Al-Farouk journal of sciences
Volume (2), Issue (3) (JUNE, 2026)
ISSN: 3135-2359

مجلة الفاروق للعلوم
المجلد (2) ملحق العدد 3 يونيو 2026
ردمد: 3135-2359

How Second Language Learning Reshapes the Brain: A Narrative Review of Neurolinguistic Evidence

Abdelmonem Mustafa Shebani
Department of English, Faculty of Arts and Languages, University of Tripoli, Libya
Email: ab.shebani@uot.edu.ly
Received: 29/6/2026 Revised: 20/7/2026 Accepted: 28/7/2026 Publication: 25/8/2026

Abstract
Second language (L2) learning is a complicated process that can lead to significant changes in the brain's function and structure. This research paper examines neurolinguistic evidence on how learning a second language reshapes the brain and identifies the major factors that influence language-related neuroplasticity. Drawing on findings from neuroimaging and cognitive neuroscience research, this review explores both structural and functional brain changes associated with second language learning; changes in grey matter, white matter connectivity, cortical organization, and neural efficiency are included. In addition, it explores the influence of age of acquisition, language proficiency, exposure, immersion, learning intensity, and individual differences as well. The review also discusses the cognitive benefits of bilingualism, particularly in executive functions, attention, working memory, and cognitive flexibility. It considers the implications of neurolinguistic evidence for English language teaching, emphasizing retrieval practice, spaced repetition, multimodal learning, meaningful interaction, feedback, and sustained exposure. The evidence suggests that L2 learning is a dynamic experience which can enhance lifelong neuroplasticity and cognitive adaptation, while also providing valuable insights for developing more effective, brain-informed language teaching practices.
Keywords: neurolinguistics; neuroplasticity; second language acquisition; bilingualism; brain and language; executive functions; English Language Teaching

Introduction
The human brain is unique; it underlies the faculty of language, i.e., the ability of expressing thoughts symbolically and share them with other people. The reasons behind this uniqueness are both genetic and epigenetic (Schumann, 2004). Neuroanatomically, the brain continues to change and adapt across the lifespan, which has an effect on the different cognitive functions and, in particular, language. This plasticity means that within anatomic, physiological, and genetic limits, skills and behaviors may change. It also indicates that a person's actions, experiences, and learning impact the shape and connections in that person's brain (Dewaele, 2009). The plastic change of the brain is called neuroplasticity. Neuroplasticity is a property of the brain that gives it the ability to undergo functional and structural changes or reconfigurations in response to environmental stimuli, cognitive demands, or behavioral experience (Li, Legault, & Litcofsky, 2014).

At the intersection of neuroscience and education, a vibrant and promising field emerges: Neuroeducation. This multidisciplinary approach aims to apply recent findings from neuroscience to the educational sphere to optimize teaching and learning processes. It becomes particularly relevant in primary education, a critical stage for a child's cognitive and linguistic development. Neuroeducation is relevant in the context of primary education, a critical developmental stage characterized by high levels of neuroplasticity that make children particularly receptive to new learning, including language acquisition. Recently, advances in neuroscience have revealed important mechanisms involved in language acquisition, such as the role of sensory input, emotional engagement, and the development of executive functions.

Evidence indicates that the L2 seems to be acquired through the same neural structures that are responsible for L1 acquisition (Abutalebi, 2008). Neural differences for an L2 may be observed, in terms of more extended activity of the neural system mediating L1 processing (Abutalebi, 2008). Those differences may disappear once a more 'native-like' proficiency is established, reflecting a change in language processing mechanisms: from controlled processing for a weak L2 system to more automatic processing.

Background

Language experience constitutes an intensive experience occurring on a daily basis and across the lifespan. It provides a powerful environmental input to the nervous system to induce anatomical changes in the human brain. Among language experiences, one is particularly rich, namely second language acquisition (SLA); the related question is to what extent functional and structural changes may be shaped during SLA. A singularity of the human species is that humans have a unique ability to learn more than one language. Bilingualism is not a marginal case in our increasingly connected and multilingual world. Note that historically, forms of bilingualism have already existed, especially when national languages and regional languages (dialects, for example) coexisted. Many people are born bilingual, while many others learn a new language later in life for a variety of reasons. It is therefore necessary to study the neurodynamics of the cognitive mechanisms underlying second language learning. In addition, applied research is faced with a major challenge: to improve learning methods and to develop suitable didactic tools.

While significant advances have been made in understanding second language acquisition and learning, the knowledge has mostly been focused on behavioral outcomes and on naturalistic L2 immersion experience. In cognitive neuroscience, how the brain handles language processing is still largely based on monolinguals. Understanding the neural mechanisms and dynamics involved in managing multiple languages is necessary to provide a diverse and realistic view of language processing for many. Therefore, joining forces between cognitive neuroscientists and applied linguists on second language acquisition and learning is a beneficial collaboration introducing linguistic diversity into cognitive neuroscience research. The purpose of this review is to facilitate the understanding of the research methodology in cognitive neuroscience and encourage cross-disciplinary collaboration in order to fill the knowledge gap on brain responses to specific pedagogical focuses.

Review Design

This study employs a narrative review design to examine the neurolinguistic evidence on how second language (L2) learning reshapes the brain. The narrative review was selected because of enabling the synthesis and interpretation of the findings from different studies using various research methods, such as neuroimaging, cognitive, and behavioral research. Unlike a systematic review, a narrative review does not follow a predefined protocol for exhaustive study identification or formal quality assessment. It aims at providing a comprehensive and interpretive overview of the existing literature, identifying major themes and trends, highlighting areas of agreement and disagreement, and discussing their implications for neurolinguistics, second language acquisition (SLA), English language teaching (ELT), and teacher education too.

Neurolinguistic Foundations

The neurolinguistic foundations explain how the brain processes, represents, and acquires language. They provide a basis for understanding how second language learning engages neural networks and leads to changes in brain structure and function.

What is Neurolinguistics?

Neurolinguistics is a branch of neuroscience that studies the diverse dimensions of the relation between the human brain and language. It is mainly concerned with the study of language production and comprehension in relation to the brain structures and functions. As Nergis (2011) points out, although neuroscience is a relatively new area of research, it has not had a short lifespan in applied linguistics because there have always been some attempts to negotiate neurological findings with social sciences, psychology, and also pedagogy in order to extract suggestions for educational practices. In one way or another, the field of neurolinguistics has fared well to this day and provided many significant research studies on how the human language is represented in the brain and how language learning neurologically takes place in both L1 and L2 systems. In terms of the nature and scope of neurolinguistic research, it should be noted that neurolinguistics mainly investigates "linguistic development of normally developing subjects, language loss in patients with brain damage, and language use by people with specific language impairment" (Nergis, 2011, p. 143).

Brain Organization for Language

Language serves as a crucial medium for human communication, entailing a multifaceted interplay of neural mechanisms. The intricate process of language acquisition and utilization necessitates a sophisticated neural framework to facilitate effective communication (Kroll, 2014). Developmentally, infants acquire the first language through exposure, without the need for explicit instruction in grammatical rules, a phenomenon Chomsky, as cited by Rosenberg (Rosenberg, 1993), attributes to an innate linguistic capability. The complex situation of this behavioral system poses challenges in pinpointing the origins of linguistic aptitude, especially in the absence of advanced tools like fMRI and EEG in early neuroscience, which could illuminate brain activity during language processing. Historically, insights into the brain's language centers stemmed from the study of individuals with brain lesions, leading to the identification of critical areas such as Broca's and Wernicke's areas. Broca's discovery revealed a specific brain locus for speech production, located in the left inferior frontal gyrus, while Wernicke's work later delineated the site responsible

for language comprehension at the left temporoparietal junction (Kroll, 2014). These findings laid the groundwork for further explorations into language neurobiology.
The brain stem consists of parts called the medulla oblongata, pons, and cerebellum. All three are related to the body's physical functions, such as breathing, heart rate, movement, reflexes, digestion, and emotional processes. The cerebral cortex deals with intellectual and language functions (Steinberg, 2001). The cerebral cortex itself consists of two parts: the left hemisphere and the right hemisphere, which are connected by the corpus callosum. The physical appearance of the left hemisphere and the right hemisphere is almost a mirror reflection, but there are slight differences here and there, on the left hemisphere, namely the Wernicke region, which is wider than the same part in the right hemisphere (N Geschwind et al., 1997) (Dardjowidjojo, 2003). Each hemisphere is divided into four major parts called lobes, namely: 1. frontal lobe, located in the front part of the brain; 2. Temporal lobe, located on the side of the brain; 3. Occipital lobe, located in the back of the brain; 4. Parietal lobe, which is located in the upper part of the brain. These four lobes have their respective duties. The frontal lobe is responsible for dealing with matters relating to cognition; the temporal lobe deals with things related to hearing; the occipital lobe deals with vision; and the parietal lobe takes care of the somesthetic sense or taste found in the hands, feet, face, etc. In the frontal lobe, there is an area known as the Broca region. The name comes from a neurosurgeon named Pierre Paul Broca, who investigated cases of speech disorders in humans and found that "we speak using the left hemisphere". Then the area associated with speech was later known as the Broca area. Then, in the temporal lobe area and somewhat protruding into the parietal area, there is an area related to comprehension known as the Wernicke area. The naming of this area is also the result of a study by a neurologist, Carl Wernicke. In all lobes, there are what are called gyri (gyrus) and sulci (sulcus). A gyrus is a kind of hill with its slopes, while a sulcus is like a valley, the part that goes inside. The gyri in the left hemisphere cortex and right hemisphere have their respective roles. The right hemisphere cortex governs elementary functions and the left side of the body, and the left hemisphere cortex controls the functions of the right body. If the right hemisphere is the presental cortex where the center of the body's movement is damaged, paralysis will occur on the left side of the body (Chaer, 2012). To connect what we hear or see with what we say, a group of fibers is called the arcuate fasciculus (arcuate fasciculus) (Dardjowidjojo, 2003). The task of these fibers is to coordinate the hearing, vision, and understanding processed in the Wernicke area with language production processes involving the inferior frontal regions. Near the Broca area, a little back, there is an area called the motor cortex. This cortex controls the utterances such as the tongue, the jaw, the lips, the teeth, and the vocal cords.

Neuroplasticity

It has been established that the brain is a highly plastic and adaptable organ. The ability of our brains to change is a fundamental part of our healthy ontogenesis, forming us into unique individuals and helping us to achieve our goals effectively (Lindenberger et al., 2017). Brain alterations occur when we face influential changes in our environment: for example, after a brain injury or disease, when we must increase the efficiency of our behavior, or while acquiring a new skill (Lindenberger & Lövdén, 2019). As for the latter, when we acquire demanding skills, we also often must face new, emergent tasks, which bring new challenges to our cognitive processes. This creates a mismatch between the functional supply of the brain structure and how demanding people experience the skill at hand (Wenger et al., 2017).

Beyond its individual impact, enabling recovery from injury and resilience against cognitive decline, neuroplasticity carries significant societal implications by informing strategies to combat neurological disorders and optimize mental health (Kumar et al., 2023; Zotey et al., 2023).

Three important principles in experienced-based neuroplasticity (Kleim & Jones, 2008): (a) for an experience to trigger structural brain changes, the increased cognitive demands must be high enough to exceed the possibilities of the existing neural resources; (b) the duration and continuity of such experiences are co-determining factors for the changes to occur, and for the time-course within which they happen; and (c) the changes occur in brain areas that sub serve the behavior relevant for the task at hand.

Neuroplasticity is a general term, defining the fact that the brain changes, recognizing the need for further definition of the term. We distinguish structural from functional neuroplasticity.

a) Structural Neuroplasticity

The term synaptic plasticity is broad and simply indicates that some form of change has occurred within a synapse. Such changes may involve several specific mechanisms, including long-term modifications in the number of receptors for particular neurotransmitters or increased synthesis of certain proteins within the cell. In contrast, synaptogenesis refers to the formation of new synapses and their integration into neural circuits (Shaw, 2001).

Structural plasticity is a natural feature of brain development and is often referred to as developmental plasticity. As the brain develops, different regions become increasingly specialized for particular functions, including the processing of signals received from the environment through sensory receptors. For instance, in the occipital region of the brain, the fourth cortical layer undergoes hypertrophy to accommodate signals transmitted through the visual pathway (Buonomano, 1998).

Neurogenesis refers to the generation of new neurons. Although it occurs predominantly during early brain development, research over the past decade has also provided evidence of neurogenesis in certain regions of the adult brain. Conversely, neuronal death occurs throughout the lifespan and may result from brain injury or programmed cell death. Other forms of structural neuroplasticity involve alterations in the density or organization of gray and white matter, which can be examined using magnetic resonance imaging.

b) Functional Neuroplasticity

Functional neuroplasticity is primarily associated with two fundamental processes: **learning and memory**. These processes can be considered specific forms of neural and synaptic plasticity, in which particular mechanisms of synaptic plasticity result in lasting modifications in the effectiveness of synaptic connections (Pascual-Leone, 2005). During learning and memory formation, enduring changes in the connections between neurons may occur as a result of structural modifications or intracellular biochemical mechanisms.

Structural Brain Changes during Second Language Learning

Dynamic Restructuring Model (DRM) describes specific trajectories for restructuring of both grey and white matter, which differ from each other and appear to happen over extended periods of time (Karrar et al., 2026). Most evidence for the classical models of experience-based neuroplasticity has emerged typically from studies looking at the acquisition of a particular skill; it follows that similar patterns would be observed in studies looking at the effects of language acquisition.

Grey Matter

A substantial portion of the beginning stages of second-language (L2) learning involves acquiring new vocabulary. In addition, beginner L2 learners must establish connections between newly encountered lexical forms and their corresponding meanings. Newly learned L2 words represent concepts associated with objects, events, and situations in the surrounding world. However, languages differ in how they organize and define semantic meanings. Consequently, learning a new language requires learners to develop semantic representations for concepts that may already be familiar to them, while recognizing that these concepts may be associated with words in substantially different ways across languages (Neumann et al., 2018).

The demands associated with vocabulary acquisition, including learning new pronunciation patterns and developing novel semantic representations, are expected to produce increases in the volume of relevant grey matter regions, particularly within the left hemisphere. This prediction is consistent with the initial stage of the DRM. Supporting this view, an early study by Osterhout et al. (2008) found that L2 training was associated with increased volume in the Supramarginal Gyrus (SMG), a region within the Inferior Parietal Lobule (IPL) that contributes to the semantic and phonological encoding of newly acquired words within the existing knowledge system. Similar findings were subsequently reported in research examining structural brain changes in children receiving foreign-language training (Della Rosa et al., 2013).

Overall, the reviewed evidence concerning grey matter indicates that learners in the early stages of language acquisition tend to demonstrate volumetric increases in brain regions associated with language learning and cognitive control. These findings are consistent with the DRM's predictions regarding the initial phase of neural restructuring. Importantly, however, such increases may subsequently decline and return toward baseline following prolonged language acquisition, corresponding to the consolidation phase proposed by the DRM.

White Matter

Changes in the volume and morphology of grey matter regions have commonly been understood as adaptations that allow the brain to accommodate the additional information acquired during language learning. However, given that the brain functions as an interconnected network, it is equally important to consider how language learning influences the structural connections between these regions. One important indicator of such connectivity is the integrity of myelin within the relevant white matter pathways. This can be assessed using measures such as Fractional Anisotropy (FA) and Radial Diffusivity (RD), which provide information about the diffusion of water within brain tissue. Higher FA values indicate more restricted and directionally organized water diffusion and are often associated with greater myelination and more efficient structural communication between brain regions. By contrast, RD measures water diffusion perpendicular to the direction of axonal fibres. Increased RD is generally associated with reduced myelin integrity and consequently greater water diffusivity.

Schlegel et al. (2012) provided evidence that L2 learning induces increases in interhemispheric connectivity, indexed by increases in the FA in the CC, an effect that has been explained by increased cognitive control demands. In this study, participants were tested on nine different occasions, a month apart, during completion of L2 training. Additionally, the study reported gradual increases in left hemispheric white matter tracts connecting regions subserving language comprehension and production such as the IFG, caudate nucleus, and STG, as well as right hemispheric tracts that are linked to these language-related brain areas.

The evidence for white matter changes in training studies generally shows increases after some period of training, which do not seem to renormalize. Viewed through the lens of the DRM, the absence of renormalization of white matter indicates either that these learners have not reached peak efficiency yet or that those increases in white matter integrity are crucial even at high levels of language expertise.

Cortical thickness

Unlike grey matter volume or density, which estimate the amount of tissue within a region, cortical thickness measures the distance between the boundary of the grey matter and white matter and the outer surface of the cortex. The thickness of the human cortex as a quantifiable parameter of cortical morphology has been of scientific and clinical interest for more than 100 years. The first map of cortical thickness was shown in the seminal work of Economo about the cytoarchitectonics of the adult human cortex in 1925 (Economo and Koskinas, 1925). Since the introduction of CT- or MRI-based tomographic imaging, changes (mainly decreases) of cortical gray matter have clinically been interpreted as atrophy and typical patterns of atrophy have been described in different kinds of degenerative diseases. Scientific interest in cortical volume measurements increased with the advent of standardized statistical methods like voxel-based morphometry (VBM) or surface cortical thickness (SCT) mapping for the analysis of gray matter changes in MR images. Using these methods, not only decreases but also increases in gray matter density have been described.

Functional Brain Changes

Recent advances in neuroscience have enabled researchers to examine brain changes in relation to life experiences associated with language use. Of particular interest is how humans adapt to the demands of acquiring two (or more) languages naturally (Bialystok, 2017), but less is known about how foreign language learning and teaching differ from naturalistic immersion experience. Naturalistic immersion experience in a second language has been examined in the field of cognitive neuroscience using a variety of methods, such as functional and structural magnetic resonance imaging (MRI, e.g., Silva & Citterio, 2017), diffusion tensor imaging (DTI, e.g., Rollans, Cheema, Georgiou, & Cummine, 2017), electroencephalography (EEG) and Event-Related Potentials (ERPs) (for a recent review, see Beres, 2017), functional near-infrared spectroscopy (fNIRS) (e.g., Wan, Hancock, Moon, & Gillam, 2018; for a general review, see; Pinti, Tachtsidis I, Hamilton, Hirsch, Aichelburg, et al., 2018), and magnetoencephalography (MEG) (e.g., Brodbeck & Pylkkänen, 2017).

MRI

Using MRI approaches, high-resolution images of grey and white matter might be captured when using diffusion tensor imaging (DTI) and voxel-based morphometry (VBM), respectively. The data analysis of MRI data is typically performed on a high-performance computing cluster rather than individual computers because of the analyses are computationally intensive. Several software packages are available for the preprocessing and analysis of DTI data (Soares et al., 2013). In this review, the researcher refers primarily to the tools included in the FMRIB Software Library (FSL)**,** a comprehensive and widely used suite of software for the analysis of structural, functional, and diffusion MRI data. FSL provides automated tools for image preprocessing, brain extraction, tissue segmentation, image registration, tract-based spatial statistics (TBSS), probabilistic tractography, and voxel-wise statistical analysis, making it one of the standard platforms for investigating structural and functional brain changes associated with language learning and neuroplasticity (Jenkinson et al., 2012; Smith et al., 2004).

EEG/ERPs

MRI-based approaches are sensitive to identifying long-term and relatively stable neuroanatomical adaptations associated with sustained language experience. However, to investigate neural responses occurring during real-time language processing, such as the recognition, acquisition, and retrieval of newly learned vocabulary, researchers frequently employ electroencephalography (EEG) and event-related potentials (ERPs). EEG has a long-established history in cognitive neuroscience as a non-invasive method for examining the electrical activity generated with neuronal populations and for investigating the temporal dynamics of cognitive processes, attention, perception, memory, and language comprehension (Beres, 2017; Luck, 2014).

Unlike magnetic resonance imaging (MRI), which provides high spatial resolution for examining structural and functional brain changes, EEG offers exceptional temporal resolution, allowing researchers to capture neural responses within milliseconds of stimulus presentation. This temporal precision makes EEG/ERP methodologies particularly valuable for examining the rapid and sequential cognitive processes involved in second-language learning, including phonological discrimination, lexical access, semantic integration, and grammatical processing (Beres, 2017).

ERPs are taken from ongoing EEG recordings averaging electrical responses that are time-locked to specific linguistic events or stimuli. This approach enables researchers to identify distinct patterns of neural activity associated with different stages of language processing and learning (Luck, 2014). Among the most widely investigated ERP components in neurolinguistic research is the N400, which reflects the processes involved in semantic access, lexical retrieval, and the integration of meaning during word and sentence comprehension (Kutas & Federmeier, 2011). The P600 component, in contrast, has been associated with syntactic processing, grammatical evaluation, and structural reanalysis during language comprehension (Beres, 2017). Early sensory-related components, including the P1, N1, and P2, provide insights into initial auditory perception and attentional mechanisms, while the mismatch negativity (MMN) reflects automatic neural sensitivity to changes in auditory pattern and phonological contrasts, making it particularly relevant to second-language speech perception and phonological learning (Beres, 2017).

Collectively, findings from EEG/ERP research demonstrate that second-language learning might produce a measurable change in the timing, amplitude, and efficiency of the neural responses. These electrophysiological adaptations give evidence of experience-dependent neuroplasticity and reveal how repeated exposure to a new language modifies the neural mechanisms underlying language perception and processing (Beres, 2017; Kutas & Federmeier, 2011).

Factors Influencing Brain Plasticity

Brain plasticity in L2 learning is impacted by some interacting factors that affect how the brain adapts to and processes a second language. These factors include age of acquisition, language proficiency, exposure, immersion, learning intensity, and individual differences.

Age of Acquisition

Age of acquisition refers to the age at which an individual begins learning or being exposed to a second language. It is an important factor in brain plasticity because the timing of language learning can influence neural organization, processing efficiency, and ultimate language attainment.

Critical period

CP effects for L2 acquisition consist of greater difficulty in learning a second language and worse learning outcomes as the age of exposure increases. As humans vary greatly in the beginning of L2 exposure, this is perhaps the most well-known of the CP phenomena. Numerous studies also show that age of exposure correlates with worse L2 performance on morphological and syntactic acceptability judgment tasks (Johnson and Newport, 1989; Hartshorne et al., 2018). While the exact nature and reliability of these effects have been questioned at times (Ioup et al., 1994), the existence of age-of-exposure effects is generally accepted. We refer the reader to several thorough reviews of the relevant evidence (Singleton, 2005; Thiessen et al., 2016; Mayberry and Kluender, 2018).

Language Proficiency

Language proficiency refers to the level of ability an individual develops in understanding and using a second language (L2), including listening, speaking, reading, writing, vocabulary, grammar, and pronunciation. As proficiency increases, learners generally process linguistic information more quickly, accurately, and efficiently. With continued practice and exposure, language processes that initially require conscious effort may become more automatic and require fewer cognitive resources. Higher proficiency may also be associated with more specialized and efficient patterns of neural activation during language processing. Thus, language proficiency reflects not only improved communicative competence but also the brain's adaptation and reorganization in response to sustained L2 learning.

Brain efficiency

Brain efficiency refers to the brain's ability to process language effectively and accurately while using fewer cognitive and neural resources. In L2 learning, increased proficiency is often accompanied by more efficient, focused, and specialized patterns of brain activation. As learners gain experience, language processes that initially require conscious effort may become increasingly automatic, allowing them to understand and produce the L2 with less cognitive effort. This efficiency can develop through repeated exposure, practice, and frequent use of the target language, reflecting the brain's ability to adapt and optimize its neural pathways during language learning. Brain efficiency can also develop through repeated exposure, practice, and frequent use of the L2. With continued learning, neural pathways involved in language processing may become increasingly optimized, reducing the cognitive effort required to perform previously demanding tasks.

Automaticity

Automaticity, in the field of psychology, is the ability to perform things without conscious effort, monitoring or occupying the mental capacity and attentional resources that are typically available for processing information. Automatic processes are known to function largely independently of the resources available to a person's mental capacity (Schiffrin & Schneider, 1977; Schneider & Schiffrin, 1977), require little attention, and are "accomplished through single-step memory retrieval" (DeKeyser, 2001: 130).

Building on the findings from research in automatic and controlled processes, Schiffrin and Schneider (1984) defined automaticity as "a fast, parallel, fairly effortless process that is not limited by short-term memory (STM) capacity, is not under direct subject control, and is responsible for the performance of well-developed skill behaviours" (p. 269). In addition, other researchers argue that automatization, that is the gradual process through which an activity becomes automatic, is more important than automaticity since the change, both qualitative and quantitative, occurring during this process is more important than the automaticity that results (Segalowitz, 2003).

Frequency of Exposure

Learning can happen in various contexts. A distinction is usually made between formal learning and informal learning. Malcolm, Hodkinson, and Colley (2003) identified four key dimensions that influence the formality of learning: process, location or setting, purpose, and content. Formal learning is typically organized and guided by a teacher who systematically presents and explains the intended learning material, followed by an assessment of learners' understanding or achievement. In contrast, informal learning develops naturally through everyday experiences and activities, often through interaction and knowledge sharing with peers. Consequently, the content of informal learning is not predetermined or clearly defined, as it emerges from learners' social and everyday contexts, and it is generally not subject to formal assessment.

Immersion

Immersion refers to a learning environment in which the learners are exposed to the target language through authentic communication in everyday, academic, and professional contexts. Unlike traditional classroom instruction, immersion provides continuous opportunities for listening, speaking, reading, and writing in the second language, resulting in increased frequency and intensity of the exposure. This sustained involvement increases more efficient language processing, helps the development of automaticity, and strengthens both linguistic competence and communicative fluency. As a result, immersion is widely recognized as one of the most effective conditions for accelerating second language acquisition and supporting long-term cognitive and neural adaptation.

Classroom learning

Classroom learning refers to the formal learning of a second language through structured teaching in educational settings. It provides learners with systematic exposure to vocabulary, grammar, pronunciation, and communicative skills under teacher guidance. Through planned lessons, interactive activities, and feedback, classroom learning creates opportunities to develop language proficiency in a supportive environment. Although the amount of language exposure is more limited than in immersion contexts, effective classroom teaching might promote meaningful language development, particularly when it emphasizes active communication, authentic language use, and consistent practice.

Learning Intensity

Learning intensity refers to the amount of time, effort, and cognitive engagement specified to the language learning within a specific period. It encompasses the frequency, duration, and concentration of learning activities. Higher learning intensity generally provides learners with greater opportunities for practice, reinforcement, and consolidation of linguistic knowledge.

Individual Differences

Individual differences refer to the learner-specific cognitive and affective characteristics that influence second language learning. Important factors include working memory, motivation, intelligence, and executive functions, all of which contribute to learners' ability to process, retain, and apply linguistic information. These differences help explain why individuals vary in the rate, efficiency, and ultimate success of language learning, even when they receive similar instruction and exposure.

Working Memory

Working memory refers to the ability to store, maintain, and process information in continuing cognitive tasks. Historically, the term "working memory" was coined to reflect an updated view of short-term memory as a cognitive resource for simultaneous information storage and manipulation, not only a passive storage device. Long (2015) suggests an important role for selective attention in noticing and processing linguistic forms during negotiated interaction. The theory suggests that selective attention, which concerns the ability to select relevant input, draws heavily on the executive functions of working memory inhibition, shifting, and updating. Selection of input involves focusing on relevant information and blocking irrelevant information (inhibition), switching between form and meaning (shifting), and also constantly monitoring and updating information (updating). Research on the associations between working memory and interactional feedback has been conducted in the framework of the interaction hypothesis (see Long, 2023 [this volume]). Skill acquisition theory (DeKeyser, 2020) holds that language learning starts with declarative knowledge about rules and discrete items. Declarative knowledge is then integrated and applied in speaking, writing, listening, and reading, and the integration and application of declarative knowledge is called proceduralization.

Motivation

Motivation plays an important role in successful second language learning, especially in the classroom. Baron (1996) defines motivation as “the internal process that cannot be directly observed, but that activates, guides and maintains overt behaviour”. Whereas Woolfolk (2004) points out, “Motivation is an inside state that arouses, directs, and maintains behaviour”. For Feldman (2004), motivation is a “factor that directs and energizes the behaviour of humans and other organisms”. Fernald & Fernald (2005) refer to motivation as “Inner influence on behaviour as represented by physiological condition, interests, attitudes, and aspirations”.

Intelligence

Intelligence is considered one of the individual factors that influence second-language (L2) learning, although its role is still a subject of ongoing debate. Several researchers argue that higher levels of intelligence can facilitate language learning, whereas others maintain that there is little or no direct relationship between intelligence and success in acquiring a second language. According to Ellis (2008), “Intelligence is the general set of cognitive abilities involved in performing a wide range of learning tasks” (p.649). Traditionally, the word “intelligence” has been used to refer to success in certain assessments evaluating linguistic and non-linguistic abilities (Brown, 2000). Intelligence has different effects on different abilities. A low-level relationship exists between intelligence and learners' listening comprehension and oral production skills, but high-level correlations occur when reading comprehension, grammar learning, and free writing tests are assessed.

Executive functions

Executive functions are closely engaged in second language learning because executive functions regulate attention, inhibitory control, cognitive flexibility, and working-memory processes required for dealing with multiple linguistic systems. While L2 learning, learners must selectively attend to relevant linguistic information, inhibit interference from the first language, and flexibly shift between languages and processing strategies. From a neurolinguistic perspective, sustained engagement of these executive processes may contribute to functional and structural adaptations in brain networks involved in cognitive control and language processing, highlighting the reciprocal relationship between executive functioning and neuroplasticity in bilingual and second-language development.

The Bilingual Brain and Cognitive Benefits

In an increasingly interconnected world, bilingualism has become a phenomenon, shaping the way individuals interact and process language. Defined as the ability to communicate in two or more languages, bilingualism is present across various cultural and professional domains, with approximately half of the global population being bilingual or multilingual (Bialystok, 2015).

One of the most well-documented benefits of bilingualism is enhanced executive function, including attentional control, task-switching, and cognitive inhibition (Bialystok, 2015). Studies show that bilinguals consistently outperform monolinguals in cognitive tasks requiring flexibility and selective attention, such as the Simon task and Stroop test (Morales, Calvo, & Bialystok, 2013). Neuroimaging research supports this claim, showing increased prefrontal cortex activation, an area linked to executive control (Abutalebi, Cappa, & Perani, 2001). Bilingualism is also associated with greater cognitive flexibility, which allows individuals to adapt to new tasks and shift between different ways of thinking (Carlson & Meltzoff, 2008). Studies on bilingual children indicate higher working memory capacity, which helps them process and retain information more efficiently (Blom et al., 2014). These cognitive benefits extend beyond linguistic abilities, contributing to learners' problem-solving skills and capacity for creative thinking. (Poarch & Van Hell, 2012). Long-term research suggests that bilingualism also has a protective effect against cognitive decline, delaying Alzheimer's and dementia symptoms by several years (Bialystok, Poarch, Luo, & Craik, 2014). fMRI research suggests that bilingual individuals may exhibit greater grey matter density in brain regions associated with memory and cognitive control, supporting neuroplasticity and enhancing cognitive resilience (Kroll, Dussias, Bice, & Perrotti, 2015; Abutalebi et al., 2001).

Educational Implications

The Declarative/Procedural (DP) model provides a foundational neuroscientific framework for reimagining English Language Teaching (ELT) pedagogy, with implications for vocabulary, grammar, and skills instruction (Ullman & Lovelett, 2018). Vocabulary acquisition benefits significantly from multimodal **learning** approaches that engage distributed neural networks across sensory, motor, and language regions, creating richer and more durable memory traces through embodied experiences such as gesturing and object manipulation (Gkintoni et al., 2025; De Felice et al., 2021). For grammar instruction, the DP model suggests that explicit rule teaching initially builds declarative knowledge in medial temporal lobe structures, but for grammatical structures to become automatically accessible in real-time communication, learners require extensive meaningful practice that facilitates the gradual transfer to procedural memory systems centered in the basal ganglia (Ullman & Lovelett, 2018). Pronunciation and listening development demand intensive perceptual training that capitalizes on the brain's neuroplastic capacity to rewire the auditory cortex for novel phonetic categories, with multimodal cues—including prosody, gestures, and facial expressions—significantly reducing cognitive load during comprehension (Li, 2023; De Felice et al., 2021). Speaking fluency depends on the proceduralization of motor programs for articulation, a process enhanced through interactive, socially embedded practice that activates frontal and temporal networks more effectively than passive observation (Netten & Germain, 2012; Iranmanesh et al., 2023).

Neuroscientific evidence has established several evidence-based learning strategies that directly inform ELT methodology, particularly retrieval practice**,** spaced repetition, and targeted feedback mechanisms (Moumouri & Katerelos, 2025; Gkintoni et al., 2023). Retrieval practice—actively recalling information rather than passively reviewing it—strengthens declarative memory consolidation and, when applied consistently, facilitates the transition of learned material from effortful recall to automatic procedural knowledge (Ullman & Lovelett, 2018). Spaced repetition distributes learning episodes over time to align with the brain's natural consolidation cycles, dramatically enhancing long-term retention compared to massed practice, with digital platforms enabling optimal algorithm-driven scheduling (Gkintoni et al., 2023). **Immersion** and social interaction create optimal conditions for neuroplastic change, as real-time communicative demands engage procedural memory systems and activate the inferior frontal gyrus and superior temporal sulcus in ways that classroom-based, decontextualized instruction cannot replicate (Li, 2023; Netten & Germain, 2012). **Feedback** serves a dual neurocognitive function: corrective input builds declarative knowledge about target forms while providing the reinforcement necessary for proceduralization, with emotionally supportive feedback reducing limbic system interference and optimizing memory consolidation (Moumouri & Katerelos, 2025; Angelovska & Roehm, 2020).

The translation of these neuroscientific insights into educational practice carries distinct implications for teachers, curriculum designers, and policymakers (Indahsari et al., 2025; Gkintoni et al., 2023). Teachers should design lessons that combine explicit instruction with opportunities for implicit practice, while creating emotionally supportive classroom environments that minimize anxiety and facilitate prefrontal cognitive functioning. They should also incorporate multimodal and embodied learning approaches that activate multiple neural pathways and differentiate instruction according to learners' individual cognitive and learning needs. (Netten & Germain, 2012; Iranmanesh et al., 2023). Curriculum designers should develop spiral curricula that revisit key content systematically through spaced repetition, incorporate retrieval practice as a central learning strategy, emphasize communicative competence rather than focusing primarily on explicit grammatical knowledge, and integrate cultural and pragmatic aspects of language as essential components of the curriculum rather than treating them as supplementary elements. (Ullman & Lovelett, 2018; Moumouri & Katerelos, 2025). Policymakers must invest in sustained teacher professional development that bridges neuroscience and pedagogy, support research-practice partnerships that test neuroscience-informed interventions in authentic classrooms, reform assessment practices to evaluate procedural competence and communicative performance rather than rote declarative knowledge, and ensure equitable access to technology-enhanced, multimodal learning resources (Gkintoni et al., 2023; Angelovska & Roehm, 2020; Indahsari et al., 2025). The collective implementation of these implications promises to transform ELT from a system focused on teaching *about* language to one that systematically harnesses the brain's remarkable neuroplasticity to build genuine, automatic communicative competence.

Conclusion

This narrative review demonstrates that second language learning is associated with the brain’s capacity for structural and functional adaptation. Neurolinguistic evidence indicates that L2 learning can have its effects on grey and white matter, neural connectivity, cortical organization, and the efficiency of language-processing networks. These changes are shaped by some interacting factors, including age of acquisition, proficiency, frequency of exposure, immersion, learning intensity, and individual cognitive differences. The reviewed literature also suggests that bilingualism may support important cognitive processes such as executive control, attention, working memory, and cognitive flexibility. From an educational point of view, these findings emphasize the importance of meaningful practice, retrieval, spaced repetition, multimodal learning, interaction, feedback, and sustained exposure. However, neuroscience should inform rather than replace established pedagogical principles. Future research should strengthen collaboration between neuroscience and applied linguistics and investigate how neurolinguistic findings can be applied and evaluated in authentic EFL classrooms. Ultimately, understanding the brain’s adaptability can help teachers and curriculum designers to create more effective learning environments that support both language development and cognitive growth.

References

Abutalebi, J. (2008). Neural aspects of second language representation and language control. *Acta Psychologica, 128*, 466–478.

Abutalebi, J., Cappa, S. F., & Perani, D. (2001). The bilingual brain as revealed by functional neuroimaging. *Bilingualism: Language and Cognition, 4*(2), 179–190.

Angelovska, T., & Roehm, D. (2020). Neurolinguistic implications for L2 learning and teaching. In J. I. Liontas (Ed.), *The TESOL encyclopedia of English language teaching*. Wiley.

Baron, R. A. (1996). *Psychology*. Prentice-Hall of India.

Beres, A. M. (2017). Time is of the essence: A review of electroencephalography (EEG) and event-related brain potentials (ERPs) in language research. *Applied Psychophysiology and Biofeedback, 42*(4), 247–255. https://doi.org/10.1007/s10484-017-9371-3

Bialystok, E. (2015). Bilingualism and the development of executive function: The role of attention. *Child Development Perspectives, 9*(2), 117–121.

Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin, 143*(3), 233–262. https://doi.org/10.1037/bul0000099

Bialystok, E., Poarch, G., Luo, L., & Craik, F. I. (2014). Effects of bilingualism and aging on executive function and working memory. *Psychology and Aging, 29*(3), 696.

Blom, E., Küntay, A. C., Messer, M., Verhagen, J., & Leseman, P. (2014). The benefits of being bilingual: Working memory in bilingual Turkish–Dutch children. *Journal of Experimental Child Psychology, 128*, 105–119.

Brodbeck, C., & Pylkkänen, L. (2017). Language in context: Characterizing the comprehension of naturalistic speech with magnetoencephalography. In S. Baillet, L. Pylkkänen, & T. Näätänen (Eds.), *The cognitive neurosciences* (5th ed.). MIT Press.

Brown, H. D. (2000). *Principles of language learning and teaching* (4th ed.). Longman.

Buonomano, D. V., & Merzenich, M. M. (1998). Cortical plasticity: From synapses to maps. *Annual Review of Neuroscience, 21*, 149–186.

Carlson, S. M., & Meltzoff, A. N. (2008). Bilingual experience and executive functioning in young children. *Developmental Science, 11*(2), 282–298.

Chaer, A. (2012). *Linguistik umum*. Rineka Cipta.

Dardjowidjojo, S. (2003). *Psikolinguistik*. Yayasan Obor Indonesia.

De Felice, S., Hamilton, A. F. C., & Ponari, M. (2021). Multimodal and embodied approaches to second language learning. *Nature Reviews Psychology*.

DeKeyser, R. (2020). Skill acquisition theory. In B. VanPatten, G. Keating, & S. Wulf (Eds.), *Theories in second language acquisition* (pp. 83–104). Routledge.

Della Rosa, P. A., Videsott, G., Borsa, V. M., Canini, M., Weekes, B. S., Franceschini, R., & Abutalebi, J. (2013). A neural interactive location for multilingual talent. *Cortex, 49*(2), 605–608. https://doi.org/10.1016/j.cortex.2012.12.001

Dewaele, J.-M. (2009). Individual differences in second language acquisition. In W. C. Ritchie & T. K. Bhatia (Eds.), *The new handbook of second language acquisition* (pp. 623–646). Emerald Group Publishing.

Ellis, R. (2008). *The study of second language acquisition* (2nd ed.). Oxford University Press.

Feldman, R. S. (2004). *Understanding psychology*. McGraw-Hill.

Fernald, L. D., & Fernald, P. S. (2005). *Munn's introduction to psychology*. AITBS Publishers.

Geschwind, N., Devinsky, O., & Schachter, S. C. (1997). *Norman Geschwind: Selected publications on language, epilepsy, and behavior*. Butterworth-Heinemann.

Gkintoni, E., Dimakos, I., Halkiopoulos, C., & Antonopoulou, H. (2023). Contributions of neuroscience to educational praxis: A systematic review. *Emerging Science Journal, 7*, 146–158.

Gkintoni, E., Vassilopoulos, S. P., & Nikolaou, G. (2025). Brain-inspired multisensory learning: A systematic review of neuroplasticity and cognitive outcomes in adult multicultural and second language acquisition. *Biomimetics, 10*(6), 397. https://doi.org/10.3390/biomimetics10060397

Hartshorne, J. K., Tenenbaum, J. B., & Pinker, S. (2018). A critical period for second language acquisition: Evidence from 2/3 million English speakers. *Cognition, 177*, 263–277. https://doi.org/10.1016/j.cognition.2018.04.007

Indahsari, D., Nugroho, H. A., & Munir, A. (2025). Bridging brain and language: Postgraduate students' perceptions of neuroeducation in English language teaching. *ELTIN Journal, 13*(1).

Iranmanesh, F., Haddad Narafshan, M., & Golshan, M. (2023). A practical investigation of brain-based teaching approach: Teaching English speaking skill to nursing students. *Strides in Development of Medical Education, 20*(1), 3–7.

Jenkinson, M., Beckmann, C. F., Behrens, T. E. J., Woolrich, M. W., & Smith, S. M. (2012). FSL. *NeuroImage, 62*(2), 782–790. https://doi.org/10.1016/j.neuroimage.2011.09.015

Johnson, J. S., & Newport, E. L. (1989). Critical period effects in second language learning: The influence of maturational state on the acquisition of English as a second language. *Cognitive Psychology, 21*(1), 60–99. https://doi.org/10.1016/0010-0285(89)90003-0

Karrar RKF, Abdelrady AH, Ibrahim DOO, Masuwd M, Nsaif RA, Alouzi K, Hmouma M, Zeat T, Aladi SHR and Alfallah B (2026). Automating language input: investigating the effect of AI-generated contextual flashcards delivered via Anki on EFL learners' sentence-level fluency. Front. Educ. 11:1862047. https://doi.org/10.3389/feduc.2026.1862047

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech, Language, and Hearing Research, 51*(1), 225–239. https://doi.org/10.1044/1092-4388(2008/018)

Kroll, J. F., Bobb, S. C., & Hoshino, N. (2014). Two languages in mind: Bilingualism as a tool to investigate language, cognition, and the brain. *Current Directions in Psychological Science, 23*(3), 159–163.

Kroll, J. F., Dussias, P. E., Bice, K., & Perrotti, L. (2015). Bilingualism, mind, and brain. *Annual Review of Linguistics, 1*(1), 377–394.

Kumar, J., Patel, T., Sugandh, F., Dev, J., Kumar, U., Adeeb, M., Kachhadia, M. P., Puri, P., Prachi, F., Zaman, M. U., Kumar, S., Varrassi, G., & Syed, A. R. S. (2023). Innovative approaches and therapies to enhance neuroplasticity and promote recovery in patients with neurological disorders: A narrative review. *Cureus, 15*(7), e41914. https://doi.org/10.7759/cureus.41914

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology, 62*, 621–647. https://doi.org/10.1146/annurev.psych.093008.131123

Li, P. (2023). The neurocognitive underpinnings of second language processing: Knowledge gains from the past and future outlook. *Language Learning, 73*(Suppl. 2), 95–138.

Li, P., Legault, J., & Litcofsky, K. A. (2014). Neuroplasticity as a function of second language learning: Anatomical changes in the human brain. *Cortex, 58*, 301–324.

Lindenberger, U., & Lövdén, M. (2019). Brain plasticity in human lifespan development: The exploration–selection–refinement model. *Annual Review of Developmental Psychology, 1*(1), 197–222. https://doi.org/10.1146/annurev-devpsych-121318-085229

Lindenberger, U., Wenger, E., & Lövdén, M. (2017). Towards a stronger science of human plasticity. *Nature Reviews Neuroscience, 18*(5), 261–262. https://doi.org/10.1038/nrn.2017.44

Long, M. (2015). *Second language acquisition and task-based language teaching*. Blackwell.

Long, M. (2023). The psycholinguistics of second language interaction. In A. Godfroid & H. Hopp (Eds.), *The Routledge handbook of second language acquisition and psycholinguistics* (pp. 335–347). Routledge.

Luck, S. J. (2014). *An introduction to the event-related potential technique* (2nd ed.). MIT Press.

Malcolm, J., Hodkinson, P., & Colley, H. (2003). The interrelationships between informal and formal learning. *Journal of Workplace Learning, 15*(7/8), 313–318.

Mayberry, R. I., & Kluender, R. (2018). Rethinking the critical period for language: New insights into an old question from American Sign Language. *Bilingualism: Language and Cognition, 21*(5), 886–905. https://doi.org/10.1017/S1366728917000724

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology, 114*(2), 187–202.

Moumouri, A., & Katerelos, A. (2025). The role of neurolinguistics in teaching Greek as a second language: A comprehensive review. *Indonesian Journal of Language Teaching and Education, 9*(2). https://doi.org/10.22437/ijolte.v9i2.48343

Nergis, A. (2011). To what extent does neurolinguistics embody EFL teaching methods? *Procedia—Social and Behavioral Sciences, 15*, 143–147.

Netten, J., & Germain, C. (2012). A new paradigm for the learning of a second or foreign language: The neurolinguistic approach. *Neuroeducation, 1*(1), 85–114.

Neumann, N., Domin, M., Erhard, K., & Lotze, M. (2018). Voxel-based morphometry in creative writers: Grey matter increase in a prefronto-thalamic-cerebellar network. *European Journal of Neuroscience, 48*(1), 1647–1653. https://doi.org/10.1111/ejn.13952

Osterhout, L., Poliakov, A., Inoue, K., McLaughlin, J., Valentine, G., Pitkanen, I., Frenck Mestre, C., & Hirschensohn, J. (2008). Second-language learning and changes in the brain. *Journal of Neurolinguistics, 21*(6), 509–521. https://doi.org/10.1016/j.jneuroling.2008.01.001

Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The plastic human brain cortex. *Annual Review of Neuroscience, 28*, 377–401.

Pinti, P., Tachtsidis, I., Hamilton, A., Hirsch, J., Aichelburg, C., Gilbert, S., & Burgess, P. W. (2018). The present and future use of functional near-infrared spectroscopy (fNIRS) for cognitive neuroscience. *Annals of the New York Academy of Sciences, 1464*(1), 5–29. https://doi.org/10.1111/nyas.13948

Poarch, G. J., & Van Hell, J. G. (2012). Executive functions and inhibitory control in multilingual children: Evidence from second-language learners, bilinguals, and trilinguals. *Journal of Experimental Child Psychology, 113*(4), 535–551.

Rosenberg, S. (1993). Chomsky's theory of language: Some recent observations. *Psychological Science, 4*(1), 15.

Rollans, C., Cheema, K., Georgiou, G. K., & Cummine, J. (2017). Pathways of the inferior frontal occipital fasciculus in overt speech and reading. *Neuroscience, 364*, 182–193. https://doi.org/10.1016/j.neuroscience.2017.09.011

Schlegel, A. A., Rudelson, J. J., & Tse, P. U. (2012). White matter structure changes as adults learn a second language. *Journal of Cognitive Neuroscience, 24*(8), 1664–1670. https://doi.org/10.1162/jocn_a_00240

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*, 1–66.

Schumann, J. (2004). The neurobiology of aptitude. In J. H. Schumann, S. E. Crowell, N. E. Jones, N. Lee, S. A. Schuchert, & L. A. Wood (Eds.), *The neurobiology of learning: Perspectives from second language acquisition* (pp. 7–21). Lawrence Erlbaum Associates.

Shaw, C., & McEachern, J. (Eds.). (2001). *Toward a theory of neuroplasticity*. Psychology Press.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127–190.

Silva, S., & Citterio, A. (2017). Hemispheric asymmetries in dorsal language pathway white-matter tracts: A magnetic resonance imaging tractography and functional magnetic resonance imaging study. *Neuroscience, 343*, 226–236. https://doi.org/10.1016/j.neuroscience.2016.11.038

Singleton, D. (2005). The critical period hypothesis: A coat of many colours. *International Review of Applied Linguistics in Language Teaching, 43*(4), 269–285. https://doi.org/10.1515/iral.2005.43.4.269

Smith, S. M., Jenkinson, M., Woolrich, M. W., Beckmann, C. F., Behrens, T. E. J., Johansen-Berg, H., Bannister, P. R., De Luca, M., Drobnjak, I., Flitney, D. E., Niazy, R. K., Saunders, J., Vickers, J., Zhang, Y., De Stefano, N., Brady, J. M., & Matthews, P. M. (2004). Advances in functional and structural MR image analysis and implementation as FSL. *NeuroImage, 23*(Suppl. 1), S208–S219. https://doi.org/10.1016/j.neuroimage.2004.07.051

Soares, J. M., Marques, P., Alves, V., & Sousa, N. (2013). A hitchhiker's guide to diffusion tensor imaging. *Frontiers in Neuroscience, 7*, Article 31. https://doi.org/10.3389/fnins.2013.00031

Steinberg, D. D. (2001). *Psycholinguistics: Language, mind, and world*. Longman.

Thiessen, E. D., Girard, S., & Erickson, L. C. (2016). Statistical learning and the critical period: How a continuous learning mechanism can give rise to discontinuous learning. *Wiley Interdisciplinary Reviews: Cognitive Science, 7*(4), 275–287. https://doi.org/10.1002/wcs.1394

Ullman, M. T., & Lovelett, J. T. (2018). Implications of the declarative/procedural model for improving second language learning: The role of memory enhancement techniques. *Second Language Research, 34*(1), 39–65.

Von Economo, C., & Koskinas, G. N. (1925). *Die Cytoarchitektonik der Hirnrinde des erwachsenen Menschen*. Julius Springer.

Wan, N., Hancock, A. S., Moon, T. K., & Gillam, R. B. (2018). A functional near-infrared spectroscopy (fNIRS) study of neural activity associated with spoken language processing in preschool children. *Developmental Cognitive Neuroscience, 30*, 166–175. https://doi.org/10.1016/j.dcn.2018.03.006

Wenger, E., Brozzoli, C., Lindenberger, U., & Lövdén, M. (2017). Expansion and renormalization of human brain structure during skill acquisition. *Trends in Cognitive Sciences, 21*(12), 930–939. https://doi.org/10.1016/j.tics.2017.09.008

Woolfolk, A. E. (2004). *Educational psychology*. Pearson Education.

Zotey, V., Andhale, A., Shegekar, T., & Juganavar, A. (2023). Adaptive neuroplasticity in brain injury recovery: Strategies and insights. *Cureus, 15*(9), e45873. https://doi.org/10.7759/cureus.45873