Original Article

Applied Linguistics Inquiry

Spring 2025, Vol. 3, No. 1, pp. 87-107

https://doi.org/10.22077/ali.2025.8828.1083

The Neuroimaging Aspects of Second Language Learning in Educational Environment: A Systematic Review of Literature

Mehran Sayyadi[1]
Reza Khany[2*]
Mehrak Rahimi[3]

[1]Ph.D. Candidate in Applied Linguistics, Faculty of Literature and Humanities, Department of English, Ilam University, Ilam, Iran
[*2]Professor of Applied Linguistics, Faculty of Literature and Humanities, Department of English, Ilam University, Ilam, Iran
[3]Associate Professor of Applied Linguistics, Faculty of Humanities, Department of English, Shahid Rajaee Teacher Training University, Tehran, Iran

ARTICLE HISTORY

Received: 15 December 2024
Revised: 18 January 2025
Accepted: 08 February 2025
Published: 31 March 2025

CORRESPONDING AUTHOR

E-mail: r.khany@ilam.ac.ir

ABSTRACT

Neuroimaging has a substantial pedagogical advantage when applied to language learners who are experiencing cognitive procedures during educational settings. Among such learners are L2 learners who may encounter new experiences that neuroimaging may be able to clarify. The purpose of this study is to investigate whether neuroimaging tools are capable of revealing more information about the experience of L2 learners. A systematic review of the literature on the use of neuroimaging in the context of L2 learning is presented in the study. According to a comprehensive search of numerous known databases, 19 articles met the criteria for extensive analysis. The results of the analysis indicate that neuroimaging tools can be used to reveal brain function during L2 learning. Furthermore, it may enable us to uncover brain function during the learning of L2 skills and its neural responses to them. Researchers have also mentioned the challenges in the implementation of neuroimaging tools in L2 procedures. In addition to presenting the testimonies found in the literature, it is emphasized that neuroimaging in L2 learning remains relatively unknown.

KEYWORDS: Systematic review; English; L2; Neuroimage

1. Introduction

The ability to communicate in a second language (L2) is crucial for success in today's globalized world. As the process of learning an L2 significantly impacts both the functional and structural aspects of the brain (Münte et al., 2002), neurolinguistics scholars focus on investigating brain functions to understand language processing more deeply (Alduais et al., 2023). It is now believed that language learning involves multiple regions of the brain, challenging the conventional view that language is primarily a left-sided cognitive function (Lindell, 2006; Quin-Conroy et al., 2024). Drawing on the fact that L2 learning involves many areas of the brain and induces changes in brain functions (Osterhout et al., 2008) intrigues necessity to understand the temporal dynamics, underlying mechanisms, and specific brain regions for defining the concept of L2 learning. Despite extensive research on L2 learning, the specific nature, timing, and manifestation of brain changes during this process remain largely unknown.

Tracking brain changes scientifically during language learning involves utilizing various techniques including neuroimaging, cognitive testing, and physiological experimentations. In this scheme, the recent surge of interest in neuroimaging aligned with the advancement of the devices and methods of data gathering and analysis has provided insights into brain structure, function, and connectivity during language acquisition. Neuroimaging as an objective, non-invasive method for evaluating human brain function, employs quantitative computational techniques to explore brain structure and function (Fedorenko & Kanwisher, 2009). Neuroimaging aids language educationists to understand which brain areas are involved in learning and using a language,

Cite this article: Sayyadi, M., Khany, R. and Rahimi, M. (2025). The neuroimaging aspects of second language learning in educational environment: A systematic review of literature. *Applied Linguistics Inquiry*, *3*(1), 87-107. doi: 10.22077/ali.2025.8828.1083

how bilingual and monolingual brains function, how brain adapts to new linguistic experiences and challenges, and how language disorders can be detected and treated (Bialystok, 2024; Zhang et al., 2024).

Although several reviews have examined the issue of neuroimaging in language education, none have specifically focused on its application in L2 learning contexts (Aldhaheri et al., 2021; Antonicelli & Rastelli, 2023; Comstock, 2024; Sulpizio et al., 2020). Developing a systematic review of existing studies in this domain is crucial to consolidate the theoretical bases of neurolinguistic field and provide a foundation for further empirical studies (Angelovska & Roehm, 2023; Gernsbacher & Kaschak, 2003). This systematic review thus aims to identify neuroimaging studies related to second language learning (L2), addressing a significant gap in the SLA and seeks answering the following questions:

1.What are the findings of neuroimaging for L2 learning?

2.What are the benefits and opportunities of using neuroimaging tools in L2 learning?

3.What are the challenges of applying neuroimaging to L2 learning studies?

2. Literature review

2.1. Neuroimaging techniques

Neuroimaging is supported by principles of neuroscience, cognitive science, and physics allowing multidisciplinary researchers track the way brain learns and processes languages. Cognitive psychology, neuroimaging, and behavioral neurology, despite their individual nuances, demonstrate overarching characteristics that underscore the integration of these disciplines (e.g., Raichle, 2009; Savoy, 2001). Neuroimaging has been a crucial component of cognitive neuroscience and mental health research during the past few decades, which has greatly enhanced our understanding of neural processes that affect cognition and behavior, as well as their modifications associated with psychiatric and neurological disorders. In recent years, computational methodologies have become increasingly pivotal in cognitive neuroimaging research (Loosen et al., 2024). By elucidating neurobiological processes and correlating experimental data with underlying mechanisms, these frameworks establish a basis for understanding complex brain-behavior interactions and predicting cognitive, behavioral, and clinical outcomes (Blanken et al., 2021; Kraus et al., 2023). Neuroimaging research has yielded numerous neurobiological insights that have transformed our understanding of learning and cognitive development (Reber, 2013; Van Atteveldt et al., 2018).

In cognitive neuroscience, various methods are employed, with the most frequently utilized in neurolinguistic studies being electroencephalography (EEG), event-related potentials (ERPs), transcranial magnetic stimulation (TMS), functional near-infrared spectroscopy (fNIRS) and Positron emission tomography (PET) (e.g., Covey et al., 2024; Kram et al., 2024; Kumar et al., 2024; Momenian et al., 2024; Provost et al., 2024).

Electroencephalography (EEG) is defined as the recording of brain activity in several parts of the nervous system and the representation of such information as a visual pattern (Sharma & Meena, 2024). The event-related potential (ERPs) denotes small voltages generated in the brain's neurons in response to particular actions or stimuli (Parviainen & Kujala, 2023). Transcranial magnetic stimulation (TMS) is a non-invasive neuroimaging technique that utilizes an electromagnetic field to induce an electric signal, thereby activating targeted brain regions (Andò et al., 2021). Functional near-infrared spectroscopy (fNIRS) quantifies changes in oxygenated (HbO2) and deoxygenated (HbR) hemoglobin levels in response to neuronal activity, facilitating the study of brain tissue metabolism (Russo & Senese, 2023). Positron emission tomography (PET) is a noninvasive clinical diagnostic technique that enables the assessment of biological functions at the molecular level. A PET scanner produces cross-sectional images generated from positron-emitting radioactive markers, known as radiopharmaceuticals, which are administered internally to the subject. By employing these brain analysis techniques, researchers can forecast specific learning outcomes or treatment consequences and thus gain more significant insights in comparison to behavioral tests.

2.2. Neuroimaging and language learning

The exploration of brain changes during the L2 learning process necessitates the utilization of electrophysiological activities. These activities in the brain can be detected non-invasively through the scalp using advanced techniques characterized by rapid advancements (Perret et al., 2024). The rapid advancements in methodologies for assessing human brain function have markedly improved L2 researchers' comprehension of brain electrophysiological changes during language learning. Further, behavioral methods such as dichotic listening are integrated with neuropsychological approaches which substantiate that language construction and comprehension predominantly occur in the brain (Guiral, 2024; Wischmann et al., 2024).

In neurolinguistics, the rapid and simultaneous classification, extraction, and integration of linguistic elements are pivotal for research in L2 learning (Godfroid & Hopp, 2023; Svaldi et al., 2024). Despite the inherent complexity of this process, children naturally assimilate it from an early age. These processes are localized in specific brain regions, particularly in the left hemisphere's language-processing areas (Monroy-Sosa et al., 2021; Rajimehr et al., 2022). Language acquisition entails both quantitative and qualitative brain transformations, reflecting enhanced language proficiency and cognitive abilities (Corrigan et al., 2022).

The neuroimaging evidence on L1-L2 association indicates that access to data in L2 requires the elimination of contradictory data in the first language (Filipović, 2022; Perkins & Zhang, 2024). Languages of a learner are always perceived as highly interconnected, and even when only one language is employed, both languages are considered initiated (Zhang et al., 2020).

A number of studies conducted in recent decades have suggested that learning circumstances may alter the pathways used by the brain in order to process new information (Friederici & Wartenburger, 2010; Sulpizio et al., 2020). While non-native learners' brain feedback is generally native-like when they are transcribing language features that are similar to their own native language, it contradicts itself at other times. During comprehension, non-native learners exhibit unusual electrophysiological responses based on linguistic features partly overlapping between L1 and L2, resulting in linguistic opposition (Grey, 2023).

As literature pinpoints, a learner's L2 competence is reflected in neural activity in specific brain areas, supporting the hypothesis that neural arrangements can be modified by particular linguistic knowledge, such as learning a new language. Neuroimaging studies have demonstrated significant neural plasticity, both on a practical and structural level, when considering language exposure to a second language (e.g., Abutalebi et al., 2013; Legault et al., 2019; Wang et al., 2020; Zhang et al., 2020). The process of language processing is greatly influenced by linguistic exposure, which results in neural changes under short-term interference. Several studies have indicated that brief exposure to language can have neural effects (e.g., Fu et al., 2024; Morgan-Short et al., 2015). However, researchers have only recently begun examining the effects of short-term language instruction in controlled exploratory settings to determine to what extent and what types of involvement with a second language can influence neural responses casually.

2.3. Review studies on neuroimaging in language education

Some systematic reviews have been conducted on the relation between neuroimaging and language learning, as outlined below. Gernsbacher and Kaschak (2003) examined neuroimaging studies related to language comprehension and discovered that language comprehension involves neural computations in various brain regions, including frontal areas in the left hemisphere and their right hemisphere counterparts. The neurophysiology of language, as explored through neuroimaging studies by Démonet et al. (2005), has revealed that clinical neuroimaging is an indispensable tool for improving the efficacy of examinations, predictions, and treatment methods for individuals with brain damage related to language. Herringshaw et al. (2016) investigated hemispheric differences in language processing and concluded that the relationship between language and the brain is complex and context-dependent, with bilateral activation observed across several different experimental conditions. Ware et al. (2021) performed a systematic review on L2 learning and neuroplasticity in aging, noting that only one study utilized neuroimaging. Their results indicate that L2 learning is associated with improvements in cognitive flexibility, self-regulation, working memory, and neural connectivity. Similarly, Deldar et al. (2020) conducted a systematic review focused on fMRI studies, investigating the relationship between language and working memory. Their findings demonstrated a clear interconnection between language and working memory, supported by the activation of limbic networks, including the basal ganglia or caudate, and several right temporal areas. Despite these review studies on language and neuroimaging issues, there remains a conspicuous absence of a systematic review specifically focusing on L2 learning through neuroimaging. The present study aims to address this gap.

3. Methodology

The current study is a 'research-focused systematic literature' utilizing Chong and Plonsky's (2024) typology of literature reviews carried out with the aim of assessing the quality and range of studies done on neuroimaging aspects of L2 learning and providing new research insights in this realm. The methodology for performing the study is explained in detail in the following sections.

3.1. Search strategy and selection of the focal literature

In the current systematic review, Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA statement guidelines were followed (Page et al., 2021). To conduct a systematic review based on PRISMA, an exhaustive examination of all research conducted on a specific topic is undertaken to address a clearly defined research question. Then, relevant research papers are selected for analysis based on a variety of inclusion and exclusion criteria. Following the selection of the studies, a systematic analysis of the results is conducted and statistical techniques are employed to synthesize results. The PRISMA principles are outlined in a 27-item checklist and a 4-phase flow diagram. The PRISMA checklist includes points concerned with every aspect of systematic reviews and meta-analyses and allows the detailed analysis of the selected articles for review addressing topics such as the title, abstract, introduction, methods, results, and discussion (Table 1).

Table 1. PRISMA 2020 item checklist (Page et al., 2021)

Selection and topic	Item #	Features	Number of items
Title	1	Title	1
Abstract	2	Abstract	1
Introduction	3 4	Rationale Objectives	2
Method	5 6 7 8	Eligibility criteria Information sources Search strategy Study selection	11

	9	Data collection process	
	10	Data items	
	11	Study risk of bias assessment	
	12	Effect measures	
	13	Synthesis of results	
	14	Reporting bias assessment	
	15	Certainty assessment	
Results	16	Study selection	7
	17	Study characteristics	
	18	Risk of bias in studies	
	19	Results of individual studies	
	20	Results of syntheses	
	21	Reporting biases	
	22	Certainty of evidence	
Discussion	23	Discussion	1
Other information	24	Registration and protocol	4
	25	Support	
	26	Competing interests	
	27	Availability of data, code, and other materials	
			Total: 27

PRISMA diagram depicts the flow of information through the different phases of a systematic review and maps out the number of records identified, included and excluded, and the reasons for exclusions (Figure 1). The diagram along with the checklist delineates the criteria for classifying, evaluating, and determining the acceptability and eligibility of studies that are to be included within the review framework and the strategies that should be deployed to carry out the review study.

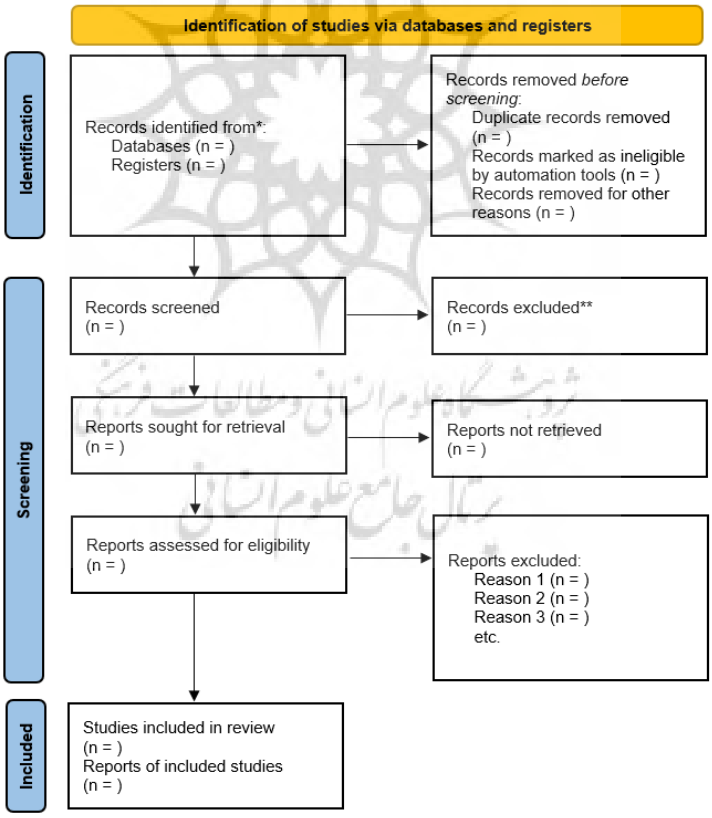

Figure 1. PRISMA 2020 flow diagram (https://www.prisma-statement.org/prisma-2020-flow-diagram)

In the pursuit of precise and accurate outcomes of the PRISMA approach, six databases were examined for this review work: Science Direct, Wiley Online Library, Sage, Taylor & Francis, Cambridge Online Library, and John Benjamin. These databases were selected due to their extensive holdings of the most frequently cited journals and articles pertinent to neuroimaging research. An extensive search was conducted in March 2024 and the inquiry was constructed using a combination of keywords in the fields of (a) Education and (b) Neuroimaging. Keywords used in the study included electroencephalography (EEG), Functional Magnetic Resonance Imaging (FMRI), Event Related Potential (ERP), transcranial Magnetic Stimulation

(TMS), Functional near-infrared spectroscopy (FNIRS), Positron Emission Tomography (PET), Magnetic resonance imaging, L2, and second language. To investigate the databases, the following terms were used: (EEG or FMRI or ERP or TMS or FNIRS or Magnetic resonance imaging or PET) AND (L2 or second language). In addition to the database query, a manual search was conducted on the following high-quality neurolinguistics journals indexed in Scopus and Clarivate: Frontiers in Human Neuroscience, Journal of Cognitive Neuroscience, Language, Cognition and Neuroscience, Bilingualism: Language and Cognition, Journal of Neurolinguistics, and Journal of Psycholinguistic Research. These journals were chosen for manual search to identify additional studies that might have been excluded due to not containing the aforementioned exact words, given their high yield in database searches.

3.2. Inclusion/exclusion criteria and search outcome

The constructed dataset comprises articles that explore the application of neuroimaging in L2 learning procedures within educational contexts. The study design, methodology, participant demographics, age, and geographic location were not restricted. However, the final selection was limited to studies conducted within L2 learning environments. Consequently, articles that investigated neuroimaging in language studies but did not specifically address L2 learning were excluded. Additionally, studies employing methods other than neuroimaging, not directly related to L2 learning, or focusing on simultaneous bilinguals rather than non-native learners from other countries were also excluded. These criteria facilitate a more profound understanding of language learning within an L2 context. L2 was defined in the study as "any language acquired after a first language system has already been established" (Littlewood, 2004, p. 502). Furthermore, neuroimaging was viewed as the method of understanding the brain through the use of spatial relationships between neurons and systems on a temporal scale (Bandettini, 2009) ranging from high (milliseconds) as in EEG devices to low (seconds) in fMRI scans to measure changes in brain activity precisely over time.

According to Figure 1, 662 articles were identified across six databases, however 212 articles were deleted due to duplication and appearance in two sets of databases. After a thorough review of the titles and abstracts of the remaining 450 articles, 248 were excluded due to their lack of relevance to L2 learning and neuroimaging directly. Additionally, 29 studies were omitted due to their non-English nature as they were written in other languages. A total of 202 articles were assessed for eligibility by reviewing their content, with 43 demonstrating no direct relevance to neuroimaging studies and utilizing associated devices to gather data so they were excluded from the review procedure. Furthermore, 53 studies were excluded for providing only general or theoretical information about L2 learning rather than specific and direct results. An additional 97 studies were excluded because their primary focus was not on L2 learning and only used L2 in their titles but there were no explanations or further details about L2 in their content so they could not be analyzed and were excluded. Consequently, 19 appropriate studies were selected for detailed analysis based on the selection process results (see Figure 2). Appendix 1 provides a summary of the reviewed studies and their characteristics.

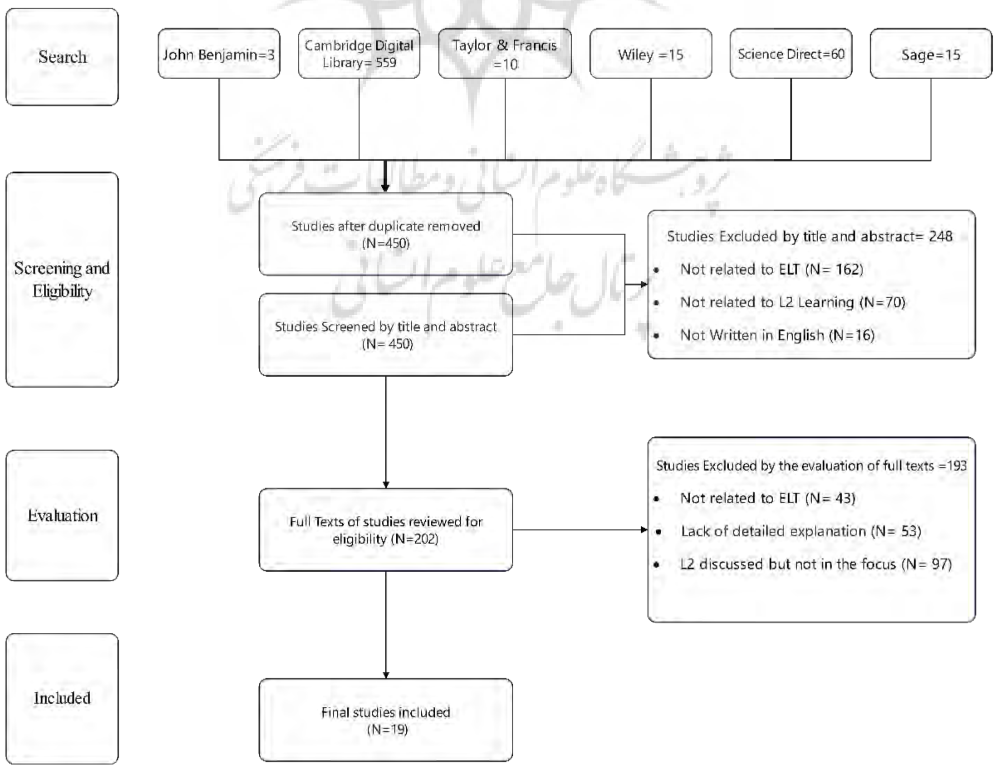

Figure 2. The diagram of study selection

3.3. Procedure

Qualitative Systematic Review Protocol was used "to minimize bias and enhance transparency and reproducibility" (Butler et al., 2016, p. 241) of this review work. As a result of conducting a careful analysis of numerous databases done both automatically and manually, evaluating the eligibility and characteristics of involved studies by following the guidelines, and integrating results by meticulous thematic analysis and integrating the results, the bias was reduced and the validity and reliability of the review procedure were increased (Shaheen et al., 2023). The following steps were taken to carry out the study (Butler et al., 2016; Davis, 2016; Mancin et al., 2024):

1) Formulating research questions to facilitate the review process: three research questions were formulated with the goal of identifying the main findings of the review studies, their contribution to L2 learning, and challenges the future researchers may encounter in this field. To be able to attain these goals, details about the design of the studies, their gathering instruments and measures, participants, type of neuroimaging devices they utilized, and types of L2 activities they used were carefully inspected.

2) Identifying a search strategy, utilizing appropriate keywords and methodologies to pinpoint pertinent literature: to be able to answer the formulated questions, a search strategy was planned and implemented by extracting the main concepts pertinent to the topic of neuroimaging aspects of L2 learning to maximize the number of relevant records retrieved in the identified databases. The following techniques were used to be able to combine suitable search terms: brainstorming keywords and phrases that describe each concept related to 'L2 education and neuroimaging' by all authors, creating a list of the keywords, selecting the keywords carefully by checking inclusion/exclusion criteria, running the primary search, evaluating the results of the first search round, and refining the keywords to come up with the final search terms (See section 3.1.).

3) Establishing review procedure pattern, involving the development of a multi-level analysis procedure that provides guidelines for study inclusion, thereby establishing a systematic framework: general requirements on how to carry out (e.g., Butler et al., 2016) and report review studies including PRISMA protocol (Page et al., 2021) as well as field-specific recommendations on how to perform secondary research in Applied Linguistics (Chong & Plonsky, 2024) were incorporated to ensure that all detailed information of the previous studies was captured and their analysis could be mapped out carefully (See section 3.2. and Figures 1 and 2).

4) Critical analysis, involving the application of methodologies to evaluate the reliability of the studies under consideration, which is essential for identifying potential biases: careful analysis of each study based on PRISMA item checklist (See Table 1) was done to ascertain that the reports incorporated the structure of a research paper and were suitable to be analyzed based on the eligibility criteria set in stages 1-3.

5) Collecting and interpreting data, involving the identification of methodologies for data collection and evaluation to ensure a comprehensive assessment of the study outcomes, by presenting different aspects of the data (Schiavo, 2019): to be able to identify and present the recurring patterns and themes in the gathered data, content analysis was carried out. The data analysis was done following the guideline suggested by Chong and Plonsky (2024) for systematic literature reviews in applied Linguistics (See section 3.4. below for details).

3.4. Data analysis

Data from the included studies in the systematic evaluation were extracted and recorded in Microsoft Excel and were subsequently categorized into two distinct sections. The first section encompasses the principal characteristics of the studies, including the author, year, country, participants, gender distribution, mean age, primary objectives, and the evaluation tools and instruments employed (Appendix 1). The second section presents the conclusions and outcomes of the evaluated studies, detailing the research objectives, and statistical measures indicating the significance of the results, along with the observed positive, neutral, or negative effects (Appendix 2). It is noteworthy to mention that the current study primarily focuses on a literature review, and the included studies did not provide effect sizes, which precluded the possibility of conducting a meta-analysis.

The coding was done in three steps based on Saldana's guidelines (2015), i.e., pre-coding, first cycle coding, and second cycle coding utilizing both manual and computer-assisted analyses.

Pre-coding phase: in this phase, the included literature was read carefully and then primarily coded by two researchers (author 1 and 3) independently.

First-cycle coding: in this phase, the primary codes established in pre-coding stage were compared in three elaboration sessions and disagreements between the coders were discussed and resolved. The inter-coder reliability was calculated by Kappa statistic and found to be .92.

The second-cycle coding: in this phase, the data were analyzed by content analysis where main themes and categories were established. Then frequencies and percentages were calculated to observe patterns and trends in the gathered data as explained in section 4. Results below. Upon interpreting the data, the findings were discussed and conclusions were drawn.

4. Results

4.1. The design of the studies and data gathering instruments

The majority of the analyzed inquiries were quantitative (89.47%) and each study employed a neuroimaging method for data collection as detailed in Appendix 1. Given the complexity of language learning, several data collection instruments were utilized to complement the neuroimaging data to either assess language proficiency at the study's onset or evaluated performance after instruction and task completion (52.63%) or examine the participants' psychological and behavioral variables (63.15%).

The tasks used in the analyzed studies were designed to measure language knowledge/competence and cognitive capabilities/variations or the combination of both in the process of neuroimaging data record. The linguistic tasks assessed lexical awareness, oral fluency, or processing of certain linguistic features. Grant et al. (2015), for instance, used lexical decision and semantic judgement tasks to examine the association between L2 learners' lexical architecture and cognitive control. Similarly, Liu et al. (2021a) utilized language switching tasks to assess the relation between language control processing and cognitive control in instructed L2 learning. Sullivan et al. (2014) incorporated verbal fluency tasks to detect neural processing modifications in the process of L2 learning during developmental stages. In the same vein, Dallas et al. (2013) used sentence processing tasks to investigate real-time processing of filler-gap dependency of L2 learners.

Psychological and behavioral measures encompass a wide range of instruments, including questionnaires and tests, used to assess participants' behavioral and psychological changes. These measures aim to support the data extracted from neuroimaging tools and provide more comprehensive results about L2 learning procedures. According to Barbeau et al. (2017), language proficiency and expertise questionnaires, as well as read-aloud protocols, were used and the results obtained with these instruments were supported by fMRI data. In their study, Grant et al. (2015) applied a language proficiency test to provide information about the participants' L2 proficiency, ensuring that any deviations in neuroimaging results caused by differences in language proficiency could be avoided, thus ensuring more reliable neuroimaging results. Alos, Sullivan et al. (2014) used vocabulary proficiency tests as pre- and post-tests to examine the relation between changes following L2 learning instruction and brain modifications throughout the continuum of bilingualism.

4.2. Participants

The research in the final dataset encompassed English learners including university (%21.05%) and school students (5.26 %) and L2 learners (73.68%). Participants of all studies were adult, with further details available in Appendix 1, although two studies (Elgort et al., 2015; Xu et al., 2019) did not specify the exact age of their participants. In all cases, the participants were L2 learners, with the exception of two works (Buchweitz et al., 2009; Xu et al., 2019) which included both native speakers and L2 learners.

4.3. Types of neuroimaging

As a result of the stimuli designed for each study in order to detect learners' brain function during language learning procedures, FMRI (52.63%) was the most frequently used neuroimaging technique for measuring brain activity. It primarily assesses brain function by measuring fluctuations in blood flow associated with neural activity, allowing researchers to identify the areas of the brain responsible for specific functions. Next comes ERP (31.57%) which is highly effective at analyzing brain activity sequences with a high degree of accuracy and precision. Furthermore, other forms of neuroimaging such as EEGs (26.31%), with the capability of detecting neuronal activity millisecond by millisecond were used. To achieve more precise results regarding language learning process, some studies used more than one type of neuroimaging technique (15.78%).

4.4. Types of L2 learning activities

Given the focus of the reviewed studies on L2 learning procedures, it is essential to identify the specific aspects of L2 learning that have been evaluated using neuroimaging tools. The majority of the studies utilized comprehension-type activities (84.21%), while the remaining used production-type learning activities (15.78%).

Comprehension-type activities encompass various tasks to concurrently or sequentially gather linguistic and neuroimaging data. In their study Nakagawa et al. (2022) utilized sentence formulation and executive function and found that the reason for sentence production difficulty in L2 is cognitive overload, which occurs during completing sentence completion activities. Koyama et al. (2014) employed visuo-spatial task processing activities and determined that the posterior lateral occipital complex displayed insufficient leftward lateralization as a consequence of increased visuo-spatial demands associated with visually complex logographic symbols, which require more right-side processing. Implementing lexical and semantic proficiency tasks, as well as cognate word processing, examined by Xu et al. (2019), indicated that distinct conjunctions have distinct modifying influences when it comes to modifying relational vagueness. Non-native speakers are more likely to experience ambiguity and, therefore, produce greater relational ambiguity as sentences are connected by conjunctions with more complex semantics than native speakers. Cognitive tasks to provide responses to upper- and lower-case sentences employed by Buchweitz et al. (2009), Choi et al. (2018), Du et al. (2023) and Koyama et al. (2014) illustrated that even non-native learners' language performance could reach the same level as native learners with training. L2 word recognition tasks based on both semantic and lexical knowledge employed by Elgort et al., (2015), Midgley et al. (2009), and Mueller (2009) revealed that the most prevalent and effective method of learning new words is through inadvertent exposure to language usage. Nonetheless, it is essential that learners with low levels of language competence explore some supplementary, more intentional learning opportunities.

Production-type activities were assessed using neuroimaging devices while subjects were engaged in constructing sentences of semantic complexity, filling in gaps, and responding to various types of questions orally. In their study, Reiterer et al. (2009) examined the hypothesis if L2 learners in their initial phases and/or bilinguals with poor fluency and less experience rely more on right-hemisphere (RH) areas when processing their L2 using EEG signals and production tasks. Their findings were in favor of RH theories indicating that RH involvement in (late) second language learners with less experience and less training in the L2 was more evident. In another study done by Dallas et al. (2013), real-time processing of sentences containing filler-gap dependencies by late-learning ESL speakers was examined. Their results suggested that, although the L2 speakers as a group are not sensitive to plausibility variations, correlational analysis indicates that more proficient L2 speakers, like the first-language (L1) speakers, are sensitive to plausibility variations while processing filler-gap sentences. In their study, Xu et al. (2019) investigated how different conjunctions affect the interpretation of a following ambiguous pronoun for non-native speakers of English in comparison to native speakers utilizing event-related potentials (ERPs). Their findings suggested that different conjunctions exert different modulating effects on resolving referential uncertainty/ambiguity and relative to native speakers, non-native speakers are more likely to encounter referential uncertainty when the sentences are conjoined by conjunctions with more complex semantics.

4.5. Measures used

The reviewed studies provide insights into brain function and modifications during language acquisition, enabling the application of neuroimaging techniques to assess the brain activities discussed in the preceding section. Three main types of neuroimaging measures or tasks were utilized including fMRI, EEG, and ERP in the process of doing language activities.

As a neuroimaging tool, fMRI provides valuable insights into various L2-related theories. In Grant et al.'s (2015) study, which was one of the pioneering studies in neurolinguistics, lexical decision tasks were analyzed using MRI and revealed a strong relationship between processing time and task type in interpreting L1 and L2 words. Another study conducted by Yang et al. (2015) used fMRI to assess individual differences in cognitive control and lexical architecture among late L2 learners, and reported that competent L2 participants demonstrated decreased brain activity in specific brain areas after training, which demonstrated improved language learning ability. The study was conducted by Barbeau et al. (2017) examined neural changes during L2 Learning using fMRI and found that the left inferior parietal lobe was associated with improved skills in the second language. It has been demonstrated by Choi et al. (2018) that uppercase texts engage specific brain regions, while lowercase texts engage multiple language-related areas, which supports the automaticity theory of language acquisition. In a similar manner, Liu et al. (2021b) explored children's cognitive flexibility and creativity as they learned languages using fMRI. As a result of their research, it was found that long periods of classroom instruction in the second language can have significant neuroplastic effects in the brain areas responsible for language control.

In the context of L2 , ERP serves as a widely used tool for collecting neuroimaging data. Wang et al. (2007) explored neurocognitive models of lexical selection through ERPs, revealing that language switching exhibits distinct neural correlates depending on the switch direction, with no specific brain region identified as a 'language switch.' Similarly, Sulivan et al. (2014) examined neural activity changes during the developmental phases of L2 learning using ERPs, noting significant neural activity shifts following brief L2 instruction. Xu et al. (2019) analyzed native and non-native speakers' interpretations of ambiguous pronouns with complex conjunctions via ERPs, finding that non-native speakers exhibited notable referential uncertainty when handling semantically intricate structures. Additionally, Du et al. (2023) utilized both ERP and EEG to investigate whether L2-specific reading skills could mitigate the influence of native language limitations, demonstrating that adults can achieve native-like neural responses in L2 reading when trained in essential skills at optimal intensity.

As a result of practical issues and limitations in managing the data gathering sessions, EEG was not commonly used by the researchers for the collection of neuroimaging data. Using EEG techniques, Midgley et al. (2009) examined how form and meaning are perceived during word recognition, as well as the role played by semantic representations. They found that L2 learners are intensively processing form representations of non-cognate translation equivalents when they are processing printed words on a form-level level, without any facilitative interaction between form equivalents. A study conducted by Dallas et al. (2013) investigated the real-time processing of filler-gap dependency sentences by late-learning English language learners using EEG, and found that the late-learning learners did not process the filler gap sentences in the same manner as the L1 learners. An EEG study by Elgort et al. (2015) examined how accidental and situational L2 word learning affects lexical competence in the L2. Based on their findings, newly learned L2 words can be identified based on both episodic and lexical semantic knowledge, and this recognition may vary depending on the learner's lexical proficiency in L2 and the context in which the word is used.

In addition to neuroimaging data, the studies also utilized objective measures for assessing language-related variables such as language proficiency through tests (Reiterer et al., 2009; Nakagawa et al., 2022), self-report language competence questionnaires (e.g., Barbeau et al., 2017), or performance tests and tasks (Yang et al., 2015).Within the studies reviewed, the most frequently employed evaluation instruments were proficiency tests (47.05%), questionnaires (29.41%), and behavioral measures (11.76%).

5. Discussion

In this study, a review of neuroimaging studies related to L2 learning procedures is presented as well as an evaluation of how neuroimaging can be applied to research on L2 learning. There may be some physiological changes that do not have behavioral implications during neuroimaging studies, and because neuroimaging relies on behavioral patterns, it might not be possible to evaluate such changes while studying neuroimaging. Consequently, researchers should consider that language learning tasks for neuroimaging must be behaviorally structured, or other complementary instruments should be used to compensate for the lack of behavioral structures. This issue has been addressed in the majority of the reviewed articles.

Appendices 1 presents an overview of the reviewed articles' characteristics and outcome, respectively. Based on the goals of the study, 19 articles from John Benjamins, Wiley, Taylor & Francis, Sage, Science Direct, and Cambridge were evaluated. The study's findings demonstrate a notable rise in neuroimaging research within the L2 context since 2015. as a result of the growing acceptance of this method and its numerous advantages.

The outcome of the study shows that the predominant imaging technique in L2 research is functional magnetic resonance imaging (fMRI), which is likely favored due to its ability to provide detailed brain imaging. This method has been widely endorsed as an effective approach for exploring L2 learning. While there is extensive literature on fMRI, there remains a significant need for additional research utilizing event-related potentials (ERP) and electroencephalography (EEG).

5.1. What are the findings of neuroimaging for L2 learning?

A thorough examination of the literature indicates that neuroimaging is a powerful tool for investigating brain function in the context of second language (L2) acquisition. Reiterer et al. (2009) found that learners with lower proficiency exhibited greater right hemisphere involvement compared to more proficient learners. Their study also highlights the importance of proficiency level in L2 learning, as Liu et al. (2021b) demonstrated that extended L2 learning leads to significant neuroplastic changes in brain regions linked to language control, as the outcomes of other studies on L2 learning have already illustrated (e.g., Choi et al., 2018; Nakagawa et al., 2022; Wang et al., 2007). Koyama et al. (2014) discovered that reduced left-ward brain lateralization is associated with enhanced right-hemisphere spatial cognition, rather than indicating increased effort by L2 learners. These results are supported by other neurolinguistic studies, showing that the brain is lateralized for specific tasks and that language has a unique role in the brain (e.g., Friederici, 2011; Pinel & Dehaene, 2010).

Neuroimaging research has significantly advanced the study of reading and writing by elucidating brain activity during these cognitive processes (Barquero et al., 2014; Schlaggar & Church, 2009). According to Buchweitz et al. (2009), learners exhibit diverse cognitive responses and varying levels of language and cross-linguistic processing at the sentence level during writing tasks. Cattinelli et al. (2013) assert that written stimuli are crucial in reading processing's initial phases, while Desroches et al. (2010) propose that neural activity during reading offers insights into language learning mechanisms. Despite widespread interest in understanding L2 processing in the brain, researchers must proceed with caution, ensuring that their findings are rigorously validated against established research outcomes.

5.2. What are the benefits and opportunities of using neuroimaging tools in L2 learning?

The application of neuroimaging technologies in SLA research offers a wide array of advantages. Scholarly works underscore that one of the most pivotal benefits is the capability to investigate brain activity during L2 learning and assess the suitability of these tasks for improving L2 learning and their incorporation into experimental research. This assertion is corroborated by numerous studies (e.g., Rastelli, 2018; Roberts & Siyanova-Chanturia, 2013) that stress the significance of utilizing metalinguistic tasks to gain a more profound understanding of the L2 learning process and its relevance in experimental research. Additionally, neuroimaging tools provide valuable insights into the behavioral patterns of L2 learners and their alignment with brain function, aiding instructors and researchers in formulating more effective strategies for L2 learning (Buchweitz et al., 2009; Elgort et al., 2015; Reiterer et al., 2009).

Neuroimaging techniques provide a more effective method for examining cognitive processes during L2 learning compared to traditional questionnaires or tests. These tools offer direct insights into brain function during L2 learning, which is unattainable through conventional methods that lack direct access to brain functions during L2 learning (Friederici & Wartenburger, 2010). Numerous studies have corroborated the complementary function of neuroimaging in the human L2 learning process (Herholz et al., 2001; Von Rhein et al., 2015; Whelan, 2007). This capability also facilitates the exploration of brain function under diverse conditions that would be challenging or impossible to study using traditional L2 learning materials, such as analyzing sentence processing in a resting state. This broadens the scope for researchers, potentially leading to the development of more effective language learning methods (Choi et al., 2018; Lum et al., 2022; Nakagawa et al., 2022).

The integration of traditional instruments with neuroimaging studies significantly enhances the precision and reliability of findings for learners. This assertion is supported by other studies, which highlight the ability of this research approach to provide insights at an individual level (Bajracharya, & Peelle, 2023; Michon et al., 2022). Consequently, learners can develop a more comprehensive understanding of brain function in the context of language learning. However, additional research is essential to fully elucidate the complexities of language processing and learning in the human brain (Makita et al., 2013; Perpiñàn, 2015; Yongqi Gu, 2016).

Numerous academic studies have confirmed the significant role of neuroimaging in advancing L2 learning (Sabourin, 2009; Zheng, & Zhang, 2024). Beyond analyzing neural changes during L2 learning processes, neuroimaging can also uncover brain data processing during these procedures (e.g., Barbeau et al., 2017; Choi et al., 2018; Midgley et al., 2011). Additionally, neuroimaging can enhance L2 learning processes and elucidate the cognitive mechanisms involved in language learning.

The reviewed studies frequently establish a connection between the integration of L2 learning into neuroimaging research and an enhancement in the interaction among various types of language production tasks. However, most studies are unable to conclusively explain how cognitive variables may affect brain function and the duration of these benefits. Liu et al. (2021a) demonstrated that prolonged engagement in L2 learning results in neural modifications. Additionally, the systematic activation of L2, combined with various L1 writing techniques, may influence neuroimaging outcomes, as supported by other studies (Kelsen et al., 2022; Tao et al., 2021). Du et al. (2023) demonstrated that only short-term, concentrated word training could affect neural responses in L2; however, this method could not determine the long-term effects of L2 exercise. Conversely, Hu and Luo (2024) suggested the application of neuroimaging studies in L2 vocabulary retention research and its effectiveness.

Several studies have shown that the process of recapturing newly acquired L2 words may involve lexical and semantic knowledge, contingent upon the individual's L2 lexical competence and the contextual introduction of the word (Elgort et al., 2015). As indicated by Barbeau et al. (2017) and Sullivan et al. (2014), the activation of the left hemisphere of the brain enhances L2 learning and the capacity to utilize various aspects of language learning. The implementation of effective strategies aimed at augmenting brain activity during L2 learning has the potential to enhance overall brain cognitive functioning (Li et al., 2014; Osterhout et al., 2008). As a result of instruction that facilitates L2 learning, skilled L2 learners exhibit reduced brain activity in specific brain regions post-instruction. These findings indicate that instruction aimed at enhancing L2 learning can lead to improved neural function (Liu et al., 2021a; Yang et al., 2015). This advancement offers the potential to integrate neuroimaging findings into L2 instruction and research.

5.3. What are the challenges associated with applying neuroimaging to L2 learning studies?

In the context of incidental contextual L2 learning, a reliable semantic agreement effect is more pronounced in higher competence L2 learners compared to their lower competence counterparts, as supported by other studies (Bardovi-Harlig & Dörnyei, 1998; Mulder et al., 2019; Pu et al., 2024). It is also essential to recognize that L2 reading comprehension requires more time than L1 reading. This temporal disparity should be considered during data extraction in L2 reading research (Dallas et al., 2013). Given the characteristics of neuroimaging in L2 learning research, it is unsurprising that these tools have been applied in educational settings to investigate the relationship between neuroimaging and L2 learning. However, it is crucial to acknowledge that psychological changes do not always correlate with behavioral changes (Sullivan et al., 2014). Researchers must be cognizant of this issue when interpreting the data obtained through this procedure. The utilization of unfamiliar words within an instructional context leads to an elevated level of extraneous cognitive load, necessitating careful management during data manipulation (Bolkan & Goodboy, 2020; Mueller, 2009; Xu et al., 2019). It is imperative that task designers recognize that not all tasks possess discriminative capabilities, a consideration that must be factored into forthcoming neuroimaging research (e.g., Dallas et al., 2013).

6. Conclusion

The aim of this research was to investigate the use of neuroimaging in educational settings among L2 learners and to clarify the effectiveness and limitations of neuroimaging in relation to L2 learning. A systematic review, complemented by manual research, identified several relevant articles, with 19 studies meeting the inclusion criteria. The analysis showed that neuroimaging is associated with various factors, including methodological approaches, instrumentation, tasks, and brain function during L2 learning. The results suggest that neuroimaging has significant potential for investigating L2 learning compared to other methodologies.

Addressing the challenges identified in this study, particularly in task design, is crucial for enhancing the understanding of the L2 learning context in follow-up studies. Further, the exact mechanisms of brain function during L2 learning remain unclear, necessitating further research. Despite the authors' efforts to adhere to systematic review guidelines, the limitations of the current study highlight the need for a comprehensive meta-analysis on neurolinguistic studies of L2 learning. Additionally, most of the reviewed studies examined only certain aspects of the L2 learning process using neuroimaging methods, and further research on different aspects, such as integrating various skills, is highly recommended. There is also a lack of evidence regarding English L2 learners with different native languages, which future studies should address to fill this gap in the literature. Future research should incorporate neuroimaging to better understand its utility in revealing the neurological processes underlying L2 learning.

7. References

*** Denotes articles systematically reviewed.**

Abutalebi, J., Della Rosa, P. A., Ding, G., Weekes, B., Costa, A., & Green, D. W. (2013). Language proficiency modulates the engagement of cognitive control areas in multilinguals. *Cortex*, *49*(3), 905-911. https://doi.org/10.1016/j.cortex.2012.08.018

Aldhaheri, T. A., Kulkarni, S. B., & Bhise, P. R. (2021). Methods of Electroencephalography in Neurolinguistics: A Systematic Review. *Grenze International Journal of Engineering & Technology (GIJET)*, *7*(1).

Alduais, A., Alduais, A., Amidfar, M., & Alizadeh Incheh, S. (2023). Neurolinguistics: A scientometric review. *Cogent Arts & Humanities*, *10*(1), 2197341. https://doi.org/10.1080/23311983.2023.2197341

Andò, A., Vasilotta, M. L., & Zennaro, A. (2021). The modulation of emotional awareness using non-invasive brain stimulation techniques: A literature review on TMS and tDCS. *Journal of Cognitive Psychology*, *33*(8), 993-1010. https://doi.org/10.1080/20445911.2021.1954013

Angelovska, T., & Roehm, D. (2023). A Selective Review of Event-Related Potential Investigations in Second and Third Language Acquisition of Syntax. *Languages*, *8*(1), 90. https://doi.org/10.3390/languages8010090

Antonicelli, G., & Rastelli, S. (2023). Event-related potentials in the study of L2 sentence processing: A scoping review of the decade 2010-2020. *Language Acquisition*, *30*(2), 163-200. https://doi.org/10.1080/10489223.2022.2141633

Bajracharya, A., & Peelle, J. E. (2023). A systematic review of neuroimaging approaches to mapping language in individuals. *Journal of Neurolinguistics*, *68*, 101163. https://doi.org/10.1016/j.jneuroling.2023.101163

Bardovi Harlig, K., & Dörnyei, Z. (1998). Do language learners recognize pragmatic violations? Pragmatic versus grammatical awareness in instructed L2 learning. *TESOL Quarterly*, *32*(2), 233-259. https://doi.org/10.2307/3587583

Barquero, L. A., Davis, N., & Cutting, L. E. (2014). Neuroimaging of reading intervention: a systematic review and activation likelihood estimate meta-analysis. *PloS one*, *9*(1), e83668. https://doi.org/10.1371/journal.pone.0083668

Bandettini, P. A. (2009). What's new in neuroimaging methods? *Annals of the New York Academy of Sciences*, *1156*(1), 260-293. https://doi.org/10.1111/j.1749-6632.2009.04420.x

*Barbeau, E. B., Chai, X. J., Chen, J. K., Soles, J., Berken, J., Baum, S., ... & Klein, D. (2017). The role of the left inferior parietal lobule in second language learning: An intensive language training fMRI study. *Neuropsychologia*, *98*, 169-176. https://doi.org/10.1016/j.neuropsychologia.2016.10.003

Bialystok, E. (2024). Bilingualism modifies cognition through adaptation, not transfer. *Trends in Cognitive Sciences*.*28*(11), 987-997. https://doi.org/10.1016/j.tics.2024.07.012

Blanken, T. F., Bathelt, J., Deserno, M. K., Voge, L., Borsboom, D., & Douw, L. (2021). Connecting brain and behavior in clinical neuroscience: A network approach. *Neuroscience & Biobehavioral Reviews*, *130*, 81-90. https://doi.org/10.1016/j.neubiorev.2021.07.027

Bolkan, S., & Goodboy, A. K. (2020). Instruction, example order, and student learning: Reducing extraneous cognitive load by providing structure for elaborated examples. *Communication Education*, *69*(3), 300-316. https://doi.org/10.1080/03634523.2019.1701196

*Buchweitz, A., Mason, R. A., Hasegawa, M., & Just, M. A. (2009). Japanese and English sentence reading comprehension and writing systems: An fMRI study of first and second language effects on brain activation. *Bilingualism: Language and Cognition*, *12*(2), 141-151. https://doi.org/10.1017/S1366728908003970

Butler, A., Hall, H., & Copnell, B. (2016). A guide to writing a qualitative systematic review protocol to enhance evidence based practice in nursing and health care. *Worldviews on Evidence Based Nursing*, *13*(3), 241-249. https://doi.org/10.1111/wvn.12134

Cattinelli, I., Borghese, N. A., Gallucci, M., & Paulesu, E. (2013). Reading the reading brain: a new meta-analysis of functional imaging data on reading. *Journal of neurolinguistics*, *26*(1), 214-238. https://doi.org/10.1016/j.jneuroling.2012.08.001

*Choi, S., Jang, K. E., Lee, Y., Song, H., Cha, H., Lee, H. J., ... & Chang, Y. (2018). Neural processing of lower-and upper-case text in second language learners of English: an fMRI study. *Language, Cognition and Neuroscience, 33*(2), 165-174. https://doi.org/10.1080/23273798.2017.1384028

Chong, s. W., & Plonsky, L. (2024). A typology of secondary research in Applied Linguistics. *Applied Linguistics Review*, *15*(4), 1569-1594. https://orcid.org/0000-0002-4519-0544

Comstock, L. (2024). The role of research design in the reproducibility of L1 and L2 language networks: A review of bilingual neuroimaging meta-analyses. *Brain and Language*, *249*, 105377. https://doi.org/10.1016/j.bandl.2023.105377

Corrigan, N. M., Yarnykh, V. L., Huber, E., Zhao, T. C., & Kuhl, P. K. (2022). Brain myelination at 7 months of age predicts later language development. *Neuroimage, 263*, 119641. https://doi.org/10.1016/j.neuroimage.2022.119641

Covey, L., Fiorentino, R., & Gabriele, A. (2024). Island sensitivity in L2 learners: Evidence from acceptability judgments and event-related potentials. *Second Language Research*, *40*(1), 19-50. https://doi.org/10.1177/02676583221116039

Dallas, A., DeDe, G., & Nicol, J. (2013). An event related potential (ERP) investigation of filler gap processing in native and second language speakers. *Language Learning*, *63*(4), 766–799. https://doi.org/10.1111/lang.12026

Davis, D. (2016). A practical overview of how to conduct a systematic review. *Nursing Standard*, *31*(12). https://doi.org/10.7748/ns.2016.e10316

Deldar, Z., Gevers-Montoro, C., Khatibi, A., & Ghazi-Saidi, L. (2020). The interaction between language and working memory: a systematic review of fMRI studies in the past two decades. *AIMS neuroscience*, *8*(1), 1. https://doi.org/10.3934/Neuroscience.2021001

Démonet, J. F., Thierry, G., & Cardebat, D. (2005). Renewal of the neurophysiology of language: functional neuroimaging. Physiological reviews, 85(1), 49 95. https://doi.org/10.1152/physrev.00049.2003

Desroches, A. S., Cone, N. E., Bolger, D. J., Bitan, T., Burman, D. D., & Booth, J. R. (2010). Children with reading difficulties show differences in brain regions associated with orthographic processing during spoken language processing. *Brain research*, *1356*, 73-84. https://doi.org/10.1016/j.brainres.2010.07.097

Du, B., Yang, Z., Wang, C., Li, Y., & Tao, S. (2023). Short-term training helps second-language learners read like native readers: An ERP study. *Brain and Language*, *239*, 105251. https://doi.org/10.1016/j.bandl.2023.105251

*Elgort, I., Perfetti, C. A., Rickles, B., & Stafura, J. Z. (2015). Contextual learning of L2 word meanings: Second language proficiency modulates behavioural and event-related brain potential (ERP) indicators of learning. *Language, Cognition and Neuroscience*, *30*(5), 506-528. https://doi.org/10.1080/23273798.2014.942673

Fedorenko, E., & Kanwisher, N. (2009). Neuroimaging of language: why hasn't a clearer picture emerged?. Language and linguistics compass, 3(4), 839-865. https://doi.org/10.1111/j.1749-818X.2009.00143.x

Friederici, A. D. (2011). The brain basis of language processing: from structure to function. *Physiological Reviews, 91*(4), 1357-1392. https://doi.org/10.1152/physrev.00006.2011

Filipović, L. (2022). First language versus second language effect on memory for motion events: The role of language type and proficiency. *International Journal of Bilingualism*, *26*(1), 65-81. https://doi.org/10.1177/13670069211022863

Friederici, A. D., & Wartenburger, I. (2010). Language and brain. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*(2), 150-159. https://doi.org/10.1002/wcs.9

Fu, Y., Bermúdez-Margaretto, B., Beltrán, D., Huili, W., & Dominguez, A. (2024). Language proficiency modulates L2 orthographic learning mechanism: Evidence from event-related brain potentials in overt naming. *Studies in Second Language Acquisition*, 1-22. https://doi.org/10.1017/S0272263123000426

Gernsbacher, M. A., & Kaschak, M. P. (2003). Neuroimaging studies of language production and comprehension. *Annual review of psychology, 54(*1), 91-114. https://doi.org/10.1146/annurev.psych.54.101601.145128

Godfroid, A., & Hopp, H. (Eds.). (2023). *The Routledge handbook of second language acquisition and psycholinguistics*. Routledge, Taylor & Francis Group.

*Grant, A. M., Fang, S. Y., & Li, P. (2015). Second language lexical development and cognitive control: A longitudinal fMRI study. *Brain and language*, *144*, 35-47. https://doi.org/10.1016/j.bandl.2015.03.010

Grey, S. (2023). Variability in native and nonnative language: An ERP study of semantic and grammar processing. *Studies in Second Language Acquisition*, *45*(1), 137-166. https://doi.org/10.1017/S0272263122000055

Guiral, J. A. (2024). Neuropsychological dimensions related to alterations of verbal self-monitoring neural networks in schizophrenic language: systematic review. *Frontiers in Psychiatry*, *15*, 1356726. https://doi.org/10.3389/fpsyt.2024.1356726

Herholz, K., Perani, D., Fazekas, F., Markus, H., Baumgartner, R. W., & Baron, J. C. (2001). A survey of neuroimaging research in European neurological departments. *European Journal of Neurology*, *8*(2), 111-117. https://doi.org/10.1046/j.1468-1331.2001.00206.x

Herringshaw, A. J., Ammons, C. J., DeRamus, T. P., & Kana, R. K. (2016). Hemispheric differences in language processing in autism spectrum disorders: A meta analysis of neuroimaging studies. *Autism Research*, *9*(10), 1046-1057. https://doi.org/10.1002/aur.1599

Hu, W., & Luo, Y. (2024). Chinese English language learners' vocabulary retention: Investigating the effectiveness of neuro/metacognitive and socio-cultural strategies. *BMC psychology*, *12*(1), 113. https://doi.org/10.1186/s40359-024-01612-0

Kelsen, B. A., Sumich, A., Kasabov, N., Liang, S. H., & Wang, G. Y. (2022). What has social neuroscience learned from hyperscanning studies of spoken communication? A systematic review. *Neuroscience & Biobehavioral Reviews*, *132*, 1249-1262. https://doi.org/10.1016/j.neubiorev.2020.09.008

*Koyama, M. S., Stein, J. F., Stoodley, C. J., & Hansen, P. C. (2014). A cross-linguistic evaluation of script-specific effects on fMRI lateralization in late second language readers. *Frontiers in human neuroscience*, *8*, 249. https://doi.org/10.3389/fnhum.2014.00249

Kram, L., Ohlerth, A. K., Ille, S., Meyer, B., & Krieg, S. M. (2024). CompreTAP: Feasibility and reliability of a new language comprehension mapping task via preoperative navigated transcranial magnetic stimulation. *Cortex*, *171*, 347-369. https://doi.org/10.1016/j.cortex.2023.09.023

Kraus, B., Zinbarg, R., Braga, R. M., Nusslock, R., Mittal, V. A., & Gratton, C. (2023). Insights from personalized models of brain and behavior for identifying biomarkers in psychiatry. *Neuroscience & Biobehavioral Reviews*, *152*, 105259. https://doi.org/10.1016/j.neubiorev.2023.105259

Kumar, U., Dhanik, K., Mishra, M., Pandey, H. R., & Keshri, A. (2024). Mapping the unique neural engagement in deaf individuals during picture, word, and sign language processing: fMRI study. *Brain Imaging and Behavior*, 1-17. https://doi.org/10.1007/s11682-024-00878-7

Legault, J., Fang, S. Y., Lan, Y. J., & Li, P. (2019). Structural brain changes as a function of second language vocabulary training: Effects of learning context. *Brain and Cognition*, *134*, 90-102. https://doi.org/10.1016/j.bandc.2018.09.004

Li, Y. (2024). Can late language learners acquire second language grammar? Evidence from linguistic to neuroscience methods. *Frontiers in Psychology*, *15*, 1421072. https://doi.org/10.3389/fpsyg.2024.1421072

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. https://doi.org/10.1016/j.cortex.2014.05.001

Lindell, A. K. (2006). In your right mind: Right hemisphere contributions to language processing and production. *Neuropsychology review*, *16*(3), 131–148. https://doi.org/10.1007/s11065-006-9011-9

Littlewood, W. (2004). Second language learning. In A. Davies, & C. Elder (Eds.), *The handbook of applied linguistics* (pp. 501–524). Malden, MA: Blackwell. https://doi.org/10.1002/9780470757000.ch20

*Liu, C., de Bruin, A., Jiao, L., Li, Z., & Wang, R. (2021a). Second language learning tunes the language control network: a longitudinal fMRI study. *Language, Cognition and Neuroscience*, *36*(4), 462-473. https://doi.org/10.1080/23273798.2020.1856898

*Liu, C., Jiao, L., Li, Z., Timmer, K., & Wang, R. (2021b). Language control network adapts to second language learning: A longitudinal rs-fMRI study. *Neuropsychologia*, *150*, 107688. https://doi.org/10.1016/j.neuropsychologia.2020.107688

Loosen, A. M., Kato, A., & Gu, X. (2024). Revisiting the role of computational neuroimaging in the era of integrative neuroscience. *Neuropsychopharmacology*, *50*(1), 103-113. https://doi.org/10.1038/s41386-024-01946-8

Lum, J. A., Clark, G. M., Bigelow, F. J., & Enticott, P. G. (2022). Resting state electroencephalography (EEG) correlates with children's language skills: Evidence from sentence repetition. *Brain and Language*, *230*, 105137. https://doi.org/10.1016/j.bandl.2022.105137

Makita, K., Yamazaki, M., Tanabe, H. C., Koike, T., Kochiyama, T., Yokokawa, H., ... & Sadato, N. (2013). A Functional Magnetic Resonance Imaging Study of Foreign Language Vocabulary Learning Enhanced by Phonological Rehearsal: The Role of the Right Cerebellum and Left Fusiform Gyrus. *Mind, Brain, and Education*, *7*(4), 213-224. https://doi.org/10.1111/mbe.12029

Mancin, S., Sguanci, M., Anastasi, G., Godino, L., Cascio, A. L., Morenghi, E., ... & De Marinis, M. G. (2024). RETRACTED: A methodological framework for rigorous systematic reviews: Tailoring comprehensive analyses to clinicians and healthcare professionals. *Methods*, *225*, 38-43.

Michon, K. J., Khammash, D., Simmonite, M., Hamlin, A. M., & Polk, T. A. (2022). Person-specific and precision neuroimaging: Current methods and future directions. *NeuroImage*, *263*, 119589. https://doi.org/10.1016/j.neuroimage.2022.119589

* Midgley, K. J., Holcomb, P. J., & Grainger, J. (2009). Masked repetition and translation priming in second language learners: A window on the time course of form and meaning activation using ERPs. *Psychophysiology*, *46*(3), 551-565. https://doi.org/10.1111/j.1469-8986.2009.00784.x

*Midgley, K. J., Holcomb, P. J., & Grainger, J. (2011). Effects of cognate status on word comprehension in second language learners: An ERP investigation. *Journal of cognitive neuroscience*, *23*(7), 1634-1647. https://doi.org/10.1162%2Fjocn.2010.21463

Momenian, M., Vaghefi, M., Sadeghi, H., Momtazi, S., & Meyer, L. (2024). Language prediction in monolingual and bilingual speakers: an EEG study. *Scientific Reports*, *14*(1), 6818. https://doi.org/10.1038/s41598-024-57426-y

Monroy-Sosa, A., Chakravarthi, S. S., Cortes-Contreras, A. P., Hernandez-Varela, M., Andres-Arrieta, V., Epping, A., & Rovin, R. A. (2021). The evolution of cerebral language localization: historical analysis and current trends. *World Neurosurgery*, *145*, 89-97. https://doi.org/10.1016/j.wneu.2020.09.028

Morgan-Short, K., Deng, Z., Brill-Schuetz, K. A., Faretta-Stutenberg, M., Wong, P. C., & Wong, F. C. (2015). A view of the neural representation of second language syntax through artificial language learning under implicit contexts of exposure. *Studies in Second Language Acquisition*, *37*(2), 383-419. https://doi.org/10.1017/S0272263115000030

Mueller, J. L. (2009). The influence of lexical familiarity on ERP responses during sentence comprehension in language learners. *Second Language Research*, *25*(1), 43-76. https://doi.org/10.1177/0267658308098996

Mulder, E., Van de Ven, M., Segers, E., & Verhoeven, L. (2019). Context, word, and student predictors in second language vocabulary learning. Applied Psycholinguistics, 40(1), 137-166. https://doi.org/10.1017/S0142716418000504

Mϋnte, T. F., Altenmϋller, E., & Jäncke, L. (2002). The musician's brain as a model of neuroplasticity. *Nature Reviews Neuroscience*, *3*, 473–478. https://doi.org/10.1038/nrn843

Nakagawa, E., Koike, T., Sumiya, M., Shimada, K., Makita, K., Yoshida, H., ... & Sadato, N. (2022). The Neural Correlates of Semantic and Grammatical Encoding During Sentence Production in a Second Language: Evidence From an fMRI Study Using Structural Priming. *Frontiers in Human Neuroscience*, *15*, 753245. https://doi.org/10.3389/fnhum.2021.753245

Osterhout, L., Poliakov, A., Inoue, K., McLaughlin, J., Valentine, G., Pitkanen, I., ... & 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

Pinel, P., & Dehaene, S. (2010). Beyond hemispheric dominance: brain regions underlying the joint lateralization of language and arithmetic to the left hemisphere. *Journal of Cognitive Neuroscience*, *22*(1), 48-66. https://doi.org/10.1162/jocn.2009.21184

Pu, P., Chang, D. Y. S., & Wang, S. (2024). Incidental learning of collocations through different multimodal input: The role of learners' initial L2 proficiency. *System*, *125*, 103416. https://doi.org/10.1016/j.system.2024.103416

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*. https://doi.org/10.1136/bmj.n71

Parviainen, T., & Kujala, J. (2023). Event-Related Potentials (ERPs) and Event-Related Fields (ERFs). In *Language Electrified: Principles, Methods, and Future Perspectives of Investigation* (pp. 195-239). New York, NY: Springer US.

Perkins, K., & Zhang, L. J. (2024). The Effect of First Language Transfer on Second Language Acquisition and Learning: From Contrastive Analysis to Contemporary Neuroimaging. *RELC Journal*, *55*(1), 162-178. https://doi.org/10.1177/00336882221081894

Perpiñán, S. (2015). L2 grammar and L2 processing in the acquisition of Spanish prepositional relative clauses. *Bilingualism: Language and Cognition*, *18*(4), 577-596. https://doi.org/10.1017/S1366728914000583

Perret, M., Neige, C., Brunelin, J., & Mondino, M. (2024). Unraveling the brain mechanisms of source monitoring with non-invasive brain stimulation: A systematic review. *International Journal of Clinical and Health Psychology*, *24*(2), 100449. https://doi.org/10.1016/j.ijchp.2024.100449

Piller, I., & Bodis, A. (2024). Marking and unmarking the (non) native speaker through English language proficiency requirements for university admission. *Language in Society*, *53*(1), 1-23. https://doi.org/10.1017/S0047404522000689

Provost, S., Fourdain, S., Vannasing, P., Tremblay, J., Roger, K., Caron-Desrochers, L., ... & Gallagher, A. (2024). Language brain responses and neurodevelopmental outcome in preschoolers with congenital heart disease: A fNIRS study. *Neuropsychologia*, 108843. https://doi.org/10.1016/j.neuropsychologia.2024.108843

Pu, H., Holcomb, P. J., & Midgley, K. J. (2016). Neural changes underlying early stages of L2 vocabulary acquisition. *Journal of Neurolinguistics*, *40*, 55-65. https://doi.org/10.1016/j.jneuroling.2014.09.004

Quin-Conroy, J. E., Bayliss, D. M., Daniell, S. G., & Badcock, N. A. (2024). Patterns of language and visuospatial functional lateralization and cognitive ability: a systematic review. *Laterality*, *29*(1), 63-96. https://doi.org/10.1080/1357650X.2023.2263199

Raichle, M. E. (2009). A brief history of human brain mapping. *Trends in neurosciences*, *32*(2), 118-126. https://doi.org/10.1016/j.tins.2008.11.001

Rajimehr, R., Firoozi, A., Rafipoor, H., Abbasi, N., & Duncan, J. (2022). Complementary hemispheric lateralization of language and social processing in the human brain. *Cell Reports*, *41*(6). https://doi.org/10.1016/j.celrep.2022.111617

Rastelli, S. (2018). Neurolinguistics and second language teaching: A view from the crossroads. *Second Language Research*, *34*(1), 103-123. https://doi.org/10.1177/0267658316681377

Reber, P. J. (2013). The neural basis of implicit learning and memory: a review of neuropsychological and neuroimaging research. *Neuropsychologia*, *51*(10), 2026-2042. https://doi.org/10.1016/j.neuropsychologia.2013.06.019

*Reiterer, S., Pereda, E., & Bhattacharya, J. (2009). Measuring second language proficiency with EEG synchronization: how functional cortical networks and hemispheric involvement differ as a function of proficiency level in second language speakers. *Second Language Research*, *25*(1), 77-106. https://doi.org/10.1177/0267658308098997

Roberts, L., & Siyanova-Chanturia, A. (2013). Using eye-tracking to investigate topics in L2 acquisition and L2 processing. *Studies in Second Language Acquisition*, *35*(2), 213-235. https://doi.org/10.1017/S0272263112000861

Rosselli, M., Ardila, A., Matute, E., & Vélez-Uribe, I. (2014). Language development across the life span: A neuropsychological/neuroimaging perspective. *Neuroscience Journal*, *2014*(1), 585237. https://doi.org/10.1155/2014/585237

Russo, C., & Senese, V. P. (2023). Functional near infrared spectroscopy is a useful tool for multi perspective psychobiological study of neurophysiological correlates of parenting behaviour. *European Journal of Neuroscience*, *57*(2), 258-284. https://doi.org/10.1111/ejn.15890

Sabourin, L. (2009). Neuroimaging and research into second language acquisition. *Second Language Research*, *25*(1), 5-11. https://doi.org/10.1177/0267658308098994

Saldana, J. (2015). *The coding manual for qualitative researchers* (3rd ed). Sage Publications.

Savoy, R. L. (2001). History and future directions of human brain mapping and functional neuroimaging. *Acta Psychologica*, *107*(1-3), 9-42. https://doi.org/10.1016/s0001-6918(01)00018-x

Schlaggar, B. L., & Church, J. A. (2009). Functional neuroimaging insights into the development of skilled reading. *Current Directions in Psychological Science*, *18*(1), 21-26. https://doi.org/10.1111/j.1467-8721.2009.01599.x

Schiavo, J. H. (2019). PROSPERO: an international register of systematic review protocols. *Medical reference services quarterly*, *38*(2), 171-180. https://doi.org/10.1080/02763869.2019.1588072

Shaheen, N., Shaheen, A., Ramadan, A., Hefnawy, M. T., Ramadan, A., Ibrahim, I. A., ... & Flouty, O. (2023). Appraising systematic reviews: a comprehensive guide to ensuring validity and reliability. *Frontiers in research metrics and analytics*, *8*, 1268045. https://doi.org/10.3389/frma.2023.1268045

Sharma, R., & Meena, H. K. (2024). Emerging Trends in EEG Signal Processing: A Systematic Review. *SN Computer Science*, *5*(4), 1-14. https://doi.org/10.1007/s42979-024-02773-w

Sullivan, M. D., Janus, M., Moreno, S., Astheimer, L., & Bialystok, E. (2014). Early stage second-language learning improves executive control: Evidence from ERP. *Brain and language*, *139*, 84-98. https://doi.org/10.1016/j.bandl.2014.10.004

Sulpizio, S., Del Maschio, N., Fedeli, D., & Abutalebi, J. (2020). Bilingual language processing: A meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *108*, 834-853. https://doi.org/10.1016/j.neubiorev.2019.12.014

Svaldi, C., Paquier, P., Keulen, S., van Elp, H., Catsman-Berrevoets, C., Kingma, A., ... & de Aguiar, V. (2024). Characterising the long-term language impairments of children following cerebellar tumour surgery by extracting psycholinguistic properties from spontaneous language. *The Cerebellum*, *23*(2), 523-544. https://doi.org/10.1007/s12311-023-01563-z

Tao, L., Wang, G., Zhu, M., & Cai, Q. (2021). Bilingualism and domain-general cognitive functions from a neural perspective: A systematic review. *Neuroscience & Biobehavioral Reviews*, *125*, 264-295. https://doi.org/10.1016/j.neubiorev.2021.02.029

Van Atteveldt, N., Van Kesteren, M. T., Braams, B., & Krabbendam, L. (2018). Neuroimaging of learning and development: improving ecological validity. *Frontline Learning Research*, *6*(3), 186. https://doi.org/10.14786/flr.v6i3.366

Von Rhein, D., Mennes, M., van Ewijk, H., Groenman, A. P., Zwiers, M. P., Oosterlaan, J., ... & Buitelaar, J. (2015). The NeuroIMAGE study: a prospective phenotypic, cognitive, genetic and MRI study in children with attention-deficit/hyperactivity disorder. Design and descriptives. *European child & adolescent psychiatry*, *24*, 265-281. https://doi.org/10.1007/s00787-014-0573-4

Wang, R., Ke, S., Zhang, Q., Zhou, K., Li, P., & Yang, J. (2020). Functional and structural neuroplasticity associated with second language proficiency: An MRI study of Chinese-English bilinguals. *Journal of Neurolinguistics*, *56*, 100940. https://doi.org/10.1016/j.jneuroling.2020.100940

*Wang, Y., Xue, G., Chen, C., Xue, F., & Dong, Q. (2007). Neural bases of asymmetric language switching in second-language learners: An ER-fMRI study. *NeuroImage*, *35*(2), 862-870. https://doi.org/10.1016/j.neuroimage.2006.09.054

Ware, C., Dautricourt, S., Gonneaud, J., & Chételat, G. (2021). Does second language learning promote neuroplasticity in aging? A systematic review of cognitive and neuroimaging studies. *Frontiers in Aging Neuroscience*, *13*, 706672. https://doi.org/10.3389/fnagi.2021.706672

Whelan, R. R. (2007). Neuroimaging of cognitive load in instructional multimedia. *Educational Research Review*, *2*(1), 1-12. https://doi.org/10.1016/j.edurev.2006.11.001

Wischmann, S., Kamper, N. R., Jantzen, L., Hammer, L., Reipur, D. B., Serafin, S., & Percy-Smith, L. (2024). Explaining neurological factors of hearing loss through digital technologies. *International Journal of Pediatric Otorhinolaryngology*, *176*, 111825. https://doi.org/10.1016/j.ijporl.2023.111825

*Xu, X., Pan, M., Dai, H., Zhang, H., & Lu, Y. (2019). How referential uncertainty is modulated by conjunctions: ERP evidence from advanced Chinese–English L2 learners and English L1 speakers. *Second Language Research*, *35*(2), 195-224. https://doi.org/10.1177/0267658318756948

*Yang, J., Gates, K. M., Molenaar, P., & Li, P. (2015). Neural changes underlying successful second language word learning: An fMRI study. *Journal of Neurolinguistics*, *33*, 29-49. http://dx.doi.org/10.1016/j.jneuroling.2014.09.004

Yongqi Gu, P. (2016). Questionnaires in language teaching research. *Language Teaching Research, 20*(5), 567-570. https://doi.org/10.1177/1362168816664001

Zhang, X., Yang, J., Wang, R., & Li, P. (2020). A neuroimaging study of semantic representation in first and second languages. *Language, Cognition and Neuroscience*, *35*(10), 1223-1238. https://doi.org/10.1080/23273798.2020.1738509

Zhang, Y., Zhao, J., Huang, H., Zhang, Z., Wu, S., Qiu, J., & Wu, Y. J. (2024). Neuroimaging evidence dissociates forced and free language selection during bilingual speech production. *Bilingualism: Language and Cognition*, 1-10. https://doi.org/10.1017/S1366728924000324

Zheng, Y., & Zhang, B. (2024). 25-year neuroimaging research on spoken language processing: a bibliometric analysis. *Frontiers in Human Neuroscience*, *18*, 1461505. https://doi.org/10.3389/fnhum.2024.1461505

پژوهشگاه علوم انسانی و مطالعات فرهنگی
پرتال جامع علوم انسانی

8. Appendices

8.1. Appendix A

Characteristics of included studies

Author (year)	Country	Participants	Number of males	Number of females	Age (mean)	Main goals of the study	Evaluation Tools	Instruments
Reiterer et al., (2009)	DenmarkAustria and UK	University Student (English students and other fields)	19	0	24	Proficiency in speaking	EEG, Questionaries	spoken auditory speech input, short interviews, Comprehension questionnaire
Barbeau et al. (2017)	Canada and UK	Adults' French learners	NM (Total=14)	NM (Total=14)	NM	Neural changes during language learning	FMRI, Questionaries	Self-reported language competence, Language Expertise and Proficiency Questionnaire (LEAP-Q).
Grant et al., (2015)	USA	Late L2 Spanish learners	NM (Total=24)	NM (Total=24)	NM	Investigating individual differences in cognitive control and lexical architecture among late-L2 learners.	FMRI, Individual differences measure, working memory measure	Lexical decision task, semantic judgement task, Spanish proficiency test
Yang et al., (2015)	China and USA	American University student's learning Chinese as L2	19	20	NM	An fMRI scan was used to analyze the neural mechanisms contributing to tonal language learning in adult L2 learners prior to and following instruction.	FMRI	Stimuli and training tasks, vocabulary instruction
Sullivan et al., (2014)	Canada and USA	University students Spanish L2 learners	NM (Total=54)	NM (Total=54)	24.5	The study aimed to determine the emergence of neural processing modifications relevant to L2 learning during developmental stages.	ERP, questionary, test	Verbal fluency tasks, social background questionnaire, Peabody Picture Vocabulary Test, Kaufman Brief Intelligence Test
Midgley et al., (2011)	France	French L2 learners	9	33	20	An investigation was conducted to determine how cognate position affects word perception in L2 learners.	ERP	Cognate and non-cognate words.
Mueller, (2009)	Germany	Japanese L2 Learners	10	11	23.9	The purpose of this study is to examine ERP elements in adult language learners with respect to syntactic and thematic procedures.	ERP	Mini-Nihongo grammar game.
Liu,, et al., (2021)	China and Poland	University students	2	18	18.52	Language control processing and cognitive control	FMRI, Questionaries Oxford placement test	Language switching tasks
Liu et al., (2021)	China and UK	Pre-school students	2	20	18.25	Children's cognitive flexibility and creativity	FMRI, Questionaries Oxford placement test	Color shape switching tasks, Self-rated questionaries
Choi et al., (2018)	Korea	English learners	9	14	22.43	Examine the changes in brain activity and connectivity before and after exposure to VR	FMRI, English for International Communication (TOEIC), Nelson-Denny Reading Test (NDRT)	Super Lab programme, 40 trials of two conditions: lower-case trials and upper-case trials,
Buchweitz, et al. (2009)	USA and Japan	Native Japanese (L1) readers and English as a second language (L2) reader	NM (Total=9)	NM (Total=9)	27.4	The brain responds differently to different writing systems and reading comprehension in a second language	FMRI, Language background questionnaire	Edinburgh Inventory, Comprehension task, Two-clause target sentences

Wang et al., (2007)	USA and China	Later English learners	6	6	19.5	Examine neurocognitive models of lexical selection	ERP	Experimental tasks, self-rated language proficiency
Nakagawa et al., (2022)	Japan	English learners	14	16	22.7	Consideration should be given to the interaction between conceptualization and articulation as well as the automated nature of grammatical encoding.	FMRI	Cartoons, sentence fragment, stimuli from the actual experiment
Koyama et al., (2014)	UK and USA	Late L2 English learners	13	32	29.3	Studying the degree to which bilingual individuals, particularly late L2 learners, display functional lateralization in first and second language processing. The purpose of this research is to examine brain activation patterns during reading tasks in L1 and L2 languages.	FMRI, Wide Range Achievement Test III, Annett Handedness Questionnaire	Block design with alternating task, visual one-back matching task, Raven's Advanced Progressive Matrices
Du et al., (2023)	China	Late L2 English learners	24	15	24.3	This study examined whether learning skills specific to L2 reading could help learners overcome the limitations imposed by their native language.	ERP, The grammar subtest of the Oxford Placement Test, EEG recording	English word-reading. A total of 200 words were selected from China's national curriculum for college English.
Dallas et al., (2013)	USA	Late L2 English learners	12	27	24.5	Investigate the real-time processing of filler-gap dependency sentences by late-learning speakers of English as a second language (L2).	Shipley Vocabulary Test, Wechsler Adult Intelligence Scale (WAIS), EEG recording	E-prime experimental software, the sentence processing task, presentation list contained 60 experimental sentences.
Midgley et al., (2009)	USA France	L2 English Learners	4	32	20.3	Analyze the time sequence in which form and meaning are perceived during word recognition, along with the role played by semantic representations. Researchers will be able to gain a deeper understanding of how these elements are activated as a result.	ERP masked repetition priming, EEG recording, EEG recording, Questionnaire	within- and cross-language primes, Visual stimuli
Elgort et al., (2015)	New Zealand USA	L2 English learners	NM (Total=26)	NM (Total=26)	NM	A study was conducted to examine the impact of accidental situational L2 word learning on lexical competence in L2.	Vocabulary Size Test, FMRI, ERP	L2 lexical proficiency, including key words in three sentences with high constraint levels.
Xu et al., (2019)	China	Both native (L1) readers and second language (L2) readers	NM (Total=49)	NM (Total=49)	NM	Analyze how native and non-native speakers interpret ambiguous pronouns with different conjunctions	ERP	60 two clause filler items, stimuli included protagonists while the other included only protagonists (equally for male and females)

8.2. Appendix B

Outcomes of included articles

Author (year)	Authors conclusion	Statistically significant	Outcomes			Limitations
			Positive	No difference	Negative	
Reiterer et al., (2009)	In the low proficiency group, the right hemisphere is more involved, especially in the L2, than in the superior performance group.	Yes		Based on other psychological indicators (self-reported attention, work load, sympathy for the speaker, and interest in the topic), no significant differences were found between the two groups.	A negative relationship is generally observed between proficiency level and synchronization density.	NM
Barbeau et al. (2017)	It was found that increased involvement of the left IPL was correlated with improved L2 function.	Yes	Reading, speaking, and comprehension skills in L2 were significantly improved in trainees.			Participants in this study were limited to a small number of adults.
Grant et al., (2015)	The neural processes involved in L2 lexical generation become increasingly similar to those involved in native language lexical generation with continued exposure.	Yes	An examination of the role of cognitive control in L2 learning and conceptual frameworks for lexical representation by late L2 learners.			It is impossible to continuously observe the evolution of lexical computation structures.
Yang et al., (2015)	It was demonstrated in the study that competent L2 participants exhibited decreased brain activity in specific brain areas following training, demonstrating improved language learning capacity.	Yes	Improved neural function for language use and argument clarification in proficient learners, indicating enhanced competence.			Inadequate focus on sound distinction competence prior to instruction, which may affect behavioral performance.
Sullivan et al., (2014)	After brief instruction in L2, significant changes were observed in neural activities related to contrasting tasks.	Yes	Spanish learners exhibited modifications in task execution after instruction.		Electrophysiological changes were not preceded by behavioral changes.	There is a shortage of bilingual students and a focus on L2 learning's initial phases.
Midgley et al., (2011)	The N400 magnitudes of cognate words in both L1 and L2 languages were lower compared with those of noncognates.	Yes	Increasing comprehension of how cognate identity affects word perception in L2 trainees.		Restricted generalization due to particular participant characteristics and language mixtures.	Limited to L1 English trainees of French, consequently restricting broader usability.
Mueller, (2009)	Word classification problems resulted in an initial failure accompanied by a P600 in commonly used sentences.	Yes	During training, trainees demonstrated a native-like understanding of well-known sentences.		Unknown words led to greater computational requirements and difficulties in data manipulation.	Differentiations among individuals may have different effects.
Liu, et al., (2021)	A long-term study of language in a classroom modulates the resting-state connectivity of the language control network, suggesting neural adaptations due to language learning.	Yes	The resting-state connectivity of the language control network is modulated by language learning, suggesting that neural adaptations are involved in this process.			In the process of language control, cognitive control plays an important role.
Liu et al., (2021)	In areas responsible for language control, long periods of classroom instruction in L2 can induce significant neuroplastic changes.	Yes	Learning L2 in the classroom significantly increased the connectivity between the dACC and LCN, and this increase was significantly correlated with behavioral language improvement switching cost		In the post-learning session, the language switch cost was significantly lower than in the pre-learning session.	A majority of the participants in the study were female, which may limit the generalizability of the results.
Choi et al., (2018)	According to the findings, uppercase text reduces reading comprehension	Yes	provide the		There was a negative effect of upper-case text on the reading	While the lower-case text set resulted in statistically significantly

	because it demands readers to use more lower-order neurocognitive resources.		first neurocognitive evidence with regard to the automaticity theory		comprehension of L2 learners, which is consistent with studies involving L1 learners.	higher response accuracy and shorter reaction times than the upper-case text set, the computed effect sizes were small.
Buchweitz et al., (2009)	Studies have demonstrated that cognitive responses can differ when processing at the sentence level within a given language, even if processing at the word level is used.	Yes	The reading comprehension of L2 was significantly more time-consuming than that of L1.			Based on the results, the L2 is systematically activated in relation to the L1 writing systems.
Wang et al., (2007)	Language switching exhibits different neural correlates depending on the direction of the switch, and no specific brain region appears to serve as a "language switch".	Yes	A comparison of the brain regions activated by forward switching compared to backward switching.			NM
Nakagawa et al., (2022)	As a result of the overload on the linguistic operation of formulating sentences and its associated executive function, it is difficult to form sentences in L2.	Yes	This study examined the process of speech production, particularly the stages of conceptualization, formulation, and articulation			Data from L1 English speakers were not included in the current study.
Koyama et al., (2014)	L2 readers are more likely to engage in visuo-spatial processing in the right hemisphere as a result of weaker leftward lateralization, rather than as a result of additional effort exhibited by the right hemisphere.	Yes	In word reading tests, there were varying accuracy scores between the L1 and L2 groups, indicating differences in cognitive performance			NM
Du et al., (2023)	If adults are trained in critical skills for reading a second language at appropriate dosages, they may be able to learn the skill of reading with native-like neural responses.	Yes	The findings of this study demonstrate that only short-term intensive and appropriate instruction specific to English letters and sound connections is effective in altering the neural responses of second-language learners.			Training benefits were not examined in this study for a period of time.
Dallas et al., 2013)	The L2 group did not process filler gap sentences in the same manner as the L1 group.	Yes	Speakers of second languages (L2) demonstrate a similar sensitivity to plausibility variations to speakers of first languages (L1).	A more native-like processing of filler-gap constructions was not associated with working memory.	Filler-gap sentences are not sensitive to plausibility variations among L2 speakers	NM
Midgley et al., (2009)	Form representations of non-cognate translation equivalents are intensively processed by L2 learners during on-going form-level processing of printed words, without any facilitative interaction between form equivalents.	Yes	There were significant interactions between repetition and the between-hemisphere language condition.	The interaction between repetition and priming type		NM
Elgort et al., (2015)	Newly learned L2 words can be recognized based both on episodic and lexical semantic knowledge. Depending on the learner's lexical proficiency in L2 and the context in which the word is used, it may vary.	Yes	In order to compensate for the lower processing efficiency of the pre-frontal cortex, bilinguals with lower proficiency engage the pre-frontal cortex when processing L2 words	Relatedness and proficiency did not interact		NM
Xu et al., (2019)	There is a greater likelihood of referential uncertainty for non-native speakers in sentences conjoined by conjunctions with complex semantics.	Yes	The effect of pronouns with conjunctions, such as "although," was greater for native speakers than for non-native speakers.		Referential uncertainty is more likely to occur when sentences are conjoined by conjunctions with complex semantics	NM