Exploring Syntactic Processing Deficits in Broca's Aphasia through Priming Paradigms

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Abstract
This research explores syntactic processing through priming in individuals diagnosed with Broca's aphasia, a condition marked by compromised syntactic capabilities resulting from damage to the left frontal lobe. Utilizing Paradigm software, the investigation assesses the relative ease and difficulty of recognizing various syntactic categories, including plurals, tenses, verbs, person-number-gender (PNG) markers, and conjunctions, among 30 Malayalam-speaking participants with Broca's aphasia. The analysis of reaction times for syntactic identification tasks indicated that plurals were the most easily identified category, whereas conjunctions presented the greatest difficulty. Statistical evaluation via the Friedman test revealed no significant differences in reaction times among the categories, implying a generalized impairment in syntactic processing rather than specific deficits related to individual categories. These results are consistent with existing research that emphasizes the increased processing demands associated with complex syntactic structures, such as conjunctions, compared to simpler forms like plurals. The study highlights the potential of syntactic priming as a therapeutic approach to improve sentence processing, offering encouraging prospects for language rehabilitation in individuals with Broca's aphasia

Introduction

According to Snowling et al. 2022, word recognition integrates the visual word form of spoken and written language to its appropriate meaning in the same way that self-directed reading and communication, together with language development, are integrated. Word itself is defined as the smallest meaningful sequence of speech sounds which can function independently. However, their integration is strongly impacted by concept of priming. While Marquis 2016 explains that priming is a type of cognitive event where previously presented related items facilitate or inhibit

performance on later tasks. According to McNamara 2005, such processes affect recognition by increasing or lagging the processing of a target word due to the degree of association between it and a prime.

Linguistic coherence and word recognition rely heavily on syntax, which is the organized arrangement of words to form grammatically correct sentences. A particular kind of priming known as syntactic priming helps with sentence processing when the structure of a new sentence resembles that of a previous one. This phenomenon enhances fluency, reduces cognitive load, and increases processing efficiency in both sentence creation and understanding (Bock & Griffin, 2000; Messenger, 2022). Understanding language processing, especially in medical conditions like aphasia, necessitates recognizing the connection between syntax and word recognition (Pickering & Branigan, 1998).

The characteristic feature of Broca's aphasia, which frequently arises from injury to the left frontal lobe, is agrammatism, which is a severe inability to comprehend complex syntactic structures and produce grammatically accurate phrases (Hagoort, 2005). During the production of complex syntactic formulations like object-relative sentences, research employing syntactic priming paradigms shows that the priming effects in Broca's aphasia are either delayed or poor (Thompson, 2011). These results point to disturbed activation dynamics that cause the construction of syntactic structures to be delayed. Consequently, people frequently use pragmatic or semantic signals to understand sentences (Rogalsky et al., 2015).

Interventions using syntactic priming have shown potential in helping people with Broca's aphasia produce stronger language. Menke et al. (2017) discovered that by lowering cognitive load and improving syntactic frame accessibility, frequent exposure to particular grammatical structures improves sentence output. Additionally, according to Tyler et al. (2011), these interventions support neuroplasticity and the functional reorganisation of disrupted language networks. Syntactic priming improves implicit learning and speeds up sentence processing in multilingual aphasics (Bernolet et al., 2013). All things considered; syntactic priming provides an adaptable method for language rehabilitation that makes use of residual syntactic abilities.

The distinctive morphosyntactic characteristics of Malayalam, a South Dravidian language that is mostly spoken in Kerala, India, include its significant syntactic reliance on conjunctions, widespread use of plural markers, and PNG-neutral verbs. Because of its agglutinative character and preference for postpositions over prepositions, it offers a great framework for assessing syntactic processing. In those with language deficits such as Broca's aphasia, these characteristics make it easier to evaluate different levels of syntactic complexity. Conjunctions, verbs, person-number-gender (PNG) markers, plurals, and tenses are the selected categories. By striking a balance between simplicity (plurals, PNG markers) and complexity (conjunctions, tenses), these categories provide a thorough grasp of syntactic abilities. In this study, the ease and difficulty of recognising different syntactic categories is

analysed using Paradigm software to investigate syntactic processing through priming in people with Broca's aphasia.

Aim

To analyze syntactic processing through priming in individuals with Broca's aphasia using Paradigm software.

Objective

To determine the easiest and most challenging syntactic category among identification tasks in individuals with Broca's aphasia

Methodology

Development of Materials

Syntactic categories were selected for identification tasks, including plurals, tenses, verbs, PNG (Person, Number, Gender) markers, and conjunctions, given their significance in Malayalam language (Appendix 1)

Stimulus Preparation

The selected words were recorded in a sound-treated room and processed using Paradigm software. Participants pressed 'Y' for correct, 'N' for incorrect, and 'P' for difficult-to-identify responses. Reaction times were recorded automatically, and task completion times were calculated using Excel.

Participant Selection

Thirty Malayalam speaking right-handed participants aged 30–70 years from Kozhikode district with a clinical diagnosis of Broca's aphasia were selected. The participants must be diagnosed as having Broca's Aphasia by a neurologist and Speech and language pathologist Diagnosis was confirmed through CT/MRI reports indicating left MCA stroke and Western Aphasia Battery (Malayalam version) scores(Philip, 1993). The participants must be administered with WAB and should have scores of Fluencies within 0-4, Comprehension within 4-10, Repetition within 0- 7.9, and Naming within 0- 8. The participants should be at least six months to one-year post-onset of a single, left hemisphere stroke at the time of the study. The participants should not have a history of drug or alcohol abuse, hospitalization for a psychiatric disorder, developmental speech/language disorders, or prior neurological disorders.

Test Administration

Demographic data were collected, and pilot studies were conducted to establish the stimulus presentation timing. Tests were conducted in a distraction-free environment. Subjects were presented with the selected primed words of each category auditorily using the Paradigm software, and participants were directed to identify the primed

and non-primed words from the presented set. The subjects were instructed to press "Y" if the word was correct/True, "N" if the term was incorrect/False, and "P" if they were unsure. The next word would not be displayed until the subject pressed any of the keys. Reaction times were analyzed automatically by the software for each presented word.

Results and Discussion

Statistical Analysis

Descriptive statistics for reaction times across five linguistic tasks—Plurals, Tenses, Verbs, PNG Markers, and Conjunctions—are summarized in Table 1. Reaction times (ms) were expressed as mean, standard deviation, minimum, and maximum values.

Table 1
Descriptive statistics for reaction times across five linguistic tasks—Plurals, Tenses, Verbs, PNG Markers, and Conjunctions.

Identification task	Mean	Standard Deviation	Minimum	Maximum
Plurals*	65139.33	19776.45	30926.00	115476.00
Tenses#	67725.73	19770.90	28481.00	122706.00
Verbs##	67862.97	29294.80	31387.00	190368.00
PNG Markers**	75306.53	44816.92	35220.00	292896.00
Conjunctions¶	77585.77	32046.01	22228.00	198433.00

*Note: *Plurals: Words denoting more than one entity, typically formed by adding "s," "es," or other markers.*
*#Tenses: Grammatical forms indicating the time of action (e.g., past, present, future). ##Verbs: Words expressing action, occurrence, or a state of being. **PNG Markers: Person, number, and gender indicators in linguistic constructs. ¶Conjunctions: Words connecting clauses, phrases, or words (e.g., "and," "but," "because").*

To evaluate whether reaction times significantly differed across tasks, a Friedman test was conducted. The test results failed to reject the null hypothesis ($p = 0.294$), indicating no statistically significant differences in reaction times among the five task categories.

The mean rank scores derived from the Friedman test are presented in Table 2. From the table, it is evident that conjunctions exhibited the highest mean rank (3.33), followed closely by PNG Markers (3.27). However, the differences did not reach statistical significance. The Friedman test assessed differences in reaction times between tasks, and the results showed that the null hypothesis ($p = 0.294$) was accepted, indicating no significant differences between categories. These findings

suggest that reaction times for identification tasks are consistent across syntactic categories, with no single task demonstrating a significantly longer or shorter processing time.

Table 2. Mean Rank Scores from the Friedman Test

Task	Mean Rank
Plurals	2.17
Tenses	2.53
Verbs	2.90
PNG Markers	3.27
Conjunctions	3.33

Discussion

According to the results, in individuals with Broca's aphasia plurals were the easiest category to identify, requiring the shortest reaction times. Tenses, verbs, and person-number-gender (PNG) markers were subsequent, while conjunctions were the most challenging, requiring the longest reaction times. According to research, grammatical categories with less complex syntactic demands are easier to understand, particularly for groups with language processing impairments such those with Broca's aphasia (Thompson & Shapiro, 2020). This is supported by the better performance in plural identification. Since it requires less cognitive effort to parse and incorporate simpler grammatical forms into sentence structures, this accessibility may be explained. According to research, priming effects can also facilitate the processing by increasing cognitive efficiency for commonly encountered forms, such as plurals (Hartsuiker& Kolk, 2020).

Since plurals are created by adding a single morpheme to the core word, they are the simplest syntactic category to recognise structurally. The high salience of these physical features facilitates their detection and processing (Clahsen& Felser, 2006). There is also the issue of familiarity. The frequent use of plurals in daily conversation enhances its familiarity (Bybee, 2007). Simple syntactic agreement with verbs, determiners, and adjectives is frequently involved in plurals. Processing complexity is reduced by this consistency (Corbett, 2000). In nature, the idea of plurals is universal. They overcome the differences in language and culture (Croft, 2003). All of these factors help to reduce the reaction time when identifying plurals.

The elevated reaction times observed in individuals with Broca's aphasia when processing conjunctions can be linked to the intricate syntactic and neuroanatomical requirements involved in handling these linguistic elements. Conjunctions play a distinctive role in syntax, exhibiting considerable variability and fulfilling a multitude of functions by linking words, phrases, or clauses in both simple and complex

manners. They often introduce ambiguities, particularly in sentences that contain several possible connections. Such ambiguities in scope and parsing emerge when the relationships among elements are not clearly defined (Sag et al., 2003). In the context of Malayalam, conjunctions present a particularly challenging category for analysis due to their multifunctionality, reliance on context, and the interaction between syntax, semantics, and pragmatics (Krishnamurti, 2003).

Conjunctions are essential indicators of syntactic dependencies and facilitate discourse-level integration, necessitating the coordination of various syntactic structures and the clarification of relationships between clauses. These processes are significantly reliant on the left inferior frontal gyrus (LIFG), which includes Broca's area, known for its role in constructing hierarchical structures and integrating syntax. Damage to the LIFG, characteristic of Broca's aphasia, impairs these functions, rendering the processing of conjunctions particularly difficult. Additionally, lesions may extend to nearby areas, such as the posterior superior temporal gyrus (pSTG) and middle temporal gyrus (MTG), which contribute to semantic integration and discourse mapping, further complicating the challenges faced. Research indicates that conjunctions impose heightened cognitive demands due to their function in establishing long-distance dependencies and their nuanced semantic characteristics, both of which necessitate intact syntactic and working memory capabilities. For instance, studies conducted by Caplan et al. (2007) demonstrate that patients with Broca's aphasia encounter difficulties with complex sentences that involve conjunctions, highlighting deficits in syntactic processing and diminished working memory capacity.

Participants performed better on tenses, verbs, and PNG markers after performing better on plurals. In order to identify tenses, participants must execute temporal processing, which involves mapping linguistic cues onto temporal mental models. Bastiaanse et al. (2011) argued that some brain regions, such as the left inferior frontal gyrus and left posterior middle temporal gyrus, which are linked to both syntactic manipulation and semantic processing, are involved in processing tenses. Tenses may take longer to comprehend than more straightforward grammatical categories like plurals, which can be explained by the simultaneous participation of semantic and syntactic processing.

Participants with Broca' aphasia showed slightly longer reaction times and more variability in verb identification than in tenses.It could be understood through the complex function verbs play in sentence structure. Damage to the left inferior frontal gyrus (LIFG) causes Broca's aphasia, which affects verb integration into sentence structures and the creation of hierarchical syntactic representations. Because of abnormalities in the brain regions responsible for morphosyntactic integration and agreement computation, people with Broca's aphasia have issues with interpreting person-number-gender (PNG) indicators. PNG markers require syntactic and semantic

coordination to preserve agreement across sentence elements because they encode grammatical properties like person, number, and gender. For determining grammatical agreement, the left inferior frontal gyrus (LIFG), in particular Broca's region, is essential. When this area is damaged, it becomes more difficult to determine the associations between sentence elements, which might result in errors or inaccuracies in PNG markers.

The lack of significant variations in reaction times across different syntactic categories in individuals with Broca's aphasia can be explained by the uniform impairment of linguistic processing mechanisms inherent to this condition. Broca's aphasia is chiefly characterized by difficulties in syntactic processing, known as agrammatism, which impacts a range of linguistic structures, including plurals, tenses, verbs, person-number-gender markers, and conjunctions, to a similar degree. A plausible rationale for this phenomenon is the damage to the left inferior frontal gyrus, a region crucial for syntactic computation and the integration of morphosyntactic elements. This widespread disruption likely results in a general slowdown in processing rather than impairments that are specific to certain categories. As a result, tasks that involve various syntactic categories may utilize overlapping neural resources, leading to comparable reaction times across different tasks. Furthermore, compensatory strategies, such as the use of lexical or semantic cues, may be consistently applied across syntactic categories, contributing to a uniformity in task performance. Patients may tend to emphasize lexical retrieval over syntactic analysis to manage their deficits, resulting in reaction times that remain consistent regardless of the complexity or nature of the task. Thus, the absence of significant differences in syntactic processing tasks among individuals with Broca's aphasia indicates a generalized syntactic impairment rather than isolated deficits, aligning with the fundamental pathophysiological mechanisms associated with this disorder.

Conclusion:

This research emphasizes the differences in syntactic processing abilities among individuals with Broca's aphasia. Participants were able to recognize plurals with relative ease, attributed to their straightforward nature; however, they encountered more difficulties with conjunctions, which require more complex cognitive processing. These results highlight the promise of syntactic priming as a therapeutic approach, suggesting that language rehabilitation can be enhanced by customizing interventions to meet the specific needs of each individual and utilizing their remaining linguistic skills.

Ethical consideration

This study was approved of IEC of AWH Special College (EC/NEW/INST/2024/4338). The study strictly adhered to the SOP formulated by IEC with regards to consent of participants, data collection protocol, documentation, confidentiality, conflict of interest and objectivity.

Conflict of Interest

There is no financial or non-financial conflict of interest among the authors, Institution, participants or caregivers.

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Appendix 1

Description of Plurals, Tenses, Verbs, PNG Markers, Person, Number and Gender markers, Conjunctions in Malayalam languagewith examples.

Plurals	Malayalam pluralization is relatively straightforward, but like many Dravidian languages, it features nuances based on context, gender, and formality. The -kaḷ and -var suffixes are the most commonly used plural markers, but some nouns exhibit irregular pluralization forms as well. • E.g.- ആളു (āḷu) – person → ആളുകൾ (āḷukaḷ) – people • വ്യക്തി (vyakti) – individual → വ്യക്തികൾ (vyaktikaḷ) – individuals
Tenses	Tense markers in Malayalam are primarily formed by adding suffixes to verb roots. The present tense is often marked by -ന്നു/-ുന്നു, the past tense by -ി/-ു, and the future tense by -ുo. The language also has perfect tense constructions that combine verb roots with auxiliary verbs. • E.g.കഴിയുക (kaṭhiyuka) – to be able → കഴിയുന്നു (kaṭhiyunnu) – is able (singular) • പറയുക (paṟayuka) – to speak → പറയുo (paṟayuṁ) – speaks (singular) • പോകുക (pōkuka) – to go → പോയി (pōyi) – went (singular) കഴിയുക (kaṭhiyuka) – to be able → കഴിയുo (kaṭhiyum) – was able (plural)
Verbs	Verbs in Malayalam are highly inflected and are a critical part of sentence structure. They conjugate for tense, aspect, number, and politeness. Verbs can be transitive or intransitive, and they are often used with auxiliary verbs to express additional nuances such as aspect or voice. e.g - പോകുക (pōkuka) – to go • Singular:

	○ ഞാൻപോകുന്നു (ñānpōkunnu) – I am going. ○ അവൻപോകുന്നു (avaṉpōkunnu) – He is going. • Plural: ○ നാംപോകുന്നു (nāṁpōkunnu) – We are going. ○ അവർപോകുന്നു (avarpōkunnu) – They are going.
PNG Markers	PNG markers in Malayalam play an important role in verb conjugation, pronouns, and adjectives by indicating the person, number, and gender of the subject. These markers ensure grammatical agreement and clarity in sentence construction. Since Malayalam verbs are PNG neutral in the sense that the verbs do not differ in form nor do they take different affixes on them according to variation in Person (First, Second, and Third), number (Singular and Plural), or Gender (Masculine, Feminine and the Third gender). e.g - □പോകുന്നു (pōkunnu) – is going (third person, singular) □പോകുന്നു (pōkunnu) – are going (third person, plural) □പോയി (pōyi) – went (past, singular) □പോയി (pōyi) – went (past, plural
Person	Person markers in Malayalam are essential for conveying who is performing an action in a sentence. They help indicate whether the subject is the speaker (first person), the listener (second person), or someone/something else (third person). The markers vary based on number (singular/plural) and formality, affecting both pronouns and verb conjugations • e.g. - First Person Singular: പോകുന്നു (pōkunnu) – I am going • Second Person Singular: പോകുന്നു (pōkunnu) – You are going • Third Person Singular: പോകുന്നു (pōkunnu) – He/She/It is going First Person Plural: പോകാം (pōkāṁ) – We will go • Second Person Plural: പോകുന്നു (pōkunnu) – You (all) are going • Third Person Plural: പോകുന്നു (pōkunnu) – They are going
Gender markers	In Malayalam, gender markers primarily affect the third-person pronouns and occasionally adjectives. The gender distinction is relatively simple and is less pervasive in verb forms, as the same verb forms are often used for both masculine and feminine subjects. • e.g-Masculine Gender:Pronoun: അവൻ (avaṉ) – he

	• Feminine Gender:Pronoun: അവൾ (avaḷ) – she • Neuter Gender: Pronoun: അത് (at) – it (used for non-living things, animals, etc.)
Conjunctions	Conjunctions are essential in Malayalam for forming complex sentences and showing relationships between ideas. They connect clauses, phrases, and words effectively and convey meaning through contrast, addition, choice, cause, and condition. • And (കൂടാതെ, *kūṭāte*): • But (പക്ഷേ, *pakṣē*): • Or (അഥവാ, *athavā*) • Because (എന്നാൽ, *ennāl*) • If (എങ്കിൽ, *eṅṅil*) • Although (ചെയ്താലും, *ceytālum̀*) • Neither... Nor (ഇല്ലാതെ... അല്ലെങ്കിൽ, *illāte... allenkil*)