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BRIDGING GENERATIVE GRAMMAR AND NEUROLINGUISTICS: CORRELATIONS BETWEEN CHOMSKYAN SYNTACTIC MODELS AND BRAIN NEURAL NETWORKS

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Abstract. This paper investigates the neurobiological reality of Noam Chomsky's Generative Grammar framework, specifically focusing on the computational operation *Merge* and hierarchical structure building. While generative linguistics long operated on abstract mathematical and cognitive planes, recent advances in functional Magnetic Resonance Imaging (fMRI), Magnetoencephalography (MEG), and neural oscillations provide empirical data aligning with Chomskyan models. This study reviews and synthesizes recent neuroimaging data (2020–2026) to map structural syntax onto specific brain networks. The results confirm that hierarchical tree structures, rather than simple linear sequences, are localized within the left Inferior Frontal Gyrus (BA 44/45, Broca's area) and supported by the Superior Temporal Gyrus via the arcuate fasciculus. This correlation strongly validates the biological basis of a dedicated human language faculty.

Keywords: Generative Grammar, Neurolinguistics, Minimalist Program, Merge, Broca's Area (BA 44/45), Hierarchical Syntax, Cortical Oscillations, Fronto-temporal Network, Chomskyan Theory.

Introduction. For decades, a fundamental schism existed between theoretical linguistics and cognitive neuroscience. Noam Chomsky's Generative Grammar, from the classical Principles and Parameters framework to the contemporary Minimalist Program, posits that human language is governed by an innate, biologically determined capacity known as Universal Grammar (UG) (Iacono, 2025). The core computational engine of this faculty is *Merge*-a recursive operation that takes two syntactic objects and combines them into a structured hierarchical set. However, early neurolinguistic models relied heavily on linear, associationist frameworks, viewing language as a chain of words processed sequentially (Skinnerian legacy). This tension introduces a critical research question: *Does the human brain process language using the hierarchical, recursive models predicted by generative grammar, or does it rely on sequential, statistical probabilities?* With the advent of high-resolution neuroimaging and neuro-computational parsing models between 2020 and 2026, researchers have begun tracking the millisecond-by-millisecond construction of syntax in the brain. This paper explores the direct correlation between Chomsky's abstract syntactic models (specifically *Merge* and hierarchical dominance) and localized neuroarchitectural dynamics, proving that the human brain operates as a generative parser.

Methods. This study utilizes a systematic review and meta-synthesis methodology, examining neuroimaging and electrophysiological empirical data published between 2020 and 2026.

Search: PubMed, PMC, bioRxiv (2020-2026)]

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[Filtering: Keywords: "Merge",]
["Hierarchical Syntax", "Broca's Area"]

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[Final Corpus Selection: 5 Core Empirical]

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[Studies (fMRI, MEG, EEG Oscillation)]

Inclusion Criteria:

Studies isolating syntactic structure-building from semantic retrieval.

Experiments contrasting hierarchical tree processing with linear sequence memory (e.g., Artificial Grammar Learning vs. Natural Language).

Research utilizing advanced neuro-computational parsers linked to neural signals (e.g., X-bar theory tracking). Data from functional Magnetic Resonance Imaging (fMRI) were analyzed for anatomical localization, Magnetoencephalography (MEG) for temporal tracking, and Event-Related Potentials (ERP) alongside delta-theta phase-amplitude coupling for frequency-domain dynamics.

Results. The synthesis of recent neuroimaging data reveals a highly localized and structured network dedicated exclusively to the generative properties of grammar. The empirical findings can be categorized into three major neural correlations: Recent individual-subject fMRI and lesion studies (Chen et al., 2023; Iacono, 2025) demonstrate that when processing hierarchical syntax, the brain consistently activates a distinct fronto-temporal network. Broca's area, specifically the **Pars Opercularis (Brodmann Area 44)** and **Pars Triangularis (BA 45)**, serves as the computational hub for *Merge*.

Brain Region	**Syntactic/Linguistic Correlate (Chomskyan Model)**	**Neurocomputational Function**
Left IFG (BA 44/45) *(Broca's Area)*	Hierarchical Structure Building / *Merge*	Generates non-linear tree structures; processes long-distance dependencies and displacement.
Posterior STG *(Wernicke's Area)*	Lexical-Syntactic Integration	Syntactic category selection (Headedness) and lexical projection.
Arcuate Fasciculus *(White matter pathway)*	Information Pipeline	Transmits phrase-structure chunks rapidly between frontal and temporal hubs.

A landmark neuro-computational parsing experiment by Coopmans et al. (2025) applied X-bar theoretical models to human brain activity during sentence comprehension. The researchers tracked whether brain states matched sequential word-by-word models or hierarchical phrase structures. The data showed that neural activation complexity metrics perfectly correlated with **X-bar tree building**, meaning the brain computes abstract structural nodes (e.g., converting a Noun Phrase [NP] and Verb Phrase [VP] into a higher-order Sentence [S] node) rather than just tracking the next incoming word. Recent EEG/MEG research in 2024–2025 shows that the brain utilizes distinct neural rhythms to register hierarchical boundaries. When a reader processes a sentence, cortical oscillations in the **delta band (1–3 Hz)** track the phrase boundaries (e.g., identifying full phrases), while **theta band (4–7 Hz)** oscillations track lexical items and their heads (Yang, 2025; Murphy, 2025). This provides absolute physical proof of the "cycles" of syntax building predicted in Chomsky's Minimalist Program.

Discussion. The empirical findings from 2020–2026 provide compelling evidence supporting the biological validity of Generative Grammar. The structural localization and temporal tracking of

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language in the brain directly refute pure connectionist or behaviorist claims that language is merely a statistical probability machine. Consider the following linguistic example showcasing Chomskyan displacement and structural hierarchy:

Example: *The boy [who the girls decoration noticed] smiled.*

In a purely linear model, the brain would struggle to connect the subject *"The boy"* with the matrix verb *"smiled"* because of the intervening relative clause. However, neurolinguistic evidence shows that during the processing of this sentence:

1. As soon as the reader hits *"noticed"*, **BA 44** fires rapidly, performing a structural *Merge* operation.
2. It recognizes a hidden structural gap (trace) and syntactically moves or links the relative clause back to *"the boy"*.
3. This non-linear computation is driven by internal structural trees, not linear distance.

Krogh & Pylkkänen (2025) confirmed via MEG that manipulating these exact syntactic dependencies activates localized fronto-temporal regions without taxing general working memory networks. This demonstrates that syntax processing relies on an independent, dedicated linguistic module-precisely what Chomsky defined as the **Language Acquisition Device (LAD)** or **Language Faculty**. Furthermore, the emergence of linguistic universals across diverse typological languages correlates with the structural architecture of the **Arcuate Fasciculus**. This white matter tract is uniquely hyper-developed in humans compared to non-human primates, explaining why only humans possess the computational capacity for recursive *Merge* (Iacono, 2025).

Conclusion. This paper concludes that there is an explicit, verifiable correlation between Chomsky's Generative Grammar and modern neurobiological models. Syntax is not an abstract mathematical fiction; it is a hardwired biological reality localized in the left fronto-temporal network of the human brain. The operation *Merge* operates through synchronized delta-theta neural oscillations, mapping incoming lexical strings into hierarchical trees via Broca's area. Future research should look deeper into how large language models (LLMs) and biological neural networks diverge in processing these structures, opening new avenues for both computational linguistics and neuropedagogy.

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