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NEUROLINGUISTICS AND THE EVOLUTION OF LANGUAGE

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Abstract
This study explores how Uzbek-speaking students process different aspects of English as a second language through the framework of the Dual-Stream Model of Language Processing. By designing three targeted tasks—Minimal Pairs Challenge, Sentence Unscramble, and Describe the Picture—the research examined students' performance in pronunciation, grammar, and productive language skills. Data were collected via Google Forms from 37 participants and analyzed using a mixed-methods approach. Quantitative results measured accuracy rates, while qualitative insights highlighted common patterns and errors. The findings revealed distinct challenges linked to both the dorsal stream (responsible for speech production) and the ventral stream (linked to sentence comprehension), with strong influence from students' native language structure. The study offers practical implications for ESL instruction, emphasizing the need for targeted phonetic training and syntax-focused activities that consider L1 interference.

Keywords: Neurolinguistics, evolution of language, second-language acquisition, Dual-Stream Model, language processing, bilingualism, dorsal stream, ventral stream, ESL learning, neural plasticity, cognitive linguistics, brain and language, functional MRI (fMRI), electroencephalography (EEG), Critical Period Hypothesis.

Introduction

Neurolinguistics has undergone a significant evolution, transforming from early speculative theories about language and the brain into an empirical science driven

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by technological advancements. The study of language has long been central to human inquiry, with early linguistic theories focusing on structure, meaning, and acquisition. However, these theories could not fully explain how language is processed in the brain, leading to the emergence of neurolinguistics as a distinct field. By combining linguistics, neuroscience, and psychology, neurolinguistics has reshaped our understanding of how humans acquire, use, and comprehend language.

The foundation of neurolinguistics was laid by early researchers such as Paul Broca (1861)[1] and Carl Wernicke (1874)[2], who identified distinct areas of the brain responsible for speech production and comprehension. Their discoveries led to the classical model of language localization, which dominated the field for decades. However, later research challenged the idea that language functions were confined to specific regions. Roger Sperry (1968)[3] and Michael Gazzaniga (1970)[4] expanded our understanding by demonstrating that both hemispheres of the brain contribute to language processing. With the development of neuroimaging techniques such as functional MRI (fMRI) and electroencephalography (EEG), researchers have since revealed that language processing involves a complex network of neural pathways rather than isolated brain areas.

One of the most significant advancements in neurolinguistics has been the introduction of the Dual-Stream Model of Language Processing by Hickok and Poeppel (2007)[5]. This model proposes that language is processed through two interconnected pathways: the dorsal stream, which links speech to motor functions, and the ventral stream, which connects speech to meaning. This framework has been particularly influential in second-language acquisition

[1] Broca, P. (1861). Remarks on the seat of the faculty of articulate language, followed by an observation of aphemia. Bulletin de la Société Anatomique de Paris, 6, 330-357.
[2] Wernicke, C. (1874). Der aphasische Symptomencomplex: Eine psychologische Studie auf anatomischer Basis. Cohn & Weigert.
[3] Sperry, R. W. (1968). Hemisphere disconnection and unity in conscious awareness. American Psychologist, 23(10), 723-733.
[4] Gazzaniga, M. S. (1970). The bisected brain. Appleton-Century-Crofts.
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research, offering explanations for why some learners struggle with pronunciation while others face difficulties in grammar and comprehension.

The application of neurolinguistics in second-language learning marks a major stage in its evolution. Studies on bilingualism by Kroll and Bialystok (2013)[6] show that learning multiple languages enhances cognitive flexibility, while research by Abutalebi and Green (2016)[7] highlights how multilingual exposure strengthens brain plasticity. These findings suggest that the brain undergoes structural and functional changes in response to language learning, making neurolinguistics a crucial field in understanding and improving second-language acquisition.

As neurolinguistics continues to evolve, its practical applications extend beyond theoretical linguistics. It has revolutionized language teaching, speech therapy, and rehabilitation for individuals with language impairments. Furthermore, neurolinguistic research plays a growing role in preserving endangered languages by identifying cognitive factors that support language retention. By bridging the gap between brain science and real-world communication, neurolinguistics provides invaluable insights into how humans learn and use language. This study aims to explore the role of neurolinguistics in second-language acquisition, with a focus on how Uzbek-speaking ESL learners process English and the implications of the Dual-Stream Model in language education.

Literature Review

Neurolinguistics has evolved significantly over the past decades, shifting from early theoretical assumptions about language processing to an empirical science informed by technological advances. Initially, language was studied as an abstract system of symbols and rules, but with the development of neuroscience, researchers began exploring how language functions in the brain. This shift has been particularly relevant in second-language acquisition, where neurolinguistics

[6] Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. Journal of Cognitive Psychology, 25(5), 497-514.
[7] Abutalebi, J., & Green, D. W. (2016). Neural mechanisms of bilingual language control. Journal of Neurolinguistics, 40, 24-34.

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provides critical insights into the cognitive and neural mechanisms that facilitate or hinder language learning.

Early Studies in Language and the Brain

The classical understanding of language processing in the brain dates back to the 19th century with the discoveries of **Paul Broca (1861)**[8] **and Carl Wernicke (1874)**[9]. Their work led to the identification of **Broca's area**, associated with speech production, and **Wernicke's area**, linked to language comprehension. Broca's discovery firstly came from studying a patient who had lost the ability to speak fluently but could still understand language. After the patient's death, an autopsy revealed damage to the left frontal lobe, which is known as Broca's area today. Furthermore, Wernicke expanded on this by identifying a separate area in the left temporal lobe—Wernicke's area—which was linked to difficulties in comprehension while maintaining fluent speech. These findings established the foundation for the classical model of language processing, which assumed that language functions were strictly localized to these two areas of the brain.

For decades, researchers relied on the lesion method, studying people with brain injuries to understand the role of specific brain areas in language. However, this approach had limitations, as it oversimplified the complexity of language processing. Later research revealed that language is not confined to isolated regions but involves an interconnected network of neural pathways. Studies in the late 20th century showed that damage to areas outside Broca's and Wernicke's regions could still worsen language abilities, leading to the idea that multiple regions of the brain contribute to speech, comprehension, and linguistic memory. Additionally, early investigations into split-brain patients by Roger Sperry (1968)[10] and Michael Gazzaniga (1970)[11] provided further insights into how

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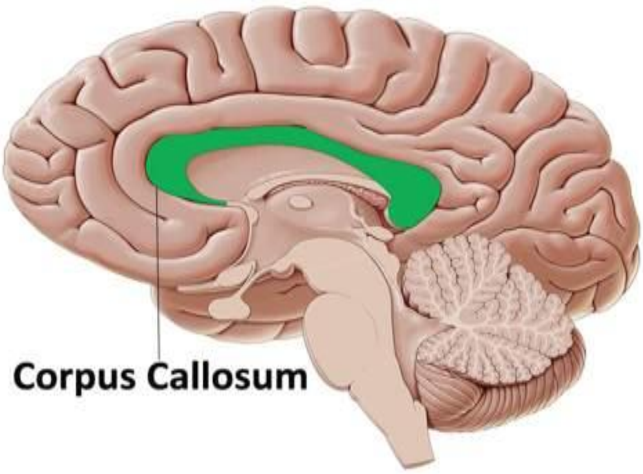
language is lateralized in the brain. Their work on patients with severed corpus callosums[1]



1. Corpus Callosum is a thick band of nerve fibers that connects the left and right hemispheres of the brain, enabling communication between them.

demonstrated that the left hemisphere plays a dominant role in language processing, while the right hemisphere contributes to intonation, pragmatics, and emotional aspects of speech. These findings reshaped how scientists viewed the neurological basis of language, paving the way for more advanced research in neurolinguistics. The lesion method, where scientists studied individuals with brain injuries, was the dominant approach for decades. However, these early studies lacked precision, as language was thought to be processed in isolated regions rather than as part of an interconnected network. For decades, these findings dominated neurolinguistic research, reinforcing the idea that language functions were strictly localized in specific brain regions.

However, by the late 20th century, new findings challenged this rigid localization theory. Studies on **split-brain patients** by **Roger Sperry (1968)**[12] **and Michael Gazzaniga (1970)**[13] revealed that language is not confined to a single hemisphere. While the **left hemisphere is dominant for grammar and syntax,** the **right hemisphere plays a role in intonation, pragmatics, and emotion in**

[12] Sperry, R. W. (1968). Hemisphere disconnection and unity in conscious awareness. American Psychologist, 23(10), 723-733.
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speech. These discoveries marked a shift toward understanding language as a **distributed neural network** rather than a function of isolated brain areas.

Evolution of Neurolinguistics and the Dual-Stream Model

The most significant shift in neurolinguistics came with the development of **neuroimaging technologies**, such as **functional MRI (fMRI) and electroencephalography (EEG),** which allowed researchers to observe the brain in action. These tools provided empirical evidence that language is processed through **multiple interacting pathways**, leading to the **Dual-Stream Model of Language Processing** proposed by **Hickok and Poeppel (2007)**[14].

This model introduced two main processing pathways:

- **The Dorsal Stream**, which links speech perception to motor functions, enabling spoken language production.
- **The Ventral Stream**, which connects speech perception to meaning, supporting comprehension and conceptual processing.

Over the past decade, this model has become foundational in explaining why **second-language learners struggle differently depending on their cognitive strengths and weaknesses**. **Kroll and Bialystok (2013)**[15] found that bilinguals rely more on the ventral stream for meaning-based processing, while monolinguals depend more on the dorsal stream for speech articulation. This suggests that **ESL learners may comprehend language better than they can produce it**, particularly in the early stages of learning.

Neurolinguistics in Second-Language Acquisition (2013–2023)

In the last ten years, research in neurolinguistics has increasingly focused on **how second-language acquisition shapes the brain**. Studies by **Pliatsikas (2021)**[16] indicate that long-term bilingualism leads to structural changes in the brain, particularly in the **hippocampus and prefrontal cortex**, enhancing **memory and cognitive flexibility**. Similarly, **Li and Grant (2020)**[17] found that second-

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[15] Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. Journal of Cognitive Psychology, 25(5), 497-514.
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language learners activate a broader neural network than native speakers, particularly in areas related to **executive function and cognitive control**.

However, despite these cognitive benefits, **challenges persist in second-language learning**. **Pronunciation difficulties** are often linked to inefficient activation of the **dorsal stream**, while **comprehension struggles** stem from weaknesses in the **ventral stream**. **Abutalebi and Green (2016)**[18] suggest that **neural plasticity** plays a key role in overcoming these challenges, but effectiveness depends on **age, exposure, and learning environment**. This aligns with **Lenneberg's (1967)**[19] **Critical Period Hypothesis**, which suggests that language learning is most effective before adolescence.

Future Directions in Neurolinguistics

The **evolution of neurolinguistics** continues, with recent studies exploring the role of **AI and machine learning in language processing**. **Pulvermüller et al. (2020)**[20] highlight that computational models can now simulate **how the brain processes syntax and semantics**, providing insights into the neural basis of grammar. Additionally, neurolinguistic research is being applied in **speech therapy, multilingual education, and even language preservation efforts**.

As neurolinguistics advances, its applications in **ESL learning** will become more refined, helping educators develop **brain-based teaching strategies**. Understanding how language is processed in the brain not only informs teaching methods but also contributes to a deeper understanding of the **cognitive evolution of language itself**.

This study builds on the growing body of neurolinguistic research to examine how **Uzbek-speaking ESL learners** process English and how insights from the **Dual-Stream Model** can inform more effective teaching strategies.

Neurolinguistics and second-language acquisition

In recent years, research on neurolinguistics and second-language acquisition has expanded significantly, focusing on how the brain adapts to learning a new language and the cognitive benefits of bilingualism. Studies such as Li and Grant

[18] Abutalebi, J., & Green, D. W. (2016). Neural mechanisms of bilingual language control. Journal of Neurolinguistics, 40, 24-34.
[19] Lenneberg, E. H. (1967). Biological foundations of language. Wiley
[20] Henningsen-Schomers, M. R., & Pulvermüller, F. (2020). A neurobiologically grounded computational model of inner speech. Scientific Reports, 10, 1-16.

(2020)[21] highlight that second-language learners show increased activity in both hemispheres, particularly in the prefrontal cortex, suggesting stronger executive function skills. Similarly, research by Pliatsikas (2021)[22] indicates that long-term bilingualism leads to structural changes in the brain, improving memory and problem-solving abilities.

While these findings reinforce the idea that learning a second language enhances brain function, they also reveal the challenges that learners face at different stages. Some struggle with pronunciation, while others find it harder to understand and process meaning in real time. The Dual-Stream Model of Language Processing, introduced by Hickok & Poeppel (2007)[23], provides a way to explain these difficulties by mapping language to specific neural pathways. Instead of treating language as a single skill, this model separates it into speech production (dorsal stream) and comprehension (ventral stream), helping us understand why certain aspects of learning English as a second language are more difficult than others. The following section will explore how this model applies to Uzbek-speaking ESL learners and how it can inform more effective teaching methods. But understanding the bigger picture of how language works in the brain isn't enough—we need to look at the specific processes that help or hinder second-language learners. This is where the Dual-Stream Model of Language Processing comes in. Instead of viewing language as a single function, this model breaks it down into two interconnected pathways, explaining why some learners struggle more with pronunciation while others find comprehension more difficult. By exploring this framework, we can get a clearer picture of how the brain handles a second language and how teaching methods can be improved to match how our brains actually work. However, while these studies provide valuable insights into the broad impact of neurolinguistics on language learning, a more detailed understanding of how specific brain mechanisms contribute to second language acquisition is needed. This is where the Dual-Stream Model of Language

[21] Li, P., & Grant, A. (2015). Second language learning success revealed by brain networks. Bilingualism: Language and Cognition, 19(4), 657-664. https://doi.org/10.1017/S1366728915000280
[22] Pliatsikas, C. (2021). Understanding structural plasticity in the bilingual brain: The Dynamic Restructuring Model. Bilingualism: Language and Cognition, 24(2), 216-218.
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Processing plays a crucial role. By analyzing how language is processed through interconnected neural pathways, this model offers a practical framework for understanding the difficulties faced by second-language learners and provides a scientific basis for more effective teaching strategies.

The Dual-Stream Model and Second Language Processing

A central theory in neurolinguistics is the Dual-Stream Model of Language Processing, introduced by Hickok & Poeppel (2007)[24]. This model provides a framework for understanding how language is processed in the brain, particularly in second-language learners. Unlike the classical Broca-Wernicke model, which suggested that speech production and comprehension are localized in separate brain areas, the dual-stream model proposes that language is processed through two interconnected pathways:

1. **Dorsal Stream (Speech Production & Phonology)** – This pathway links speech sounds to motor functions, allowing individuals to produce spoken language. It is crucial for second-language learners who struggle with pronunciation, fluency, and articulation.
2. **Ventral Stream (Meaning & Comprehension)** – This pathway connects speech sounds to meaning, helping learners understand words, idioms, and figurative expressions. ESL students often face challenges in this area when interpreting complex sentences or unfamiliar vocabulary.

Research shows that second-language learners activate different neural patterns compared to native speakers. Kroll & Bialystok (2013)[25] found that bilinguals rely more on the ventral stream for meaning-based processing, while monolinguals show stronger activation in dorsal stream regions for direct speech articulation. This suggests that ESL students may comprehend language better than they can produce it, particularly in the early stages of language learning.

[24] Hickok, G., & Poeppel, D. (2007). The cortical organization of speech processing. Nature Reviews Neuroscience, 8(5), 393-402.
[25] Kroll, J. F., & Bialystok, E. (2013). Understanding the consequences of bilingualism for language processing and cognition. Journal of Cognitive Psychology, 25(5), 497-514. https://doi.org/10.1080/20445911.2013.799170

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Another key factor in second-language processing is neural plasticity. Studies by Abutalebi & Green (2016)[26] suggest that multilingual exposure strengthens the connections between the dorsal and ventral streams, making it easier for bilingual individuals to switch between languages and develop stronger speech control. However, younger learners demonstrate higher adaptability, supporting Lenneberg's (1967)[27] Critical Period Hypothesis, which states that language learning is more effective before adolescence.

Methodology

This study set out to explore how Uzbek-speaking students learning English as a second language process different aspects of language through the lens of the Dual-Stream Model of Language Processing. To do this, students took part in three key exercises: the Minimal Pairs Challenge (to assess pronunciation and phonological processing), Sentence Unscramble (to evaluate word order comprehension), and Describe the Picture (to test speaking and writing skills). These tasks were conducted online via Google Forms, which allowed for easy data collection and analysis.

A mix of **quantitative and qualitative methods** was used to examine the results. The quantitative aspect measured how many answers were correct, while the qualitative side focused on patterns in student mistakes. The main objective was to determine whether students struggled more with **speech production (dorsal stream)** or **sentence comprehension (ventral stream).**

Results

The findings revealed that students had distinct difficulties depending on the type of task.

1. **Minimal Pairs Challenge (Pronunciation & Phonology – Dorsal Stream)**

- The most frequent errors involved **vowel length confusion**, particularly with **"ship" vs. "sheep"** and **"bit" vs. "beat."**

[26] Abutalebi, J., & Green, D. W. (2016). Neural mechanisms of bilingual language control. Journal of Neurolinguistics, 40, 24-34.
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- Many students also found it difficult to differentiate between **"full" vs. "fool."**
- These results suggest that recognizing and producing vowel length differences is a major challenge, pointing to **weaknesses in the dorsal stream, which handles speech-motor coordination.**

2. **Sentence Unscramble (Word Order & Grammar – Ventral Stream)**

- A common mistake was arranging words in a way that followed Uzbek grammar rather than English. For instance, students wrote **"They are the park going to"** instead of **"They are going to the park."**
- This occurred because Uzbek allows for more flexible word order, whereas English follows a stricter **Subject-Verb-Object (SVO) structure**.
- These results suggest that students struggled to internalize English syntax rules, highlighting **difficulties in the ventral stream, which processes meaning and sentence structure.**

3. **Describe the Picture (Speaking & Writing – Dorsal & Ventral Interaction)**

- Many responses contained **short, incomplete sentences** (e.g., "I see four woman two man.")
- Students also struggled with **word retrieval**, leading to simple descriptions instead of more detailed sentences.
- This indicates that both **speech production (dorsal stream) and sentence processing (ventral stream)** require further reinforcement.

Discussion

These findings align with previous research on second-language learning. Many studies have shown that learners often struggle with **pronunciation due to neural differences in the dorsal stream**, while **sentence structure errors arise from challenges in the ventral stream**.

Additionally, the results confirm that Uzbek-speaking students tend to apply **native language grammar rules to English**, which leads to **word order mistakes**. This supports past research on **L1 interference**, where first-language habits influence second-language acquisition.

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Conclusion

This study highlights how the Dual-Stream Model of Language Processing can explain the challenges faced by Uzbek-speaking students when learning English. By distinguishing between **speech production difficulties (dorsal stream)** and **sentence comprehension challenges (ventral stream),** educators can create more effective teaching strategies.

Moving forward, teachers can use these insights to enhance ESL instruction:

1) For pronunciation difficulties, incorporating more **phonetic training** and minimal pair drills can help improve accuracy.

2) For grammar and sentence structure issues, using **visual sentence-building exercises** and direct comparisons between Uzbek and English could make learning smoother.

By applying neurolinguistic insights to ESL education, we can help students navigate the complexities of second-language learning in a way that feels more natural and intuitive.

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