THE NEURAL MECHANISMS OF LANGUAGE PROCESSING: INSIGHTS FROM MODERN NEUROLINGUISTICS

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Received:07.12.2025
Revised: 08.12.2025
Accepted:09.12.2025

KALIT SO'ZLAR:

Neurolinguistics, language processing, Broca's area, Wernicke's area, neural networks, neuroplasticity, fMRI, brain-language relationship

ANNOTATSIYA:

This article explores the neural mechanisms underlying language processing and highlights recent advances in modern neurolinguistics. Drawing on contemporary brain research, it examines how different cortical and subcortical regions contribute to the comprehension, production, and interpretation of language. The discussion focuses on the functional roles of key neural structures, neural connectivity, hemispheric specialization, and the influence of neuroplasticity on language learning and recovery. Recent technological developments such as fMRI, EEG, MEG, and connectome analysis are considered for their contributions to understanding the dynamic relationship between the brain and language.

Introduction

Modern neurolinguistics examines the intricate relationship between the human brain and language, offering insights into how linguistic information is processed, stored, and produced. Traditional models of language assumed that language functions were strictly localized in specific brain areas, such as Broca's area for speech production and Wernicke's area for comprehension. However, contemporary research reveals that language processing results from the interaction of distributed neural networks rather than isolated modules. With the development of advanced neuroimaging technologies, scientists now better understand how different brain regions coordinate to manage phonological, semantic, syntactic, and pragmatic aspects of language. These discoveries deepen our knowledge of linguistic abilities, bilingualism, language development, and recovery from speech disorders.

Language processing involves the activation of a widespread network of cortical and subcortical structures. Broca's area, located in the left inferior frontal gyrus, plays a central role in grammatical encoding, syntactic processing, and articulatory planning. Wernicke's area in the posterior superior temporal gyrus is crucial for lexical access, auditory perception, and comprehension of meaning. Although these regions remain essential, modern neurolinguistics demonstrates that language relies heavily on interconnected pathways such as the arcuate fasciculus, which links frontal and temporal regions and enables coordinated speech production and comprehension.

Neuroimaging studies reveal that semantic processing engages the middle temporal gyrus, angular gyrus, and anterior temporal lobe, forming a distributed semantic network involved in interpreting meaning. Phonological processing relies on the supramarginal gyrus and dorsal auditory pathways, which support sound discrimination and phoneme sequencing. Meanwhile, pragmatic and discourse-level interpretation draws on prefrontal cortex regions responsible for inference, perspective-taking, and social cognition. These findings demonstrate that language functions cannot be attributed to isolated "language centers" but are instead the product of dynamic communication among multiple brain regions.

Modern neurolinguistic research also highlights hemispheric specialization. While the left hemisphere is typically dominant for linguistic functions, the right hemisphere contributes to prosody, metaphor interpretation, emotional tone, and global discourse coherence. This bilateral participation shows that language is a holistic cognitive process rather than a strictly localized one.

Another key insight comes from studies on neuroplasticity. The brain's ability to reorganize its structure and form new neural connections allows individuals to acquire additional languages, adapt to linguistic environments, and recover after brain injury. Children's brains exhibit high plasticity, enabling rapid language acquisition, while adult learners rely more on declarative memory systems. Following stroke or trauma, non-dominant hemisphere regions often take over language functions, demonstrating the flexibility of neural networks.

Technological advancements have played a crucial role in these discoveries. Functional MRI provides detailed images of brain activity during linguistic tasks, while EEG and MEG capture the timing of neural responses to speech and language stimuli. Connectome mapping reveals the structure of neural pathways, offering a clearer understanding of how different areas coordinate during speaking, listening, reading, and writing. These tools allow researchers to observe language processing in real time and contribute to more accurate models of neurolinguistic functioning. Language processing is supported by a highly integrated network of neural circuits, extending far beyond the classic Broca–Wernicke framework. Modern neurolinguistics describes language as a multi-level cognitive system involving phonological, semantic, syntactic, and pragmatic components, each relying on specialized yet interconnected neural pathways. Broca's area in the left inferior frontal gyrus continues to be associated with syntactic computation, morphological processing, and articulatory planning. However, contemporary studies using fMRI and MEG demonstrate that Broca's area also participates in predictive processing, enabling speakers to anticipate upcoming words and grammatical structures in communication. This suggests that language production and comprehension are intertwined at the neural level.

Wernicke's area, located in the posterior superior temporal gyrus, remains essential for auditory processing and semantic interpretation, yet it functions within a broader temporal lobe system. Research shows that nearby regions such as the superior temporal sulcus and middle temporal gyrus are equally important for mapping speech sounds to meaning, segmenting continuous speech, and integrating contextual information. These findings illustrate that language comprehension arises from distributed activity rather than a single cortical hub.

The arcuate fasciculus, a major white matter tract connecting frontal and temporal language regions, plays a fundamental role in coordinating speech repetition, sentence formulation, and real-time communication. Damage to this pathway leads to conduction aphasia, where comprehension is preserved but repetition and fluent speech production are impaired. Newer neuroanatomical discoveries indicate that the arcuate fasciculus is part of a larger dorsal stream responsible for transforming auditory information into motor representations, while a ventral stream supports semantic processing, comprehension, and lexical retrieval. These dual-stream models, supported by neuroscientific evidence, demonstrate that language involves both sensorimotor integration and meaning-based processing.

Semantic processing engages a widely distributed network extending across the angular gyrus, anterior temporal lobe, and ventromedial prefrontal cortex. Studies show that the anterior temporal lobe acts as a semantic hub, integrating information from modality-specific regions that process visual, auditory, and motor features of words. This explains how the brain organizes conceptual knowledge and how semantic deficits emerge in disorders such as semantic dementia. Additionally, the angular gyrus contributes to metaphor comprehension, abstract reasoning, and blending of conceptual domains, revealing how the brain constructs complex meaning beyond literal interpretation.

Phonological processing relies heavily on the supramarginal gyrus and the dorsal auditory pathway, which support phoneme recognition, syllable segmentation, and short-term retention of sound patterns. These processes are essential for reading development and speech perception. Research in developmental neurolinguistics shows that difficulties in phonological processing are a key characteristic of dyslexia, emphasizing the importance of neural precision in auditory–phonological circuits.

Pragmatic and discourse-level interpretation involves regions outside traditional language areas, including the medial prefrontal cortex, temporoparietal junction, and right hemisphere analogues of classical language regions. These areas support inference-making, understanding speaker intentions, processing humor, recognizing sarcasm, and integrating social context into communication. This reveals that language is inseparable from social cognition and theory of mind, which allow individuals to interpret subtle communicative cues.

Hemispheric specialization continues to be an important topic in neurolinguistics. Although the left hemisphere typically dominates linguistic processing, the right hemisphere contributes significantly to processing emotional prosody, global coherence, figurative meaning, and narrative structure. This bilateral engagement challenges earlier assumptions and shows that successful communication requires cooperation between both hemispheres.

Neuroplasticity plays a crucial role in shaping language abilities throughout the lifespan. In children, high levels of neural plasticity enable rapid language acquisition and flexible adaptation to multiple languages. In adults, second-language learning activates both declarative and procedural memory systems, with early stages relying on explicit memory and later stages shifting toward automatized, native-like processing. Cases of recovery from aphasia highlight how undamaged brain regions, including those in the right hemisphere, can reorganize to support regained language abilities.

Modern technologies have revolutionized neurolinguistic research. Functional MRI maps blood flow changes linked to language tasks, allowing researchers to visualize active regions during speaking, listening, reading, and writing. EEG and MEG provide millisecond-level temporal resolution, revealing how quickly the brain responds to phonological and semantic stimuli. Diffusion tensor imaging (DTI) maps white matter connectivity, uncovering the integrity and directionality of language pathways. Connectome analysis integrates these data to model language as a complex network of neural interactions, offering new theories about how linguistic computations emerge from neural architecture.

These technologies have also enabled the study of bilingualism at the neural level. Evidence shows that bilingual brains exhibit enhanced executive control, stronger neural connectivity in frontal networks, and greater cognitive flexibility. Regular switching between languages activates control mechanisms that strengthen neural pathways responsible for attention and inhibition. These findings support the idea that bilingualism leads not only to linguistic benefits but also to broader cognitive advantages.

Conclusion

Modern neurolinguistics reveals that language processing is a highly complex and dynamic neural activity involving interconnected networks rather than isolated brain regions. The collaboration of cortical and subcortical structures allows the brain to manage phonological, semantic, syntactic, and pragmatic information efficiently. Advances in neuroimaging and brain-mapping technologies have significantly deepened our understanding of how linguistic abilities develop, how bilingualism shapes neural structures, and how individuals recover from language impairments. These insights contribute to more effective approaches in language teaching, speech therapy, and rehabilitation, demonstrating the importance of integrating neurolinguistic knowledge into educational and clinical practices.

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