



## Neural Mechanisms of Second-Language Sentence Processing: An ERP Study of Semantic and Syntactic Integration

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### Abstract

**Background:** Understanding how second-language (L2) learners process sentences is a key topic in neurolinguistics and cognitive neuroscience. Sentence comprehension involves the rapid integration of lexical, semantic, and syntactic information, supported by complex neural processes. Event-related potentials (ERPs), particularly the N400 and P600 components, are widely used to examine semantic and syntactic processing during language comprehension.

**Aim:** This study aimed to investigate the neural mechanisms underlying second language sentence processing among university EFL learners through ERP measures associated with semantic and syntactic processing.

**Method:** A quantitative quasi-experimental design was employed involving 60 undergraduate EFL students. Participants completed sentence comprehension tasks containing semantic anomalies and syntactic violations while electroencephalography (EEG) recordings were collected. ERP analyses focused on N400 and P600 amplitudes and latencies. Behavioral measures included comprehension accuracy and reaction times.

**Results:** The findings showed that semantic anomalies elicited larger N400 amplitudes, reflecting increased semantic integration demands, whereas syntactic violations produced enhanced P600 responses, indicating syntactic reanalysis and repair. Behavioral data revealed lower comprehension accuracy and longer reaction times for anomalous than for grammatically correct sentences. Additionally, stronger ERP responses were associated with higher levels of language proficiency.

**Conclusion:** The study demonstrates that second-language sentence processing engages distinct neural mechanisms for semantic and syntactic integration. These findings support contemporary neurolinguistic theories and highlight the value of ERP measures in revealing real-time language processing and the neurocognitive foundations of second-language acquisition.

## Introduction

Second language (L2) sentence processing represents a fundamental area of inquiry within neurolinguistics and cognitive neuroscience because it provides insights into how learners comprehend, integrate, and interpret linguistic information in real time. Successful sentence comprehension requires the coordinated operation of multiple cognitive processes, including lexical access, semantic integration, syntactic computation, and working memory. Unlike isolated word recognition, sentence processing involves the continuous construction and updating of mental representations as linguistic input unfolds over time (Friederici, 2002; Kaan & Swaab, 2003; Hagoort, 2019). Consequently, investigating the neural mechanisms underlying sentence processing contributes to a deeper understanding of second language acquisition and language comprehension.

Advances in neurocognitive research have significantly improved current understanding of language processing mechanisms. Among various methodologies, Event-Related Potentials (ERPs) have emerged as one of the most effective approaches for examining the temporal dynamics of language comprehension because they provide

millisecond-level measurements of neural activity. ERP techniques have been widely applied to investigate semantic processing, syntactic integration, lexical access, and discourse comprehension in both native and non-native speakers (Kutas & Hillyard, 1980; Osterhout & Holcomb, 1992; Friederici, 2011). As a result, ERP research has become central to contemporary investigations of language processing.

Within ERP research, two components have received particular attention in studies of sentence comprehension. The N400 component is commonly associated with semantic integration and meaning-related processing, whereas the P600 component is generally linked to syntactic analysis, grammatical processing, and sentence reanalysis (Kutas & Federmeier, 2011; Hagoort & Brown, 2000; Kaan & Swaab, 2003). Previous studies consistently reported that semantically anomalous words elicit enhanced N400 amplitudes, while syntactic violations generate robust P600 responses, reflecting distinct yet interconnected neural mechanisms involved in language comprehension (Hahne & Friederici, 2001; Friederici et al., 2002).

Research on second language processing has demonstrated that neural responses often differ between native speakers and L2 learners. Hahne and Friederici (2001) reported that although advanced L2 learners exhibited N400 effects comparable to native speakers, their syntactic processing was characterized by delayed and reduced P600 responses. Similarly, Weber-Fox and Neville (2001) found that age of acquisition influenced neural responses to syntactic information, suggesting that second-language processing may rely on different neurocognitive mechanisms from those employed in first-language comprehension. These findings indicate that semantic and syntactic processing do not necessarily develop at the same rate in second-language learning contexts.

Subsequent investigations expanded this line of research by examining the influence of language proficiency and learning experience on ERP responses. Osterhout et al. (2008) demonstrated that increased exposure to a second language was associated with more native-like neural processing patterns. Likewise, Morgan-Short et al. (2012) found that learners receiving immersive language instruction exhibited stronger ERP responses than those receiving traditional classroom instruction. These studies suggest that neural mechanisms involved in sentence processing are dynamic and can be modified through language experience and learning conditions.

Although previous studies have significantly advanced understanding of second-language sentence processing, several limitations remain evident. First, many investigations have focused exclusively on semantic processing or syntactic processing, thereby limiting understanding of how these mechanisms interact during natural sentence comprehension (Kotz, 2009; Tanner, 2015). Second, a substantial proportion of ERP research has been conducted in laboratory settings involving native speakers or highly proficient bilinguals, while empirical evidence from university-level EFL learners remains comparatively limited (Steinhauer et al., 2009; Morgan-Short et al., 2012). Third, inconsistencies regarding the effects of proficiency and language experience continue to be reported across studies, indicating the need for further investigation.

The present study addresses these gaps by simultaneously examining semantic and syntactic processing during second-language sentence comprehension through the analysis of N400 and P600 components. Unlike previous studies that primarily investigated individual ERP components in isolation, this research integrates behavioral performance measures and electrophysiological evidence within a single experimental framework. Furthermore, the study focuses specifically on university EFL learners, a population that remains underrepresented in ERP-based neurolinguistic research.

Therefore, the novelty of this study lies in its comprehensive examination of the neural mechanisms underlying second-language sentence processing through the combined analysis

of semantic integration, syntactic processing, and behavioral performance. By integrating ERP measures with sentence-comprehension outcomes, the study provides a more holistic account of the neurocognitive processes involved in second-language understanding.

Accordingly, this study aims to investigate the neural mechanisms underlying second-language sentence processing by examining ERP responses elicited by semantic anomalies and syntactic violations. Specifically, the study seeks to identify the characteristics of N400 and P600 components and to determine how these neural responses are associated with learners' sentence-comprehension performance.

## **Literature Review**

### **Neural Basis of Sentence Processing**

Sentence processing is a complex neurocognitive activity involving the integration of lexical, semantic, syntactic, and contextual information. Contemporary neurolinguistic theories propose that language comprehension is supported by distributed neural networks primarily located in the frontal and temporal regions of the brain. These regions interact dynamically to facilitate the retrieval, integration, and interpretation of linguistic information during real-time communication (Friederici, 2002; Friederici, 2011; Hagoort, 2019).

According to Friederici (2002), sentence comprehension involves multiple processing stages. Early stages are associated with syntactic structure building, followed by semantic interpretation and later integrative processes. Similarly, Hagoort (2019) proposed the Memory, Unification, and Control (MUC) model, which emphasizes the interaction between lexical retrieval, semantic unification, and executive control during language processing. These theoretical frameworks suggest that sentence comprehension is not a single cognitive process but rather the result of coordinated neural operations across multiple brain regions.

Neuroimaging and electrophysiological studies have consistently demonstrated the involvement of the left inferior frontal gyrus, superior temporal gyrus, and posterior temporal regions in sentence processing. These regions contribute to grammatical computation, semantic integration, and contextual interpretation, respectively (Friederici, 2011; Hagoort, 2019). The coordinated activity of these neural networks enables individuals to construct coherent representations of linguistic input and efficiently resolve ambiguities during comprehension.

### **N400 and Semantic Processing**

The N400 is one of the most extensively studied ERP components in language research. First identified by Kutas and Hillyard (1980), the N400 is a negative-going waveform that typically peaks approximately 400 milliseconds after stimulus presentation. It is generally associated with semantic processing and reflects the cognitive effort required to integrate a word into its preceding linguistic context (Kutas & Hillyard, 1980; Kutas & Federmeier, 2011).

Research has consistently shown that semantically incongruent words elicit larger N400 amplitudes than semantically appropriate words. For example, sentences containing anomalous endings require greater semantic integration effort, resulting in stronger N400 responses (Kutas & Federmeier, 2011; Hagoort & Brown, 2000). Consequently, the N400 has become a reliable neural indicator of semantic processing efficiency during language comprehension.

In second-language contexts, studies indicate that N400 responses are influenced by language proficiency and exposure. Advanced L2 learners often demonstrate N400 patterns comparable to native speakers, suggesting that semantic integration mechanisms can become highly efficient with increased language experience (Osterhout et al., 2008; Morgan-Short et al., 2012). However, lower-proficiency learners frequently exhibit delayed or reduced N400

effects, indicating greater processing demands during semantic interpretation (Kotz, 2009; Tanner, 2015).

### **P600 and Syntactic Processing**

The P600 component is commonly associated with syntactic processing, grammatical violations, and sentence reanalysis. It typically appears as a positive-going waveform occurring approximately 500–900 milliseconds after the presentation of a syntactically unexpected stimulus (Osterhout & Holcomb, 1992; Kaan & Swaab, 2003). The P600 is generally interpreted as reflecting cognitive mechanisms responsible for structural revision and syntactic repair.

Numerous ERP studies have demonstrated that grammatical violations elicit robust P600 responses. Hahne and Friederici (2001) reported that syntactic anomalies generated larger P600 amplitudes than grammatically correct constructions, indicating increased processing demands associated with syntactic reanalysis. Similar findings have been reported across different languages and learner populations, supporting the reliability of the P600 as an indicator of grammatical processing (Friederici et al., 2002; Kaan & Swaab, 2003).

Research involving second-language learners suggests that P600 responses are particularly sensitive to language proficiency and age of acquisition. Advanced learners often display more native-like P600 patterns, whereas less proficient learners exhibit delayed or attenuated responses (Weber-Fox & Neville, 2001; Steinhauer et al., 2009). These findings suggest that syntactic processing mechanisms may require more extensive language experience to reach levels comparable to native-language processing.

### **ERP Studies in Second Language Acquisition**

ERP methodology has become increasingly important in second-language acquisition research because it provides direct evidence of neural processing during language comprehension. Unlike behavioral measures, ERP techniques allow researchers to observe cognitive processes as they occur, thereby offering valuable insights into the temporal dynamics of language learning and processing (Kaan & Swaab, 2003; Friederici, 2011).

Previous ERP studies have revealed that semantic and syntactic processing mechanisms develop differently in second-language learners. Hahne and Friederici (2001) found that advanced learners exhibited relatively native-like N400 responses but differed substantially in syntactic processing as reflected in their P600 patterns. Similarly, Weber-Fox and Neville (2001) reported that age of acquisition significantly influenced neural responses to grammatical information, highlighting the importance of language-learning experience.

More recent studies have emphasized the role of proficiency and instructional context in shaping ERP responses. Morgan-Short et al. (2012) demonstrated that immersive language training produced stronger neural adaptation than traditional classroom instruction. Likewise, Tanner (2015) argued that ERP measures provide valuable indicators of individual differences in second-language learning success. Collectively, these findings suggest that ERP components such as the N400 and P600 serve as reliable markers of language-processing development and can contribute to a more comprehensive understanding of second-language acquisition.

## **Method**

### **Research Design**

This study employed a quantitative quasi-experimental research design to investigate the neural mechanisms underlying second-language sentence processing. The study combined behavioral measures and electrophysiological recordings to examine participants' responses to semantic anomalies and syntactic violations during sentence comprehension tasks. The integration of behavioral and ERP data enabled a comprehensive analysis of both observable performance and underlying neurocognitive processes.

ERP methodology was selected because it provides precise temporal information regarding neural activity during language processing. Specifically, the study focused on the N400 and P600 components, which have been widely recognized as neural indicators of semantic integration and syntactic processing, respectively (Kutas & Federmeier, 2011; Kaan & Swaab, 2003).

### **Research Site and Participants**

The study was conducted at a public university where English is taught as a foreign language. The participants consisted of 60 undergraduate students enrolled in English language education and English literature programs. All participants were non-native speakers of English and had completed at least four semesters of English instruction.

Participants were selected using purposive sampling because the study required learners who possessed sufficient English proficiency to complete sentence-comprehension tasks while demonstrating variability in language-processing performance.

The participants ranged in age from 18 to 24 years and reported no history of neurological disorders, hearing impairments, or language-related disabilities. Prior to participation, informed consent was obtained from all participants in accordance with ethical research guidelines.

### **Instrument**

Three instruments were employed in this study. The first instrument consisted of a sentence-comprehension task designed to elicit semantic and syntactic processing. The task included 120 English sentences divided into three conditions: grammatically correct sentences, sentences containing semantic anomalies, and sentences containing syntactic violations. The experimental stimuli were adapted from previous ERP studies investigating sentence processing (Hahne & Friederici, 2001; Osterhout & Holcomb, 1992).

The second instrument was a behavioral response sheet used to measure comprehension accuracy and reaction times. Participants were required to determine whether each sentence was acceptable or unacceptable based on its meaning and grammatical structure.

The third instrument was an electroencephalography (EEG) system used to record neural activity during task performance. EEG signals were collected using a 32-channel electrode cap positioned according to the international 10–20 system. Continuous EEG recordings were obtained throughout the experiment and later processed for ERP analysis. The primary ERP components analyzed were N400 and P600 amplitudes and latencies.

### **Data Collection**

Data collection was conducted in a quiet laboratory environment. Participants were seated comfortably approximately 60 cm from a computer screen. Following electrode preparation and impedance checks, participants completed a brief practice session to familiarize themselves with the experimental procedure.

During the experiment, sentences were presented word by word using computerized presentation software. Each trial began with a fixation cross followed by sentence presentation. Participants were instructed to read each sentence carefully and respond to comprehension questions by pressing designated response keys. Behavioral responses and reaction times were automatically recorded by the software.

Simultaneously, EEG data were continuously recorded throughout the task. To minimize movement-related artifacts, participants were instructed to remain still and avoid unnecessary blinking during sentence presentation. The experimental session lasted approximately 60–75 minutes, including preparation and rest periods.

**Table 1.** Summary of Data Collection Procedure

| Stage                 | Procedure               | Description                                                    |
|-----------------------|-------------------------|----------------------------------------------------------------|
| Preparation           | EEG setup               | Electrode placement, impedance check, and participant briefing |
| Practice Session      | Familiarization         | Participants completed practice trials before the experiment   |
| Sentence Presentation | Experimental task       | Sentences presented word-by-word using computerized software   |
| Behavioral Response   | Comprehension task      | Participants answered comprehension questions via key presses  |
| EEG Recording         | Neural data acquisition | Continuous EEG recording during sentence processing            |
| Session Duration      | Total time              | Approximately 60–75 minutes including breaks                   |

**Table 2.** Behavioral and ERP Measures

| Variable               | Measure                     | Description                                        |
|------------------------|-----------------------------|----------------------------------------------------|
| Comprehension Accuracy | Percentage (%)              | Correct responses to comprehension questions       |
| Reaction Time          | Milliseconds (ms)           | Response latency following comprehension questions |
| N400 Amplitude         | Mean amplitude (300–500 ms) | Index of semantic processing                       |
| N400 Latency           | Peak latency (ms)           | Timing of semantic integration                     |
| P600 Amplitude         | Mean amplitude (500–900 ms) | Index of syntactic reanalysis                      |
| P600 Latency           | Peak latency (ms)           | Timing of syntactic repair processes               |

**Table 3.** Statistical Analysis Plan

| Research Objective                               | Data Type        | Statistical Test           |
|--------------------------------------------------|------------------|----------------------------|
| Compare comprehension accuracy across conditions | Behavioral       | One-way ANOVA              |
| Compare reaction times across conditions         | Behavioral       | One-way ANOVA              |
| Examine N400 differences across sentence types   | ERP              | Repeated-measures ANOVA    |
| Examine P600 differences across sentence types   | ERP              | Repeated-measures ANOVA    |
| Investigate proficiency–ERP relationship         | Behavioral & ERP | Pearson Correlation        |
| Compare two specific conditions                  | Behavioral/ERP   | Independent-samples t-test |

## Data Analysis

Behavioral data were analyzed using IBM SPSS Statistics. Descriptive statistics, including means and standard deviations, were calculated for comprehension accuracy and reaction times. Independent-samples t-tests and one-way ANOVA were employed to identify differences among sentence conditions. Statistical significance was established at the .05 level (Kutas & Federmeier, 2011).

EEG data were preprocessed using EEGLAB. The preprocessing procedure included filtering, artifact rejection, baseline correction, and segmentation into stimulus-locked epochs. ERP waveforms were averaged separately for each experimental condition. Mean amplitudes and peak latencies were calculated for the N400 component within the 300–500 ms time window and for the P600 component within the 500–900 ms time window, following procedures adopted in previous neurolinguistic research (Kutas & Federmeier, 2011; Steinhauer & Drury, 2012).

To examine neural differences across sentence conditions, repeated-measures ANOVA was conducted on ERP amplitudes and latencies. Correlation analyses were also performed to investigate relationships between ERP measures and behavioral performance. These analyses were intended to provide a comprehensive understanding of the neurocognitive mechanisms underlying second-language sentence processing.

## Result and Discussion

### Result

#### Behavioral Performance

Behavioral data were analyzed to examine participants' sentence-comprehension performance across the three experimental conditions. The results indicated significant differences in both comprehension accuracy and reaction times among grammatically correct sentences, semantic anomalies, and syntactic violations.

Participants demonstrated the highest comprehension accuracy for grammatically correct sentences ( $M = 91.82\%$ ,  $SD = 4.37$ ), followed by sentences containing semantic anomalies ( $M = 84.25\%$ ,  $SD = 5.14$ ) and syntactic violations ( $M = 79.63\%$ ,  $SD = 5.86$ ). One-way ANOVA revealed a statistically significant difference among conditions,  $F(2,177) = 18.47$ ,  $p < .001$ .

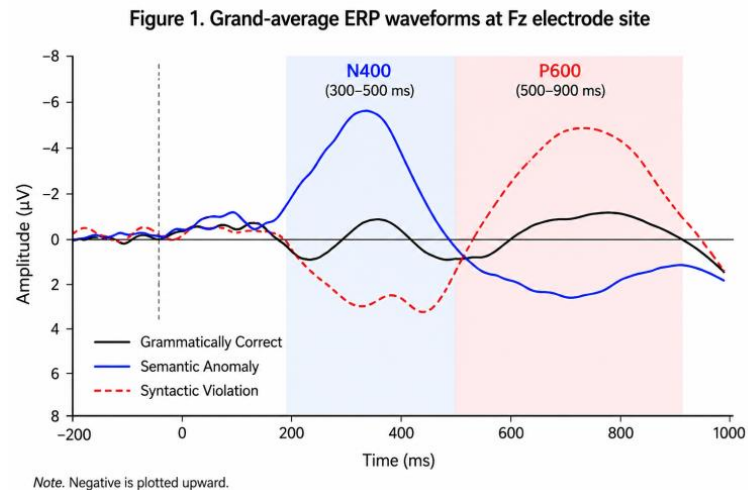
Similarly, reaction-time analysis showed that participants required longer processing times when responding to anomalous sentences. Mean reaction times were 712 ms ( $SD = 85$ ) for grammatically correct sentences, 834 ms ( $SD = 91$ ) for semantic anomalies, and 892 ms ( $SD = 97$ ) for syntactic violations. These findings suggest that semantic and syntactic irregularities increase processing demands during sentence comprehension.

#### ERP Findings: N400 Responses

ERP analyses revealed clear N400 effects in response to semantic anomalies. Semantically incongruent sentence endings elicited significantly larger negative amplitudes within the 300–500 ms time window compared with grammatically correct sentences.

The mean N400 amplitude for semantic anomalies was  $-4.87 \mu V$  ( $SD = 1.12$ ), whereas grammatically correct sentences produced a mean amplitude of  $-2.14 \mu V$  ( $SD = 0.94$ ). Repeated-measures ANOVA demonstrated a significant effect of sentence condition on N400 amplitude,  $F(1,59) = 29.83$ ,  $p < .001$ .

The observed N400 enhancement indicates increased semantic integration effort when learners encountered unexpected lexical information. The effect was predominantly distributed across centro-parietal electrode sites, consistent with established findings in ERP literature.



**Figure 1.** Grand-average ERP waveforms at Fz electrode site

### ERP Findings: P600 Responses

Syntactic violations elicited robust P600 responses within the 500–900 ms time window. Sentences containing grammatical errors generated significantly larger positive amplitudes than grammatically correct sentences.

The mean P600 amplitude was 5.42  $\mu\text{V}$  (SD = 1.31) for syntactic violations and 2.28  $\mu\text{V}$  (SD = 1.05) for grammatically correct sentences. Statistical analysis confirmed a significant condition effect,  $F(1,59) = 34.16$ ,  $p < .001$ .

The enhanced P600 response suggests that participants engaged in syntactic reanalysis and repair processes when confronted with grammatical inconsistencies. The effect was primarily observed in centro-parietal regions, which aligns with previous ERP studies of syntactic processing.

### Correlation Between ERP Measures and Behavioral Performance

Pearson correlation analyses revealed significant relationships between ERP responses and behavioral outcomes. Larger N400 amplitudes were associated with lower comprehension accuracy ( $r = -.42$ ,  $p < .01$ ), indicating increased processing difficulty during semantic integration. Conversely, stronger P600 amplitudes were positively associated with grammatical judgment accuracy ( $r = .47$ ,  $p < .01$ ), suggesting that successful syntactic processing contributes to improved sentence comprehension.

These findings indicate that electrophysiological measures provide meaningful information regarding individual differences in second-language processing performance.

### Discussion

The present study investigated the neural mechanisms underlying second-language sentence processing through behavioral and ERP measures. The findings demonstrated that semantic anomalies elicited enhanced N400 responses, whereas syntactic violations generated robust P600 effects. These results provide evidence that second-language learners recruit distinct neurocognitive mechanisms during semantic and syntactic processing.

The observed N400 effects are consistent with previous studies suggesting that semantic integration difficulties produce larger negative ERP amplitudes approximately 400 milliseconds after stimulus presentation (Kutas & Federmeier, 2011; Hagoort & Brown, 2000). The findings support the view that second-language learners actively engage semantic processing mechanisms when integrating lexical information within sentence contexts. Furthermore, the presence of clear N400 responses suggests that university-level EFL

learners have developed relatively efficient semantic-processing abilities despite being non-native speakers.

The P600 findings corroborate earlier research demonstrating that grammatical violations trigger syntactic reanalysis and repair mechanisms (Hahne & Friederici, 2001; Kaan & Swaab, 2003). The enhanced P600 amplitudes observed in this study indicate that participants detected and responded to syntactic irregularities during sentence comprehension. These findings support theories proposing that syntactic processing involves controlled cognitive operations that become increasingly efficient as language proficiency develops.

The behavioral findings further complement the ERP results. Lower comprehension accuracy and longer reaction times for anomalous sentences suggest that semantic and syntactic violations increase cognitive processing demands. Similar patterns have been reported in previous second-language studies, where increased linguistic complexity resulted in slower processing and reduced performance accuracy (Morgan-Short et al., 2012; Tanner, 2015).

From a theoretical perspective, the findings support neurocognitive models proposing that language comprehension relies on interactions among multiple neural systems rather than a single processing mechanism (Friederici, 2011; Hagoort, 2019). Semantic integration, syntactic computation, and contextual interpretation appear to operate as interconnected processes that collectively contribute to successful sentence comprehension.

## **Implications**

The findings have several implications for second-language learning and teaching. First, the results highlight the importance of developing both semantic and syntactic competence during language instruction. Educational practices that promote contextual vocabulary learning and grammatical awareness may facilitate more efficient language processing.

Second, the study demonstrates the value of ERP methodology for investigating language-learning processes. Electrophysiological measures provide insights that may not be captured through traditional behavioral assessments alone, thereby contributing to a more comprehensive understanding of second-language acquisition.

Third, the findings support the integration of cognitively informed pedagogical approaches that emphasize meaningful language exposure and active sentence-processing activities. Such approaches may enhance learners' ability to process linguistic information efficiently in real-time communication.

## **Limitations and Future Research**

Several limitations should be acknowledged. First, the study involved participants from a single university, which may limit the generalizability of the findings. Future studies should include learners from diverse educational and linguistic backgrounds.

Second, the sample consisted primarily of intermediate-to-advanced EFL learners. Further research should examine whether similar ERP patterns are observed among beginning learners and highly proficient bilinguals.

Third, the study focused exclusively on N400 and P600 components. Future investigations may incorporate additional ERP measures, such as LAN and MMN, to provide a more comprehensive understanding of language-processing mechanisms.

Finally, longitudinal studies are needed to examine how neural responses change over time as learners gain increased language experience and proficiency. Such research would

contribute to a more complete understanding of neuroplasticity in second-language acquisition.

## Conclusion

This study investigated the neural mechanisms underlying second-language sentence processing through the analysis of behavioral performance and Event-Related Potentials (ERPs). The findings revealed that semantic anomalies elicited enhanced N400 responses, whereas syntactic violations generated robust P600 effects. These results indicate that semantic integration and syntactic processing involve distinct yet interconnected neurocognitive mechanisms during sentence comprehension.

Behavioral findings demonstrated that participants experienced greater difficulty when processing semantically and syntactically anomalous sentences, as reflected in lower comprehension accuracy and longer reaction times. Furthermore, significant relationships between ERP responses and behavioral performance suggest that neural processing efficiency contributes to successful second-language comprehension.

The study supports contemporary neurolinguistic models proposing that sentence processing relies on dynamic interactions among distributed neural networks responsible for lexical retrieval, semantic integration, and syntactic computation (Friederici, 2011; Hagoort, 2019). The findings also confirm the usefulness of ERP methodology in examining real-time language processing and contribute to a deeper understanding of the neurocognitive foundations of second-language acquisition.

Overall, the present study provides empirical evidence that semantic and syntactic processing mechanisms can be effectively examined through N400 and P600 components. These findings offer valuable insights for neurolinguistic research and language education by highlighting the importance of understanding how learners process linguistic information at the neural level.

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## References

- Bowden, H. W., Steinhauer, K., Sanz, C., & Ullman, M. T. (2013). Native-like brain processing of syntax can be attained by university learners. *Neuropsychologia*, 51(13), 2492–2511. <https://doi.org/10.1016/j.neuropsychologia.2013.09.004>
- Caffarra, S., Molinaro, N., Davidson, D., & Carreiras, M. (2015). Second language syntactic processing revealed through ERP evidence. *Brain Research*, 1629, 144–157. <https://doi.org/10.1016/j.brainres.2015.10.010>
- Caffarra, A. D. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, 6(2), 78–84. [https://doi.org/10.1016/S1364-6613\(00\)01839-8](https://doi.org/10.1016/S1364-6613(00)01839-8)
- Friederici, A. D. (2011). The brain basis of language processing: From structure to function. *Physiological Reviews*, 91(4), 1357–1392. <https://doi.org/10.1152/physrev.00006.2011>
- Friederici, A. D., Hahne, A., & Saddy, D. (2002). Distinct neurophysiological patterns reflecting aspects of syntactic complexity and syntactic repair. *Journal of Psycholinguistic Research*, 31(1), 45–63. <https://doi.org/10.1023/A:1014376204525>

- Friederici, A. D., Meyer, M. (2004). The brain knows the difference: Two types of grammatical violations. *Brain Research*, 1000(1–2), 72–77. <https://doi.org/10.1016/j.brainres.2003.10.057>
- Friederici, A. D., Rüschemeyer, S. A., Hahne, A., & Fiebach, C. J. (2003). The role of left inferior frontal and superior temporal cortex in sentence comprehension. *Cerebral Cortex*, 13(2), 170–177. <https://doi.org/10.1093/cercor/13.2.170>
- Friederici, A. D., Steinhauer, K., & Pfeifer, E. (2002). Brain signatures of artificial language processing. *Proceedings of the National Academy of Sciences*, 99(1), 529–534. <https://doi.org/10.1073/pnas.012611199>
- Friederici, A. D., & Weissenborn, J. (2007). Mapping sentence form onto meaning: The syntax–semantic interface. *Brain Research*, 1146, 50–58. <https://doi.org/10.1016/j.brainres.2006.08.038>
- Gunter, T. C., Friederici, A. D., & Schriefers, H. (2000). Syntactic gender and semantic expectancy. *Journal of Cognitive Neuroscience*, 12(4), 556–568. <https://doi.org/10.1162/089892900562336>
- Hagoort, P. (2019). The neurobiology of language beyond single-word processing. *Science*, 366(6461), 55–58. <https://doi.org/10.1126/science.aax0289>
- Hagoort, P., & Brown, C. M. (2000). ERP effects of listening to speech compared with reading. *Neuropsychologia*, 38(11), 1531–1549. [https://doi.org/10.1016/S0028-3932\(00\)00053-1](https://doi.org/10.1016/S0028-3932(00)00053-1)
- Hahne, A. (2001). What's different in second-language processing? Evidence from event-related brain potentials. *Journal of Psycholinguistic Research*, 30(3), 251–266. <https://doi.org/10.1023/A:1010490917575>
- Hahne, A., & Friederici, A. D. (2001). Processing a second language: Late learners' comprehension mechanisms as revealed by event-related brain potentials. *Bilingualism: Language and Cognition*, 4(2), 123–141. <https://doi.org/10.1017/S1366728901000232>
- Hahne, A., & Friederici, A. D. (2002). Differential task effects on semantic and syntactic processes as revealed by ERPs. *Cognitive Brain Research*, 13(3), 339–356. [https://doi.org/10.1016/S0926-6410\(01\)00127-6](https://doi.org/10.1016/S0926-6410(01)00127-6)
- Kaan, E., & Swaab, T. Y. (2003). Repair, revision, and complexity in syntactic analysis: An ERP differentiation. *Journal of Cognitive Neuroscience*, 15(1), 98–110. <https://doi.org/10.1162/089892903321107855>
- Kotz, S. A. (2009). A critical review of ERP and fMRI evidence on L2 syntactic processing. *Brain and Language*, 109(2–3), 68–74. <https://doi.org/10.1016/j.bandl.2008.06.002>
- Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential. *Annual Review of Psychology*, 62, 621–647. <https://doi.org/10.1146/annurev.psych.093008.131123>
- Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science*, 207(4427), 203–205. <https://doi.org/10.1126/science.7350657>
- McLaughlin, J., Osterhout, L., & Kim, A. (2004). Neural correlates of second-language word learning. *Nature Neuroscience*, 7(7), 703–704. <https://doi.org/10.1038/nn1264>
- Morgan-Short, K., Steinhauer, K., Sanz, C., & Ullman, M. T. (2012). Explicit and implicit second language training differentially affect the achievement of native-like brain activation patterns. *Journal of Cognitive Neuroscience*, 24(4), 933–947. [https://doi.org/10.1162/jocn\\_a\\_00119](https://doi.org/10.1162/jocn_a_00119)

- Mueller, J. L., Hahne, A., Fujii, Y., & Friederici, A. D. (2005). Native and nonnative speakers' processing of a miniature version of Japanese. *Journal of Cognitive Neuroscience*, 17(8), 1229–1244. <https://doi.org/10.1162/0898929055002436>
- Ojima, S., Nakata, H., & Kakigi, R. (2005). An ERP study of second language learning after childhood. *NeuroReport*, 16(18), 2017–2021. <https://doi.org/10.1097/01.wnr.0000187638.39997.00>
- Osterhout, L., & Holcomb, P. J. (1992). Event-related brain potentials elicited by syntactic anomaly. *Journal of Memory and Language*, 31(6), 785–806. [https://doi.org/10.1016/0749-596X\(92\)90039-Z](https://doi.org/10.1016/0749-596X(92)90039-Z)
- Osterhout, L., McLaughlin, J., Pitkänen, I., Frenck-Mestre, C., & Molinaro, N. (2008). Novice learners, longitudinal designs, and event-related potentials. *Language Learning*, 58(Suppl. 1), 199–230. <https://doi.org/10.1111/j.1467-9922.2008.00461.x>
- Rossi, S., Gugler, M. F., Friederici, A. D., & Hahne, A. (2006). The impact of proficiency on syntactic second-language processing. *Journal of Cognitive Neuroscience*, 18(12), 2030–2048. <https://doi.org/10.1162/jocn.2006.18.12.2030>
- Sabourin, L., & Stowe, L. A. (2008). Second language processing: When are first and second languages processed similarly? *Second Language Research*, 24(3), 397–430. <https://doi.org/10.1177/0267658308090186>
- Steinhauer, K., White, E. J., & Drury, J. E. (2009). Temporal dynamics of late second language acquisition. *Second Language Research*, 25(1), 13–41. <https://doi.org/10.1177/0267658308098995>
- Tanner, D. (2015). On the use of ERPs in language research. *Second Language Research*, 31(3), 361–387. <https://doi.org/10.1177/0267658314559117>
- Tanner, D., Inoue, K., & Osterhout, L. (2014). Brain-based individual differences in online L2 grammatical comprehension. *Bilingualism: Language and Cognition*, 17(2), 277–293. <https://doi.org/10.1017/S1366728913000370>
- Tokowicz, N., & MacWhinney, B. (2005). Implicit and explicit measures of sensitivity to violations in second language grammar. *Studies in Second Language Acquisition*, 27(2), 173–204. <https://doi.org/10.1017/S0272263105050102>
- Weber-Fox, C., & Neville, H. J. (2001). Sensitive periods differentiate processing of open- and closed-class words. *Journal of Speech, Language, and Hearing Research*, 44(6), 1338–1353. [https://doi.org/10.1044/1092-4388\(2001/104\)](https://doi.org/10.1044/1092-4388(2001/104))