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NEUROLINGUISTIC ANALYSIS OF BILINGUAL BRAIN PROCESSES: A COMPARATIVE STUDY OF UZBEK AND ENGLISH

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Abstract
This paper presents a neurolinguistic analysis of bilingual brain processing in Uzbek-English bilinguals. It examines the impact of bilingualism on brain activity, focusing on code-switching mechanisms and interference effects. The study utilizes neurotechnologies such as EEG, fMRI, and ERP to observe how bilinguals perceive and process language. The findings indicate that Uzbek-English bilinguals employ different strategies at the syntactic and lexical levels, enhancing their neural adaptability. These results have significant implications for education, translation, and language learning, as they contribute to a deeper understanding of bilingual cognitive processes.

Keywords: Neurolinguistics, bilingualism, code-switching, interference, cognitive processes, EEG, fMRI.

Аннотация:
в данной статье проводится нейролингвистический анализ обработки языковой информации в мозге билингвов, владеющих узбекским и английским языками. Рассматриваются изменения в мозговой деятельности при билингвизме, механизмы языкового переключения (код-шифтинг) и интерференции. В исследовании использованы нейротехнологии, такие как ЭЭГ, fMRI и ERP, для наблюдения за восприятием и обработкой языка у билингвов. Результаты показывают, что узбекско-английские билингвы

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применяют различные стратегии на синтаксическом и лексическом уровнях, что способствует повышению нейропластичности мозга. Эти выводы имеют важное значение для сферы образования, перевода и изучения иностранных языков, так как позволяют глубже понять когнитивные процессы билингвов.

Ключевые слова: нейролингвистика, билингвизм, переключение кодов, интерференция, когнитивные процессы, ЭЭГ, fMRI.

Introduction

This section provides a brief overview of bilingualism and its cognitive and neurolinguistic dimensions, followed by a general description of the grammatical and lexical differences between Uzbek and English. It also explains the relevance and primary objective of the study. The central research question is: How does bilingualism affect the human brain?

Neurolinguistic features of Uzbek and English. Bilingualism is a linguistic and neurocognitive phenomenon that significantly influences the human brain and its functional processes. Research indicates that bilingualism may enhance the brain's adaptability and strengthen its neuroplastic properties (Bialystok, 2009). It has also been associated with executive-control abilities such as regulating attention, filtering relevant information, and managing working-memory resources (Green, 1998). From a neurolinguistic perspective, bilingual language processing actively involves several brain regions, including Broca's area, Wernicke's area, the dorsolateral prefrontal cortex, and the anterior cingulate cortex.

Grammatical and lexical differences between Uzbek and English. Uzbek and English belong to different language families, resulting in substantial differences in their grammatical and lexical systems. Uzbek is an agglutinative language in which noun and verb forms are modified primarily through the addition of suffixes. English, by contrast, is predominantly analytical and relies more heavily on word order, function words, and auxiliary verbs.

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Lexically, English has Germanic roots, although a considerable proportion of its vocabulary derives from Latin and French. The Uzbek lexicon, meanwhile, is predominantly Turkic but has also developed under the considerable influence of Persian-Tajik and Arabic. These structural and lexical differences may cause the two languages to be processed differently in the brains of Uzbek–English bilinguals.

In the context of contemporary globalization, bilingualism is becoming increasingly widespread, making the investigation of its cognitive and neurobiological foundations both scientifically and practically significant. The present study provides a neurolinguistic analysis of language processing in Uzbek–English bilinguals. Using such technologies as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), and event-related potentials (ERPs), the study aims to investigate bilingual language processing and determine how grammatical and lexical differences between the two languages influence neural processing demands.

By addressing these questions, the study seeks to contribute to a deeper understanding of both the theoretical and practical dimensions of bilingualism and neurolinguistics.

Neurolinguistics is the field concerned with the relationship between language and the brain. It investigates the neurobiological foundations of language acquisition, processing, and production. **Bilingualism** is generally defined as the ability to know and actively use two or more languages. Research suggests that bilingualism not only develops linguistic competence but may also influence executive functions, memory, and attention (Bialystok, 2009).

Because bilingual individuals must continually manage and alternate between two languages, their brains adapt to processing words and grammatical structures from different linguistic systems. Such adaptation stimulates neuroplastic processes and may produce changes in neural connectivity compared with monolingual language processing.

Several theories have been proposed to explain how bilingualism is represented and processed in the brain:

According to Kim et al. (1997), the neural processing of two languages depends partly on the age at which the first and second languages are acquired. When both

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languages are acquired during early childhood, they tend to activate largely overlapping brain regions. When the second language is acquired later, however, certain aspects of its processing may involve neural regions that differ from those used for the first language.

Green's (1998) Inhibitory control model explains language switching and language inhibition in the bilingual brain. According to this model, bilingual individuals continually use executive-control mechanisms to select the appropriate language and suppress interference from the non-target language.

Bialystok's (2009) work examines the influence of bilingualism on executive functioning. Her research indicates that bilingual children and adults may demonstrate advantages over monolingual individuals in certain tasks involving attention control and cognitive flexibility.

The left cerebral hemisphere is generally regarded as dominant for many language-related processes. Broca's and Wernicke's areas are located in this hemisphere and are traditionally associated with speech production and language comprehension.

Bilingual language processing, however, may also involve contributions from the right hemisphere. In broad terms:

– **The left hemisphere** is primarily involved in syntactic and grammatical processing and in the formation and production of words.

– **The right hemisphere** contributes to interpreting meaning, understanding context, and processing pragmatic aspects of communication.

Because bilingual individuals must continually control and alternate between their languages, bilingualism may increase functional cooperation between the two hemispheres. EEG and fMRI studies indicate increased involvement of neural systems associated with attention and inhibitory control during bilingual language processing.

Code-switching refers to the alternation between two languages by a bilingual speaker. It may be influenced by several factors:

–the complexity of the topic;

–the language proficiency of the interlocutor;

–the social or emotional context.

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From a neurobiological perspective, code-switching is associated with the activation of the dorsolateral prefrontal cortex, a brain region involved in executive functioning. According to Green (1998) and Abutalebi et al. (2008), the bilingual brain adapts to the continual management and switching of languages, which may support cognitive flexibility and higher levels of cognitive control.
Understanding the neural manifestations of code-switching and cross-language interference is important for determining how bilingual individuals acquire and use their languages. A comprehensive understanding of the neurolinguistic foundations of bilingualism therefore requires identifying how two languages are processed in the brain and which mechanisms regulate their use. These theoretical foundations provide a scientific basis for the subsequent stages of the study and contribute to a deeper understanding of the relationship between bilingualism and neurolinguistics.

Research methodology

The study examines how bilingualism affects language processing at the neurophysiological level by employing modern **neurotechnological methods**. The principal methods include the following:

– **Electroencephalography (EEG):** EEG is used to measure neural electrical activity. It enables the investigation of brain-wave patterns and neurophysiological responses associated with language processing.

– **Functional magnetic resonance imaging (fMRI):** fMRI measures changes associated with cerebral blood flow and helps identify the brain regions actively involved in language perception and processing.

– **Event-related potentials (ERPs):** ERPs are used to measure neural responses to specific linguistic stimuli. This method makes it possible to examine the timing of language processing and identify differences in grammatical and lexical processing.

A combination of these methods is used to conduct an in-depth analysis of language-related processes in Uzbek–English bilinguals.

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Participants

The study involves **Uzbek–English bilinguals** selected according to the following criteria:

– Uzbek is their **native language**, and they are **fluent in English**;

– they actively use both languages in their daily lives, including in education, employment, or communication;

– their age of second-language acquisition can be determined, distinguishing early bilinguals from late bilinguals;

– they have no known neurological or psychological conditions that could affect brain function.

The participants are divided into two groups:

1. Early bilinguals: individuals who have been proficient in both languages since childhood.

2. Late bilinguals: individuals who acquired their second language at school or later.

This classification allows for a more precise analysis of differences in bilingual language processing.

Language tests and experimental tasks

Various **psycholinguistic tests and experiments** are conducted to evaluate how two languages are processed in the brain.

1. Lexical decision task

– Participants are shown words and nonwords, or pseudowords, on a screen.

– They must respond quickly and accurately by indicating whether each item is a real word.

– EEG and ERP measurements are used to examine word-recognition speed and the brain's neural responses.

2. Syntactic processing task

– Participants are presented with grammatically correct and grammatically incorrect sentences.

– Their neural responses during sentence processing are recorded and analyzed.

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– This task makes it possible to assess how bilingualism influences the comprehension and processing of grammatical structures.

3. Semantic priming task

– Participants are presented with words in one language or with stimuli involving both languages.

– Their responses to semantically related and unrelated words are measured.

– This task helps investigate how semantic networks are organized and activated in the bilingual brain.

4. Code-switching and interference experiment

– Participants are required to alternate rapidly between the two languages while speaking.

– EEG and fMRI data obtained during language switching are analyzed.

– The degree of cross-language interference—that is, the extent to which one language affects the other—is assessed.

This study provides an in-depth analysis of language processing in the brains of Uzbek–English bilinguals using neurotechnological methods such as EEG, fMRI, and ERP. It examines the speed of lexical and syntactic processing, code-switching, and cross-language interference to identify the neurobiological foundations of bilingualism. The findings obtained through these methods are analyzed in the following section.

The analysis focuses on:

- EEG and fMRI findings, where available;
- word-selection speed and the neural effects of grammatical structures in Uzbek and English;
- the cognitive advantages and challenges associated with bilingualism;
- code-switching and cross-language interference.

Research findings

The findings are based on data obtained through EEG and fMRI.

EEG findings revealed significant differences in the **N400 and P600 components** during language processing in Uzbek–English bilinguals. The

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N400, which is associated with semantic incongruity, was elicited during lexical selection in both languages, suggesting the activation of broader semantic associations.

The **P600 component**, which is commonly associated with syntactic reanalysis and the processing of grammatical violations, was recorded in response to grammatically complex structures. Owing to the syntactic differences between Uzbek and English, late bilinguals required more time to process grammatically incorrect sentences.

fMRI findings indicated increased activation in the **prefrontal cortex, Broca's area, and anterior cingulate cortex** during bilingual language processing. This activation was associated with the control of code-switching and cross-language interference.

Word-selection speed and the neural effects of grammatical structures in Uzbek and English

Lexical selection

– The experiments demonstrated that lexical selection was **faster in Uzbek than in English**, as Uzbek was the participants' native language and its lexical information was processed more automatically.

– Lexical selection in English was **slightly slower**, particularly when participants encountered complex word combinations.

– The broader the participants' vocabulary in both languages, the faster the lexical-selection process occurred.

Neural effects of grammatical structures

– Because Uzbek and English differ considerably in their grammatical systems, the cognitive and neural demands associated with syntactic processing also differed.

– The relatively **flexible word order of Uzbek** meant that changes in sentence structure did not create substantial difficulty for the bilingual participants.

– Because English has a comparatively fixed word order, bilingual participants required more time to detect incorrectly positioned words within English sentences.

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Cognitive advantages

Attention and executive functions: Bilingual participants demonstrated an enhanced ability to regulate attention and filter out irrelevant information compared with monolingual individuals.

Working memory: Bilingualism may strengthen working memory because bilingual speakers must keep two languages potentially active while selecting one and suppressing the other.

Cognitive flexibility: The findings indicated that bilingual participants were able to acquire new syntactic and semantic information more rapidly.

Challenges

Cross-language interference: Because both languages may be activated simultaneously in the bilingual brain, interference from one language was observed during the processing of the other.

Grammatical complexity in the second language: Late bilinguals experienced greater difficulty adapting to the grammatical rules of English.

Code-switching and automatic translation: Some participants switched languages unconsciously during conversation. This reflects the continual involvement of language-control mechanisms in bilingual speech production.

Code-switching

The experiments indicated that the **prefrontal cortex** and **anterior cingulate cortex** were more actively engaged during code-switching.

Switching rapidly to the second language required bilingual participants to manage more complex grammatical and executive-control processes.

Switching from English to Uzbek occurred more rapidly because returning to the native language was a more automatic process.

Cross-language interference

– EEG findings revealed interference effects caused by the simultaneous activation of words from both languages.

– Literal translation occurred more frequently during translation from English into Uzbek.

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– Such interference may **affect grammatical adaptation and semantic processing**.

Overall, the findings indicate that bilingualism has a **significant influence on linguistic, cognitive, and neurophysiological processes**. From the perspective of brain activity, lexical selection, syntactic processing, and code-switching are more complex in bilinguals than in monolinguals. Nevertheless, the efficiency of these processes may increase over time as bilingual language use becomes more established.

These findings have important implications for education, translation, and linguistic research and require more detailed investigation in future studies.

Comparison with previous research

When compared with previous research on bilingualism and neurolinguistics, the findings demonstrate several important similarities and differences. For example, **Bialystok (2009)** emphasized the development of executive functions in bilingual individuals, which is consistent with the findings of the present study. Increased activation of the **prefrontal cortex and anterior cingulate cortex** was observed among bilingual participants, supporting the theory of bilingual executive control proposed by **Green (1998) and Abutalebi et al. (2008)**.

However, the present findings revealed a **higher degree of lexical interference during language switching among Uzbek–English bilinguals**. This may be associated with the differences between early and late bilinguals reported by **Kim et al. (1997)**. These findings suggest that the neural processing of bilingualism may vary according to the structural characteristics of the languages involved.

Neural mechanisms of language acquisition and control

Language acquisition and processing are regulated by multiple neural systems. The **EEG and fMRI findings** indicated that:

– Owing to the characteristic agglutinative structure of Uzbek as the participants' native language, syntactic adaptation in Uzbek was **faster and required fewer processing resources**.

– The relatively fixed word order and analytical grammar of English required **greater involvement of the prefrontal cortex** during language processing.

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– The bilingual brain employed **language-inhibition mechanisms** to manage the two languages, resulting in increased activation in Broca's area and the anterior cingulate cortex.

Furthermore, **semantic priming experiments** demonstrated that bilingual participants activated meaning-related associations across their two languages more rapidly, suggesting that their semantic networks are interconnected. These findings indicate a high degree of cognitive flexibility among bilingual individuals.

Cognitive benefits

Enhanced executive functions: Bilingualism may support attentional control, cognitive flexibility, and working-memory performance.

Increased neuroplasticity: The continual management and switching of languages may provide regular cognitive stimulation and strengthen functional neural connections.

Delayed cognitive decline in later life: Some studies suggest that lifelong bilingualism may contribute to cognitive reserve and delay the clinical manifestation of symptoms associated with dementia, including Alzheimer's disease.

Potential challenges

Cross-language interference: The rules of one language may sometimes be incorrectly applied to the other language.

Code-switching and automatic translation: Switching between languages may become difficult, particularly in complex linguistic contexts.

Syntactic processing delays: Late bilinguals may require more cognitive resources to process the grammatical features of their second language.

Recommendations for education

Bilingual education systems: Flexible teaching methods should be developed to address the specific needs of bilingual learners.

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Code-switching as a pedagogical strategy: The purposeful use of code-switching may help students understand linguistic material and acquire new languages more effectively.
Interactive teaching informed by neuroscience: The use of visual and auditory materials may support the brain's language-learning processes.

Recommendations for translation
Neurolinguistic training for translators: Translators may benefit from training designed to increase awareness of cross-language interference and the cognitive mechanisms involved in translation.
Managing code-switching and interference: Translators working with bilingual texts should pay particular attention to unintended language switching and structural transfer between languages.

Recommendations for language teaching
Creating a bilingual environment from an early age: Because second-language acquisition is influenced by age, meaningful exposure to two languages should be encouraged from the early stages of development.
Strengthening grammatical and semantic adaptation: Bilingual learning materials should be developed to help learners compare and process the structures and meanings of both languages.
Training in automatic language switching: Structured language-switching activities may help learners improve language control and reduce interference.
The findings demonstrate how bilingualism may influence brain function from **neurobiological, linguistic, and cognitive perspectives**. Language-processing mechanisms in Uzbek–English bilinguals were examined, with particular attention to grammatical processing, lexical selection, and code-switching. The findings may provide an important scientific foundation for future developments in **education, translation, and linguistic research**.

Conclusion
This study aimed to investigate, from a neurolinguistic perspective, **how language processing occurs in the brains of Uzbek–English bilinguals**. The findings support the following principal conclusions:

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1. Effects of bilingualism on the brain

–EEG and fMRI findings indicated that **the bilingual brain demonstrates considerable adaptability when managing two languages**.

–The active involvement of the prefrontal cortex, Broca's area, and anterior cingulate cortex confirms that these regions play important roles in **managing code-switching and cross-language interference**.

2. Differences between Uzbek and English language processing

–Lexical selection was **faster in Uzbek** because the participants' native language was processed more automatically.

–Processing English grammatical structures required **greater cognitive resources**, particularly among late bilinguals.

–Switching from English to Uzbek occurred **more rapidly than switching from Uzbek to English**, because returning to the native language was a more automatic process.

3. Cognitive benefits and challenges of bilingualism

–Cognitive benefits: The bilingual participants demonstrated strong attentional control, working-memory performance, and cognitive flexibility.

–Challenges: In certain situations, code-switching and cross-language interference may cause delays in syntactic and semantic processing.

These findings are relevant to **education, translation, and language learning** and may contribute to the development of new pedagogical and translation strategies based on neurolinguistic principles.

Directions for future research

Although this study provides a scientific foundation for investigating bilingualism and neurolinguistics, further research is required in the following areas:

I. Differences in language processing between early and late bilinguals

–Further investigation is required to determine how neural language-processing mechanisms differ between individuals who acquire their second language early and those who acquire it later.

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–Future studies should identify the ages at which syntactic and semantic interference are most likely to occur.

II. Neurobiological effects of multilingualism

–Future research should examine brain function in multilingual individuals who speak Uzbek, English, and one or more additional languages.

–Their language-processing mechanisms should be compared with those of bilingual individuals.

III. Applications of neurotechnology

–EEG and fMRI methods could be used to investigate language learning as it occurs.

–Future studies could explore the use of **neurofeedback**, which allows individuals to regulate aspects of their brain activity using real-time neural feedback, in bilingual language learning.

IV. Approaches adapted to education and translation

–The effects of bilingualism on educational processes should be investigated further to improve language-teaching methodology.

–Neurolinguistic training programmes should be developed to help translators manage code-switching and reduce cross-language interference.

This study is among the works that provide a focused analysis of language processing in the brains of Uzbek–English bilinguals. Its findings contribute to understanding the neurobiological and linguistic dimensions of bilingualism and establish a foundation for future research.

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