Implicit and Explicit Processes in Language Acquisition and Learning: A Systematic Review of Neuroimaging Studies

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Abstract

The acquisition of English as a non-native language can occur in either second language (L2) or foreign language (FL) contexts, which differ significantly in the cognitive and neural processes involved. While L2 acquisition tends to rely on implicit and procedural mechanisms, FL learning is based on explicit and declarative processes. From a cognitive neuroscience perspective, several studies have explored whether these contextual differences lead to distinct patterns of brain activation specific to English learning. A systematic review was conducted of studies published between 2015 and 2024 in the Scopus, PubMed, and ScienceDirect databases. Empirical investigations employing neuroimaging techniques (DTI, EEG, ERP, fMRI, fNIRS) to analyze linguistic processing in English L2 or FL contexts were included. After applying inclusion and exclusion criteria, and refining the selection to focus exclusively on English, 18 primary studies were selected following the PRISMA 2020 guidelines. The reviewed studies indicate that English L2 acquisition in natural contexts predominantly activates multimodal networks associated with procedural memory, whereas English FL learning in formal educational settings involves greater activation of executive networks and declarative memory. Furthermore, differences in functional connectivity patterns were observed depending on the type of learning context. The evidence suggests that immersion contexts favor more automatic, holistic, and socially integrated linguistic processing, whereas classroom contexts promote more controlled and analytical processing. These findings underscore the need to adapt pedagogical strategies to the neurocognitive dynamics specific to each English learning context and highlight the importance of clearly distinguishing between L2 and FL in future research.

Keywords: implicit learning, explicit learning, brain activation, procedural memory, declarative memory, language processing, functional connectivity

1. Introduction

English, as the most widely taught and learned non-native language globally, provides a unique context for examining how different learning environments shape neurocognitive processes (Deng et al., 2023). Generally, English L2 acquisition in naturalistic and social environments promotes the activation of multimodal networks associated with implicit, distributed, and contextual processing (Di Pisa et al., 2021; Jeong et al., 2021; Kim et al., 2024). In contrast, English FL learning in formal academic settings tends to recruit executive and control circuits, supporting explicit, analytical, and attention-driven language processing (Cai, 2022; Schwab et al., 2020).

The results of this systematic review confirm that the context of non-native English language learning—whether through second language (L2) acquisition or foreign language (FL) learning—significantly influences brain activation patterns, the type of memory involved, and the processing mechanisms of linguistic stimuli. In this review, we operationally distinguish between L2 and FL learning. L2 refers to the acquisition of English in naturalistic and immersive contexts, where learners are regularly exposed to the language in daily life, and the process relies predominantly on implicit and procedural mechanisms (Birdsong, 2018; Ullman, 2020). By contrast, FL refers to the learning of English in formal educational contexts, where exposure is limited to classroom settings and the process is primarily explicit and declarative (Li et al., 2022). This distinction provides the conceptual foundation for analyzing the neurocognitive patterns reported in the reviewed studies. In practice, English FL learners are typically located in countries where English is not the dominant language, rely on classroom-based instruction as their main source of input, and experience limited exposure beyond a few instructional hours per week. This operational clarification enhances replicability by specifying the environment and instructional intensity that characterize FL learning.

Having established the distinction between L2 acquisition and FL learning, the reviewed evidence points to specific neural mechanisms underlying each context. Among these, the inferior frontal gyrus (IFG) consistently emerged as a key region across both conditions. In FL learners, the IFG exhibited heightened activation during tasks requiring conscious phonological encoding and grammatical rule application (Ghazi-Saidi et al., 2015; Macbeth et al., 2021). Conversely, in English L2 acquisition, the IFG co-activated with auditory and social integration areas such as the superior temporal gyrus (STG) and the temporoparietal junction (TPJ), facilitating more automatic, distributed processing during natural language exposure (Jeong et al., 2021; Tu et al., 2022).

Beyond the IFG, another key structure consistently highlighted is the hippocampus. This region was prominently associated with explicit memory formation during English FL learning. Studies indicated greater hippocampal involvement during lexical memorization tasks and the conscious retrieval of newly learned English vocabulary (Bartolotti et al., 2017; Kousaie et al., 2021). Notably, resting-state EEG studies have shown that English FL learners develop increased beta power in frontoparietal networks, supporting controlled and effortful processing (Macbeth et al., 2021). In contrast, procedural memory systems, linked to basal ganglia and motor planning areas, were more active during English L2 acquisition (Fromont et al., 2020; Luk et al., 2020), aligning with the automatic and contextualized nature of learning through immersion.

Several neuroimaging studies demonstrated that English L2 acquisition fosters stronger integration across multimodal brain networks. For instance, resting-state qEEG studies revealed that alpha and gamma oscillations predicted faster English L2 learning rates by supporting broader network communication (Prat et al., 2016). Additionally, fMRI studies found that acquiring English in immersion settings induced modality-dependent changes in auditory and visual cortices, reflecting the dynamic nature of naturalistic learning environments (Fromont et al., 2020).

Plasticity in gray and white matter was another important finding. Studies such as Bellander et al. (2016) and Nacar Garcia et al. (2018) reported increased gray matter volume in the inferior parietal lobule and fusiform gyrus after English second language learning, suggesting that neural adaptations are context-sensitive and modality-specific. Although some findings from other language backgrounds have been informative, the current review focuses specifically on the patterns observed in English language learners.

The type of linguistic input also played a critical role in shaping neural responses. Research using functional near-infrared spectroscopy (fNIRS) showed that phonological training through pseudowords in English L2 learners led to significant hemodynamic responses in the right middle temporal gyrus (Wang et al., 2023; Yang et al., 2024). Similarly, ERP studies demonstrated distinct patterns of P3b and N400 components depending on whether the learning context was naturalistic or structured, highlighting differences in attention allocation and semantic integration (Fromont et al., 2020; Schwab et al., 2020).

Beyond neural activation, differences in functional connectivity were evident. English FL learners exhibited more segregated connectivity within frontal executive networks, associated with analytic language processing (Lui et al., 2021). In contrast, English L2 learners developed more distributed and integrated networks linking auditory, motor, and social brain regions, supporting more holistic communicative abilities (Cuevas et al., 2021; Elmer et al., 2023).

Socio-contextual factors further modulated these patterns. Immersion experiences, where learners were surrounded by English-speaking communities, enhanced pragmatic competence and activation in social cognition areas such as the TPJ and STS (Ding et al., 2021). Conversely, English FL learners trained in isolated classroom environments exhibited greater reliance on cognitive control systems rather than communicative fluency networks (Kepinska, de Rover, et al., 2017; Macbeth et al., 2021).

Despite these advances, significant gaps persist. Many studies fail to precisely differentiate between L2 and FL contexts, often using broad terminology without addressing critical variables such as age of acquisition, type of exposure, and linguistic environment (Calvo et al., 2023; Hämäläinen et al., 2017). Furthermore, there is a lack of longitudinal studies that systematically track the neurocognitive evolution of English L2 and FL learners over time (Luk et al., 2020), limiting our understanding of the dynamic processes involved in long-term language development.

Thus, this review underscores the need for future research to adopt more precise terminological distinctions in the study of L2 and FL. It also highlights the importance of designing longitudinal and multimodal neuroimaging studies focused specifically on English language learning, while incorporating sociocultural variables into the analysis of English learning contexts. By bridging cognitive neuroscience, English language education, and sociolinguistics, future work could yield a more comprehensive and ecologically valid understanding of the neural mechanisms underlying the complex phenomenon of English L2 acquisition and FL learning.

2. Method

This study adopts a qualitative, descriptive, and analytical approach, employing a systematic review design to rigorously identify, evaluate, and compare empirical studies published between 2015 and 2024. The review was conducted following standardized methodological principles to ensure transparency, reproducibility, and comprehensiveness in the selection and analysis of sources. To structure the research process, a PICOT-based framework was utilized for formulating focused research questions and defining inclusion criteria (see Table 1). This framework provided a systematic foundation for guiding the search strategy, screening process, and synthesis of findings related to the neurocognitive mechanisms involved in English L2 acquisition and FL learning.

Table 1. PICOT Framework for the Systematic Review

Element	Question	Answer
P (Population)	Who are the participants?	Students of FL or L2.
I (Intervention/Exposure)	What phenomenon/intervention is being studied?	Processes of implicit acquisition (automatic, uninstructed) in L2.
C (Comparison)	What is being compared?	Processes of explicit learning (controlled, instructed) in FL.
O (Outcome)	What is being measured or compared?	Differences in brain activity, type of memory activated (procedural vs. declarative), and sensitivity to context (immersion vs. formal instruction).
T (Timeframe)	What is the time frame?	Studies published between 2015 and 2024 using functional or structural neuroimaging techniques.

The systematic search strategy was conducted across three electronic databases: Scopus, PubMed, and ScienceDirect. For Scopus, the following search equation was used: (neuroimaging OR fMRI OR EEG OR PET) AND ("second language acquisition" OR "foreign language learning") AND ("cognitive processes" OR "working memory" OR "emotional processing" OR "neural plasticity") AND (attention OR memory OR "language processing") AND (2015.2024).

In PubMed, the search equation applied was: ("neuroimaging" OR "fMRI" OR "EEG" OR "PET") AND ("language acquisition" OR "second language acquisition" OR "foreign language learning") AND ("cognitive processes" OR "brain activation" OR "neural plasticity" OR "brain connectivity") AND (attention OR memory OR "language processing") AND ("2015/01/01": "2024/12/31").

Finally, for ScienceDirect, the search equation was: (neuroimaging OR "fMRI" OR "EEG" OR "PET") AND ("second language acquisition" OR "foreign language learning") AND (attention OR memory OR "language processing" OR "cognitive processes").

The inclusion criteria comprised primary empirical studies published between 2015 and 2024 that employed neuroimaging techniques—such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), event-related potentials (ERP), functional near-infrared spectroscopy (fNIRS), or diffusion tensor imaging (DTI)—to examine cognitive mechanisms including automation, implicit learning, explicit learning, or controlled processing involved in the acquisition or learning of a non-native language (L2 or FL). Only open-access peer-reviewed articles that specifically analyzed brain activation patterns, functional connectivity, or neural structures associated with linguistic processing were considered eligible for inclusion. Studies focusing on clinical populations, systematic reviews, meta-analyses, conceptual papers, or investigations unrelated to neuroimaging or language learning were excluded.

Following the PRISMA 2020 guidelines, a systematic search was conducted across three databases (Scopus, PubMed, and ScienceDirect), identifying 111 records. After the removal of 3 duplicate entries, 108 titles and abstracts were screened for relevance. Of these, 37 full-text reports were sought for retrieval, and 36 were successfully retrieved and assessed. Following full-text evaluation, 11 reports were excluded based on wrong study design (n = 2), wrong population (n = 4), wrong outcomes (n = 4), or wrong publication type (n = 1). Consequently, 24 primary studies were initially included.

Subsequently, in order to align the final sample strictly with the focus on English language acquisition and learning, an additional refinement was applied, excluding studies not centered on English. This resulted in a final total of 18 empirical studies that constitute the foundation of the present review. The complete study selection process, including reasons for exclusion at each stage, is visually summarized in Figure 1.

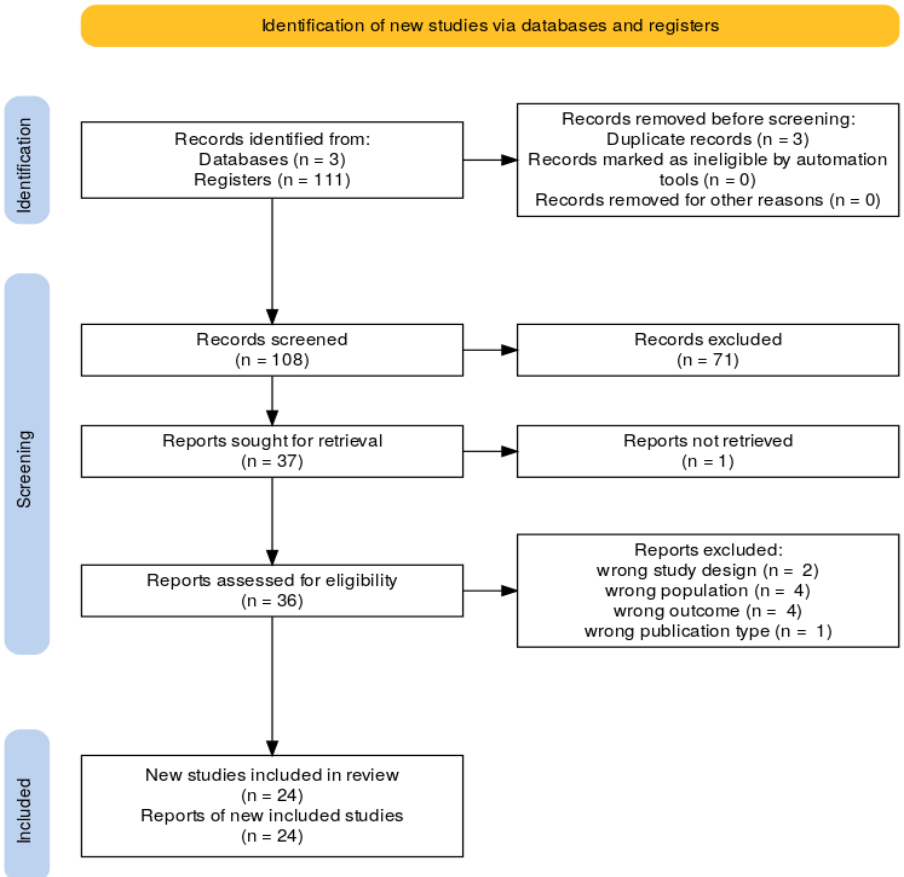

Figure 1. Study Selection and Screening Flow Diagram Following PRISMA 2020 Guidelines

3. Results

A total of 24 primary studies were initially included in this systematic review following the PRISMA 2020 guidelines. Subsequently, a refinement of the selection was conducted to ensure a focused analysis on English language acquisition and learning, excluding studies that addressed other target languages or did not clearly specify English as the language of study. As a result, 18 studies were retained for detailed analysis. These studies encompassed various experimental designs, types of linguistic processing, and neuroimaging techniques, providing a comprehensive overview of brain activation patterns associated with English language acquisition and learning. A detailed summary of the primary studies included in this review is provided as Supplementary Material.

Table 2 summarizes the main brain activation patterns associated with different types of cognitive and linguistic processing involved in L2 acquisition and FL learning, specifically focused on English. The reviewed studies reveal that phonological and semantic processing are primarily associated with key structures such as the arcuate fasciculus (AF), inferior fronto-occipital fasciculus (IFOF), angular gyrus (AG), superior temporal gyrus (STG), and inferior frontal gyrus (IFG), emphasizing their central role in auditory perception, phonological integration, and linguistic control. Executive functions, including resistance to proactive interference, are linked to frontal structures such as the IFG, anterior cingulate cortex (ACC), and middle frontal gyrus (MFG), reflecting the demands of explicit linguistic processing. Accent production and articulation tasks prominently engage the left insula and motor cortex, underscoring the procedural aspects of L2 oral production. Moreover, phonological versus orthographic processing differences involve activation of the left inferior parietal lobule (LIPL), indicating the interaction between phonological awareness and literacy in English learning. Studies also report that phonological and cognitive tasks activate broader frontotemporal regions, while phonetic perception of pseudowords is associated with right temporal areas, highlighting the flexibility and distribution of neural resources in L2 acquisition and FL learning contexts. These findings underscore the complex and distributed neural mechanisms that underpin both implicit acquisition and explicit learning of English as a non-native language.

Table 2. Brain Activation Patterns and Linguistic Processing

Brain Areas	Processing	Technique	Authors
Angular Gyrus (AG), Superior Temporal Gyrus (STG), IFG, MTG	Auditory perception, top-down integration	fMRI	(Kajiura et al., 2021)
IFG, ACC, MFG, Corpus Callosum (CC)	Executive control, proactive interference resistance	Structural MRI + DTI	(Macbeth et al., 2021)
Left Inferior Parietal Lobule (LIPL)	Phonological vs. orthographic processing	fMRI (longitudinal and cross-sectional)	(Zhang et al., 2023)
Left Insula, Motor Cortex	Accent production, articulation	fMRI	(Ghazi-Saidi et al., 2015)
Frontal, temporoparietal regions	Phonological, cognitive processing	fNIRS	(Wang et al., 2023)
Right Middle Temporal Gyrus (RMTG), Right Fusiform Gyrus (FG)	Phonetic perception, pseudowords	fNIRS	(Yang et al., 2024)
IFG, MFG, STG, occipital regions, hippocampus	Lexical-semantic, syntactic, auditory and visual processing	Longitudinal fMRI	(Sakai et al., 2021)
STS, MTG, TPJ, hippocampus, motor areas	Semantic processing, social interaction	fMRI	(Jeong et al., 2021)
Global connectivity + right hemisphere	Syntactic, analytical processing	EEG (oscillations and connectivity)	(Kepinska, Pereda, et al., 2017)
Hippocampus, posterior parietal cortex	Lexical processing, inhibitory control	fMRI	(Bartolotti et al., 2017)
Non-specific, global modularity	Reading, morphology, phonology	EEG (resting-state, modularity analysis)	(Lui et al., 2021)
IFG, Insula	Semantic-phonological processing	tDCS + fMRI	(Fiori et al., 2018)
Parietal (P3b), frontal (N2b)	Prosodic processing, lexical stress	ERP (P3b, N2b components)	(Elmer et al., 2023; Schwab et al., 2020)
Frontal, temporal regions, resting-state connectivity (alpha, beta, gamma)	Resting-state functional connectivity related to bilingualism; modulation of attentional and phonological networks	Resting-state EEG	Elmer et al. (2023)

Table 3 illustrates the neurocognitive differentiation between implicit acquisition and explicit learning processes in language, specifically within the context of English L2 acquisition and FL learning. Implicit acquisition, characteristic of immersion contexts, predominantly engages procedural memory systems, as evidenced by the activation of distributed brain regions such as the IFG, MFG, STG, hippocampus, and occipital areas—structures associated with automatic phonological, semantic, and syntactic processing. Furthermore, the implicit learning of artificial grammar patterns demonstrates widespread right hemisphere connectivity, supporting the proceduralization of linguistic rules without the involvement of conscious awareness. In contrast, explicit learning, typical of formal instructional contexts, activates declarative memory networks, as reflected in the hippocampus, posterior parietal cortex, and electrophysiological components such as the P3b and N2b, which are associated with conscious attentional control during prosodic and lexical tasks. Additionally, tasks involving semantic-phonological integration reveal a hybrid engagement of procedural and semantic memory systems through the IFG and insula, illustrating the elevated cognitive demands of explicit linguistic learning.

These findings reinforce the hypothesis that the type of linguistic experience—whether immersive and unconscious or formal and deliberate—not only modulates the memory systems recruited but also determines the specific neural circuits activated during English language acquisition and learning.

Table 3. Differences Between Procedural and Declarative Memory

Type of Memory	Type of Processing	Brain Regions Involved	Authors
Working memory / control	Explicit (prosodic)	P3b (parietal), N2b (frontal)	(Schwab et al., 2020)
Declarative	Explicit (lexical)	Hippocampus, posterior parietal cortex	(Bartolotti et al., 2017)
Procedural	Implicit (artificial grammar)	Global connectivity, right hemisphere	(Kepinska, de Rover, et al., 2017)
Procedural/semantic	Explicit (semantic-phonological)	IFG, Insula	(Fiori et al., 2018)
Procedural	Implicit (phonological)	IFG, MFG, STG, hippocampus, occipital regions	(Sakai et al., 2021)
Declarative	Explicit (phonological vs. orthographic)	Left Inferior Parietal Lobule (LIPL)	(Zhang et al., 2023)

Table 4 illustrates how the learning context modulates brain activation patterns associated with English L2 acquisition and FL learning. Natural and socially immersive L2 acquisition contexts promote the activation of multimodal and socially oriented networks, including the TPJ, STS, and MTG, which support automatic, integrative, and sensory-rich linguistic processing. In contrast, FL learning in formal academic or artificial environments predominantly recruits executive and consciously controlled neural circuits, characterized by directed attention, analytical processing, and explicit rule application. Notably, while educational technologies introduce multimodal elements into FL learning, they continue to elicit brain activation patterns that are sensitive to the type and modality of linguistic input, maintaining a differentiation from naturalistic acquisition contexts. These findings emphasize that the type of learning environment not only shapes the cognitive nature of English language acquisition and learning but also determines the specific neurocognitive networks engaged during linguistic processing.

Table 4. Brain Activation According to Learning Context and Language Type (L2 vs. FL)

Learning Context	Language Type	Technique	Brain Regions Involved	Key Observations	Authors
Social, natural	L2	fMRI	TPJ, STS, MTG	Multimodal activation in contextual implicit acquisition	(Jeong et al., 2021)
Immersion in L2 country	L2	fMRI	IFG, STG, MFG	Modality-driven changes (reading vs. listening)	(Sakai et al., 2021)
Formal schooling	FL	EEG	Global connectivity	Increased executive activation, formal reading	(Lui et al., 2021)
Technological (app-based)	FL	fNIRS	RMTG, fusiform gyrus	Connectivity sensitive to type of input	(Yang et al., 2024)
Artificial, non-contextual	FL	EEG	Frontal beta activity, lateralization	Reduced contextual involvement, more structural processing	(Kepinska, Pereda et al., 2017)

4. Discussion

This section discusses the findings of the systematic review in relation to three central themes: brain activation patterns linked to linguistic processing, differences between procedural and declarative memory systems, and the modulation of brain activation according to learning context and language type (L2 versus FL).

The first major finding relates to the patterns of brain activation associated with different types of linguistic processing in English language acquisition and learning. The IFG is consistently implicated in both language-specific functions, particularly phonological and syntactic processing, and in executive control tasks such as attentional modulation, inhibitory control, and working memory—processes especially relevant during explicit linguistic tasks (Fiori et al., 2018; Macbeth et al., 2021). In FL contexts, particularly in English language learning through formal instruction, the IFG shows heightened activation during tasks requiring conscious attention and explicit grammatical management, reflecting the cognitive demands of rule-based, deliberate language learning (Schwab et al., 2020). In contrast, in English L2 acquisition contexts, the IFG is also activated but in coordination with regions such as the STG and the TPJ, which are linked to auditory and social integration (Jeong et al., 2021). This co-activation suggests a more automatic, distributed, and context-sensitive processing pattern, typical of naturalistic language exposure. These findings align with theoretical models that distinguish between implicit acquisition and explicit learning, indicating that the neural architecture supporting each process is shaped by the nature of linguistic experience (Li et al., 2022).

A second key finding of this review concerns the differential involvement of declarative and procedural memory systems in English language learning, depending on the context and nature of the process. The hippocampus, a central component of the declarative memory system, supports explicit learning by enabling the conscious encoding, storage, and retrieval of lexical and semantic information—patterns particularly evident among FL learners in formal educational environments (Bartolotti et al., 2017; Macbeth et al., 2021). By contrast, L2 acquisition in natural immersion contexts relies more on procedural structures such as the basal ganglia and motor-related regions, which underlie the gradual automatization of phonological and syntactic patterns through sensorimotor repetition (Jeong et al., 2021; Kepinska, de Rover, et al., 2017). These findings are consistent with the Declarative/Procedural Model (Ullman, 2020) which posits that declarative memory predominates in explicit language learning, whereas procedural memory supports the implicit acquisition of grammatical and phonological regularities through practice and exposure.

The third thematic axis focuses on how learning context and language type (L2 versus FL) modulate brain activation and connectivity. In natural English L2 acquisition contexts, multimodal networks such as the TPJ, STS, and MTG are preferentially activated, enabling the integration of linguistic input with social meaning and contextual cues—processes essential for pragmatic competence and naturalistic language use (Jeong et al., 2021; Tu et al., 2022). Their activation reflects experiential and implicit learning mechanisms, indicating that immersion in communicative environments fosters more spontaneous, socially grounded, and holistic English language development than formal instruction (Cuevas et al., 2021; Yang et al., 2024). From a pedagogical perspective, these findings highlight the value of incorporating communicative, project-based, and context-rich activities into English curricula, an approach consistent with sociocognitive perspectives that view language development as inherently tied to social interaction and multimodal experience (Atkinson et al., 2023).

Relatedly, differences in functional connectivity patterns according to the learning context further support the distinction between L2 acquisition and FL learning. Functional connectivity refers to the coordinated activation and synchronization of distinct brain regions that jointly support complex cognitive and linguistic processes. Studies based on EEG and fMRI show that formal English FL instruction tends to strengthen connectivity within executive and analytical networks, as evidenced by more structured and specialized brain modularity patterns (Lui et al., 2021; Schwab et al., 2020). Such strengthening likely reflects the cognitive demands of rule-based and deliberate language learning, which are characteristic of formal instructional environments. This pattern emphasizes the reliance of foreign language learners on executive and analytical neural networks.

In contrast, immersion in natural English L2 contexts promotes more integrated connectivity among sensory, social, and linguistic regions (Elmer et al., 2023; Jeong et al., 2021). This distributed organization supports greater communicative fluency and adaptability, highlighting the distinct neurocognitive profile of L2 acquisition compared to FL learning. This more distributed neural organization may facilitate greater communicative fluency, pragmatic flexibility, and the capacity to dynamically adapt to diverse sociolinguistic contexts, whereas the more specialized and modular organization observed among FL learners is associated with higher grammatical precision but reduced spontaneity in oral production (Macbeth et al., 2021).

An additional factor that modulates these connectivity patterns is the age of acquisition (AoA). Neuroimaging evidence suggests that earlier exposure to English in immersive L2 contexts promotes greater reliance on implicit and procedural mechanisms, supported by distributed activation in auditory and sensorimotor regions (Kepinska, Pereda, et al., 2017). By contrast, later FL learning in formal instructional environments tends to engage more declarative and executive resources, reflected in heightened activation of frontal areas such as the IFG and hippocampus (Birdsong, 2018). These differences underscore that AoA interacts with learning context, helping to explain the variability observed across studies.

These findings suggest that English language teaching programs might benefit from integrating immersive, interaction-rich experiences that promote distributed neural engagement, ultimately enhancing both fluency and contextual adaptability alongside grammatical accuracy (Wei, 2023). Building on this, the evidence also indicates that English FL instruction should incorporate strategies to compensate for the limited natural exposure typical of classroom contexts. For instance, curriculum designers could integrate multimodal and communicative tasks that simulate immersion-like conditions, such as project-based learning, peer interaction in English, and the use of digital technologies for authentic input. In immersion settings, as observed in English-speaking countries, learners are surrounded by a constant flow of linguistic and cultural stimuli that naturally reduce the need for deliberate effort to communicate; this underscores the importance of recreating stimulus-rich environments in FL classrooms. By scaffolding explicit instruction with contextualized and repeated practice, educators can foster the gradual transition from declarative to procedural knowledge, thereby providing a more ecologically valid and brain-informed framework for English language teaching. For assessment, we recommend prioritizing performance-based measures (e.g., task-based interaction, pragmatic comprehension, and real-time fluency) over decontextualized grammar tests, aligning evaluation with the neurocognitive shift from declarative to procedural knowledge.

5. Conclusion

The results of this systematic review confirm that the type of learning context, whether natural or formal, significantly modulates brain activation patterns and the type of memory involved in the processing of a non-native language. L2 acquisition in natural contexts favors implicit, multimodal, and distributed processing, whereas FL learning in school contexts relies on executive networks requiring conscious control and declarative memory. These findings underscore that the distinction between L2 and FL is not merely terminological but is rooted in observable neurocognitive differences identified through neuroimaging techniques. Moreover, they highlight the importance of considering contextual differences when planning pedagogical approaches and language teaching strategies for non-native English language learners.

Based on the gaps and limitations identified in the reviewed studies, several directions for future research are proposed. First, future studies should more clearly and consistently define the distinction between L2 and FL, taking into account not only geographical settings but also the social and educational characteristics of linguistic exposure. Second, it is recommended to design longitudinal studies that can track neurocognitive changes over time, particularly among learners transitioning from formal to natural learning environments, or vice versa. Additionally, it would be valuable to incorporate multimodal methodologies combining functional and structural neuroimaging techniques (e.g., fMRI and DTI) to obtain a more comprehensive understanding of English language acquisition and learning processes.

6. Limitations

Despite the valuable insights provided by this systematic review, certain limitations should be acknowledged. First, a recurring issue identified across the reviewed studies is the lack of standardized nomenclature regarding the distinction between second language (L2) acquisition and foreign language (FL) learning. Many works used these terms interchangeably without clearly specifying the contextual factors that differentiate naturalistic acquisition from formal instructional learning. This conceptual imprecision complicates cross-study comparisons and challenges the development of theoretically grounded conclusions regarding the neurocognitive mechanisms involved in English language acquisition and learning. Moreover, some studies lacked detailed information regarding critical participant variables such as age of acquisition, length and quality of linguistic exposure, and the sociocultural context of learning. These factors are known to significantly modulate brain plasticity, influence neural network development, and shape the cognitive strategies employed during language learning. Failure to report or control for these variables can obscure important distinctions between different learning trajectories and outcomes. Better standardization and comprehensive reporting are thus essential not only for advancing research but also for informing the design of English language teaching interventions grounded in accurate neurocognitive evidence. The field would benefit from the establishment of international guidelines that define key terminology and require the systematic reporting of critical learner and exposure variables in studies investigating second and foreign language acquisition.

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Authors' contributions

Prof. MJGA conceived the study idea and was primarily responsible for the study design. Prof. MJGA, Dr. CCR, and Prof. GZV jointly conducted the literature search, screening, and data extraction. All three authors contributed to drafting the first version of the manuscript. Prof. MJGA led the writing process and Dr. CCR provided critical revisions. All authors read and approved the final manuscript.

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Competing interests

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Informed consent

Not applicable

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

References

Atkinson, D., Burhan-Horasanll, E., Sagre Barboza, A., Mejía-Laguna, J. A., Oguilve, V., & Ribeiro, A. D. C. (2023). Beyond learning opportunities: Focused encounters in a sociocognitive approach to second language acquisition and teaching. *IRAL - International Review of Applied Linguistics in Language Teaching*. https://doi.org/10.1515/iral-2023-0118

Bartolotti, J., Bradley, K., Hernandez, A. E., & Marian, V. (2017). Neural signatures of second language learning and control. *Neuropsychologia*, *98*, 130-138. https://doi.org/10.1016/j.neuropsychologia.2016.04.007

Bellander, M., Berggren, R., Mårtensson, J., Brehmer, Y., Wenger, E., Li, T. Q., … Lövdén, M. (2016). Behavioral correlates of changes in hippocampal gray matter structure during acquisition of foreign vocabulary. *NeuroImage*, *131*, 205-213. https://doi.org/10.1016/j.neuroimage.2015.10.020

Birdsong, D. (2018). Plasticity, variability and age in second language acquisition and bilingualism. *Frontiers in Psychology*, *9*, 1. https://doi.org/10.3389/fpsyg.2018.00081

Cai, M. (2022). Influence of Social Media on Corporate Communication Social Responsibility Under Entrepreneurial Psychology. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.870373

Calvo, N., Grundy, J. G., & Bialystok, E. (2023). Bilingualism modulates neural efficiency at rest through alpha reactivity. *Neuropsychologia*, *180*. https://doi.org/10.1016/j.neuropsychologia.2023.108486

Cuevas, P., He, Y., Billino, J., Kozasa, E., & Straube, B. (2021). Age-related effects on the neural processing of semantic complexity in a continuous narrative: Modulation by gestures already present in young to middle-aged adults. *Neuropsychologia*, *151*. https://doi.org/10.1016/j.neuropsychologia.2020.107725

Deng, L., Zhang, L. J., & Mohamed, N. (2023). Exploring native and non-native English speaker teachers' perceptions of English teacher qualities and their students' responses. *Frontiers in Psychology*, *14*. Retrieved from https://doi.org/10.3389/fpsyg.2023.1175379

Di Pisa, G., Pereira Soares, S. M., & Rothman, J. (2021). Brain, mind and linguistic processing insights into the dynamic nature of bilingualism and its outcome effects. *Journal of Neurolinguistics*, *58*. https://doi.org/10.1016/j.jneuroling.2020.100965

Ding, G., Mohr, K. A. J., Orellana, C. I., Hancock, A. S., Juth, S., Wada, R., & Gillam, R. B. (2021). Use of Functional Near Infrared Spectroscopy to Assess Syntactic Processing by Monolingual and Bilingual Adults and Children. *Frontiers in Human Neuroscience*, *15*(February), 1-16. https://doi.org/10.3389/fnhum.2021.621025

Elmer, S., Besson, M., Rodriguez-Fornells, A., & Giroud, N. (2023). Foreign speech sound discrimination and associative word learning lead to a fast reconfiguration of resting-state networks. *NeuroImage*, *271*. Retrieved from https://doi.org/10.1016/j.neuroimage.2023.120026

Fiori, V., Kunz, L., Kuhnke, P., Marangolo, P., & Hartwigsen, G. (2018). Transcranial direct current stimulation (tDCS) facilitates verb learning by altering effective connectivity in the healthy brain. *NeuroImage*, *181*, 550-559. https://doi.org/10.1016/j.neuroimage.2018.07.040

Fromont, L. A., Royle, P., & Steinhauer, K. (2020). Growing Random Forests reveals that exposure and proficiency best account for individual variability in L2 (and L1) brain potentials for syntax and semantics. *Brain and Language*, *204*. https://doi.org/10.1016/j.bandl.2020.104770

Ghazi-Saidi, L., Dash, T., & Ansaldo, A. I. (2015). How native-like can you possibly get: Fmri evidence for processing accent. *Frontiers in Human Neuroscience*, *9*(OCTOBER), 1-12. https://doi.org/10.3389/fnhum.2015.00587

Hämäläinen, S., Sairanen, V., Leminen, A., & Lehtonen, M. (2017). Bilingualism modulates the white matter structure of language-related pathways. *NeuroImage*, *152*, 249-257. https://doi.org/10.1016/j.neuroimage.2017.02.081

Jeong, H., Li, P., Suzuki, W., Sugiura, M., & Kawashima, R. (2021). Neural mechanisms of language learning from social contexts. *Brain and Language*, *212*. https://doi.org/10.1016/j.bandl.2020.104874

Kajiura, M., Jeong, H., Kawata, N. Y. S., Yu, S., Kinoshita, T., Kawashima, R., & Sugiura, M. (2021). Brain activity predicts future learning success in intensive second language listening training. *Brain and Language*, *212*. https://doi.org/10.1016/j.bandl.2020.104839

Kepinska, O., de Rover, M., Caspers, J., & Schiller, N. O. (2017). Whole-brain functional connectivity during acquisition of novel grammar: Distinct functional networks depend on language learning abilities. *Behavioural Brain Research*, *320*, 333-346. https://doi.org/10.1016/j.bbr.2016.12.015

Kepinska, O., Pereda, E., Caspers, J., & Schiller, N. O. (2017). Neural oscillatory mechanisms during novel grammar learning underlying language analytical abilities. *Brain and Language*, *175*, 99-110. https://doi.org/10.1016/j.bandl.2017.10.003

Kim, J., Ishdorj, S., Jeon, J., & Kim, J. (2024). Identifying Vital Factors for Enhancing Safety Communication among Foreign Construction Field Workers. *Buildings*, *14*(6). https://doi.org/10.3390/buildings14061714

Kousaie, S., Chen, J. K., Baum, S. R., Phillips, N. A., Titone, D., & Klein, D. (2021). Bilingual language experience and the neural underpinnings of working memory. *Neuropsychologia*, *163*. https://doi.org/10.1016/j.neuropsychologia.2021.108081

Li, S., Hiver, P., & Papi, M. (2022). *The Routledge Handbook of Second Language Acquisition and Individual Differences*. Taylor & Francis. https://doi.org/10.4324/9781003270546

Lui, K. F. H., Lo, J. C. M., Ho, C. S. H., McBride, C., & Maurer, U. (2021). Resting state EEG network modularity predicts literacy skills in L1 Chinese but not in L2 English. *Brain and Language*, *220*. https://doi.org/10.1016/j.bandl.2021.104984

Luk, G., Pliatsikas, C., & Rossi, E. (2020). Brain changes associated with language development and learning: A primer on methodology and applications. *System*, *89*, 102209. https://doi.org/https://doi.org/10.1016/j.system.2020.102209

Macbeth, A., Higby, E., Atagi, N., & Chiarello, C. (2021). Evidence for cognitive and brain reserve supporting executive control of memory in lifelong bilinguals. *Neuropsychologia*, *160*. https://doi.org/10.1016/j.neuropsychologia.2021.107958

Nacar Garcia, L., Guerrero-Mosquera, C., Colomer, M., & Sebastian-Galles, N. (2018). Evoked and oscillatory EEG activity differentiates language discrimination in young monolingual and bilingual infants. *Scientific Reports*, *8*(1). https://doi.org/10.1038/s41598-018-20824-0

Prat, C. S., Yamasaki, B. L., Kluender, R. A., & Stocco, A. (2016). Resting-state qEEG predicts rate of second language learning in adults. *Brain and Language*, *157-158*, 44-50. https://doi.org/10.1016/j.bandl.2016.04.007

Sakai, K. L., Kuwamoto, T., Yagi, S., & Matsuya, K. (2021). Modality-Dependent Brain Activation Changes Induced by Acquiring a Second Language Abroad. *Frontiers in Behavioral Neuroscience*, *15*(March), 1-10. https://doi.org/10.3389/fnbeh.2021.631957

Schwab, S., Giroud, N., Meyer, M., & Dellwo, V. (2020). Working memory and not acoustic sensitivity is related to stress processing ability in a foreign language: An ERP study. *Journal of Neurolinguistics*, *55*. https://doi.org/10.1016/j.jneuroling.2020.100897

Tu, L., Zhou, F., Omata, K., Li, W., Huang, R., Gao, W., Zhu, Z., Li, Y., Liu, C., Mao, M., Zhang, S., & Hanakawa, T. (2022). Increased Gray Matter Volume Induced by Chinese Language Acquisition in Adult Alphabetic Language Speakers. *Frontiers in Psychology*, *13*(April), 1-11. https://doi.org/10.3389/fpsyg.2022.824219

Ullman, M. T. (2020). *The Declarative/procedural model. A Neurobiologically Motivated Theory of First and Second Language* (3rd ed., pp. 174-215). Routledge. https://doi.org/10.4324/9780429503986-7

Wang, L., Yang, J., Sun, B., Wang, D., Liu, R., He, J., & Xia, M. (2023). Influence of high-level mathematical thinking on L2 phonological processing of Chinese EFL learners: Evidence from an fNIRS study. *Thinking Skills and Creativity*, *47*. https://doi.org/10.1016/j.tsc.2023.101242

Wei, L. (2023). Artificial intelligence in language instruction: impact on English learning achievement, L2 motivation, and self-regulated learning. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1261955

Yang, J., Li, Y., Wang, L., Sun, B., He, J., Liang, Z., & Wang, D. (2024). Mobile application-based phonetic training facilitates Chinese-English learners' learning of L2. *Learning and Instruction*, *93*. https://doi.org/10.1016/j.learninstruc.2024.101967

Zhang, J., Li, H., Zhang, M., Wang, Z., Ao, X., Jian, J., Wei, N., Liu, H., Ding, G., & Meng, X. (2023). Functional preference of the left inferior parietal lobule to second language reading. *NeuroImage*, *270*. https://doi.org/10.1016/j.neuroimage.2023.119989