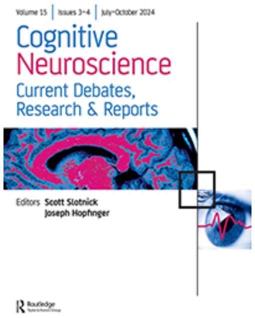

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COMMENTARY

Grounding the computational principles of language in neurobiology requires cross-modal and cross-linguistic data

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ABSTRACT

Murphy's discussion (2025) of his recent ROSE model includes explicit linking hypotheses connecting computational, algorithmic, and implementational levels in the study of language and its neurobiological basis. Here, I argue that establishing the neural basis of the abstract principles underlying natural language syntax will require new data from sign languages, tactile sign languages, as well as typologically diverse spoken languages. The assumption of modality-independent processes for structure building lies at the heart of ROSE, but the proposed correlates for hierarchical and sequential operations must be subjected to empirical test across languages and modalities in the future.

KEYWORDS

Syntax; hierarchical structure; parsing models; language modality; linguistic diversity; sign language; tactile sign language

Establishing the abstract nature of the computational principles of language requires data from sign languages as well as typologically diverse spoken languages. In linguistics, the biological matrix underlying our species-specific ability to combine individual lexical items (i.e., words or signs) into phrases and sentences has traditionally been referred to as Universal Grammar (Chomsky, 1965, 2005; Friederici et al., 2017). Despite the use of the term *grammar*, the study of Universal Grammar is not concerned with 'language universals' (i.e., grammatical structures shared by all of the world's different languages; Evans & Levinson, 2009; Trettenbrein, 2015). Instead, 'the most appropriate terminology for describing the contents of Universal Grammer may turn out to be terminology of neuroscience' (Bolender, 2010). In this spirit, Murphy (2025) elaborates on his recent ROSE model (Murphy, 2024) and attempts to identify possible elements of a so-called Universal Neural Grammar. This commentary focuses on the need for probing the stipulations of ROSE using data from different modalities in which language can be externalized (e.g., the visuo-kinaesthetic modality of sign languages or the haptic sense in case of tactile sign languages used by deafblind people; Emmorey, 2021; Obretenova, 2010; Trettenbrein et al., 2025) as well as data from lesser-studied spoken languages (Malik-Moraleda et al., 2022), all of which remain significantly underexplored in the current literature.

Starting from a computational-level analysis of natural language syntax, ROSE provides a number of tentative but explicit linking hypotheses to the algorithmic and implementational levels capturing how syntactic structure is built during actual language comprehension and production. The three classical levels of analysis in cognitive science (i.e., computational, algorithmic, and implementational; Marr, 1982) are famously disconnected and there is a well-known and clear mismatch between the basic units of linguistic and neuroscientific analysis (e.g., 'noun phrase' vs. 'neuron'; Poeppel & Embick, 2013). Moreover, there is a possibility that the units studied at the different levels may be ontologically incommensurable (Embick & Poeppel, 2015; Poeppel & Embick, 2013), but the jury is still out on that one as both our understanding of the fundamental units of linguistics and neuroscience are still incomplete and evolving. That is, still very little is known about how the brain actually computes (Gallistel, 2016, 2017; Gallistel & King, 2009; Trettenbrein, 2016). Forging tentative links between the different levels of analysis is the task of any experimenter and theorist in the cognitive neuroscience of language (van der Burght et al., 2023) and ROSE provides explicit linking hypotheses for all of them (e.g., low-frequency synchronization and cross-frequency coupling code for recursive structural inferences, etc.). However, the purported links between the levels put forward as part of ROSE remain tentative and

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correlational in nature but can be subjected to empirical test in appropriate experiments.

The insight that language can be expressed in different modalities (i.e., speech, sign, and tactile sign) and the typological diversity of the world's languages tentatively support the central role of abstract hierarchical representations in ROSE. Cognitive science has demonstrated that sign languages are natural languages with complex organization at all levels of linguistic analysis (e.g., phonology, semantics, and syntax) articulated using the hands, face, and body (Klima et al. 1979; Mathur and Rathmann 2014; Stokoe 1960). With regard to their neural basis, the processing of sign languages also recruits primarily left-hemispheric perisylvian cortex, though the way in which the core and extended language network work in tandem with other bilateral networks for the processing of modality-specific information differs (Emmorey, 2021; Trettenbrein et al., 2021, 2025). Significantly, combinatorial processing in sign language also recruits the left posterior inferior frontal gyrus as well as the left posterior middle temporal gyrus and sulcus (Trettenbrein, Meister, et al., 2024). For the tactile sign languages used by deafblind people, both linguistic (Checchetto et al., 2018; Edwards & Brentari, 2020) and neural data (Obretenova, 2010) are sparse but indicate that basic principles of linguistic organization and where they are processed in the brain may also extend to the tactile modality. In sum, these findings suggest that the hierarchically structured representations over which the language system computes can be mapped to the sensorimotor system in drastically different ways.

Typological diversity and especially language in different modalities should be explored as future testing ground for many of the explicit predictions of ROSE. Linguistic diversity matters because, for example, MERGE is operationalized as *combine* and approximated by *node count* in ROSE. However, measures such as node count are only transparent in isolating languages where terminals correspond to lexical items (e.g., the English phrase *drive fast* vs. the single morphologically modified sign DRIVE-fast in German Sign Language [DGS] expressing the same proposition). Furthermore, node count depends not only on the type of parsing model but is also strongly influenced by typological parameters: In DGS and many spoken languages, adjectives follow the noun (e.g., BOAT RED in DGS or *barco rojo* in Spanish as opposed to the English *red boat*). Such structures are difficult for left-corner parsers because there is no syntactic reason to project an open node after processing the noun (though there may be prosodic or semantic ones), different from English where adjectives may project an open node because they ultimately have to followed by a noun (cf. Trettenbrein, Maran, et al., 2024). In general, parsing models are unfortunately rarely available for lesser-studied languages regardless of modality and modality-specific aspects are usually not accounted for: A key example is the simultaneous presence of a variety of syntax-relevant cues in sign language processing (e.g., manual signs are accompanied by non-manual components with an overt syntactic function such as raised eyebrows marking a tropicalized structure in DGS) which contrasts with the strict sequentially of speech.

The assumption of modality-independent and cross-linguistic processes for syntactic structure building is at the heart of ROSE and inherited directly from generative grammar, but the proposed different correlates for hierarchical and sequential operations need to be subjected to empirical test. Because hierarchical representations are still language-specific but rely on supposedly universal operations, experiments with typologically diverse languages and different modalities can provide an ideal testing ground to determine the cross-linguistic validity of the proposed linking hypotheses and the degree to which representations and operations are similar across languages and modalities.

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