Aligning psycholinguistics, neuroscience, and aphasiology with respect to grammatical encoding

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Abstract

The influential model of sentence production developed by Bock and Levelt (1994) posits two stages of grammatical encoding: functional processing and positional processing. This model is sometimes referred to as the "consensus model" of grammatical encoding, given its wide support within psycholinguistic research. However, most research in the cognitive neuroscience of syntax does not align well with this two-stage consensus model. We will review recent research on the neurobiology of syntax, focusing on lesion-symptom mapping in people with aphasia, and in particular on the agrammatism-paragrammatism distinction. We will illustrate how a two-stage model of grammatical encoding aligns well with this distinction but does not precisely match the processing levels of functional and positional processing proposed by Bock and Levelt. We will illustrate how this consensus model can be revised in order to better accommodate the data. Finally, we will evaluate extant models of syntax and the brain, illustrating their respective adequacy and inadequacy with respect to accounting for these phenomena as well as their poor alignment with the consensus psycholinguistic model. We argue that models which involve two stages of grammatical encoding are more fruitful for pursuing relationships between psycholinguistics, aphasiology, and neuroscience.

Overview

Poeppel & Embick (2005) made a now-classic argument regarding the "Granularity Mismatch Problem": the misalignment between the terms and concepts of linguistics and neuroscience. Here we advocate for one very specific alignment between linguistics, neuroscience, and aphasiology:

- Psycholinguistic theory has settled on a "consensus model" of two stages of syntactic encoding during sentence production (Bock & Levelt, 1994; Ferreira & Slevc, 2007): functional processing (reflecting the generation of hierarchical structure, driven by semantic considerations) and positional processing (sequencing of elements, driven by phonological and motor considerations).
- There are two general clinical profiles in which grammatical structure during sentence production is disordered in aphasia: agrammatism (syntactic reduction/simplification) and paragrammatism (fluent but grammatically incoherent speech with syntactic errors). These profiles have been well-established historically and in the clinic. However, modern lesion-symptom mapping has also provided evidence in favor of a double dissociation of these profiles with respect to underlying brain damage (Matchin et al., 2020; but see also Casilio et al., 2024).
- The functional neuroimaging literature on syntax in the healthy brain has converged on roughly two cortical zones of activation for syntax-related manipulations: the posterior temporal lobe and inferior/middle frontal lobe. These effects come from manipulations of processing complexity, such as noncanonical and/or complex sentence structure vs. canonical and/or simpler sentences, as well as manipulations of representational complexity, such as structured sentences vs. non-structured word lists (Matchin, 2021).
- The first stage of syntactic encoding, functional processing, corresponds to the posterior temporal brain system, which, when damaged, produces paragrammatism, and the second stage, positional processing, corresponds to the inferior/middle frontal brain system, which, when damaged, produces agrammatism.

We will review each of these areas of research, making the argument that, all things being equal, theoretical models which facilitate alignment among these fields are stronger than those which do not. We argue that the two-stage consensus model of psycholinguistic encoding provides a solid foundation for understanding neurobiology and aphasiology, particularly when updated according to insights obtained from formal linguistic analysis (concerning the alignment of lexical and syntactic representations). This alignment may produce fruitful avenues of future interdisciplinary research. While there are interdisciplinary one-stage alternatives that have been promoted in the literature, these models are typically postulated in isolation in each subfield without strong integrative evidence and do not sufficiently address key empirical findings motivating two-stage models.

It should be noted that we are not making any claims regarding the precise temporal dynamics of these models. Although some two-stage models advocate for a strictly serial rather than parallel processing model, we leave this question for future work and focus on high-level computational processes. Similarly, we focus primarily on the aphasiology and hemodynamic literature on functional localization rather than temporal dynamics and electrophysiological research.

Two-stage psycholinguistic models of grammatical encoding during sentence production

Overview of the Two-Stage Model of Grammatical Encoding

Two prominent models of sentence production, the Bock & Levelt (1994) model and the Ferreira & Slevc (2007) model, both outline a two-stage process of grammatical encoding. According to these models, speaking begins with a message-level representation that captures the speaker's intended meaning. This representation serves as the raw material for grammatical encoding, which is divided into two major processing steps: functional processing and positional processing. Each step is further broken down into sub-processes, including lexical selection, function assignment, constituent assembly, inflection, and so on.

Functional Processing

Lexical selection involves retrieving lemmas—abstract word forms that include meaning and associated grammatical features such as syntactic category (e.g., noun, verb) and verbal transitivity (e.g., transitive, intransitive). Importantly, lemmas do not include phonological information and are not explicitly sequenced at this stage. For example, consider the sentence originally used by Bock and Levelt: *"She was handing him some broccoli."* At this stage, the lemmas for *she*, *him*, *broccoli*, and *hand* are retrieved along with their grammatical information.

Function assignment links participant roles (e.g., actor, undergoer) to grammatical roles (e.g., subject, object). In the example, the feminine pronoun lemma (*she*) is linked to the subject role, the masculine pronoun lemma (*him*) is linked to the dative function, *broccoli* to the accusative function, and *hand* to the main verb function. By assigning the subject role to *she*, the speaker commits to an active structure. Another key feature of this stage is that the ordering of constituents is not yet fixed; their sequencing is determined at the positional level.

Positional Processing

At the positional level, constituent assembly creates an ordered arrangement of word slots based on pre-stored phrasal frames. In English, the dominant subject-verb-object (SVO) structure dictates that the subject precedes the verb, and the verb precedes the object. This stage also determines the internal structure of phrasal units, such as ensuring that articles precede nouns (e.g., *the broccoli*).

The final stage of grammatical encoding—inflection—is responsible for creating morphological slots. In English, this involves details such as number, tense, and aspect, which are often bound to other words. For example, the verb *handing* carries tense information (past progressive). Importantly, inflectional affixes are represented as an intrinsic part of the grammatical frame, ensuring that these details are seamlessly integrated into the final utterance.

The Ferreira & Slevc (2007) “Consensus Model” involves a similar premise to the Bock & Levelt model. It begins with a “message encoding” stage, but splits into two streams that each have two stages corresponding to the functional/positional distinction: “content processing” (lemma retrieval followed by morphological (sub-word) encoding) and “structure building” (function assignment based on thematic roles, followed by constituent assembly, both based on the message and without direct reference to lemmas). As a consequence of this, the Consensus Model allows syntactic structure building to be independent from lemma retrieval (based on evidence from syntactic priming: that syntactic structures can be primed independently from the lemmas that they are composed of). The two streams (content processing and structure building) are joined again at the stage of phonological and phonetic encoding (the exact mechanism for this is vague, but it has been suggested that this can be attributed to the general “coordination problem” in cognitive science, Bock (1987)).

Evidence Supporting a Two-Stage Model

Here, we briefly review the evidence for and against the model (for further discussion, see Ferreira & Engelhardt, 2006). Two primary sources lend support to the two-stage model: spontaneous speech errors and data from experiments on lexical and syntactic priming, as well as the computation of subject-verb agreement. One prominent type of spontaneous speech error is semantic substitution, which appears to stem from a problem with lexical selection. For example, a sentence like *"She was handing him some broccoli"* might become *"She was handing him some cauliflower."* These substitutions retain the overall meaning of the intended word and almost always belong to the same grammatical category, such as noun, verb, adjective, adverb, or preposition. Errors in function assignment, known as word exchange errors, occur when elements are assigned to incorrect grammatical roles. For example, *"She was handing him some broccoli"* might become *"He was handing her some broccoli."* These errors typically involve words that belong to the same grammatical category but serve different grammatical functions in the sentence. Another type of exchange error is a sound exchange error, such as *"larietal pobe"* instead of *"parietal lobe."* While word exchange errors typically involve words from different phrases, sound exchange errors usually occur within a single phrase and often involve words belonging to different grammatical classes.

An important feature of word and sound exchange errors is that they almost exclusively involve words from major lexical categories—nouns, verbs, adjectives, and adverbs—rather than function words—such as pronouns, auxiliary verbs, or prepositions—or functional morphology.

This observation suggests that major lexical categories and function words may be generated by distinct processes. Supporting this distinction is another type of exchange error, known as a stranding error, which typically occurs within phrases. Garrett (1980) illustrates this with the example *"I went to get my park trucked"* instead of the intended *"I went to get my truck parked."* In stranding errors, open-class elements like nouns and verbs are misordered, while closed-class elements, such as prepositions and inflectional markers, remain correctly positioned. These errors indicate that inflectional morphemes are integral components of the phrasal frame and that such processing takes place at the level of positional processing.

Lexical priming experiments further illustrate the distinction between functional processing and positional processing. When a word's meaning is primed (semantic priming), it influences where the word is placed in the sentence—for example, a primed noun is more likely to become the subject. However, when a word's sound is primed (phonological priming), it has a much weaker effect, mostly influencing the final stages of sentence production, like word ordering or last-minute adjustments. In some cases, phonological priming can cause slight changes in word placement, suggesting that some adjustments in linear order may happen during a final review of the sentence before it is spoken. This supports the idea that meaning and grammatical roles are determined early (functional processing), while phonological forms and linear order are determined later (positional processing).

Syntactic priming—the tendency to reuse sentence structures recently heard or produced—also supports the two-stage model of language production by demonstrating a distinction between grammatical roles (subject, object, etc.) and linear order. For example, after hearing a passive sentence like *"The ball was thrown by the boy"* or a prepositional dative like *"The driver showed the overalls to the mechanic,"* speakers are more likely to use those same structures in subsequent speech. Furthermore, other studies show that the linear order of elements in the sentence can be primed independently of its structure ("*the ball was on the table*" vs "*on the table was the ball*"), further suggesting that sentence structure is initially represented in an abstract hierarchical form (dominance relationships) before being linearized into a specific word order.

The process by which speakers compute subject-verb agreement during sentence production also provides evidence for the two-stage model. For example, in the phrase *"The spokesman who defended the actions,"* the singular head noun *spokesman* must agree with the main verb, even though there is a plural noun (*actions*) embedded within the subject. Experiments have shown that agreement errors, where the verb incorrectly agrees with the plural noun instead of the singular head noun, occur equally often in yes/no questions (*"Are the helicopter for the flights safe?"*) and declarative sentences (*"The helicopter for the flights are safe"*). This consistency suggests that agreement is determined based on hierarchical relationships (i.e., which noun dominates grammatically) rather than the linear order of words in the sentence. Such findings indicate that agreement relations are computed during an earlier stage of sentence production, before the specific word order is finalized at the positional level.

Evidence Against a Two-Stage Model

According to the two-stage model, phonological information should not influence the assignment of grammatical roles during the functional stage. However, evidence from phonological priming experiments suggests otherwise, potentially supporting a one-stage model of syntactic encoding. In Bock (1987), participants who encountered a phonologically related prime (e.g., the word *trump*) were more likely to produce sentences influenced by that wordform. For instance, when shown a picture of a truck towing a car, participants were more likely to say *"The car is being towed by a truck"* instead of *"The truck is towing the car."* This suggests that the phonological relationship between *trump* and *truck* caused some interference or inhibition, affecting sentence structure.

The two-stage model predicts that phonological primes should have no impact on the functional stage, as this stage is concerned solely with meaning and grammatical roles, not phonology. The observed effect of phonological priming undermines this strict separation by showing that sounds can influence sentence production at earlier stages than the model allows. However, one possibility is that phonological priming effect reflects a later stage of sentence production, such as when the utterance is reviewed for overall acceptability (the "monitoring" stage). Another possibility is that semantic, syntactic, and phonological information might be retrieved simultaneously, even if dominance and linear order are still computed separately. Additionally, the inhibitory effect of phonological priming, as opposed to the facilitation typically seen in semantic priming, might be due to lateral inhibition among phonological competitors—a phenomenon that merits further study.

An additional piece of potential evidence against the two-stage model concerns structural priming. In English, a dative sentence can appear in two forms: the prepositional dative (*The driver showed the overalls with the stains to the mechanic*) and the shifted prepositional dative (*The driver showed to the mechanic the overalls with the stains*). While both structures share the same hierarchical (dominance) relations—assigning the verb (*showed*), object (*overalls*), and recipient (*mechanic*) their respective roles—they differ in linear order, as the prepositional phrase (*to the mechanic*) precedes or follows the object. According to the two-stage model, the shared hierarchical structure should enable priming between these forms, but experiments by Pickering et al. (2002) found no evidence of this, suggesting that dominance and linear relations might be computed simultaneously, as proposed by a single-stage model (see similar evidence from subject-verb agreement in English in favor of single-stage models from Haskell and MacDonald, 2005).

However, the lack of priming observed in Pickering et al. (2002) may be attributed to the relative rarity of the shifted prepositional dative in English and its dependence on strict discourse conditions, which could weaken its priming potential. Additionally, the rigid word order of English may limit the generalizability of these findings, highlighting the need to study languages with more flexible word order patterns for further insight. Finally, it is unclear if in fact there is a shared hierarchical structure for these two representations at all. Ultimately, the bulk of current psycholinguistic evidence supports a fundamental distinction between functional and positional processing proposed by Bock & Levelt (1994) and further ensconced in the consensus model proposed by Ferreira and Slevc (2007).

On Lemmas and the lexicon-syntax distinction

Though the evidence strongly supports these models in terms of the two-stage approach to grammatical encoding, this is not a full endorsement of the other aspects of those models. In particular, these models are centered around a "lemma" representation which separates morphosyntax (structure below the word level) from phrasal syntax (structure above the word level). There is a growing consensus in linguistic theory that syntax and morphology are part of the same system and must be able to interact freely (Bruening, 2018; Jackendoff, 2017; Goldberg, 1995; Halle & Marantz, 1993, a.o.), and furthermore, that the "word" level is not easily definable in the first place (Haspelmath, 2017, 2023). As Krauska & Lau (2023) discusses, the formulation of lemmas as syntactic atoms with unique lexical concepts and forms is very problematic and causes these models to struggle with many examples from natural language. In particular, these models cannot accommodate languages that involve a great deal of morphological complexity (as seen in polysynthetic and agglutinative languages), cases where morphological structure interacts with phrasal syntax (as seen for German verbs with separable prefixes, Vietnamese idiomatic collocations (Noyer, 1998), and Mandarin separable verbs (Yu et al., 2024)), and cases where the meaning or form of a syntactic object is dependent on its syntactic context and cannot be determined in isolation (as seen in a variety of languages, including Hiaki (Harley, 2014)). See Matchin & Hickok (2020), Matchin (2023), and Ramchand (2024) for additional arguments from linguistics, psycholinguistics, and neuroscience regarding the convergence of syntax and the lexicon at the levels of representation and processing. The combined evidence suggests that contrary to many received views of linguistic processing in which syntax and lexicon are categorically distinct entities, these instead should be viewed as parts of the same underlying coherent system.

The non-lexicalist model of linguistic structure generation (Krauska & Lau, 2023; Krauska, 2024) relies on two sets of mappings between independent representations of meaning and syntax, and between syntax and form, where linear order is not provided by the hierarchical syntax. However, consistent with the models and evidence previously discussed, the non-lexicalist model still relies on multiple stages of syntactic encoding, where Functional Processing is instantiated in the mappings between meaning and syntax, and syntax and form, while Positional Processing is instantiated as a post-syntactic linear control mechanism that engages prosodic representations to manipulate the linear order of phonological forms. The extent to which this control system capitalizes on purely domain-general operations or control operations that have become specialized for linguistic representations is an open question, although we believe that there is strong empirical evidence for functional specialization of frontal control and memory systems for syntactic processing (see Matchin, 2018 for a review).

In this light, there is evidence from neurobiology and aphasia that both “syntactic” and “lexical” effects are observed in the same brain areas or the same patients. This has sometimes been offered as evidence in favor of single-stage models of linguistic processing (Dick et al., 2001; Fedorenko et al., 2020). However, in a non-lexicalist approach, the relevant major divide in representation and processing is not between syntax and lexicon, but rather between Functional and Positional processing, both of which contain aspects which might otherwise be referred to as “syntax” and “lexicon”. Thus, from this perspective, two independent brain systems or two different patients with different patterns of brain damage may both show “syntactic” and “lexical” effects, yet this may be driven by completely different underlying processing systems (Matchin, 2023). This is a potentially interesting area of future research, which could explore the extent to which syntactic and lexical effects or errors which appear similar on the surface may actually result from distinct systems or deficits.

The Two-Stage Model in Neurolinguistics and Aphasiology

As we will see below, the two-stage model of syntactic encoding during sentence production aligns well with observations from neurolinguistics and aphasiology. Functional neuroimaging research has identified two broad cortical zones strongly implicated in syntactic processing: the posterior temporal lobe and inferior/middle frontal lobe (Matchin, 2021). Aphasiology has identified two major syndromes of grammatical deficits in aphasia: agrammatism and paragrammatism. Existing evidence suggests that the posterior temporal lobe supports the first stage of grammatical encoding: function assignment. When this system is damaged, paragrammatism appears to result, reflecting deficits in this first stage of encoding such as lexical omissions and structurally incoherent sequences. It appears that inferior/middle frontal systems support the second stage of grammatical encoding: positional assignment. When this system is damaged, agrammatism appears to result, reflecting intact structural representations but impoverished output.

Neurolinguistic models of syntax

There is substantial diversity of opinions regarding the neurobiology of syntax. However, oversimplifying this diversity, models can be broken down roughly into three camps: inferior frontal gyrus (IFG) only, IFG + posterior temporal lobe (PTL) jointly, and non-localized or distributed (Yeaton, 2024). Using an automated meta-analysis under the NeuroSynth framework (Yarkoni et al., 2011), we see that journal articles which frequently use terms like “grammatical” or “syntactic processing” report activations in the inferior and middle frontal gyri, as well as in the posterior temporal lobe much more often than those that do not mention these terms (Fig. 1). As such, we start with two assumptions: 1) syntactic processing is not distributed uniformly across the cortex, or even the language network, but is localizable within that network, and 2) syntactic processing occurs in one or more of a small set of candidate regions in the frontal and posterior temporal lobes.

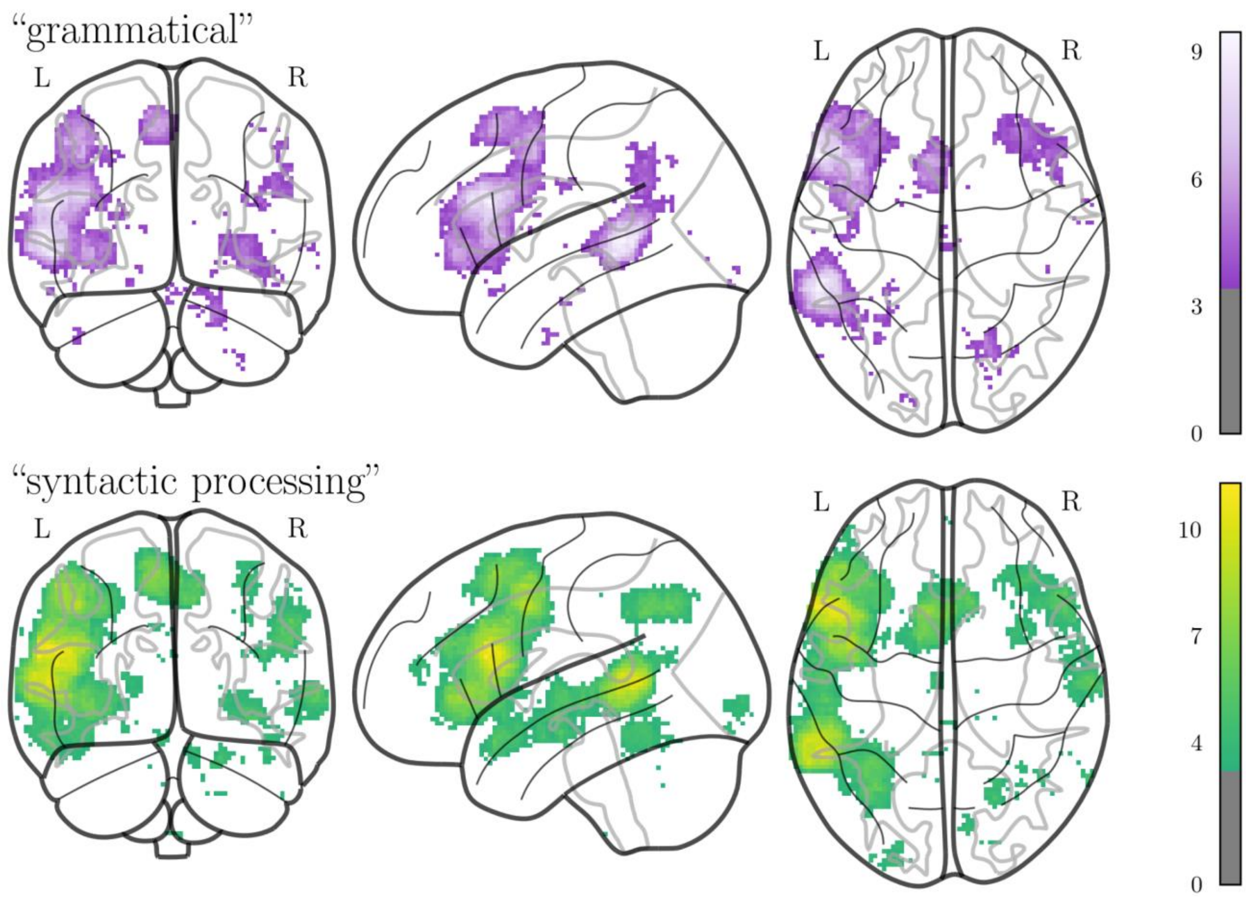

Figure 1. Automated meta-analyses of the neuroimaging literature for terms "grammatical" (236 studies included) and "syntactic processing" (203 studies included). Figures are thresholded at p<0.01.

The first of these assumptions is not universally accepted. A small camp of theorists (i.e., the non-localized/distributed camp mentioned above) has asserted that no part of the neural language system is specialized for syntactic operations (Fedorenko et al., 2012; Blank et al., 2016). This assertion is largely based on data from fMRI wherein they do not find regions of the individually-localized language network which are more activated for sentential than lexical or semantic variables (Fedorenko et al., 2020). Instead, they assert that a) the language system is carrying out semantic composition rather than hierarchical syntax, and b) hierarchical syntax is largely epiphenomenal to semantic composition (Fedorenko et al., 2016).

Inferior frontal lobe only

Under the IFG-only view, the IFG is the seat of the generative "Merge" (Friederici, 2018) or "Unify" (Hagoort, 2016; Hulten et al., 2019) operations that combine atomic linguistic elements into hierarchical trees. Indeed, a large number of functional imaging studies addressing syntactic processing in either production or comprehension implicate the inferior frontal lobe in manipulations of inflection (Marslen-Wilson & Tyler, 2007), syntactic complexity (Pallier et al., 2011; Pattamadilok et al., 2016), and word order canonicity (Europa et al., 2019). Under this account, the atomic elements (i.e., the lexicon) are stored in the posterior temporal lobe (Hagoort, 2016). The observed activation of the PTL in sentence processing is therefore explainable as lexical access (Grande et al., 2012; Wang et al., 2021) or semantic operations like thematic role assignment (Finocchiaro et al., 2015; Zaccarella et al., 2017) rather than syntactic structure building.

Frontal lobe + temporal lobe

The last mainstream camp is one that proposes a division of labor in syntactic processes between frontal and temporal regions (Matchin & Hickok, 2020). Under this proposal, the lexicon is composed of treelets: lemma-like elements which contain structural & semantic information (Hagoort, 2016; Matchin & Hickok, 2020). These treelets are accessed and assembled into hierarchical structures in the posterior temporal lobe (Bozic et al., 2015), and then converted into a linear string in the inferior frontal lobe (Chang et al., 2018). The implication of both the inferior frontal and posterior temporal lobes in hierarchical syntactic processing is well-established in both production and comprehension (Walenski et al., 2019; Giglio et al., 2022). Recent work has also shown that the posterior temporal lobe is sensitive to hierarchical structure (Murphy et al., 2024) and that stimulating it interferes with non-canonical sentence comprehension (Riva et al., 2023). This separation between frontal and posterior temporal regions provides evidence in favor of a two-stage model: the posterior temporal regions support functional processing, and the frontal regions support positional processing.

We return to the neurobiology of syntactic processing below in light of the data from expressive syntactic disorders, presented next.

The agrammatism-paragrammatism distinction in aphasia

Characterizations of deficits by production of omissions of grammar or in non-fluent speech

Adolf Kussmaul, a German medical researcher known primarily for his research on dyslexia (Rehnberg & Walters, 2017), is often distinguished as the first to dissociate grammatical deficits from other deficits in language subsequent to stroke. Kussmaul is considered one of the first researchers to note that aphasic patients often have difficulties producing grammatical sentences (1877; as cited in Goodglass, 1997; Tesak & Code, 2008). He suggested that people with Broca's aphasia in particular produced fewer verbs compared to nouns, omitted and/or substituted functional morphemes (e.g., function words and inflections), and had difficulty with semantically reversible sentences. He advocated for the recognition of two separate aphasic syndromes:

‘*aktaphasie*’ [akataphasia], associated with word ordering errors and omission of verbs (lexical syntax), and ‘*agrammatismus*’ [agrammatism], associated with omissions and substitutions of (bound) functional morphemes. Kussmaul’s observations centered upon production deficits. While he noted deficits to all three levels of grammatical structures, he distinguished deficits in different grammatical structures to distinct syndromes. However, Kussmaul did not largely distinguish errors of omission from misuse. The symptoms he described in both of these syndromes—particularly errors in word order and morphosyntax—might today be termed agrammatism (Thompson, 2019). Deficits in verb use, particularly omissions, are also associated with agrammatism, but are not considered its defining feature.

Contemporaries of Kussmaul also documented similar disturbances to grammatical structuring in speech production. For example, William Henry Broadbent, a British physician, described a condition in his patients which he called “ataxic or aphasic” (1872, p. 174). Noting that others, such as Bastian, Hughlings Jackson, W. Ogle, and Sanders, described similar conditions, Broadbent noted 10 cases of aphasic stroke patients in his care who could at most produce a few nouns in their speech. He distinguished ataxic aphasia from the “amnesic or amnemonic” condition, the former describing a patient who “remembers words, and rehearses sentences in his mind, but has lost the power of utterance”, and the latter describing patients who had forgotten words. Broadbent noted that for amnesic patients, “the mental rehearsal of phrases is imperfect.” Though Broadbent is not often noted as an important researcher of grammar processing in aphasia today (e.g., Goodglass, 1997), he was considered influential by British researchers at the turn of the 20th century (Mills, 1904). Later scholars attributed the term ‘jargon aphasia’ to Broadbent (Bannister, 1974), though this term is better attributed to Hughlings Jackson (1932). Although neither Broadbent nor his named predecessors described grammar/syntax specifically, the deficits they described did correspond to a more modern definition of telegraphic speech in agrammatic aphasia. In particular, Broadbent referred to the exclusive use of nouns and interjections (formulaic speech), though not providing any analyses of the grammatical properties of the words. Thus, Broadbent’s work provided additional early evidence for a correlation between agrammatism and a reduction in verbs.

Arnold Pick, a Czech psychiatrist, also contributed to early research on grammatical deficits in aphasia (Tesak & Code, 2008). Pick promoted use of Kussmaul’s term ‘agrammatism’ in his book, *Die agrammatischen Sprachstörungen* [The agrammatic language disorders] (1913). Pick laid out his own framework of aphasic syndromes based on Wernicke’s work: motor aphasia, resulting from frontal lesions, and sensory aphasia, resulting from temporal lesions. Within this framework, he further distinguished parallel disorders of grammar: motoric agrammatism from sensoric agrammatism. He attributed motoric agrammatism as a result of economy of effort, which he considered a speech motor syndrome. He described “pure cases” as characterized by “disturbances in the use of auxiliary words, incorrect word inflections, and erroneous prefixes and suffixes,” contrasting the “telegraphic style” in motor agrammatism with “erroneous grammatical constructions (paragrammatisms)” in sensoric agrammatism (p. 268). Pick suggested an additional term to describe less severe cases as ‘pseudo-agrammatism’. Sensoric agrammatism he attributed to pre-motor processes since he considered grammar to be the integration of processes. Pick recognized that his characterization of sensoric agrammatism was comparable to a syndrome described by his contemporary, Karl Kleist: ‘paragrammatism’. Although Pick did not ascribe modern terminology, his behavioral characterizations of the dichotomy between two syndromes as a non-fluent syndrome of omissions and a fluent syndrome of ungrammatical insertions may be the first to resemble the modern dichotomy.

Although it has been suggested that little attention had been paid to the grammatical processing in aphasia since Pick’s work (Goodglass & Berko, 1960), in the following decades other researchers did take up the topic (Tesak & Code, 2008). Behavioral symptoms similar to a modern definition of agrammatism include 'motor aphasia' (Goldstein, 1948) and 'syntactic aphasia' (Wepman & Jones, 1964). Notably, Russian neuropsychologist Alexander Luria (1970), described 'efferent motor aphasia' as a pre-motor condition affecting the organization of speech arising as a “result of a pathological inertia of individual articulatory impulses shortly following trauma, and the disturbance of inner speech which develops in subsequent stages as the result of motor agrammatism and loss of the predicative significance of words” (p. 197).

Though earlier characterizations of agrammatism included both reduction in hierarchical structures and certain lexical syntactic categories in speech, more modern characterizations of agrammatism have focused on disturbances to morphosyntax in speech. This characterization rests largely upon work by American researcher Harold Goodglass. Using techniques borrowed from the field of psychology, Goodglass experimentally examined grammatical deficits in people with agrammatic aphasia (typically Broca’s aphasia patients). For example, Goodglass and Hunt (1958) described how each of the three <s> inflections in English dissociate in vulnerability to error in aphasic speech[1]. Due perhaps to the strength of Goodglass’s work or the fact that his research reinvigorated interest in agrammatism, his examination of grammatical deficits in aphasia have guided characterizations since. For instance, Bastiaanse and Thompson (2011, p. 2) described agrammatic production by “omissions and substitutions of grammatical morphemes”, citing Goodglass as their source. Though most researchers center their definition of agrammatism on errors of morphosyntax, others have provided broader characterizations which include hierarchical structure of speech production, for example, as “the simplification of grammatical structure and omission of function words and morphemes” (Matchin et al., 2020, p. 208). They too cite Goodglass as inspiration for this definition.

It may be helpful to compare modern descriptions of agrammatism to Kussmaul’s characterizations of agrammatism and akataphasia. Bastiaanse et al. described both omissions and

[1] Dissociations between the <s> inflections on plural nouns, 3pSg verbs and genitives have also been the topic of work by Goodglass and Berko (1960) and Stockbridge et al. (2020).

substitutions of morphosyntax, which more closely aligns to Kussmaul's distinction of agrammatism as omissions and substitutions of morphosyntax. Matchin et al.'s description of agrammatism including reductions in hierarchical structures along with reductions omissions/simplifications in morphosyntax combines both characteristics from Kussmaul's agrammatism and akataphasia. On the other hand, these modern characterizations do not include a reduction of verbs (or other lexical syntactic categorizes) as stereotypical in agrammatism, although it has been correlated to agrammatism in select patients (Thompson, 2019), and there is renewed interest in understanding potential dissociations between grammatical deficits at distinct structural levels (Ardila, 2001; Faroqi-Shah, 2013; Kiran & Edmonds, 2004; Matchin et al., 2020; Matchin & Hickok, 2020).

Characterizations of deficits by production of ungrammatical insertions or in fluent speech

Although Broadbent noted that Hughlings Jackson had described similar patients, Hughlings Jackson's description of patients with jargon aphasia patients might have best been described as paragrammatic. The term 'paragrammatism' was first coined by German neurologist Karl Kleist, a trainee of Wernicke's. Kleist characterized paragrammatism by "sound-dumbness, naming dumbness and syntactic dumbness" (1914; as cited in Papathanasiou & Coppens, 2017, p. 26). In contrast to agrammatic patients, patients with paragrammatism produce sentences that are "wrongly chosen and thereby amalgamate and contaminate each other… phrases and sentence constructions are not completed… The spoken expression is not simplified… [but] conditioned by a strong overproduction of word sequences, it swells to confused *sentence monsters* (emphasis added)" (p. 10-11). This could be interpreted as the juxtaposition of phrases and clauses that violate hierarchical structuring rules as well as the misuse of words in inappropriate structural nodes. Morphosyntactic errors as substitutions or agreement violations, noted in more modern descriptions, were absent (Matchin et al., 2020).

A similar condition to Kleist's paragrammatism was described by English neurologist Henry Head as 'syntactical aphasia' (1920). Head, referencing Hughlings Jackson, described syntactical aphasia by "jargon" speech (p. 136). Head further notes about a patient of this type:

> …talks with great rapidity when once started; the words may be recognizable but badly put together, or, if the loss is more severe, they may be pure jargon. The rhythmic movements of the phrase are affected; they are hurried and slurred, and the patient cannot "touch off" the words so as to produce a correctly coherent sentence. In the lighter forms of this defect there is no difficulty in finding words or names, which may be intelligible, especially if the subject of the conversation is known. (p. 136)

Like Kleist, Head's linguistic description characterized syntactical aphasia by structural misalignment, with no specification of morphosyntactic agreement violations. Interestingly, his non-syntactic descriptions highlight rapid, slurred speech and meaningless utterances. A similar description had been noted in the speech of patients with schizophrenia and other psychiatric conditions (Bleuler & Brill, 1924). In fact, unlike agrammatism which received inconsistent attention until the end of the 20th century, paragrammatism was not considered outside of psychiatry for several decades after Head's research.

Compared to research on grammatical *reductions* in aphasia, relatively less research has been conducted on grammatical *insertions* in aphasia. Only several decades after becoming renowned for his research on agrammatism did Harold Goodglass delve into productive deficits due to insertions, using Klein's term agrammatism (1993). And even since this time, research referencing paragrammatism has remained more limited (see Matchin & Hickok, 2020). This may be part of the reason that less consensus exists in defining paragrammatism. Recent revived interest in paragrammatic syndromes notwithstanding, even today definitions of paragrammatism are less consistent and typically vague. For example, the Encyclopedia of Clinical Neuropsychology, providing a single paragraph on the syndrome. In the entry, researcher Brenda Wilson defined paragrammatism as "substitution errors in pronouns and verb tense" in fluent aphasia (2011, p.2562). For reference, the entry for agrammatism is over 2 pages in length, describing characteristics that typify agrammatism as well as common co-occurring characteristics (Turkstra & Thompson, 2011). Matchin et al. (2020) also noted that raters had less difficulty characterizing agrammatism compared to paragrammatism. In order to address this discrepancy, recent work by the same group has proposed more concrete utterance-level diagnostics for identifying and characterizing paragrammatic discourse (Fahey et al., forthcoming). Furthermore, the kinds of errors committed by participants presenting with paragrammatic output closely mimic those observed in healthy participants, however in paragrammatism they occur much more often.

Analyzing Agrammatism and Paragrammatism Through the Lens of the Two-Stage Model: Insights from Empirical Studies

It should be noted that determining the exact level of processing impairment in sentence production is challenging. For instance, it can be difficult to distinguish between a deficit at the positional level and one caused by issues in earlier stages, such as the message or functional processing levels, which provide input to the positional level. Caramazza and Hillis (1989) proposed a potential solution: an impairment specifically at the positional level could be identified by observing structural difficulties in sentence production that co-occur with intact single-word retrieval and normal comprehension of reversible sentences. Similarly, in a non-lexicalist account, an impairment in positional processing (post-syntactic linearization operations) could be identified by observing difficulties in places where there is a greater amount of optionality in the linear order of elements or context-dependence in the form of those elements based on their linear order, while elements that have less optionality and/or a context-independent form (e.g., many content words in English) would be more or less preserved. Such a profile would indicate that functional operations—like lemma retrieval and thematic role assignment—are functioning correctly, thereby localizing the impairment to the stage where grammatical elements of the sentence are realized for production. That said, both agrammatic and paragrammatic errors can be analyzed within the framework of both functional- and positional-level processing impairments.

The functional level, for example, involves processing verbal argument structure. The transitive verb *tickle* requires two roles: the subject (e.g., "the woman") and the object (e.g., "the man"), which—in some languages, including English—are placed in a strict linear order. Studies (e.g., Berndt et al., 1997) show that individuals with agrammatism often struggle with verb retrieval, particularly with activating argument structure properties which can result in simplified syntax or incomplete sentences. Patients with impaired verb retrieval might fail to include necessary components (e.g., the object) when constructing a sentence. When these patients are explicitly provided with the target verb, their ability to complete sentences improves significantly, which could suggest that the problem lies in accessing the abstract representation of verbs at the functional level. However, this difficulty could also be interpreted as a deficit in positional processing, as a consequence of having a more complex syntactic structure that is more challenging to linearize.

In function assignment—another operation in the functional processing stage of grammatical encoding—some agrammatic patients display reversal mapping errors, where the intended roles are incorrectly assigned (Saffran et al., 1980; Caramazza & Berndt, 1985; Schwartz et al., 1985; Berndt, 1987; Caramazza & Miceli, 1991). For example, instead of saying "*The girl is kissing the boy,*" a patient might say "*The boy is kissing the girl.*" These errors are particularly common in situations where both participants are animate and capable of serving as the agent (Caramazza & Miceli, 1991). Such reversal errors are less likely to occur when only one participant is animate, highlighting the difficulty in correctly assigning roles when ambiguity or optionality exists, as well as the role that semantics can play in constraining sentence constructions.

Selective disruption at the positional level is also attested: some patients with brain injuries display syntactic simplification—where sentence structures are significantly reduced but grammatical morphemes remain intact. This pattern suggests a specific deficit in constituent assembly rather than a broader impairment in grammatical encoding (Saffron 1989). Conversely, other patients may generate complex sentences but struggle with producing (i.e.: omission or misuse of) closed-class functional elements, such as determiners, auxiliary verbs, and prepositions (Nadeau & Rothi, 1992). This performance profile points to a disruption in inserting functional items into the syntactic frame, while the ability to construct syntactic structure remains relatively intact.

Specific functional elements may also be selectively impaired: free-standing function words like articles and prepositions may be affected differently than bound inflections like verb tense markers (Miceli et al., 1989; Saffran et al., 1989). Some patients produce determiners correctly but fail to generate accurate verb inflections, while others show the opposite pattern. These double dissociations suggest that function words and inflections may be processed by separate mechanisms during sentence construction, or involve the same set of mechanisms that incur different processing costs. Even more specifically, semantically driven prepositions (e.g., "up" in "*She ran up the stairs"*) may behave differently than those that are less semantically transparent (e.g., "up" in *She called up her friend*) (Friederici, 1982; Kohen et al., 2011).

Bock and Levelt (1994) suggest that functional morphemes are not stored separately from lexical items, but that they have complex lemmas that constrain their use, citing the fact that aphasic patients frequently omit function words despite their frequency. Meanwhile, speakers of highly inflected languages with aphasia do not seem to produce bare word forms (Ardila, 2001; Fabbro & Frau, 2001; Paradis, 2001; but see Månsson & Ahlsén, 2001). Bock and Levelt suggest that freestanding functional morphemes are inserted into frames during constituent assembly through an additional operation, citing the evidence from attraction errors. We posit that the appropriate functional morphemes are selected in connection with syntactic relations during functional assignment.

Unfortunately, the majority of aphasia research has examined English (779/1184 articles in a 2011 review by Beveridge and Bak). English is an analytic language, meaning that words are often composed of a single morpheme, and the order of those words is relatively fixed. Consequently, the structures and processes involved in English and other European languages are over-represented in the analysis of syntactic deficits in aphasia. No reviews have examined which structures have been tested across languages, with most reviews focusing on language genealogy (Beveridge & Bak, 2011). Though English is over-represented in aphasia research, the vast majority of languages investigated have been fusional (e.g., German, Italian, Dutch, French, Spanish; Beveridge & Bak, 2011). The focus on analytic and fusional languages in describing syntactic deficits can introduce confounds, while failing to account for morphological complexity and missing other patterns of grammatical and linguistic deficits that could exist.

Relatively few agglutinative languages have been investigated, and only one has examined a polysynthetic language (Kalaallisut (West Greenlandic); Nedergaard et al., 2020). Kalaallisut is a polysynthetic language, where a single phonological word can be composed of many highly productive morphemes. The linear order of the morphemes within a (phonological) word is fixed, though the order of words in a sentence is relatively free. In a case study, Nedergaard et al (2020) observed that speakers of Kalaallisut with agrammatic aphasia produced the same number of morphemes per word as healthy controls, with the same error rate as healthy controls, but did produce fewer words per utterance. Their evidence suggested that when syntactic structure is a strong cue for the linear order of the morphemes within the word (or the linear order is provided directly by the syntax), it is not a problem for people with agrammatic aphasia, while places with a greater degree of optionality or flexibility in linear order are more challenging. This single study provides relatively preliminary data for grammatical deficits in a polysynthetic language; the case study included only 5 participants, no standard diagnostic protocol exists for the language, and no neuroimaging data was available for those patients due to lack of access to facilities. However, these data are consistent with findings from agglutinative languages, which observed that speakers with agrammatic aphasia produced few ungrammatical substitutions or omissions (Finnish, Japanese, and Turkish; respectively, Menn & Obler, 1990; Niemi et al., 1990; Slobin, 1991). Importantly, paragrammatism is not diagnosed outside of English, marking an important caveat in this alignment between diagnosable errors and processing research.

Parsimony between neurolinguistic models, (par)agrammatism, and the two-stage sentence production model

As mentioned above, there are three mainstream neurolinguistic models for the localization of grammatical encoding in sentence production: non-localized, frontal-only, and frontal + posterior temporal. Under the non-localized/distributed account that the construction of hierarchical phrases and sentences is not localized in the brain, they assert that the apparent syntactic deficits observed in agrammatism are not a syntactic deficit *per se*, but rather a resource-rational adaptation in response to increased cognitive and linguistic demand (Fedorenko et al. 2022). In a footnote of the same paper, they concede that resource-rationality would not explain the patterns of linguistic behavior observed in paragrammatism, and that patients with fluent aphasia must have some loss of linguistic knowledge. They do not, however, explain how a distributed syntactic system would give rise to different kinds of syntactic deficits.

The frontal-only view of the neurobiology of syntax is at odds with findings that deficits in receptive syntactic competence are associated with damage to the posterior temporal lobe rather than the frontal lobe (Fahey et al., 2024), since only the frontal lobe should be carrying out syntactic computation (Zaccarella et al., 2017; Friederici, 2020). Furthermore, a framework in which only the inferior frontal lobe was involved in syntactic computation would struggle to account for the data observed in (par)agrammatism. It is well-specified how damage to the inferior frontal lobe would impact morphological and/or linearization processing (Marslen-Wilson & Tyler, 2007), however it remains unclear under this approach how two *behaviorally and neurally dissociable* syntactic disorders might arise from damage to a single syntactic hub in the frontal lobe.

The frontal + posterior temporal account draws heavily on data from aphasia in which participants with agrammatic-like speech—indicating a breakdown in linearization processes—tend to have middle and inferior frontal lobe lesions (Matchin & Hickok, 2020; Matchin et al., 2020). In contrast, participants with posterior temporal lobe lesions tend to have relatively fluent speech with degraded hierarchical structure (Matchin et al., 2020; Casilio et al., 2024). The fluency of the speech is facilitated by “successful” linearization (Krauska & Lau, 2023). This division of labor is further supported by evidence from comprehension: participants with circumscribed frontal lobe lesions do not present with syntactic comprehension deficits (Matchin et al., 2023), however damage to the posterior temporal lobe appears to impact receptive syntax (Fahey et al., 2024). Despite previous evidence of frontal lobe lesions impacting sentence comprehension (e.g.: Wilson et al., 2014), the evidence points to this being the result of impaired phonological working memory rather than a breakdown in the ability to parse the structure (Rogalsky & Hickok, 2011). The frontal + posterior temporal model therefore appears to present the best parsimony with available neurolinguistic and clinical data, as well as with the two stage grammatical encoding model.

Conclusions

In this work, we have attempted to sketch out the lay of the land regarding three relatively separate lines of research on syntactic processing: psycholinguistic, aphasiological, and neurolinguistic. While these domains have been investigated largely distinctly from one another, we note major promising convergences: a two-level system of syntactic encoding, roughly corresponding to a first level of abstract, hierarchical structure, mapping onto a linearization algorithm which determines the order of elements. This in turn corresponds to two different underlying brain systems supporting syntactic aspects of sentence production: posterior temporal lobe supports hierarchical structure building, followed by morphosyntactic linearization in the inferior/middle frontal lobe. These two systems, when damaged, produce categorically distinct grammatical deficits in aphasia: paragrammatism—characterized by grammatical errors with otherwise fluent speech—results from damage to the first level of hierarchical syntactic encoding in posterior temporal lobe, and agrammatism—characterized by telegraphic speech with omission of functional elements—results from damage to the second level of linearization in inferior/middle frontal lobe. We believe that this alignment of multiple literatures and fields makes possible interdisciplinary work that would not otherwise be possible.

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