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AI-ENHANCED MODELING OF PHONETIC INTERFERENCE AND COGNITIVE PATTERNS IN AZERBAIJANI-GERMAN BILINGUALISM

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The integration of Artificial Intelligence (AI) into cognitive linguistics has redefined the study of bilingual speech production. This research examines the phonological interplay within

the "Azerbaijani-German" pair—two typologically distinct linguistic systems. The study specifically focuses on how the rigid law of vowel harmony (synharmonism) in Azerbaijani affects the acquisition of German consonantal structures and vowel quality in young learners. The study utilized the PRAAT software suite to record and analyze acoustic markers, including F1/F2 formants, pitch variance, and temporal duration. To evaluate lexico-syntactic deviations within children's media discourse, Natural Language Processing (NLP) models were implemented for high-precision data mining. The occurrence of spontaneous self-correction was identified as a primary marker of emerging linguistic awareness and cognitive control.

Keywords: Bilingualism; Acoustic Interference; Artificial Intelligence; Phonological Asymmetry; Metalinguistic Awareness; Natural Language Processing (NLP).

The application of AI-driven tools has transitioned the study of bilingualism from qualitative observation to empirical, data-driven science. The Phonological Filter: The study identifies Azerbaijani synharmonism as a persistent structural filter that obstructs the precise production of German vocalisms. Neural network analysis of spectrograms confirmed the presence of microscopic sound insertions at the junctions of dense consonant groupings. Semantic Competition: During cognitive processing, bilingual children often experience overlapping conceptual fields. NLP models helped map patterns of "lexical retrieval failure," where the learner defaults to L1 structures to express complex abstract concepts in the target language (L2). The Power of Self-Correction: The findings demonstrate that effective language acquisition is rooted in the ability to perceive the "boundaries" between different linguistic systems. In this context, AI serves as a cognitive simulator, predicting potential zones of interference and fostering a proactive learning environment.

This study posits that advancing to the highest stage of bilingualism—biliteracy—is achieved not through the mechanical expansion of vocabulary, but through the development of conscious metalinguistic reflection. Consequently, the role of Artificial Intelligence in language pedagogy must undergo a paradigm shift: moving from passive error correction toward intelligent predictive modeling (AI-Driven Scaffolding). Rather than merely flagging mistakes, such systems activate the learner's internal mechanisms for self-correction. The formation of bilingualism within typologically unrelated languages offers significant scientific insight.

Regarding semantic competition. The practice of teachers in Azerbaijani schools today shows that some students learning a second (non-native) language often encounter overlapping "linguistic fields." This is a completely natural and even expected phenomenon in cognitive linguistics. In this regard, specialized NLP models and frameworks help identify the root causes of this process's failure, resulting in the student involuntarily turning to their native language. Parallel to this, the so-called "target language" is designed to reflect more complex concepts. These two phenomena are designated in linguistics as "L1" and "L2," respectively.

Experiments conducted by researchers potentially prove that the most productive learning of a second language by Azerbaijani students largely depends on their ability to differentiate and correctly perceive linguistic systems. Significantly, in this format, AI acts as a kind of alarm system, anticipating potential disruptions and alerting both teachers and students in advance. This makes learning more active and effective.

The "Azerbaijani-German" pair serves as a unique model for cognitive exploration due to their structural divergence: Azerbaijani is a strictly organized agglutinative system, where the law of synharmonism (vowel harmony) forms the bedrock of its phonological structure.

German, in contrast, relies on a complex inflectional-analytical framework, featuring unique vocalisms (umlauts) and dense consonant clusters that are entirely foreign to the Turkic phonetic matrix. Drawing on Wilhelm von Humboldt's concept of language as a "thought-generating process," it can be argued that an Azerbaijani-speaking child transitioning to German does more than switch lexical codes; they encounter a fundamentally different cognitive worldview. The "inner form" of the Azerbaijani language, governed by synharmonism, conflicts with German grammatical structures. This automatic transfer of native linguistic habits onto foreign soil inevitably triggers articulatory resistance and profound phonological asymmetry. Historically, speech errors and semantic "glitches" in Azerbaijani children learning German were viewed through a narrow didactic lens—simply as a lack of proficiency. However, the nature of these deviations stems from immense cognitive tension. This tension arises during the collision of two diametrically opposed algorithms of speech production.

While foundational works exist regarding phonetics [1; 2] and the psycholinguistics of child speech [3; 4; 5], contemporary linguistics lacks integrated cognitive-computational models. The absence of research utilizing AI algorithms to explain the mechanics of acoustic and semantic interference in this specific language pair underscores the relevance and necessity of the current study. This article seeks to bridge the existing scientific divide by integrating instrumental phonetics with cognitive linguistics. Leveraging empirical data—including the analysis of children's media discourse and acoustic speech modeling—we demonstrate the transformative potential of AI algorithms. In this study, Artificial Intelligence is employed not merely to document phonological discrepancies but to explore the mechanisms of metalinguistic reflection, which serve as the cornerstone of comprehensive biliteracy.

It is important to recognize that highly professional bilingual teaching depends not so much on the mechanistic acquisition of vocabulary, but on the development of skills across all areas of linguistics. In this regard, the role and significance of AI is difficult to overestimate, as it decisively and symptomatically facilitates a linguistic shift in both syntagmatics and paradigmatics. To put it more clearly and intelligibly, AI at the present stage of history is smoothly transitioning from error correction and independent error correction to natural modeling. This primarily concerns the genetic support of AI. That is, in addition to error correction, students' internal reserves and their ability to self-correct are actively utilized, which is important and promising from a scientific perspective.

Today, there is a considerable body of specialized literature on both phonetics [1; 2] and child psycholinguistics [3; 4; 5]. However, modern linguistics clearly lacks cognitive frameworks based on integration parameters. There is also a lack of work on the AI system's algorithm. Yet, acoustics and interference prevention factors in the language sphere as a whole directly depend on this. Therefore, this area of research in cognitive linguistics should be considered relevant and timely.

This article also aims to shed some light on the integration of phonetics with the aforementioned discipline. Drawing on existing empirical data and media discourse among young children, we sought to advance the idea of speech modeling using acoustics. In doing so, we further demonstrate the powerful efficiency of AI. Firstly, it is currently used as a chronograph for certain inconsistencies in phonology. Secondly, it facilitates a more detailed study of metalinguistics in general. The latter is a true panacea for literacy in bilingualism.

According to Lev Vygotsky's theory, thought is not simply expressed in words but finds its ultimate realization within them. For an Azerbaijani-speaking child, acquiring

German is a rigorous process of constructing new conceptual frameworks. Verbose explanations (as seen in programs like Dingsda) and semantic deviations should not be dismissed as a simple lack of vocabulary. Instead, they represent the visible manifestation of intense cognitive labor. Drawing on the concrete-situational scenarios of their native culture, the child gradually builds abstract connections within a new linguistic environment [3]. Linguistic systems differ not only in their phonemic inventories but also in the functional weight of their subsystems. The eminent linguist Academician Aghamusa Akhundov described Azerbaijani phonetics as a "mathematically precise structure." Within this framework, the law of synharmonism (vowel harmony) is more than an acoustic phenomenon; it is the structural axis of the entire morphological organization [1].

In Azerbaijani speech, transitions between vowels are strictly homogeneous (limited to either front or back series). German lacks this harmony, featuring dense consonant clusters and a complex system of grammatical gender. This dissonance poses challenges not only for young learners but also for Automatic Speech Recognition (ASR) systems trained on standard German (Hochdeutsch). Consequently, the acoustic deviations in a bilingual child’s speech are frequently misinterpreted by modern neural networks.

In contemporary research, auditory perception alone is insufficient for a profound understanding of speech deformations. The use of the PRAAT software suite in conjunction with machine learning algorithms opens significant new horizons:

Spectrogram Analysis: AI detects micro-fluctuations in formants (F1 and F2), illustrating how the inertia of synharmonism hinders the precise articulation of German umlauts (ö, ü, ä). By integrating the phonological parameters of the native language into a neural network, we can predict with high accuracy typical errors at consonant junctions (e.g., in words like Herbst or Strumpf). These models provide the foundation for developing Intelligent Tutoring Systems (ITS) tailored to the specific linguistic hurdles of the individual learner. Traditional perceptual assessment, which relies on the researcher's subjective hearing, is giving way to high-precision computational methods. AI technologies allow for the conversion of abstract phonological categories into quantifiable acoustic data, ensuring objective evaluation in the study of bilingual speech.

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МОДЕЛИРОВАНИЕ ФОНЕТИЧЕСКОЙ ИНТЕРФЕРЕНЦИИ И КОГНИТИВНЫХ ПАТТЕРНОВ В АЗЕРБАЙДЖАНО-НЕМЕЦКОМ ДВУЯЗЫЧИИ С ИСПОЛЬЗОВАНИЕМ ИИ

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Интеграция искусственного интеллекта (ИИ) в когнитивную лингвистику изменила подход к изучению двуязычного речевого производства. В данном исследовании рассматривается фонологическое взаимодействие в рамках пары «азербайджанско-немецкий» — двух типологически различных языковых систем. В частности, исследова-

ние фокусируется на том, как жесткий закон гармонии гласных (сингармонизм) в азербайджанском языке влияет на усвоение немецких согласных структур и качества гласных у юных учащихся. В исследовании использовался программный пакет PRAAT для записи и анализа акустических маркеров, включая форманты F1/F2, вариативность высоты тона и временную длительность. Для оценки лексико-синтаксических отклонений в детском медиадискурсе были использованы модели обработки естественного языка (NLP) для высокоточной обработки данных. Возникновение спонтанной самокоррекции было определено как основной маркер формирующегося языкового восприятия и когнитивного контроля.

Ключевые слова: билингвизм; акустические помехи; искусственный интеллект; фонологическая асимметрия; металингвистическое восприятие; обработка естественного языка (NLP).