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THEORETICAL FOUNDATIONS OF NEUROLINGUISTICS AND CONTEMPORARY RESEARCH DIRECTIONS

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Abstract. Neurolinguistics investigates the neural substrates of human language by integrating methods from cognitive science, linguistics, and neuroscience. This article outlines the theoretical evolution of the field—from classical lesion-based models to contemporary distributed-network accounts—and surveys six active research directions: language acquisition, bilingualism, reading and dyslexia, syntax-semantics integration, clinical aphasia rehabilitation, and the emerging convergence between artificial intelligence and neurolinguistic research. Evidence drawn from fMRI, EEG, MEG, and computational modelling demonstrates that language is processed by large-scale, dynamically interacting cortical and subcortical networks. The article argues that future advances require methodological pluralism, cross-linguistic diversity, and stronger integration of clinical and theoretical perspectives.

Keywords: neurolinguistics, brain and language, neural networks, bilingualism, fMRI, language acquisition.

INTRODUCTION

Neurolinguistics is the scientific study of how the brain encodes, processes, stores, and produces language. It draws on clinical neurology, cognitive linguistics, and cognitive neuroscience to answer a fundamental question: what biological mechanisms make human language possible? The field has significant practical implications for diagnosing and treating acquired language disorders such as aphasia, developmental conditions including dyslexia and specific language impairment, and neurodegenerative diseases affecting communication.

Its historical roots lie in two 19th-century clinical discoveries. In 1861, Paul Broca demonstrated that damage to the posterior inferior frontal gyrus of the left hemisphere caused expressive aphasia—loss of fluent speech with relatively preserved comprehension. In 1874, Carl Wernicke identified that lesions to the superior temporal gyrus produced the opposite pattern: fluent but semantically incoherent speech alongside severely impaired comprehension. These observations established the principle of hemispheric lateralisation and generated the classical Broca-Wernicke model, which dominated neurological thinking for over a century[1].

Contemporary neuroimaging has revealed the limits of this classical framework. Language engages a vast network of cortical and subcortical regions far beyond the two eponymous zones, and processing unfolds through rapid, parallel activation of distributed circuits rather than sequential relay between discrete modules. The present article traces this theoretical evolution and surveys six research directions shaping the field today (Table 1).

Table 1.

Major Research Domains in Contemporary Neurolinguistics

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Research Domain	Core Focus	Key Methods
Language Acquisition	L1/L2 learning, critical period	EEG, longitudinal studies
Bilingualism	Code-switching, cognitive control	fMRI, MEG, priming
Reading & Dyslexia	Phonological processing, VWFA	Eye-tracking, ERP (N400)
Syntax & Semantics	Neural structure-building	fMRI, P600, N400
Clinical / Aphasia	Language rehabilitation	Lesion mapping, TMS, tDCS
AI & Computational NL	LLM vs. human cognition	Brain-score benchmarks, RSA

LITERATURE REVIEW AND RESEARCH METHODOLOGY

The Broca-Wernicke-Lichtheim diagram conceptualised language as two cortical centres—motor and auditory word images—connected by a fibre pathway.

While elegant, the model failed to account for the full complexity of aphasia and neglected contributions from right-hemispheric and subcortical structures. The Dual-Stream model (Hickok & Poeppel, 2000, 2007) offered the most influential modern revision: a dorsal stream connecting superior temporal to premotor cortex mediates sensorimotor integration and speech production, while a ventral stream projecting toward inferior frontal cortex underpins phonological-to-semantic mapping. Crucially, both streams are initially bilateral, challenging strict left-hemisphere dominance. Friederici's (2017) Hierarchical Network Model further identified a temporal architecture in which early phonological analysis in the superior temporal gyrus precedes later syntactic and semantic integration in Broca's area and the angular gyrus—a sequence supported by ERP evidence (ELAN, P600, N400)[1].

Neurolinguistics employs a suite of complementary techniques that differ in spatial and temporal resolution. Functional MRI (fMRI) offers millimetre-level spatial resolution via BOLD signals, enabling whole-brain localisation of lexical, syntactic, and semantic processes, but its temporal resolution is limited to the order of seconds. Electroencephalography (EEG) and its event-related potential (ERP) derivative provide millisecond temporal precision, revealing canonical linguistic signatures: the N400 (semantic anomaly), P600 (syntactic reanalysis), and ELAN (early syntactic violation). Magnetoencephalography (MEG) combines EEG-like temporal resolution with superior source localisation, making it valuable for phoneme perception and sentence comprehension studies.

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Voxel-based lesion-symptom mapping (VLSM) statistically relates patterns of brain damage to specific language deficits across patient cohorts, providing causal anatomical inference unavailable from correlational imaging. Transcranial magnetic stimulation (TMS) and direct-current stimulation (tDCS) allow targeted disruption or enhancement of cortical excitability, supplying the causal evidence that correlational methods cannot. Table 2 summarises key brain regions and their associated functions as established by these methods.

Table 2.

Key Brain Regions and Associated Language Functions

Brain Region	Language Function	Evidence Source
Broca's Area (BA 44/45)	Syntax, speech production	fMRI, lesion studies
Wernicke's Area (BA 22)	Lexical-semantic comprehension	fMRI, VLSM
Angular Gyrus (BA 39)	Reading, cross-modal integration	fMRI, rTMS
Superior Temporal Sulcus	Speech perception, phonology	MEG, EEG
Prefrontal Cortex (DLPFC)	Working memory, L2 control	fMRI, TMS

RESULTS AND DISCUSSION

Research on language acquisition reveals that the infant brain is primed for language from birth: neonates discriminate the rhythmic properties of their native language from non-native languages within days, reflecting in utero exposure. Longitudinal EEG and MEG studies document progressive specialisation of perisylvian cortices during the first year, paralleling the emergence of babbling. For second-language (L2) acquisition, neuroimaging consistently shows that early, proficient bilinguals activate overlapping networks for L1 and L2, while late learners with lower proficiency recruit additional prefrontal working-memory resources, reflecting more effortful processing.

The bilingual brain simultaneously manages two linguistic systems, engaging cognitive control networks—particularly the left DLPFC and anterior cingulate cortex—to suppress the non-target language. This ongoing competition underlies the well-documented trade-off between slower lexical access and enhanced executive function in bilinguals. Code-switching studies using EEG and fMRI reveal elevated processing costs at unexpected language switches, implicating both language-specific and domain-general control systems. Recent work employs portable fNIRS and mobile EEG to study bilinguals in naturalistic conversational contexts, moving beyond constrained laboratory paradigms[2].

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Reading co-opts neural circuits originally dedicated to object recognition and spoken language. The left fusiform Visual Word Form Area (VWFA) responds selectively to written words and serves as a hub connecting orthographic input to phonological and semantic representations. Cross-linguistic fMRI comparisons demonstrate VWFA engagement across alphabetic, syllabic, and logographic writing systems, with greater phonological-area recruitment for alphabetic readers. Developmental dyslexia—characterised by a phonological processing deficit—is associated with reduced grey matter in temporoparietal regions, hypoactivation of the left superior temporal and angular gyri, and diffusion tensor imaging differences in the arcuate fasciculus. Intensive phonological instruction partially normalises these activation patterns.

Classical ERP research distinguished syntactic (P600) and semantic (N400) processing via distinct components, implying partially segregated systems. However, interactive models demonstrate that semantic plausibility modulates syntactic repair from an early stage. The anterior temporal lobe mediates rapid phrase-level semantic composition (confirmed by intracranial EEG and MEG), while Broca's area integrates complex hierarchical syntactic dependencies. A central open question is whether these regional contributions reflect modular linguistic processors or reflect more general working-memory and prediction operations shared with non-linguistic cognition[5].

Modern clinical neurolinguistics moves beyond classical aphasia taxonomy toward lesion network mapping—characterising patients by the functional connectivity profile of the damaged region within the broader language network, which better predicts recovery than lesion location alone. Evidence-based therapies—constraint-induced language therapy, semantic feature analysis, script training—demonstrate efficacy in chronic aphasia, with neuroimaging revealing the plasticity mechanisms that support gains. Non-invasive brain stimulation (tDCS applied to perilesional or right-hemisphere homologous cortex) is increasingly used as an adjunct to behavioural treatment.

Large language models (LLMs) such as BERT and GPT-family transformers have created a new dialogue with neurolinguistics. Representational similarity analysis and neural predictivity benchmarks reveal moderate-to-substantial correlations between intermediate model layers and BOLD signals in superior temporal and inferior frontal cortices, particularly for lexical and syntactic features. This convergence raises profound questions: does distributional learning from text alone encode sufficient information to predict brain activity, or does the alignment reflect superficial commonalities in the representational demands of any efficient linguistic system? Answering these questions requires adversarially testing model predictions against neuropsychological dissociations—a methodological bridge between AI and clinical neurolinguistics[7].

Three overarching themes emerge from this review. First, the replacement of discrete-centre models by distributed-network accounts represents genuine theoretical progress. Language is an emergent property of coordinated activity across fronto-temporo-parietal networks, modulated by subcortical structures. The Dual-Stream and Hierarchical Network models organise this complexity, but neither commands consensus, and synthesis remains a priority.

Second, methodological pluralism is essential. The traditional reliance on fMRI and lesion analysis is now productively combined with the millisecond resolution of EEG/MEG, the causal leverage of TMS/tDCS, and the ecological validity of portable imaging technologies. No single method is sufficient; triangulation across methods is the hallmark of rigorous neurolinguistic research[4].

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Third, the field must overcome a persistent Indo-European bias. Most neurolinguistics studies involve speakers of English and Western European languages. Agglutinative languages such as Uzbek, Turkish, and Finnish—where grammatical information is encoded through rich suffixation rather than word order—provide critical test cases for models of morphological processing. Cross-linguistic diversity is not merely an empirical desideratum but a theoretical necessity if the field is to make claims about universal properties of language in the brain.

CONCLUSION

Neurolinguistics has undergone a paradigm shift over the past three decades, evolving from a localisationist framework grounded in clinical observation to a network-level science powered by advanced neuroimaging and computational modelling. Language is now understood as a property of large-scale, dynamically interacting neural systems rather than a product of discrete cortical centres. The six research directions reviewed here—language acquisition, bilingualism, reading, syntax-semantics integration, aphasia rehabilitation, and AI–brain alignment—collectively define the field's frontier and illustrate its interdisciplinary vitality. Future progress requires sustained collaboration among linguists, neuroscientists, clinicians, and computer scientists, and must prioritise typological diversity in research samples to build genuinely universal accounts of language in the brain.

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