIFG) mediates selection between highly activated candidate representations. Adapted by permission from Nature Publishing Group: Lau, Colin, and Poeppel. 2008. A cortical network for semantics: (De)constructing the N400. *Nature Reviews Neuroscience*, 9 (12): 920–933.

1.7. Thematic role assignment: Semantic and syntactic features

- Thematic role assignment: Relationship between the verb and its arguments is computed to assign them to thematic roles in a sentence.
- Subject-verb agreement, case information, lexical restriction information are taken into account.
- Takes place in a left fronto-temporal network involving the inferior frontal gyrus, and the middle and superior temporal gyri.
- Different languages vary as to types of information that are relevant for the assignment of thematic roles.
- Parallel processing for computing syntactic structure, and establishing semantic relationships; may interact.
- Integration phase: Syntactic reanalysis and repair.
- Interpretation phase: Involves situational and communicative aspects, also knowledge about the world.



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1.8. Processing prosodic information

- Prosody = rhythm, melody, pitch
- When processing speech, prosodic information is needed, in addition to syntactic and semantic info.
- Prosodic information helps in determining syntactic and semantic structure (linguistic prosody).
- Also used for other purposes, such as discerning the speaker's emotional state (emotional prosody).
- Linguistic prosody: Used to assign phrase boundaries within sentences.
- Example: "The man said the woman is stupid."
- Processing of prosodic information occurs mainly in the right hemisphere, vs. syntactic info. in the left.
- During speech processing, the RH and LH interact, with the interaction mainly going leftwards.

1.9. Functional neuroanatomy of neural comprehension

- Presents a general model of the brain basis of language comprehension, w.r.t. the neuroanatomy of the brain regions supporting syntactic, semantic, and prosodic processes.
- Also describes the temporal relation and interaction of these different functions as comprehension proceeds.

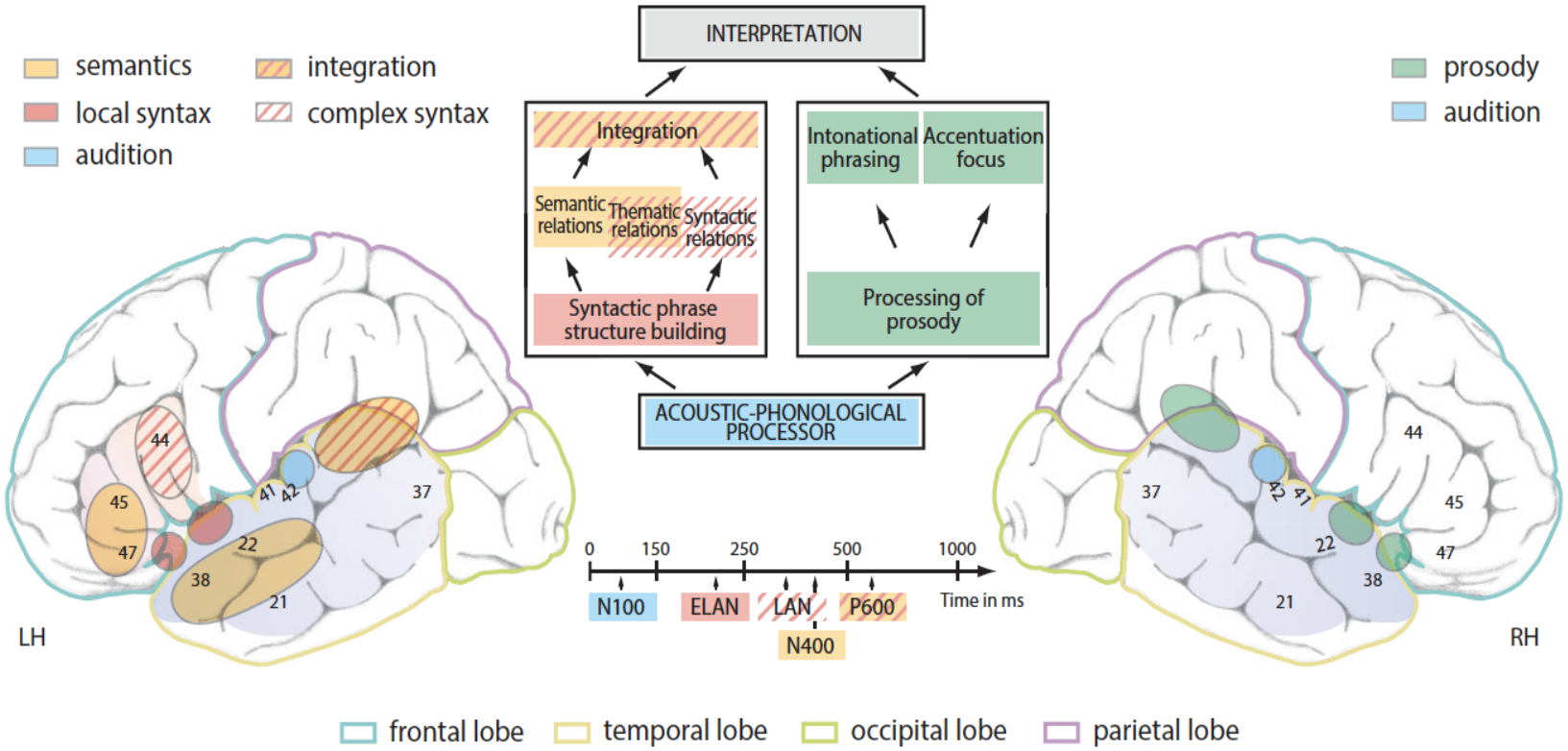

Figure 1.21
Neurocognitive language comprehension model. Functional neuroanatomy of language with its processing phases as defined in the initial neurocognitive language comprehension model (different processing stages are indicated by the color-coded boxes in the model displayed in the center). Language-relevant brain areas are displayed schematically in the left hemisphere (LH) and right hemisphere (RH). Functions of the areas are color-coded and labeled in the legend to the left and the right of the figure. The temporal course of the different subprocesses is displayed at the bottom of the figure as a time line in milliseconds (ms) listing the language-related ERP effects.

Chapter 2: Excursions

- Core language system consists of syntactic rules and lexicon.
- Two other parts:
  - External sensory-motor interface, used for speech perception and production.
  - Internal conceptual-intentional interface, connects with mental concepts and intentions.

- Language comprehension and production, see diagram.
  - Left side: Language production
  - Right side: Language comprehension
  - Both sides access lexicon and syntactic rules (middle circle).
  - Context and available world knowledge appear there as well.
- Conceptual-intentional interface?

- Language comprehension and communication beyond the core language system
  - Contextual knowledge, gestures,...
  - Remains to be integrated into a neuro-based model.

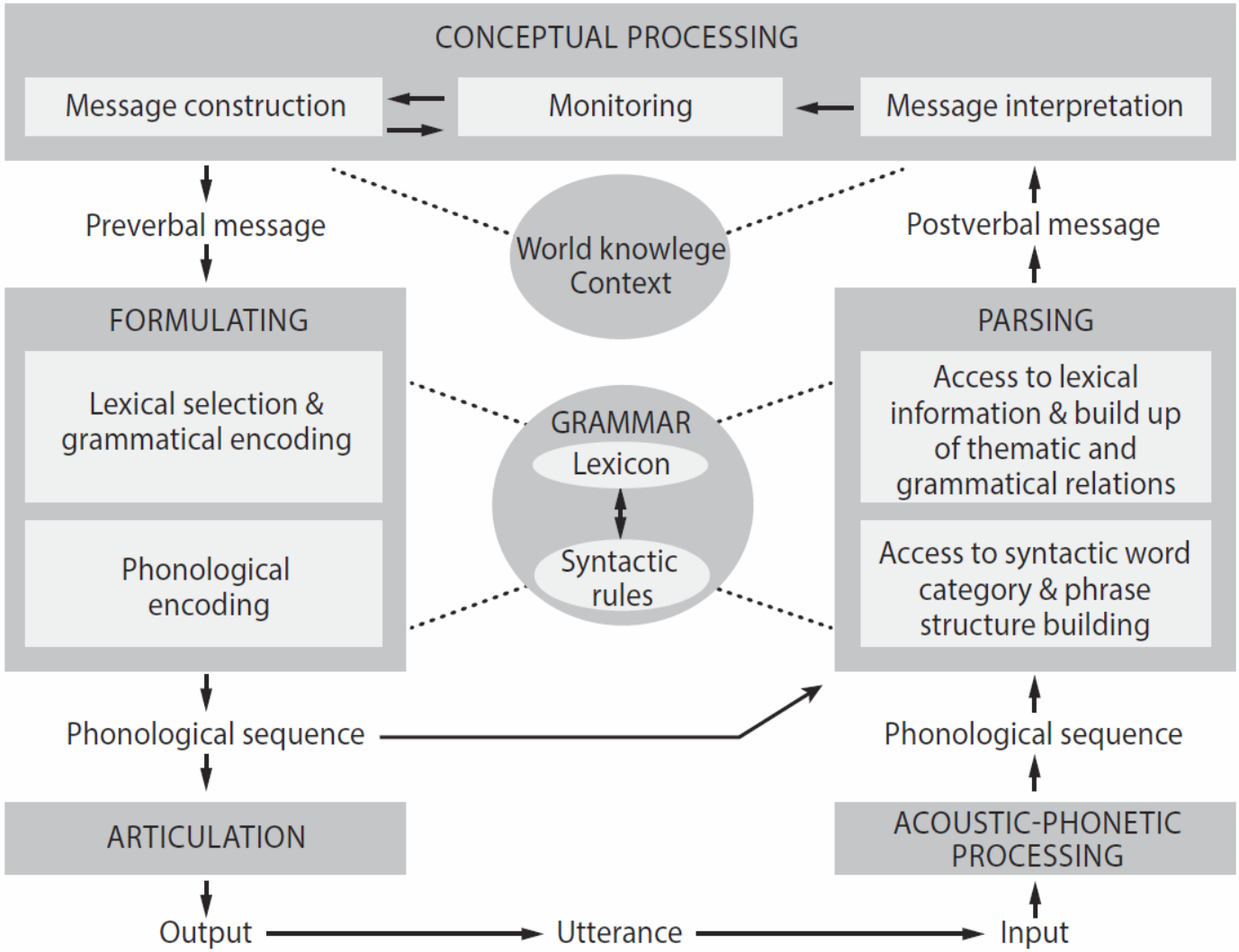

Figure 2.1
Model of language production and comprehension. Central knowledge bases are represented as circles, processes are represented as boxes. For a detailed description see text. Adapted from Friederici and Levelt (1988). Sprache. In *Psychobiologie. Grundlagen des Verhaltens*, ed. Klaus Immelmann, Klaus Scherer, Christian Vogel and Peter Schmoock, 648–671. Stuttgart: Gustav Fischer.

Interesting research questions?

- Abstract models for some of these regions, analyze their behavior:
  - From phonemes to words.
  - Structure of the lexicon.
  - From words to phrases, BA 44 and other regions.
  - From phrases to sentences: Merge, hierarchy, BA 44 etc.
- What is unique in the human brain, w.r.t. language processing?
- Connection between BA 44 and temporal cortex, as mentioned by Chomsky?
- Interplay between syntax and semantics?
- Contributions from Right Hemisphere?
- Consider processing at different levels of abstraction, areas and interactions vs. low-level neural models.