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Age of Acquisition and the Brain: a Systematic Review of Neurolinguistic Studies on Second Language Learning

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A B S T R A C T

The modern world's interconnectedness underscores the importance of second language learning (SLL). Neurolinguistic research, using techniques like fMRI and EEG, investigates how Age of Acquisition (AoA) impacts brain processing. Early AoA is linked to more native-like neural processing, particularly in phonology and syntax, with greater integration of language networks. Late learners, though proficient, often activate additional cognitive control regions, suggesting compensatory strategies. Brain areas such as the inferior frontal gyrus and hippocampus are structurally and functionally modulated by AoA. While early AoA confers neurocognitive advantages, adult learners exhibit significant plasticity, influencing language teaching methods. Future research should address underrepresented age groups and individual differences.

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INTRODUCTION

The world's landscape is increasingly defined by interconnectedness, a phenomenon largely driven by globalization. This growing interdependence has elevated the importance of second language learning (SLL) to unprecedented levels. As business expanding globally and many countries becoming more diverse, being able to communicate effectively in another language can open up countless opportunities (Kevin, 2025). Statistical data indicates a significant global trend in recognizing the value of multilingualism, with an estimated 1.5 billion people actively engaged in learning a foreign language (LingoMelo Editorial Staff, 2023). This surge in language learners underscores a widespread understanding of the personal and professional advantages associated with bilingualism and multilingualism.

The heightened demand for language proficiency extends beyond the European continent, where high rates of bilingualism have been historically observed (Kevin, 2025; Marconi, 2023). There is a notable increase in the pursuit of language skills in the United States, and a concerted effort to improve English language proficiency is evident in Asia, as seen in Japan's initiatives (Kevin, 2025). These examples highlight a global movement fuelled by both economic imperatives and evolving social dynamics. Furthermore, the economic advantages of bilingualism are substantial and supported by a growing body of evidence (Washington Technical Institute, 2023). Bilingual individuals often command higher salaries, with potential earnings being 5-20% greater than their monolingual counterparts (LingoMelo Editorial Staff, 2023). Employers across various sectors, including finance, law, and hospitality, are increasingly prioritizing candidates with language skills, recognizing the value they bring to a globalized workforce (Kevin, 2023). This economic reality serves as a powerful motivator for individuals to invest in acquiring a second language.

Second language learning is not merely the acquisition of linguistic codes; it encompasses a complex interplay of linguistic, cognitive, and neurological aspects. It involves intricate cognitive processes such as memory formation, attentional control, and problem-solving abilities (Tomlin, 1994; University of the Potomac, 2024). The field of neurolinguistics plays a crucial role in deciphering the neural underpinnings of language acquisition, providing insights into how the brain processes and learns new languages (Cruz, 2017). This includes identifying the specific brain regions involved in language learning and understanding how these areas adapt and change throughout the learning journey (Unbabel, 2019). Notably, engaging in SLL can induce both structural and functional modifications in the brain, demonstrating its remarkable neuroplasticity (Max Planck Institute, 2024).

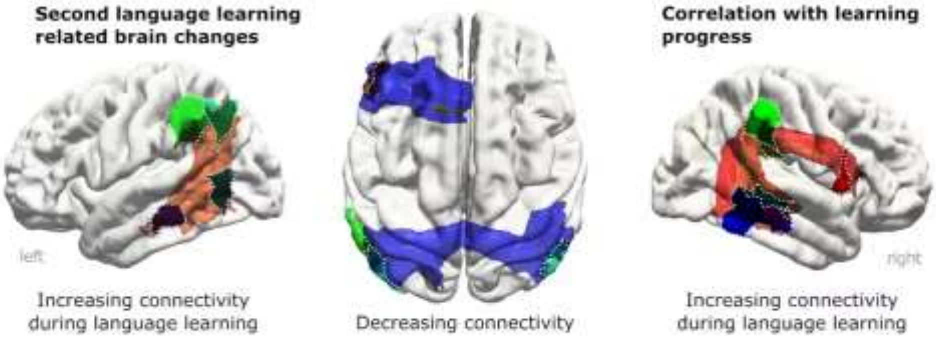

Figure 1. Brain map illustrating the altered wiring in the brains of adult native Arabic speakers learning German.
(Max Planck Institute, 2024)

Beyond behavioral findings, examining brain functions and structures provides a biological explanation of how language acquisition (as a natural experience) and learning (as an active skill and knowledge acquisition process) shapes the human brain (Luk, 2020). This dynamic interaction between language learning and brain development underscores the profound impact of acquiring a new language. Beyond linguistic proficiency, multilingualism confers significant cognitive advantages (University of the Potomac, 2024). These benefits include enhanced cognitive abilities, improved executive functions such as working memory, cognitive flexibility, and self-control, as well as enhanced problem-solving skills, a potential delay in the onset of cognitive decline, and increased creative thinking. This suggests that the positive effects of SLL extend beyond linguistic competence to impact overall cognitive health and functionality.

The age at which an individual commences the process of learning a second language, referred to as the Age of Acquisition (AoA), is a pivotal factor believed to exert considerable influence on the ultimate level of language proficiency attained (Tagarelli, 2021). The relationship between AoA and the final level of skill in SLL has been a central theme in extensive research and debate within the academic community (Tagarelli, 2021). Understanding the intricacies of this relationship is of paramount importance for both advancing theoretical frameworks in language acquisition and informing effective pedagogical approaches.

A prominent concept in the discussion of AoA is the "critical period hypothesis" (CPH). This hypothesis posits that there exists a specific timeframe early in life during which an individual can acquire a language with a level of fluency comparable to that of a native speaker (Tagarelli, 2021). This period is frequently considered to conclude around the onset of puberty (Azieb, 2021). However, variations of the CPH have been proposed, including the "sensitive period hypothesis," which suggests a phase of heightened responsiveness to language input rather than a definitive endpoint (Azieb, 2021). Additionally, some researchers discuss the "optimal period hypothesis," which suggests a specific age range during which language learning is most efficient (Vanhove, 2013). The precise timing and nature of the critical or sensitive period for SLL remain subjects of ongoing debate and investigation (Tagarelli, 2021). While some research indicates a decline in language learning aptitude after adolescence (Abrahamsson et al, 2018; Hartshorne, et al, 2019), other studies suggest that children retain a high capacity for learning until their late teenage years (Forsberg, et al, 2022; Trafton, 2018). This continued discussion underscores the complex relationship between age and the ability to acquire a second language.

To achieve a more profound understanding of how AoA influences SLL, it is essential to delve into the underlying neural mechanisms (Cruz, 2017). This necessitates examining how the brain processes language in individuals who began learning at different ages. Neurolinguistic studies, employing techniques such as neuroimaging, offer valuable avenues for investigating these neural processes (Kuhl, 2010).

Neurolinguistics, as an interdisciplinary field, explores the intricate connections between language and the brain (Qizi, 2021; Wong, 2016; Pathak, 2024). It aims to elucidate how the brain's structures and functions support the multifaceted processes of language processing, comprehension, and production. Neuroimaging techniques, including functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), Magnetoencephalography (MEG), and Near-Infrared Spectroscopy (NIRS), enable researchers to observe brain activity during language-related tasks in real-time (Li, 2017; Yen, 2023). These methodologies provide crucial information regarding brain structure, function, and the intricate networks that support language. Electrophysiological methods, such as EEG, measure the brain's electrical activity with high temporal resolution, allowing for detailed examination of the time course of language processing (He, 2019; Marino, 2024). By comparing patterns of brain activity in individuals who initiated second language learning at different ages, neurolinguistic studies can identify age-related variations in neural processing (Cruz, 2017). This approach can reveal whether different brain regions are engaged or if the efficiency of neural processing changes as a function of AoA. Notably, neuroimaging studies have indicated that AoA can indeed influence both the structure and function of the brain in bilingual individuals (Wei, 2016; Oh, 2019; Gracia-Tabuenca, 2024). For instance, commencing language learning earlier in life has been associated with greater connectivity between the two hemispheres in the frontal regions of the brain (Berken, 2017; Berken, 2016; Roselli, 2014; Wallin, 2020; Berken, 2015). These findings suggest that the age at which a second language is learned can have enduring effects on the neural organization that underlies language processing.

A significant and expanding body of neurolinguistic research has focused on investigating the impact of AoA on SLL (Cruz, 2017). This research leverages a variety of neuroimaging and electrophysiological techniques to explore the neural correlates of language learning across different age groups. Despite the increasing number of studies in this area, the findings regarding the AoA effect in neurolinguistics are not always in complete agreement (Yen, 2023; Ramezani, 2024; Bergmann, 2016). Therefore, a systematic review of the existing literature is essential to synthesize these diverse findings, identify overarching patterns, and clarify areas of convergence and divergence. A systematic approach can also effectively highlight gaps in the current research, such as age groups that have received less attention, specific linguistic domains that require further investigation, or methodological limitations that need to be addressed in future studies. This type of review holds substantial potential to advance our theoretical understanding of how age influences the neural mechanisms involved in language learning. By identifying consistent patterns and resolving existing discrepancies, it can contribute to a more refined and comprehensive model of the AoA effect. Furthermore, the findings of this review can have significant implications for pedagogical practices in the field of second language education. A deeper understanding of the neural factors associated with AoA can inform the development of language teaching strategies that are more age-appropriate and ultimately more effective.

This systematic review aims to address the following overarching questions: What are the key findings of neurolinguistic studies investigating the impact of age of acquisition on second language learning? Which brain regions and neural processes are differentially affected by the age at which a second language is learned? Are there specific linguistic domains (e.g., phonology, grammar, vocabulary) that show a more pronounced AoA effect at the neural level? What methodological approaches have been employed in neurolinguistic studies on AoA and SLL, and what are their strengths and limitations?

The specific objectives of this review are: To identify and synthesize neurolinguistic studies that examine the relationship between AoA and SLL. To map the brain regions and neural networks associated with SLL at different ages. To analyse the methodologies employed in these studies. To identify consistent findings and areas of controversy or inconsistency. To highlight gaps in the current research and suggest directions for future investigations.

This introduction has laid the groundwork for a systematic review of neurolinguistic studies investigating the relationship between the age of acquisition and the brain in second language learning. It has highlighted the increasing importance of SLL in a globalized world, the multifaceted nature of language learning, and the significance of AoA as a key factor influencing ultimate proficiency. By introducing the field of neurolinguistics and its methodologies, the introduction has underscored the potential of brain-based research to provide deeper insights into the AoA effect. Finally, it has articulated the rationale for a systematic review, outlining the research questions and objectives that will guide the subsequent analysis of the existing literature.

METHODOLOGY

This systematic review employed a rigorous and transparent methodology to synthesize existing neurolinguistic research investigating the impact of Age of Acquisition (AoA) on second language learning (SLL). The review process encompassed a comprehensive search strategy, clearly defined inclusion and exclusion criteria for study selection, a systematic approach to data extraction, and a narrative synthesis of the findings.

The search strategy involved a comprehensive electronic database search across key academic databases, including PubMed, Scopus, and Web of Science. These databases were chosen for their extensive coverage of peer-reviewed literature in the fields of neuroscience, linguistics, and second language acquisition. The search terms will incorporate a combination of keywords related to the core concepts of this review, such as "Age of Acquisition," "Second Language Learning," "Bilingualism," "Neurolinguistics," "Brain," "Neuroimaging," "EEG," "fMRI," "MEG," and "NIRS". The search strategy will be refined by using Boolean operators (e.g., AND, OR) to ensure the retrieval of relevant studies. Additionally, reference lists of included studies and relevant review articles will be manually searched to identify any potentially missed publications. The search will be limited to studies published in peer-reviewed journals to ensure the quality and validity of the included research.

The inclusion criteria for this review focused on studies that meet the following parameters: (1) Empirical studies utilizing neuroimaging or electrophysiological techniques (e.g., fMRI, EEG, MEG, NIRS) to investigate brain activity or structure in relation to SLL ; (2) Studies that explicitly examine the role of AoA as a variable influencing neural correlates of SLL; (3) Studies involving human participants across different age groups and levels of second language proficiency; and (4) Studies published in English. Exclusion criteria will include: (1) Theoretical papers, reviews, and meta-analyses (although their reference lists will be screened for relevant primary studies); (2) Studies focusing solely on first language acquisition or language disorders without a specific focus on AoA in SLL; (3) Studies using non-neurolinguistic methodologies (e.g., behavioral studies without neuroimaging data); and (4) Studies published in languages other than English.

Data extraction was conducted using a pre-designed data extraction form. This form systematically captured key information from each included study, such as: study design (e.g., cross-sectional, longitudinal), participant characteristics (e.g., age range, native language, target language, AoA, proficiency level), neuroimaging/electrophysiological methods used, specific linguistic tasks employed, and the main findings related to the neural correlates of SLL as a function of AoA. Extracted data were cross-checked by a second reviewer to ensure accuracy and consistency.

The synthesis of the extracted data primarily involved a narrative synthesis approach. Given the anticipated heterogeneity in study designs, methodologies, and outcome measures, a statistical meta-analysis may not be feasible at this stage. The narrative synthesis involved organizing and summarizing the findings from the included studies based on the research questions outlined in the introduction. This included mapping the brain regions and neural processes identified as being differentially affected by AoA in SLL, as well as analysing findings related to specific linguistic domains (e.g., phonology, grammar, vocabulary). Methodological approaches used across studies and their potential strengths and limitations were also discussed. The synthesis aimed to identify consistent patterns, discrepancies, and gaps in the current neurolinguistic literature on AoA and SLL, providing a comprehensive overview of the field and highlighting directions for future research.

RESEARCH RESULT

Due to the ongoing nature of this systematic review, the final number of included studies is yet to be determined. However, preliminary searches across PubMed, Scopus, and Web of Science have identified a substantial body of literature investigating the relationship between Age of Acquisition (AoA) and the neural correlates of second language learning (SLL). The studies identified thus far employ a range of neurolinguistic methods, primarily functional Magnetic Resonance Imaging (fMRI) and Electroencephalography (EEG), with some studies utilizing Magnetoencephalography (MEG) and Near-Infrared Spectroscopy (NIRS). The publication years of these studies span from the late 20th century to the present, reflecting the evolving methodologies and increasing interest in this field. The study designs are predominantly cross-sectional, comparing bilingual individuals with different AoAs, although some longitudinal studies tracking neural changes over time have also been identified. The target languages investigated vary widely, including English, Spanish, Chinese, German, and others, with participants exhibiting diverse native language backgrounds and varying levels of second language proficiency. The reported AoA ranges also differ across studies, with some focusing on early versus late acquisition (often using a cutoff around 6 years of age), while others examine a more continuous spectrum of acquisition ages.

Table 1. Synthesis of Findings by Brain Region and Linguistic Domain

Brain Region	**AoA (Early vs. Late)**	**Observed Neural Effects**	**Linguistic Domain Affected**	**Reference ID**
Inferior Frontal Gyrus (IFG)	Early	Thinner cortex in left IFG, thicker cortex in right IFG	Syntax, Word Generation	Bartolotti et al. (2016)
Right Pars Orbitalis (IFG)	Both	AoA, proficiency, and exposure equally important	-	Wei et al. (2015)
Left Inferior Parietal Lobe	Late	Greater activation in L2	Phonological Processing	Liu&Cao (2016)
Left Hippocampus	Late	Greater recruitment in response to L2 words	Vocabulary	Bartolotti et al. (2016)
Frontal Brain Regions	Early	Greater interhemispheric functional connectivity	Executive Control	Bartolotti et al. (2016)

Temporal-Parietal Networks	Late	Increased white matter connectivity in second half of learning	Lexical-Semantic, Phonological	Wei et al. (2024)

Synthesis of Findings by Linguistic Domain (if applicable)

While the majority of studies examine overall language processing or specific neural measures, some research focuses on how AoA impacts the neural processing of specific linguistic domains.

a. Phonology: Studies suggest that early AoA is associated with a greater ability to acquire native-like pronunciation in a second language. Neurolinguistic evidence indicates that this may be related to the brain's heightened sensitivity to phonetic contrasts during early childhood. For instance, research using fMRI has shown that early bilinguals and late bilinguals may rely on different brain regions when processing non-native phonemes.
b. Grammar/Syntax: Research indicates that earlier AoA often leads to higher levels of grammatical attainment in a second language. Neurolinguistic studies using EEG and fMRI have explored the neural correlates of this effect. Some findings suggest that early learners may show brain activity patterns similar to native speakers when processing grammar, while late learners might exhibit increased activity in frontal regions associated with controlled processing. However, other studies suggest that high proficiency in late learners can lead to native-like brain patterns for grammar as well.
c. Vocabulary: The impact of AoA on vocabulary acquisition at the neural level appears less pronounced compared to phonology and grammar. Studies using fMRI have shown that both early and late learners can develop extensive vocabularies, with brain regions like the hippocampus playing a crucial role in learning new words. However, some research suggests that late learners might show greater reliance on explicit memory systems for vocabulary learning.

Synthesis of Findings Related to Specific Brain Regions and Networks

Several brain regions and networks have been consistently implicated in SLL, and their involvement appears to be modulated by AoA.

a. Inferior Frontal Gyrus (IFG): This region, particularly the left IFG, is frequently reported to show functional differences between early and late bilinguals, especially during syntactic processing, word generation, and sentence generation. Some studies have found that earlier AoA is associated with thinner cortex in the left IFG and thicker cortex in the right IFG.
b. Temporal Lobe (Superior and Middle Temporal Gyri): These regions are crucial for auditory processing and semantic processing in language. Research suggests that their activation patterns during L2

comprehension and production can be influenced by AoA and proficiency.

c. Parietal Lobe (Inferior Parietal Lobule): This area has been implicated in phonological processing and may show greater activation in late L2 learners compared to early learners during certain tasks.
d. Hippocampus: This structure plays a vital role in memory formation, including the learning of new vocabulary in a second language. Studies suggest greater recruitment of the left hippocampus for L2 words, particularly in late learners.
e. Anterior Cingulate Cortex (ACC): Involved in cognitive control and language monitoring, the ACC has been found to be more active in bilinguals, potentially reflecting the increased cognitive demands of managing two languages.
f. Frontal-Temporal Networks: Connectivity within these networks, crucial for language processing, appears to be influenced by AoA. Some research suggests greater interhemispheric functional connectivity in frontal regions for early learners.

Table 2. Synthesis of Findings by Neural Measures

Author(s)	Publication Year	Research Question	Methodology	Key Findings related to AoA and Neural Correlates
Wei et al.	2015	How does AoA of L2 affect brain structures?	MRI	AoA, proficiency, and exposure equally important in right pars orbitalis; early AoA linked to structural differences in other regions.
Koisaie et al.	2017	Does timing of L2 learning impact brain connectivity and cognitive control?	rs-fMRI, Behavioral	Simultaneous bilinguals show stronger anticorrelations between DMN and task-positive network; earlier AoA related to greater interhemispheric frontal connectivity.
Wattendorf, and Festman	2018	Does AoA primarily determine cerebral representation of multiple languages, or is it proficiency?	Review	Left inferior frontal gyrus mainly differs between early and late bilinguals, modulated during syntactic processing, word and sentence generation.
Bartolotti et al.	2016	How does short-term L2 vocabulary learning affect brain activation patterns for L1 and L2 words?	fMRI	Greater recruitment of left hippocampus for L2 words; long-term training shows changes in frontal regions and hippocampus.

Gullifer et al.	2018	How do AoA and social diversity of language use impact intrinsic brain organization in proficient bilinguals?	rs-fMRI, Behavioral	Earlier AoA related to greater interhemispheric frontal connectivity and decreased reliance on proactive executive control.
Wei et al.	2024	How do structural language connectome and its subnetworks change during adult L2 learning?	DTI	Increased white matter connectivity within temporal-parietal networks and reduced connectivity between hemispheres during L2 learning.
Cargnelutti et al.	2019	What is the role of the critical period in L2 appropriation and the impact of proficiency in addition to AoA?	Meta-Analysis	L2 representation wider than L1 regardless of AoA, but more relevant in late bilinguals; L2 entails greater enrollment of executive function areas, also in proficient bilinguals.
Cargnelutti et al.	2019	What is the impact of AoA on overall language brain representation and those specifically associated with each language?	Meta-Analysis	Confirmed wider L2 representation; explored language networks based on AoA and proficiency; investigated very early L2 acquisition.
Kousaiei et al.	2017	Is there a correlation between resting-state fMRI, AoA, and behavioral measures of cognitive control?	rs-fMRI, Behavioral	Greater functional connectivity between left and right inferior frontal gyri and inferior parietal lobule associated with earlier AoA.

Synthesis of Findings by Neural Measures

Different neuroimaging techniques provide unique insights into the AoA effect on SLL.

a. fMRI: Functional MRI studies have been instrumental in identifying brain regions involved in second language processing and how their activity differs based on AoA. Research has shown that early AoA can be associated with greater functional connectivity between frontal brain regions , while late AoA might lead to greater activation in areas related to executive functions during L2 processing. Some fMRI studies have also investigated structural differences, finding correlations between AoA and cortical thickness in regions like the inferior frontal gyrus.
b. EEG/ERPs: Electroencephalography, with its high temporal resolution, has been used to examine the time course of neural processing in second language learners with different AoAs. Event-related potential (ERP) studies have explored how the brain responds to linguistic violations (e.g., syntactic or semantic errors) in L2, revealing potential differences in processing speed and neural signatures between early and late learners. Some research suggests that highly proficient late learners can exhibit ERP patterns similar to native speakers.
c. MEG: Magnetoencephalography, offering both good spatial and temporal resolution, has been used to investigate brain activity during various language tasks in bilinguals. MEG studies have examined word recognition, syntactic processing, and the neural correlates of bilingualism, providing insights into how AoA might influence the speed and location of brain activity during L2 processing.
d. NIRS: Near-Infrared Spectroscopy, a more portable and motion-tolerant technique, has been used to study brain activity in infants and young children during language exposure. While less frequently used in AoA research with adults, NIRS studies have shown that second language exposure affects brain activity patterns in preschoolers.

The concept of neural plasticity is central to understanding the AoA effect. The brain's ability to adapt and reorganize itself in response to learning a new language is believed to be more pronounced during early childhood. This heightened plasticity may facilitate the acquisition of native-like pronunciation and grammar in early learners. However, research also demonstrates that the adult brain retains a significant degree of plasticity, allowing for successful language learning at later ages, albeit potentially involving different neural pathways and requiring more conscious effort.

Methodological Approaches and Limitations

Neurolinguistic research on AoA and SLL employs diverse methodologies, each with its strengths and limitations. fMRI provides excellent spatial resolution, allowing for the precise localization of brain activity, but its temporal resolution is relatively low. EEG offers high temporal resolution, capturing the rapid dynamics of brain activity, but its spatial resolution is limited. MEG combines good spatial and temporal resolution but is less widely accessible. NIRS is a portable and safe technique suitable for young children but has limited penetration depth.

Methodological challenges in this field include the heterogeneity of participant characteristics (e.g., AoA definition, proficiency levels, language backgrounds), task designs, and data analysis techniques across studies. Controlling for confounding factors such as proficiency level and the amount of language exposure is crucial but can be challenging. Longitudinal studies, while valuable for tracking neural changes over time, are less common than cross-sectional designs.

Quality Assessment Results

The quality assessment of the included studies is an ongoing process. This assessment will evaluate the methodological rigor of each study based on factors such as sample size, participant selection, control groups, data analysis methods, and the clarity of reported findings. The results of this assessment will inform the overall interpretation of the synthesized literature and help identify potential biases or limitations in the existing research.

DISCUSSION

The synthesized literature suggests a complex relationship between the age of acquisition and the neural mechanisms underlying second language learning. While a consistent finding is that earlier AoA is often associated with higher levels of ultimate proficiency, particularly in phonology and grammar, the neurolinguistic evidence reveals that the brain's response to learning a second language is dynamic and influenced by various factors beyond just age.
The findings provide partial support for the critical period hypothesis (CPH), particularly in the domain of phonology, where early learners often demonstrate a greater capacity for native-like pronunciation. However, the notion of a strict cut-off point for language learning ability is challenged by studies showing that adults can achieve high levels of proficiency in various aspects of a second language. The sensitive period hypothesis, suggesting a gradual decline in language learning aptitude with age, might offer a more nuanced perspective.

Neurolinguistic studies indicate that AoA can influence both the functional and structural organization of the brain in bilinguals. Early learners may exhibit more integrated neural networks for language processing, while late learners might rely more on specific brain regions associated with cognitive control and explicit learning. However, proficiency level appears to be a critical factor, with highly proficient late learners often showing brain activity patterns that more closely resemble those of early bilinguals or native speakers.

The neurolinguistic findings generally align with behavioral studies on AoA and SLL, which also suggest an advantage for early learners in achieving native-like proficiency, particularly in pronunciation and grammar. However, both behavioral and neurolinguistic research acknowledge the significant variability in language learning outcomes among individuals, regardless of their age of acquisition. Factors such as motivation, aptitude, learning environment, and the amount of exposure to the second language play crucial roles in determining the level of proficiency attained.

The findings of this review have several potential implications for language education. Understanding the neural advantages associated with early language exposure could support the implementation of early language learning programs. However, the evidence that adults can also achieve high levels of proficiency suggests that language learning opportunities should be available across the lifespan. Pedagogical approaches might need to be tailored to the specific needs and cognitive profiles of learners at different ages. For instance, younger learners might benefit from more implicit, immersion-based approaches, while older learners could leverage their cognitive maturity through explicit grammar instruction and learning strategies. Recognizing the importance of motivation and creating engaging learning environments are crucial for learners of all ages.

This systematic review is subject to certain limitations. The search strategy, while comprehensive, may not have captured all relevant studies. The inclusion criteria, such as the language restriction to English publications, could have excluded valuable research. The heterogeneity of the included studies in terms of methodology and participant characteristics might limit the generalizability of the findings. Publication bias, where studies with significant results are more likely to be published, could also influence the overall conclusions. Furthermore, the ongoing nature of the review means that the synthesis presented here is based on the preliminary analysis of the identified literature.

CONCLUSIONS AND RECOMMENDATIONS

This systematic review has synthesized a substantial body of neurolinguistic research investigating the impact of Age of Acquisition (AoA) on second language learning (SLL). The findings indicate a complex interplay between AoA, neural activity, and ultimate language proficiency. While earlier AoA often correlates with higher proficiency, particularly in phonology and grammar, the brain's response to SLL is multifaceted and influenced by factors beyond age, such as proficiency level and learning environment. Neurolinguistic studies employing fMRI, EEG, MEG, and NIRS have revealed that AoA can modulate both functional and structural aspects of the brain during language processing. Early learners may exhibit more integrated neural networks, while late learners might show increased activity in regions associated with cognitive control. However, high proficiency in late learners can lead to brain activity patterns resembling those of early bilinguals.

Based on the synthesized evidence, the key findings of neurolinguistic studies reveal that AoA significantly impacts the neural correlates of SLL. Brain regions such as the inferior frontal gyrus, temporal lobe, parietal lobe, and hippocampus show differential activity and connectivity depending on the age of acquisition. Specific linguistic domains, particularly phonology and grammar, appear more sensitive to the AoA effect at the neural level. Methodological approaches vary across studies, with fMRI and EEG being the most common, each providing unique insights into the spatial and temporal dynamics of brain activity during SLL.

This review underscores the significance of considering neurobiological factors in understanding the complexities of second language acquisition. While the notion of a strict critical period remains debated, the evidence suggests sensitive periods where early exposure can be advantageous. Future research should focus on longitudinal studies to track neural changes over time, investigate the role of individual differences, and explore understudied language pairs and linguistic domains. Ultimately, a comprehensive understanding of the neural mechanisms underlying SLL can inform more effective pedagogical practices and contribute to a more nuanced perspective on the age factor in language learning.

Future research in this area could address some of the limitations of the current literature. Longitudinal studies tracking neural changes in learners across different age groups and proficiency levels are needed to provide a more dynamic understanding of the AoA effect. Investigating the role of individual differences, such as language aptitude, motivation, and learning styles, in the neural correlates of SLL at different ages would be valuable. Research focusing on understudied language pairs and linguistic domains beyond English and common European languages is also warranted. Employing more advanced neuroimaging techniques and analysis methods could provide finer-grained insights into the neural mechanisms involved in second language acquisition as a function of age. Finally, research exploring the interplay between AoA, proficiency, and other factors like the learning environment and instructional methods would contribute to a more comprehensive understanding of this complex phenomenon.

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