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LINGUISTICS | REVIEW ARTICLE

Neurolinguistics: A scientometric review

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Abstract: This scientometric study aimed to map the knowledge domains of neurolinguistics, an interdisciplinary field of linguistics, to provide a comprehensive understanding of the development process and structural relationships of scientific knowledge in neuroscience. A total of 5,104 neurolinguistics documents published between 1913 and 2022 were analysed and visualized from three databases, Scopus, WOS, and Lens, using CiteSpace 5.8.R3 and VOSviewer 1.6.18. Knowledge production was mapped by country, university, journal, publisher, research field, and author, and examined using scientometric indicators, including co-citation networks, citation networks, sigma metrics, and clusters of topics. The identified clusters include discourse processing of flexible word order language language-ready brain, and language talent in cultural neurolinguistics; object knowledge of agrammatic aphasia; early experience of cerebral localization; language in autism spectrum disorder; and language evolution in relation to cognitive adequacy in language-ready brain. This study provides valuable insights into the field of neurolinguistics and offers a visual representation of the development process of scientific knowledge in neuroscience.

Subjects: Cognitive Neuroscience of Language; Applied Linguistics

Keywords: neurolinguistics; right hemisphere role; left hemisphere role; language disorders; speech disorder; acquired aphasia; developmental dysphasia; scientometric review

1. Introduction

1.1. The rise of neurolinguistics

Modern neurolinguistics emerged in the 1960s by combining the principles of cognitive neuroscience and linguistics at that time, which were particularly influenced by ideas and methods of previous, mostly medical disciplines such as aphasiology (Mancing & Marston, 2022).

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Aphasiology—the study of language and speech disorders caused by brain damage—is still an important part of neurolinguistics today (Caplan, 2001). However, although neurolinguistics as a separate scientific discipline can only be considered from the middle of the 20th century onwards, researchers have been interested in the relationship between language and the brain for five millennia (Alduais, 2013; H. A. Whitaker, 1998).

One of the earliest documents mentioning the relationship between language and the brain is called the *Edwin Smith Papyrus*. It comes from ancient Egypt and dates from around 1700 BC. BC, although it is believed that its original is up to five thousand years old (Alduais, 2013; P. Eling, 2015). Many centuries later, the ancient Greeks considered language to be part of the human general knowledge and memory. Accordingly, information or knowledge was considered only a particular form of memory, language and speech disorders that can be called aphasia today were then interpreted as partial memory loss (P. Eling, 2015). The Greek physician Hippocrates (460–370 BC) described a patient who had lost "memory for letters" and noted that speech disorders were often accompanied by paralysis of the part of the body opposite to the side of the brain damage (LaPointe, 2013).

Aristotle- much like the ancient Egyptians—also advocated a cardiocentric view of the human mind. Although Aristotle's localization of mental abilities proved to be wrong, his theory of mind and memory was very influential for an exceptionally long time and was based on the so-called *laws of association*. Also, he was familiar with several types of speech disorders (Ahlsén, 2006; P. Eling, 2015). Shortly after Aristotle, Herophilus developed his ventricular theory of brain function (Mildner & Liker, 2008 . Ventricular theory was the dominant model of brain functioning during the late Old Age and during the Middle Ages, until the 17th century (H. A. Whitaker, 2006).

The version of ventricular theory that was dominant during the Middle Ages is now called the Medieval Cell Doctrine (H. A. Whitaker, 1998). From the 11th century onwards, there were reports of language-related neurophysiological disorders that were interpreted in accordance with medieval doctrine. For example, Guillaume de Conches reported on a soldier who suffered an injury to the back of the head, which caused amnesia due to which the man was unable to remember his name or the names of his acquaintances. The medieval doctrine lasted through the Renaissance until the 17th century, when most of its claims were challenged by theoretical and experimental arguments (H. A. Whitaker, 2006).

During the Renaissance (15th and 16th centuries), connections between language or speech disorders and specific injuries evident in the brain were created for the first time. Then there was a shift in medical theory and practice, a transition from speculative and descriptive approaches that relied on classical texts to "analysis of mental functions in relation to the brain" (P. Eling, 2015, p. 681). Neurophysiological research continued to be conducted on such Renaissance foundations in the 17th and 18th centuries (H. A. Whitaker, 2006).

Two cases from the 17th century contributed significantly to the development of neurolinguistics, primarily because they brought the accuracy of the analysis to a previously un-achieved level. Johann Schmidt writes about a patient who often replaces and mixes words, who does not recognize letters and cannot read, but who can write when dictated to him. This case was analysed by Peter Rommel in the text *De aphonia rara* believing Rommel's observation to be "a nicely described dissociation between voluntary and automatic speech" (H. Eling & W, 2010, p. 572), which is the first time that this dissociation has been recognized at all. The Swiss physician Johannes Jakob Wepfer in his work *Observationes Medico-practicae de Affectibus Capitis Internis & Externis* (dated approximately 1690, but posthumously published only in 1727) under case no. 98, entitled "Loss of Memory", writes in detail about transient language disorders that include anomia (inability to remember) and syntactic agrammatism (H. Eling & W, 2010 . Wepfer was one of the first physicians to associate language disorders with damage to the left side of the brain (H. A. Whitaker, 2006).

Advances in experimental brain research and in the study of speech pathology led to the replacement of medieval cell doctrine by localizing certain functions in certain parts of the brain, although imprecise and general. Such research and their improvement marked the 18th century (H. A. Whitaker, 2006). In the text *De sedibus et causis morborum per anatomen indagatis*, Giovanni Battista Morgagni lists several cases of speechlessness/muteness associated with apoplexy and head trauma. Morgagni, like Wepfer, observed that speech disorders were associated with paralysis of the right side of the body and injury to the left hemisphere (H. Eling & W, 2010). The first extensive work dedicated to the topic of aphasia was the chapter of *Die Sprach-mnesie* in the book *Samlung von Beobachtungen aus der Arzneygelahrtheit* by Johann Gesner (H. Eling & W, 2010). Gesner's interpretation was one of the earliest attempts to give aphasia a functional explanation (P. Eling, 2015). In addition, Gesner's ideas are the first case of interpreting the functioning of the mind using the *theory of association* (*associationism*) (Ahlsén, 2006).

At the end of the 18th century, the idea of discrete localization of functions in the brain was prevailed in medicine, which, among others, was significantly advocated by the French philosopher *Étienne Bonnot de Condillac* as part of his philosophy of mind (Bouton, 1991). Most of the language or speech disorders known today were by then if not already explained, then at least recognized, and theories about the association of these disorders with certain brain damage were continuously increasing (H. Eling & W, 2010).

In the 19th century, there was a significant shift in the study of the relationship between language and the brain. The German physician Franz Joseph Gall studied the relationship between human nature and the brain, postulating the claim that mental functions are innate and localized in parts of the brain. Gall believed that evidence for the existence of mental organs in the brain could be collected by studying and measuring the indentations and bumps on the surface of the brain. This approach to the study of the skull was first called *craniology*, later known as *phrenology*. Although abandoned at the end of the 19th century, it marked the research of the mind and brain in the first half of the 19th century and made a significant contribution to the development of neuropsychology. The phrenological theory was inspired by the Scottish doctor Alexander Hood, who in 1824 published in the journal *The Phrenological Journal and Miscellany* a very detailed description of a case in which patient Adam M'Conochie fell ill due to a stroke in his left frontal lobe, which was known in the late 19th century as Broca's aphasia (H. A. Whitaker, 2006).

According to Gallo, the critical attitude was taken by the French doctor Pierre Flourens, who claimed that the brain (i.e., its surface part, the cortex) functions (H. A. Whitaker, 2006; Mildner & Liker, 2008). On the other hand, the cardiologist Jean-Baptiste Bouillaud attempted to defend the localist theory by presenting several cases in which speech disorders were associated with frontal lobe damage. In addition, he distinguished speech disorders from word memory disorders, thus anticipating to some extent the difference between Broca and Wernicke's aphasias that were discovered in the second half of the 19th century (H. A. Whitaker, 2006).

At the end of the first half of the 19th century, progress in research into the relationship between language and the brain was made in two respects. First, it was clear what aspect of language should be localized, obviously due to the different clinical observations of language disorders. Second, because of the advances in the study of mental functions and their association with certain parts of the brain, it became clear where to localize (Ahlsén, 2006).

In the second half of the 19th century, Gall's phrenological theory began to lose its importance, but his theory of the localization of mental functions in the brain became more dominant. An important confirmation for the localization of mental functions was presented by the French doctor and anthropologist Paul Pierre Broca who performed autopsies on a number of people who had speech problems and discovered that most of them had brain damage (or lesions) on the left frontal lobe, in an area known today as *Broca's area*. Phrenologists claimed in the early nineteenth century that different areas of the brain performed distinct functions and that language was primarily controlled by the frontal areas of the brain, but Broca's research was likely the first to provide empirical evidence for this relationship (Dronkers et al., 2007; H. A. Whitaker, 2006; LaPointe, 2013).

The German doctor Carl Wernicke took the next significant step in the development of nineteenth-century neurolinguistics. He discovered that there are cases in which the ability to understand speech is impaired due to brain damage. The area for speech comprehension (*Wernicke's area)* is located at the temporal lobe (usually left) hemisphere of the brain. Damage to that part of the brain leads to *Wernicke's aphasia*, a disorder in which speech is fluent and grammatical but meaningless, and comprehension of meaningful speech is impaired (H. A. Whitaker, 1998).

The twentieth century was marked by the rapid development of theories and experimental methods for researching the relationship between language and brain, along with the emergence of neurolinguistics in the 1960s as an interdisciplinary field drawing on theory and research from linguistics and neuroscience. Also, significant efforts were made to localize language in the brain (Goodglass, 1998). In his work *Aphasia and Kindred Disorders of Speech* (1926), The English neurologist Henry Head associates the appearance of aphasia with an intelligence disorder and distinguishes between verbal, syntactic, nominal, and semantic aphasia (P. Eling, 2006). In his famous article *The third frontal lobe plays no special role in the function of language* (1906), the French neurologist Pierre Marie, a supporter of the holistic approach, claims that aphasia is caused by a lack of general intelligence, and that the third frontal lobe plays no role in language function. Proponents of more holistic views of aphasia such as the German psychiatrist Kurt Goldstein, later supported the idea that Broca's aphasia could not be associated with localized brain damage (P. Eling, 2006).

A significant contribution to neurolinguistics—as part of the localist approach—was made by the German neurologist Korbinian Brodmann, who created a "map" of the brain surface, dividing the brain into areas according to its cellular structure and functions. These fifty or so areas are therefore called Brodmann areas, and they are still in use today (Amunts, 2008).

By the end of the first half of the twentieth century, research methods in what became known as neurolinguistics in the 1960s progressed in two directions. On the one hand, there have been ongoing efforts to investigate, describe, and distinguish various developmental and acquired language and speech disorders (aphasias). On the other hand, attempts have been made to link these disorders to specific areas of the brain, primarily based on postmortem studies of brain damage (Caplan, 2001; P. Eling, 2015). For these two closely related research areas, Eric Lenneberg coined the term *aphasiology* in 1960. However, the term *neurolinguistics* was introduced in the late 1940s and early 1950s by Edith Crowell Trager, Henri Hecaen, and Alexandr Luria. Later in the 1970s, neurolinguistics was introduced and made popular in the United States by Harry Whitaker who founded the journal "Brain and Language" in 1974 (P. Eling, 2006; Peng, 1985).

This interdisciplinary field as a separate science has two origins: Russian and American. Lev Vygotsky inspired a series of psycholinguistic and neurolinguistic studies with his book *Thinking and Speech* (1934) in which he explored the relationship between the conceptual level of language and the realization of language through speech (Caplan, 2001; P. Eling, 2015). Prominent Russian neuropsychologist Alexander Luria (1902–1977), inspired by such research, applied the principles of Vygotsky's principles in clinical settings. His vast experience with patients with brain damage has allowed him to create his famous model of brain function. Based on this model, language is a controlling mechanism for human behaviour. Roman Jakobson also dealt with neurolinguistic topics. Jakobson was primarily interested in children's language development and diverse types of aphasia, but he argued that aphasia should be studied within the framework of structural linguistics instead of within holistic and behavioural psychology (P. Eling, 2015).

In the United States, Norman Geschwind founded the Boston Department of Aphasia, where he researched behavioural neurology in the spirit of connectionism (Mildner & Liker, 2008; P. Eling, 2006). Neurolinguistics, among other things, was also indebted to the elaboration of Wernicke's earlier model of language; this new model was named the *Wernicke-Geschwind* model. Although outdated today, this model had a significant impact on neurolinguistic research at that time (Mildner & Liker, 2008).

In the late 1960s and 1970s, the first textbooks and journals dedicated exclusively to neurolinguistic topics began to appear, which marked the emancipation of neurolinguistics as a separate scientific discipline. Linguist Harry Whitaker launched, as an editor, the famous book series *Perspectives in Neurolinguistics and Psycholinguistics*, with 27 volumes. In 1974, he was one of the founders of the influential journal *Brain and Language* and edited the highly comprehensive neurolinguistic books *Handbook of Neurolinguistics* and *Handbook of the Neuroscience of Language*. In 1985, Fred Peng founded the *Journal of Neurolinguistics*, and Chris Code and David Muller started the journal *Aphasiology* in 1987 (P. Eling, 2015).

Since the 1970s, brain imaging methods applicable to living patients have been developed, such as electroencephalography, magnetoencephalography, functional magnetic resonance imaging, tomography, etc., which contributed to modern neurolinguistic cognition. An overview of modern neurolinguistic research methods is given by Stemmer and Whitaker (Stemmer & Whitaker, 1998) and Ahlsen (Ahlsén, 2006). This is where the history of neurolinguistics ends somewhere, and its present begins.

1.2. The scope of neurolinguistics

Neurolinguistics is the study of the relationship between the human nervous system and language (Stavrakaki, 2005). In other words, neurolinguistics studies neural systems in the brain that control language acquisition, comprehension, and production. The main objective of the field of neurolinguistics is to understand and explain the neurological bases of language and speech, and to characterize the mechanisms and processes involved in the use of language (Nuessel, 2006). The study of neurolinguistics is broad; it includes language and speech disorders, aphasias in adults and in children, as well as reading disorders and lateralization of function with respect to language and speech processing (Aminoff et al., 2013; Stavrakaki, 2005).

Ongoing efforts in neurolinguistics research are focused on developing models that would be able to describe and explain how language is presented in the brain, how it is produced and how the brain controls processes such as speaking, listening, reading and writing (Goodglass, 1998). Neurolinguists are concerned with questions such as: What is so unique about humans that makes language learning possible—why is our communication system so complex and unique from that of other animals? Is it true that each language we speak is stored in a different area of our brain? Is the left side of the brain really specialized for language? How do we switch between languages? How do we keep them from interfering with each other? Do those who read left to right think differently than those who read from right to left? What about people who read using other symbols, like Chinese or Japanese? if we learn multiple languages from birth, how are our brains different from the brain of someone who speaks only one language? If we lose the ability to speak or read following a stroke, how effectively can we learn to speak again? What kind of therapy have been shown to be effective, and what new types of language therapy appear to be promising (Alduais, 2013)?

What disciplines should be considered in neurolinguistics? *Brain and Language* affirms that its interdisciplinary focus includes the fields of linguistics, neuroanatomy, neurology, neurophysiology, philosophy, psychology, psychiatry, speech therapy, and computer science. These disciplines are perhaps the most involved in neurolinguistics, but several other disciplines are also highly relevant, having contributed theories, methods, and findings in neurolinguistics. They include neurobiology, anthropology, chemistry, cognitive science, and artificial intelligence. Thus, the humanities, medical, natural and social sciences, as well as technology are all represented (Ahlsén, 2006; LaPointe, 2013).

Brain imaging techniques, for example, are used to study and better understand the brain in relation to language. We can see which brain areas are activated in certain oral and written language tasks, and see how electrical activity varies and depends on the task we are performing: listening to nouns, verbs, etc. (Papanicolaou et al., 2006).

The term *neurolinguist* was first associated with *aphasiology*. Gradually, however, neurolinguists became interested in other pathologies of language. Although aphasiology is the starting point of neurolinguistics, in recent years neurolinguists have focused on other areas. This is due to the contribution of new techniques for investigating the brain. These modern brain imaging techniques have contributed to a better understanding of the anatomical organization of language functions (Goodglass, 1998).

1.3. Purpose of the present study

Three decades ago, a review was conducted to sum up 30 years of research in neurolinguistics (Locke, 1992). However, this review, focused on developmental neurolinguistics, which according to the authors, focused on physiological aspects of speech, genetic origin of speech, nature of prelinguistic behaviour, development of motor speech, and the limiting influences of inefficient intelligence, hearing, and environment. Much research has been produced in neurolinguistics before and since then. Therefore, this scientometric review (SmR) includes published research from 1913 till 2022. Further, we considered data from different databases to ensure being more inclusive. These databases included Scopus, WOS, and Lens. To explore the state-of-art scholarship in neurolinguistics, we utilized science mapping approach (Chen, 2017) to identify and visualize current and emerging trends (X. X. Liu et al., 2013) and patterns in existing literature related to neurolinguistics (Chen et al., 2019).

This study aimed to guide the research by posing four main questions: (1) What is the extent of the corpus of knowledge in neurolinguistics from 1913 to 2022, as determined by the volume of scholarly output in each year, region, institution of higher education, source, publisher, field of study, and author? (2) Who are the most influential and central scholars in neurolinguistics during this period and which ones are expected to experience a rise in citation counts? (3) What are the most commonly searched terms for information on neurolinguistics? and (4) What are some of the most frequently studied topics and themes in neurolinguistics? These questions were designed to provide a comprehensive overview of the field's trends and contributions over the specified time frame.

2. Methods

2.1. Research methods

Scientometrics is the "study of artifacts; one examines not science and scholarship but the products of those activities" (Glänzel & Schoepflin, 1994, p. 491). The goal of scientometric research is to analyse "the quantitative aspects of the production, dissemination and use of scientific information with the aim of achieving a better understanding of the mechanisms of scientific research as a social activity" (Chellappandi & Vijayakumar, 2018, p. 6). As to whether scientometric studies can be used to evaluate the quality of research is an open question. In this regard, a previous research mentioned that "the task of determining quality papers is especially difficult in BIS [bibliometrics, informetrics and scientometrics] due to the very heterogeneous origin of the researchers" (Egghe, 1994, p. 390). However, the main objective of these studies is to "reveal characteristics of scientometric phenomena and processes in scientific research for more efficient management of science" (Parkinson, 2011, p. 1).

When conducting scientometric research, scientometric indicators are utilized to guide the evaluation. Indicators referring to elements (e.g., publication, citation and reference, potential, etc.) or type indicators are included (e.g., quantitative, impact) (Parkinson, 2011). Relevant to our examination is the concept "mapping knowledge domains." It pertains to the act of producing "an image that shows the development process and the structural relationship of scientific knowledge"—using maps that are "useful tools for tracking the frontiers of science and technology, facilitating knowledge management, and assisting scientific and technological decision-making" (Huang et al., 2021, 6201). In the past, scientometric studies have been restricted to the medical, health, applied, and pure sciences; however, recent research calls for the implementation of this method in all disciplines (Sooryamoorthy, 2020). This SmR investigates the field of neurolinguistics as an interdisciplinary linguistics field that integrates with other fields such as neurology, neuroscience, cognitive sciences, biology, physiology, and so on.

2.2. Measures

As previously stated, both bibliometric and scientometric studies are regarded as tools for guiding the assessment of produced knowledge in the chosen field/concept (e.g., neurolinguistics). Bibliometric indicators are commonly found in knowledge databases (e.g., Scopus, WOS, and Lens) (Birkle et al., 2020; Burnham, 2006; Penfold, 2020; Pranckutė, 2021). Typically, scientometric indicators are provided by scientometric software. For instance, in this SmR, we used CiteSpace 5.8. R3 (Chen, 2014)and VOSviewer 1.6.18 (van Eck & Waltman, 2022). The bibliometric and scientometric indicators used in this study are summarized in Table 1.

2.3. Data-collection and sample

Data was retrieved from three databases: Scopus, WOS, and Lens. There are a few reasons why these databases were added. First, in addition to being knowledge databases, Scopus and WOS also host sources that are included based on quality (Birkle et al., 2020; Burnham, 2006; Pranckutė, 2021). Second, Lens is regarded as being more thorough and containing information that the first two databases do not (Penfold, 2020).

We searched the data on Thursday, 17 March 2022. Providing that the title, abstract, and keywords are provided in English, we did not include any language restrictions. The results in other languages were scarce, so we manually verified this. The types of documents we considered were articles, review articles, book chapters, and books. Books was only activated in Lens as the analysis of retrieved books in CiteSpace was hindered. In Table 2, the search strings used in the three databases as well as the other specifications are listed.

Since our focus was on "neurolinguistics" and any related concepts, we restricted our keyword search to this aspect. In other words, we did not include specific search terms that could also be used within the field of neurolinguistics. For example, we did not use "Broca's aphasia" or "sentence processing". This was carried out for several reasons. First, we will limit our review to the most important aspects of neurolinguistics, omitting any subtopics or issues. Second, to avoid a cumbersome review. To identify the keywords synonymous to neurolinguistics, we conducted preliminary research on Google and Google Scholar. These included neurolinguistics (Lamendella, 1979), neuroscience of language (Stemmer & Whitaker, 2008), neurology of language (Brain, 1961), neurological linguistics (Crystal, 2008), neurophysiology of language (Hartwigsen, 2015), neurobiology of language (Hickok & Small, 2015), and brain and language or vice versa (Phillips & Sakai, 2005).

2.4. Data analysis

We followed a number of procedures prior to and during data analysis. First, Scopus data was exported in three formats: Excel sheets for bibliometric analysis, RIS for CiteSpace, and CSV for VOSviewer. The RIS file was converted to WOS format to comply with CiteSpace's requirements. Second, the data was retrieved from WOS in two formats: text documents converted to Excel sheets for bibliometric analysis, and plain text for CiteSpace and VOSviewer. Thirdly, data was extracted from Lens in two formats: CSV for the bibliometrics analysis and full record CSV for VOSviewer.

Table 1. Bibliometric and scientometric indicators for measuring the development of neurolinguistics

Element / **Indicator**	**Definition/specification/ retrieved data**	**Database/Software**		
		Scopus	**WOS**	**Lens**
Bibliometric				
Year	Production size by year	√	√	√
Country	Top countries publishing in the field	√	√	√
University	Top universities, research centres, etc.	√	√	√
Source	Top journals, book series, etc.	√	√	√
Publisher	Top publishers	X	√	√
Subject area	Top fields associated with the field	√	√	√
Author	Top authors publishing in the field	√	√	√
Citation	Top cited documents	√	√	√
Scientometric		**CiteSpace**	**VOSviewer**	
Betweenness centrality	A path between nodes and is achieved when located between two nodes (Freeman, 1979)	√	X	
Burst detection	Determines the frequency of a certain event in certain period (e.g., the frequent citation of a certain reference during a period of time) (Kleinberg, 2002)	√	X	
Co-citation	When two references are cited by a third reference (Chen, 2016). CiteSpace provides document co-citation network for references, and author co-citation network for authors. In VOSviewer, co-citation defined as “the relatedness of items is determined based on the number of times they are cited together” (van Eck & Waltman, 2022, p. 5). Units of analysis include cited authors, references, or sources.	√	√	
Silhouette	Used in cluster analysis to measure consistency of each cluster with its related nodes (Chen, 2014)	√	X	
Sigma	To measure strength of a node in terms of betweenness centrality citation burst (Chen, 2014)	√	X	
Clusters	“We can probably eyeball the visualized network and identify some prominent groupings” (Chen, 2014, p. 23).	√	√	

(*Continued*)

Scientometric		CiteSpace	VOSviewer
Citation	"The relatedness of items is determined based on the number of times they cite each other" (van Eck & Waltman, 2022, p. 5). Units of analysis include documents, sources, authors, organizations, or countries.	√	√
Keywords	CiteSpace provides co-occurring author keywords and keywords plus. In VOSviewer, co-occurrence analysis is defined as "the relatedness of items is determined based on the number of documents in which they occur together" (van Eck & Waltman, 2022, p. 5). Units of analysis include author keywords, all keywords, or keywords plus.	√	√

Before beginning the analysis in CiteSpace, duplicate documents were removed using CiteSpace and Mendeley. Excel was used to generate bar graphs for bibliometric analysis. Using Excel sheets, tables were generated for citation reports and converted into figures.

For the scientometric analysis, both programs' default settings were utilized. We independently created network visualization, overlay visualization, and density visualization for each database's data. The analysis was performed three times on Scopus and WOS: cooccurrence analysis by all keywords, co-citation by source, and co-citation by cited author. The analysis was performed four times for Lens: cooccurrence analysis for all keywords, citation by author, citation by source, and citation by document. For CiteSpace, the following analyses for Scopus and WOS were conducted three times each: co-citation by document (references), co-citation by cited author, and occurrence (keywords). We produced narrative summaries, cluster summaries, visual maps, and burst tables.

3. Results

3.1. Result overview

The findings are divided into two main categories. The first section details the bibliometric indicators of the development of neurolinguistics. These indicators are extracted from inform)‹ ion gathered from Scopus, Web of Science (WOS), and Lens databases. The bibliometric indicators include publications by year, the top 10 countries, universities, journals, publishers, subject/research areas, and authors. The second section outlines the neurolinguistics development indicators analysed through scientometric techniques utilizing CiteSpace and VOSviewer software programs. These indicators consist of citation, co-citation, and co-occurrence measures.

3.2. Bibliometric indicators for the development of neurolinguistics

3.2.1. Overview of neurolinguistics studies from Scopus, web of science, and lens

There were 869 neurolinguistics papers in Scopus, 572 in the WOS, and 3,663 in Lens. For each database, the data period ranged from 1913 to 2022, 1985 to 2022, and 1961 to 2022. A total of 600 articles were included in Scopus, 130 review articles, 103 book chapters, and 36 books. There were 479 articles in the WOS, one review article, 28 book chapters, and two early access articles.

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Table 2. Search strings for data retrieval on neurolinguistics

WOS "neurolinguistics" (Topic) or "brain and language" (Topic) or "language and brain" (Topic) or "neuroscience of language" (Topic) or "language neuroscience" (Topic) or "neurophysiology of language" (Topic) or "language neurophysiology" (Topic) or "neurological linguistics" (Topic) or "neurobiology of language" (Topic) or "language neurobiology" (Topic) or "neurology of language" (Topic) or "language neurology" (Topic) and Articles or Review Articles or Book Chapters or Early Access (Document Types) Thursday, 17 March 2022, 572 results from Web of Science Core Collection, 1985–2022
Scopus (TITLE-ABS-KEY ({neurolinguistics}) OR TITLE-ABS-KEY ({brain and language}) OR TITLE-ABS-KEY ({language and brain}) OR TITLE-ABS-KEY ({neuroscience of language}) OR TITLE-ABS-KEY ({language neuroscience}) OR TITLE-ABS-KEY ({neurophysiology of language}) OR TITLE-ABS-KEY ({language neurophysiology}) OR TITLE-ABS-KEY ({neurological linguistics}) OR TITLE-ABS-KEY ({neurobiology of language}) OR TITLE-ABS-KEY ({language neurobiology}) OR TITLE-ABS-KEY ({neurology of language}) OR TITLE-ABS-KEY ({language neurology})) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re") OR LIMIT-TO (DOCTYPE , "ch") OR LIMIT-TO (DOCTYPE , "bk")) Thursday, 17 March 2022, 869 document results, 1913–2022
Lens (Title: (AND neurolinguistics) OR (Abstract: (AND neurolinguistics) OR (Keyword: (AND neurolinguistics) OR Field of Study: (AND neurolinguistics)))) OR ((Title: (AND ("brain and language" AND)) OR (Abstract: (AND ("brain and language" AND)) OR (Keyword: (AND ("brain and language" AND)) OR Field of Study: (AND ("brain and language" AND))))) OR ((Title: (AND ("language and brain" AND)) OR (Abstract: (AND ("language and brain" AND)) OR (Keyword: (AND ("language and brain" AND)) OR Field of Study: (AND ("language and brain" AND))))) OR ((Title: (AND ("neuroscience of language" AND)) OR (Abstract: (AND ("neuroscience of language" AND)) OR (Keyword: (AND ("neuroscience of language" AND)) OR Field of Study: (AND ("neuroscience of language" AND))))) OR ((Title: (AND ("language neuroscience" AND)) OR (Abstract: (AND ("language neuroscience" AND)) OR (Keyword: (AND ("language neuroscience" AND)) OR Field of Study: (AND ("language neuroscience" AND))))) OR ((Title: (AND ("neurophysiology of language" AND)) OR (Abstract: (AND ("neurophysiology of language" AND)) OR (Keyword: (AND ("neurophysiology of language" AND)) OR Field of Study: (AND ("neurophysiology of language" AND))))) OR ((Title: (AND ("language neurophysiology" AND)) OR (Abstract: (AND ("language neurophysiology" AND)) OR (Keyword: (AND ("language neurophysiology" AND)) OR Field of Study: (AND ("language neurophysiology" AND))))) OR ((Title: (AND ("neurological linguistics" AND)) OR (Abstract: (AND ("neurological linguistics" AND)) OR (Keyword: (AND ("neurological linguistics" AND)) OR Field of Study: (AND ("neurological linguistics" AND))))) OR ((Title: (AND ("neurobiology of language" AND)) OR (Abstract: (AND ("neurobiology of language" AND)) OR (Keyword: (AND ("neurobiology of language" AND)) OR Field of Study: (AND ("neurobiology of language" AND))))) OR ((Title: (AND ("language neurobiology" AND)) OR (Abstract: (AND ("language neurobiology" AND)) OR (Keyword: (AND ("language neurobiology" AND)) OR Field of Study: (AND ("language neurobiology" AND))))) OR ((Title: (AND ("neurology of language" AND)) OR (Abstract: (AND ("neurology of language" AND)) OR (Keyword: (AND ("neurology of language" AND)) OR Field of Study: (AND ("neurology of language" AND))))) OR (Title: (AND ("language neurology" AND)) OR (Abstract: (AND ("language neurology" AND)) OR (Keyword: (AND ("language neurology" AND)) OR Field of Study: (AND ("language neurology" AND)))))))))))))) Thursday, 17 March 2022, Scholarly Works (3,663), 1961–2022

Lens contained 2,655 articles, 431 book chapters, 369 books, 89 dissertations, and 50 preprints. These documents were primarily in English, but also included documents in Portuguese, French, Spanish, German, Russian, Catalan, Czech, Croatian, Italian, Chinese, and Polish. Because the analysis is based on the title, keywords, abstract and references, these all include this information in English. The inclusion of these data was considered in order to avoid bias with respect to published data in English.

Figure 1A-Dshow the length of production by year for the three databases. Knowledge production in neurolinguistics has increased significantly in recent years, reaching its peak in 2015 in Scopus with 64 publications, in 2018 in the WOS with 56 publications, and in 2020 in Lens with 197 publications. The range of publications per year is 1–65 in Scopus, 1–56 in the WOS, and 1–197 in Lens. The lowest number of publications occurred in previous year in all databases. Among the 869 documents in Scopus, 662 were published between 2000 and 2022, 572 in the WOS, of which 512 were published between 2000 and 2002, and 3,663 in Lens, of which 2,630 were published between 2000 and 2022. Consequently, there has been an increase in the production of knowledge in the field of neurolinguistics over the past two decades.

3.2.2. Production of neurolinguistics research by country and university

Figure 2A-C depicts the top ten countries producing neurolinguistics-related knowledge. The United States achieves the highest ranking across all three databases with a publication count that is significantly greater than that of all other nations. In the three databases, the second and third positions are switched between Germany and the United Kingdom. Among these nations are Russia, which is present in Scopus, and Australia, which is present only in Scopus and Lens. Again, these nations are in North/South America, Europe, and Australia, except for China, which is in Asia.

Figure 3A-C lists the top ten universities and/or research institutions producing neurolinguistics-related knowledge. All these universities are in either Europe or the United States. While the University of California is ranked first in Scopus and WOS, the Max Planck Society in Germany is ranked first in Lens.

3.2.3. Production of neurolinguistics research by journal and publisher

Figure 4A-C demonstrates the top ten neurolinguistics research journals. The first publication is titled “Brain and Language,” followed by “Journal of Neurolinguistics” and “Aphasiology.” The top journals in the three databases may be categorized as neuroscience (e.g., Neuroimage), psychology (e.g., Frontiers in Psychology), or linguistics journals (e.g., Language Sciences).

Figure 5A-B displays the top ten publishers of neurolinguistics knowledge. Scopus does not contain publisher’s information, so these lists are limited to the WOS and Lens databases. While “Elsevier” achieves the highest ranking in both databases, the remaining publishers vary between the two. While “Cambridge University Press” is ranked seventh in the WOS, it is ranked fourth in Lens.

3.2.4. Production of neurolinguistics by research area, keywords, and cooccurrence

Neurolinguistics, an interdisciplinary branch of linguistics, integrates with a variety of research fields, as shown in (Figure 6A-C). The top four subject areas publishing in neurolinguistics are social sciences, arts and humanities, neuroscience, and psychology, as shown in Figure 6A. Neuroscience, linguistics, psychology, and speech-language pathology are the top four research fields related to neurolinguistics, as shown in Figure 6B. These are further confirmed in Figure 6C, which introduces the top four fields of study as psychology, neurolinguistics, cognitive science, and cognition. Lens reveals more specialized fields associated with neurolinguistics (e.g., psycholinguistics, neurolinguistics programming).

3.2.5. Production of neurolinguistics by authors

Undoubtedly, the contribution to the field of neurolinguistics is not restricted to a specific number of authors, and a single article constitutes a contribution to the field. However, we intended to demonstrate the authors who produced the most neurolinguistics-related knowledge, as shown in (Figure 7A-D). As can be seen, (Arbib, 2005) is the author with the most publications in neurolinguistics across all three databases. The remainder of the list differs based on the database. For example, (Caplan et al., 1996) is ranked tenth on Scopus, second on Lens, but not on the WOS. Obviously, this is because not all journals listed on Scopus also appear on the WOS. Figure A-D shows the top 10 authors according to their author ID. Once again, we can see (Arbib, 2005) remains the first followed by (Hagoort, 2013) and (Friederici, 2003).

3.3. Scientometric indicators for the development of neurolinguistics

3.3.1. Overview of neurolinguistics studies from Scopus, web of science, and lens

This section offers the scientometric analysis of the Scopus, WOS, and Lens database retrieval results. It emphasizes the influence of specific concepts, authors, references, and developing trends about neurolinguistics.

Figure 1. Neurolinguistics knowledge production size measured by year.

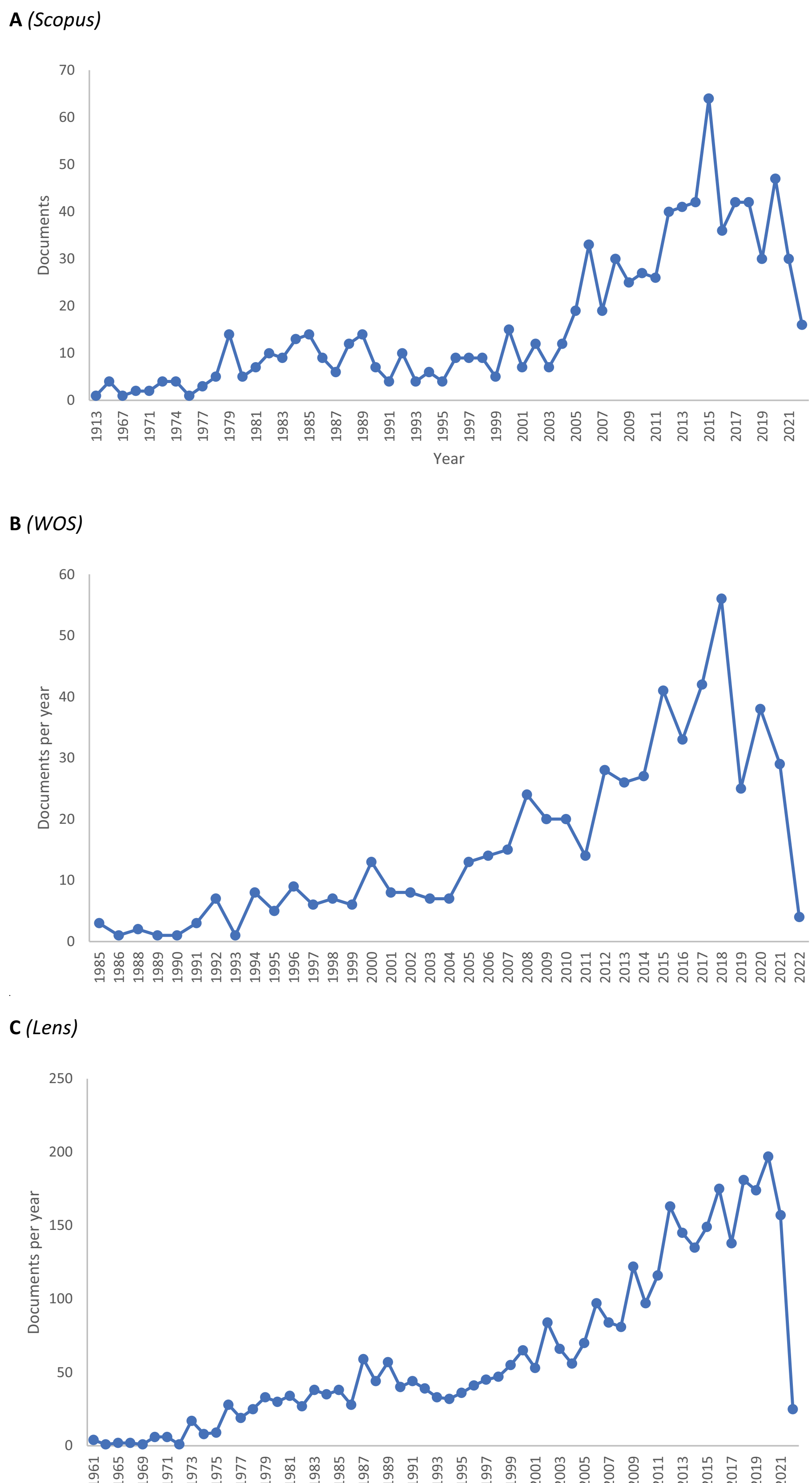
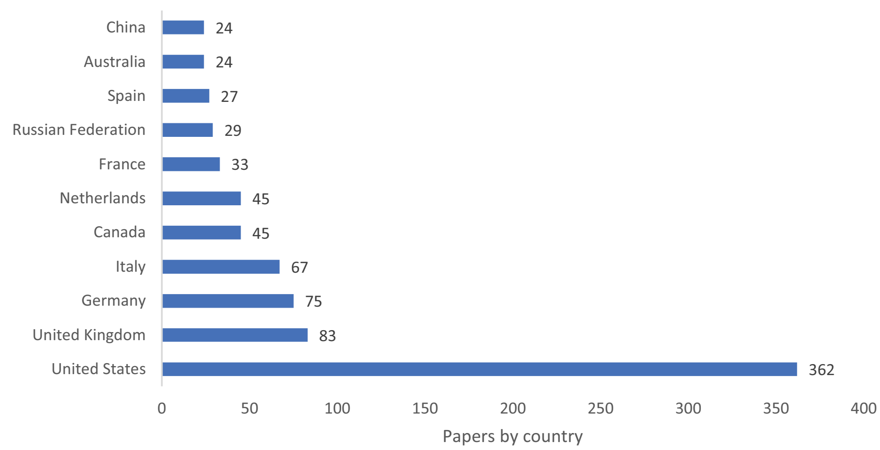
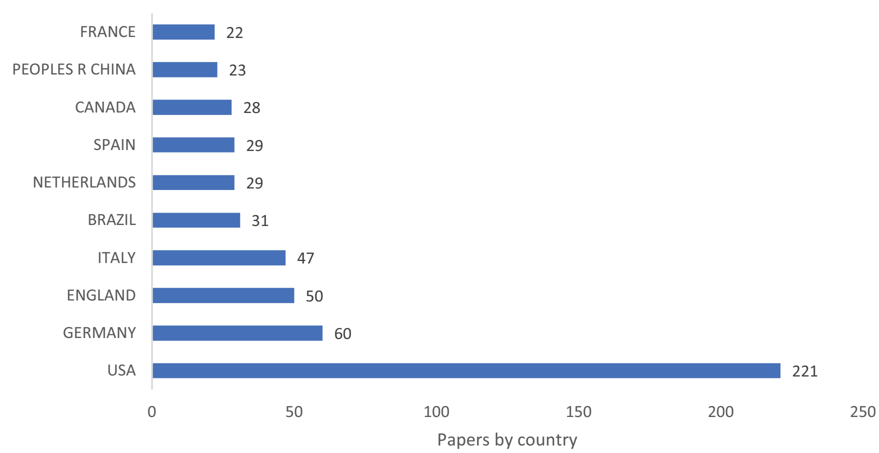


Figure 2. Neurolinguistics knowledge production size measured by country.

A *(Scopus)*



B *(WOS)*



C *(Lens)*

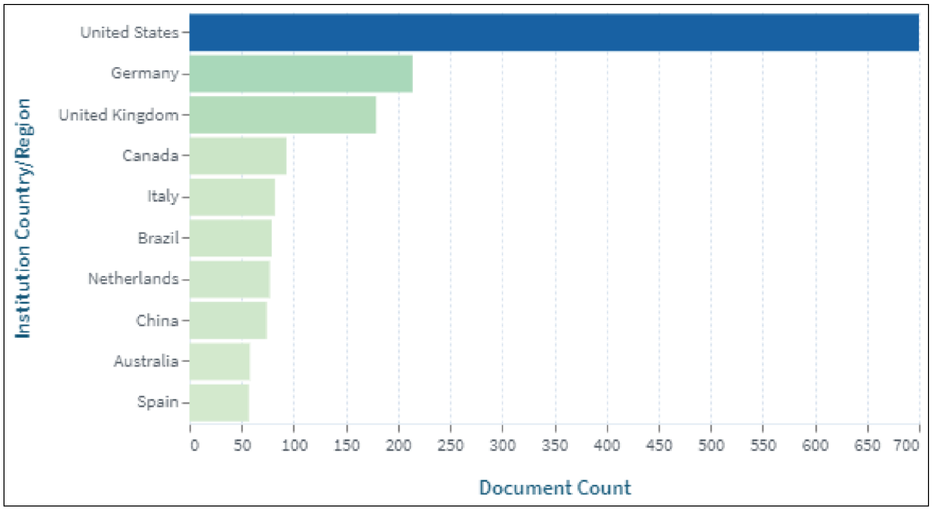


Figure 3. Neurolinguistics knowledge production size measured by university/ research centre.

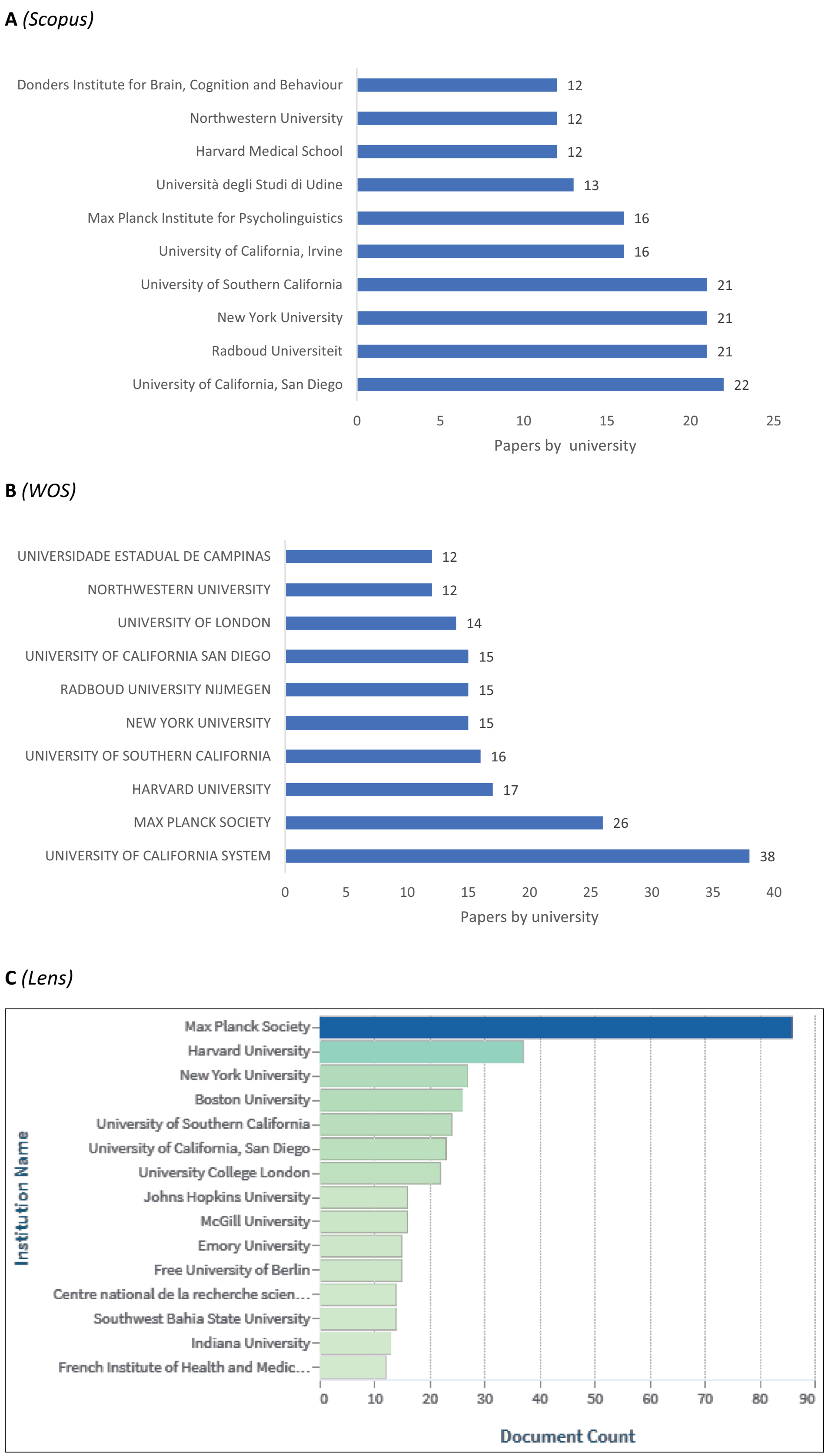
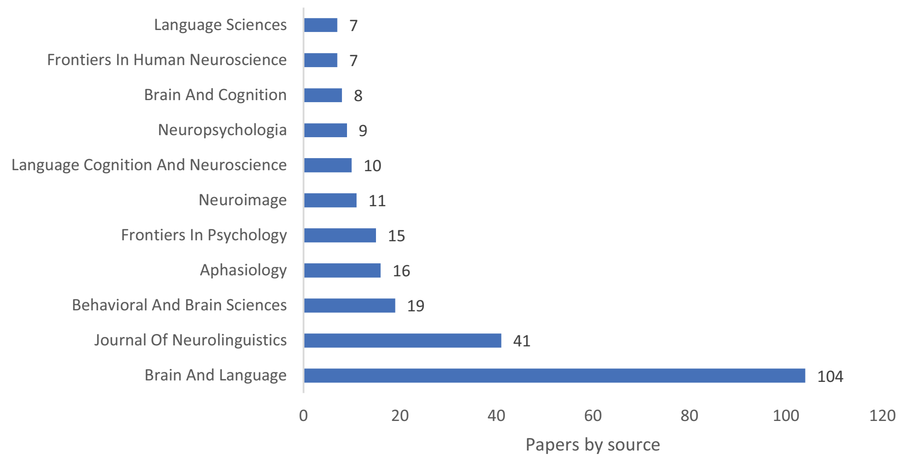
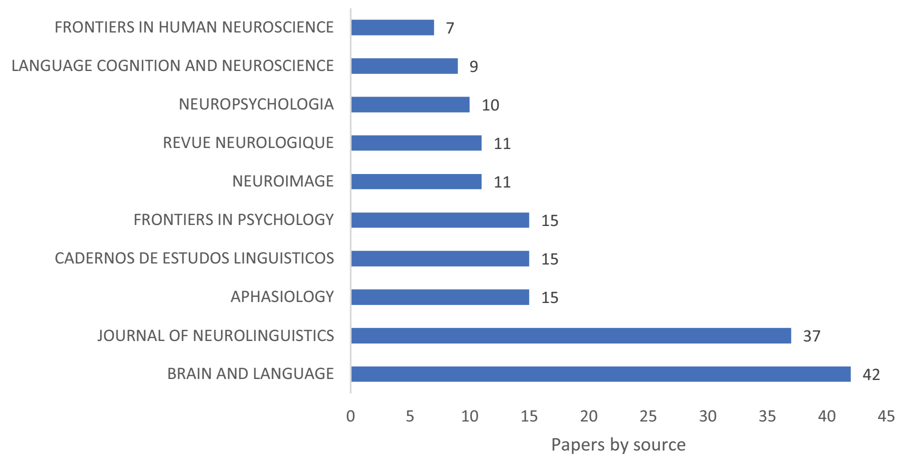


Figure 4. Neurolinguistics knowledge production size measured by source.

A *(Scopus)*



B *(WOS)*



C *(Lens)*

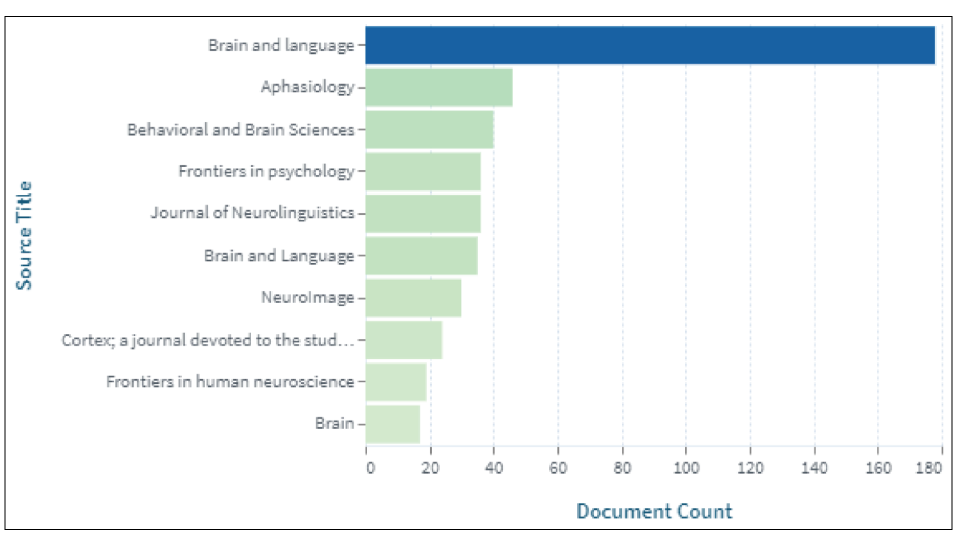
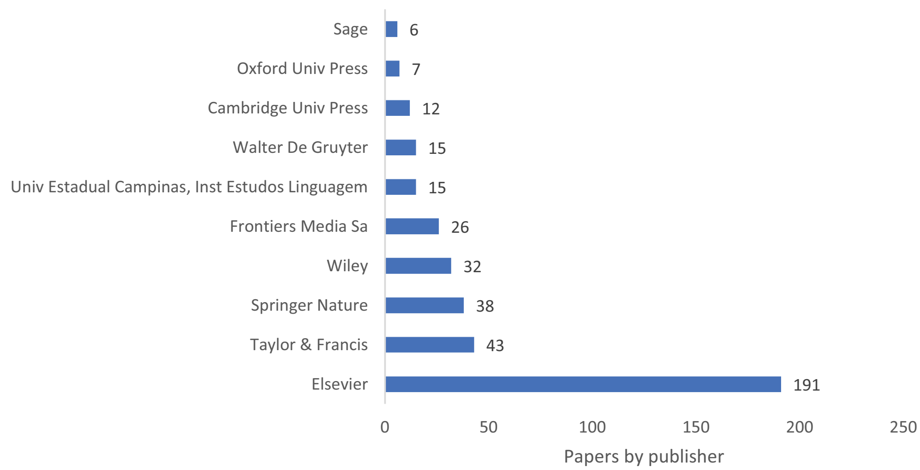
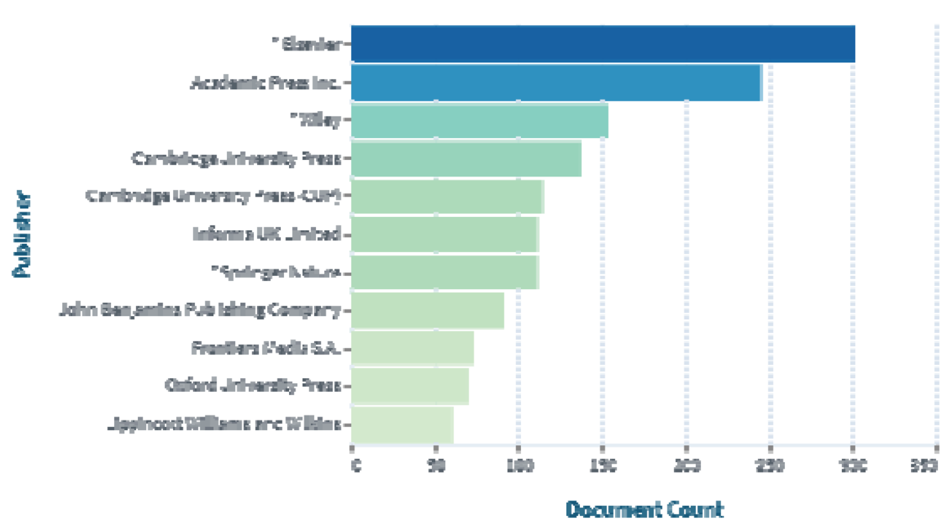


Figure 5. Neurolinguistics knowledge production size measured by publisher.

A *(WOS)*



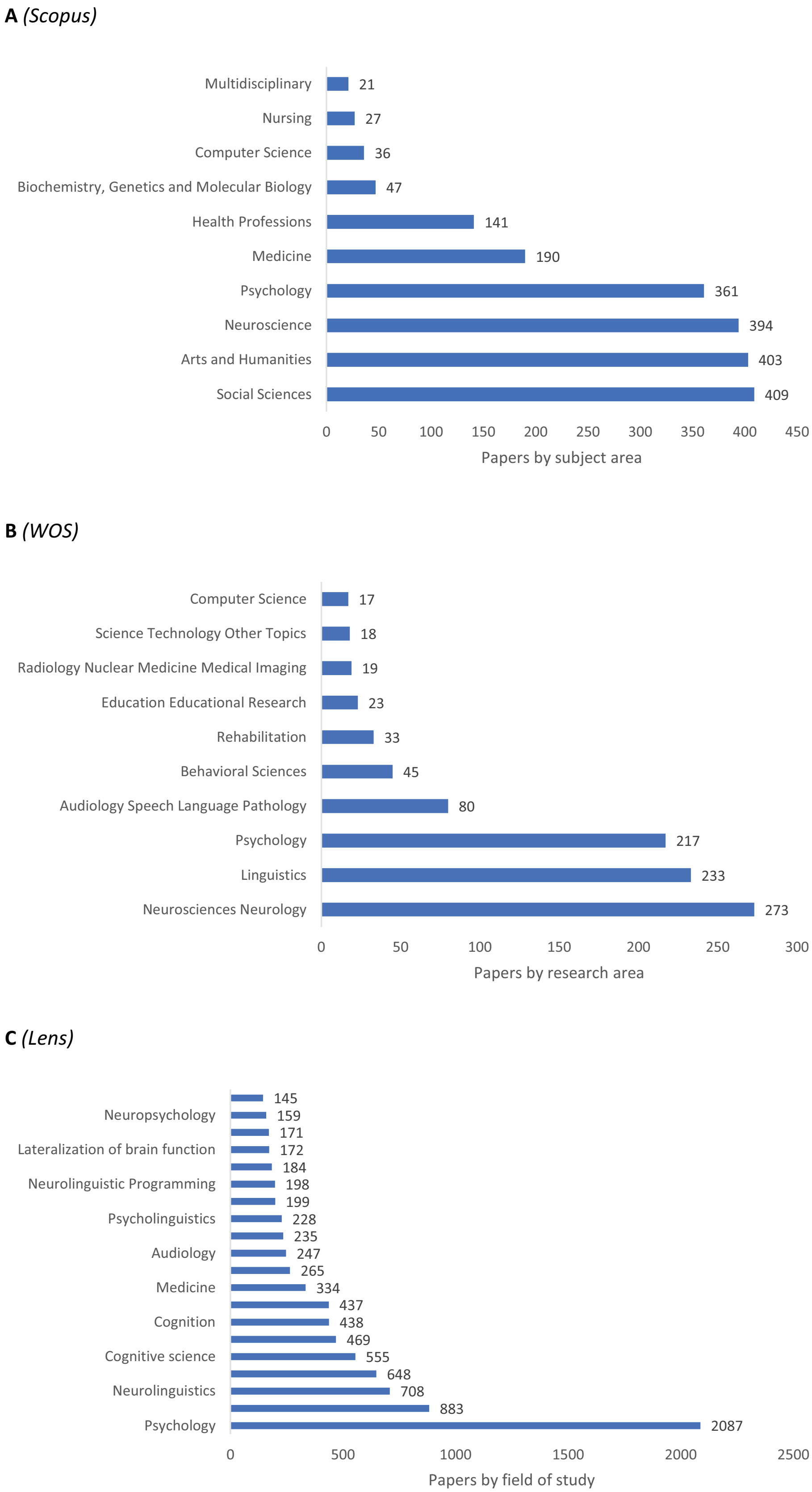
B *(Lens)*



We initially displayed the top terms with the highest citation bursts using data from Scopus and WOS and CiteSpace (Figure 8A-B). The green line represents the research period. The red line denotes the start and finish of the burst phase. The term with the greatest increase in citations in Scopus between 1974 and 1987 is (central nervous system = 28.7), while between 2008 and 2017 for the WOS it is (sentence comprehension = 5.27). The citation burst differs based on the database. For example, keywords such as physiology, aphasia, and diagnosis are exclusive to Scopus, whereas others are exclusive to the WOS (e.g., prefrontal cortex, speech perception, and memory).

These are further depicted in network visualizations with clusters and authors (Figure 9A-D). The most often addressed subjects in neurolinguistics include language processing, cerebral dominance, words hemisphere, brain organization, the human mirror neuron system, and alpha activity. Figure 9B shows a more comprehensive list of these issues, including cortical representation, sentence comprehension, and aphasic symptoms, among others, as the most discussed topics in the published research extracted from the WOS database. Figures 9C-D depict the most frequently referenced references and the search terms used to locate them. These include subjects such as

Figure 6. Neurolinguistics knowledge production size measured by research area .



brain activity, aphasia, the neurolinguistic model, and semantic jargon, among others (See Figure 9C). More linguistic issues, such as linguistic theory, word classes, and single-word processing, are included in the WOS database (See Figure 9D).

The cooccurrence of used terms is an additional crucial aspect. Using VOSviewer, we constructed three visual network maps for the presence of the three databases' most frequent neurolinguistics keywords (Figure 10A-C). Each hue reflects a different direction for neurolinguistics research. For instance, the red color indicates that significant attention is being paid to neurolinguistics-related language research. The studies highlighted in yellow appear to be related to neurolinguistics. The words in purple are aphasia and language as a human faculty (See Figure 10A). These hues will alter according on the databases. For instance, in Figure 10B, the color pink denotes neurolinguistics-related phrases. Green symbolizes syntactic and neurolinguistic terms. In Figure 10C, blue represents keywords associated with investigated populations.

We developed three visual network maps for co-citation and citation by author using VOSviewer (Figure 11A-C). Each hue denotes a co-citation or citation for authors' network. The greater the size of the circle, the more frequently the author is co-referenced or quoted. For instance, (Caramazza & Brones, 1979; Chomsky, 2002; Friederici, 2003; Hickok et al., 1998) are the most co-cited authors

Figure 7. Neurolinguistics knowledge production size measured by author.

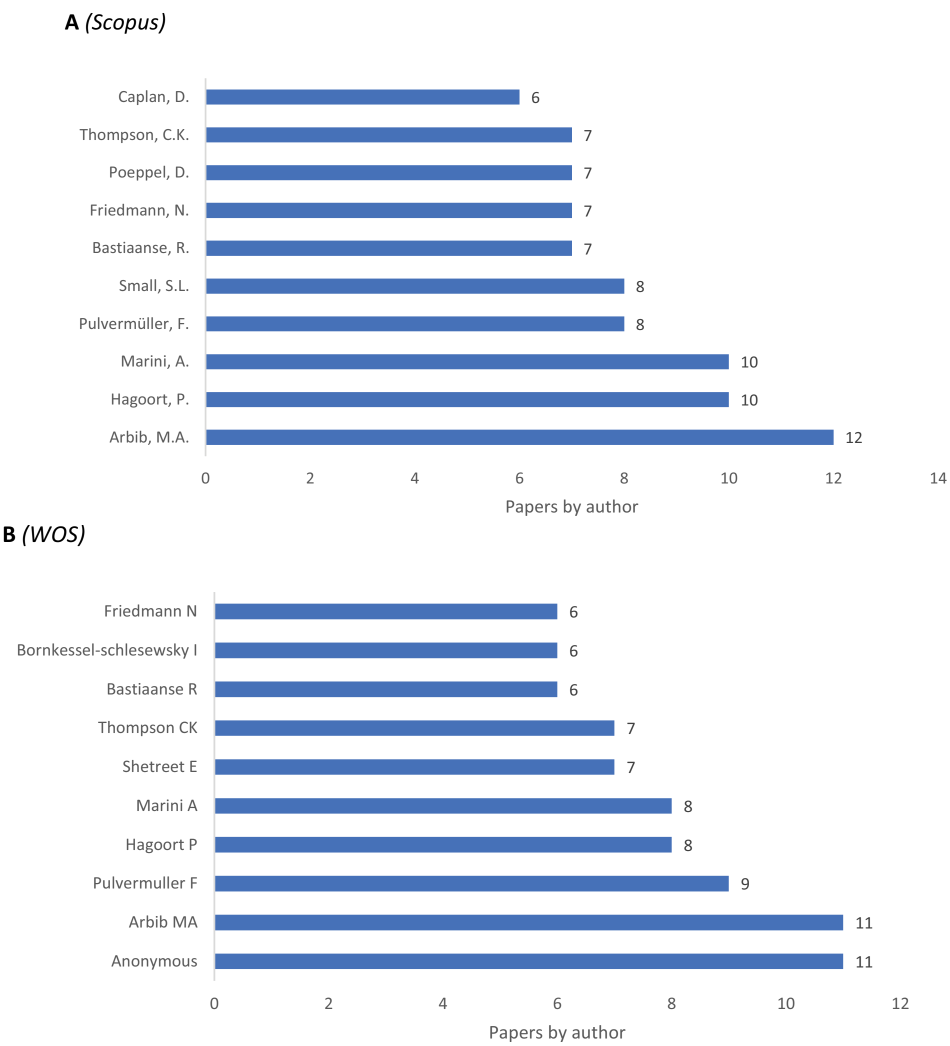
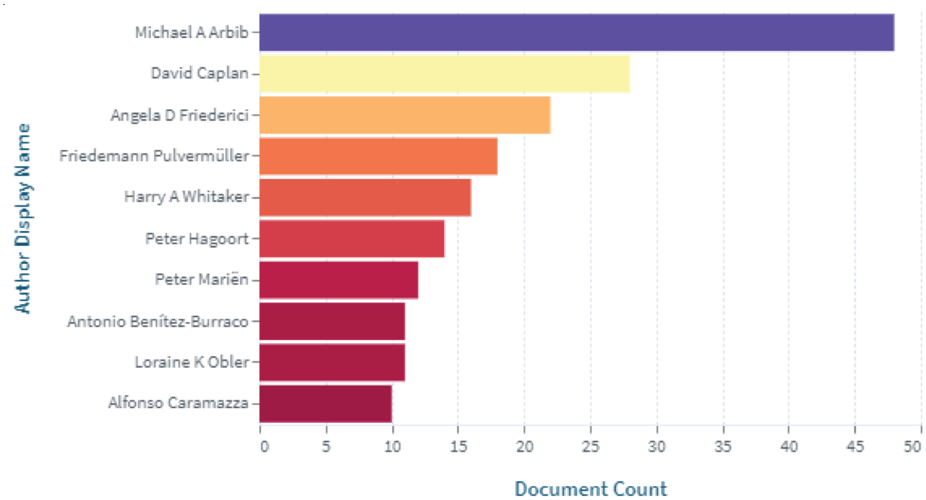
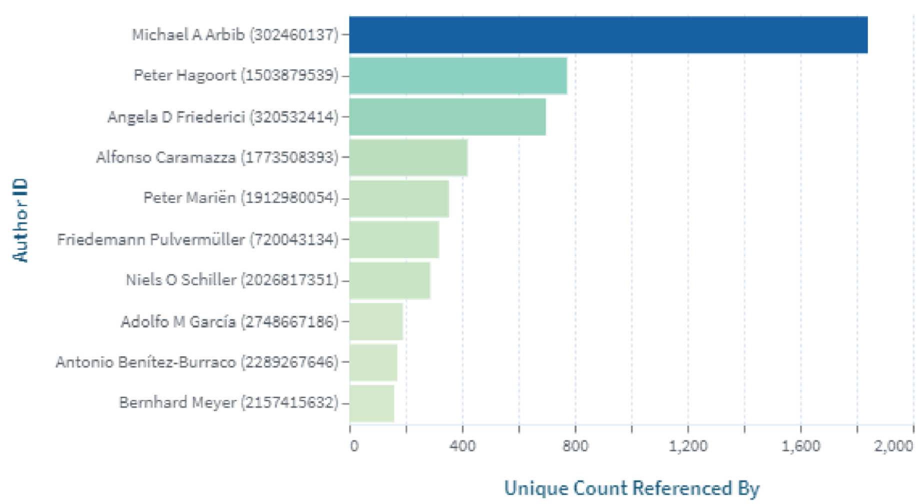


Figure 7. (Continued).

C *(Lens)*



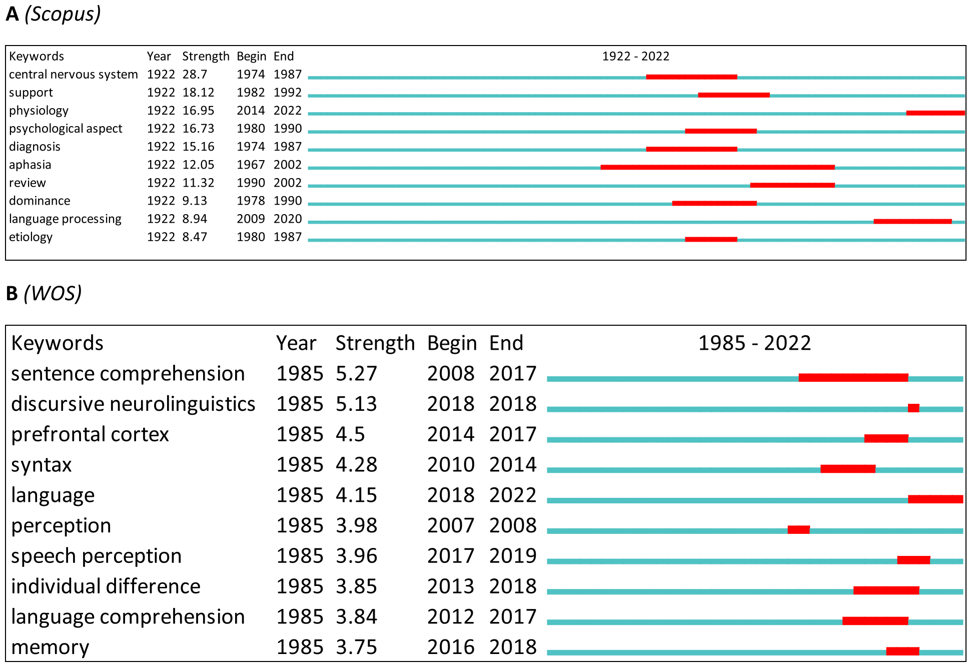
D *(Lens)*



in Figure 11A. The same authors are also repeated in Scopus database with some others like (Arbib, 2005; Paradis, 1986) (See Figure 11B). According to Figure 11C using the Lens database, the most cited authors are (Arbib, 2005; Caplan et al., 1996; Schwab et al., 2020).

We created three visual network maps for co-citation and citation by source using VOSviewer (Figure 12A-C). Each color denotes a network for co-citation or source citation. The wider the circle, the greater the source's co-citations, or citations. In Figure 12A, for instance, "Brain and Language," "Neuroimage," and "Cortex" appear to represent three distinct paths of journals, even though they all publish research in neurolinguistics. Using the WOS database containing more significant journals, these appear comparable in Figure 12B. (e.g., Journal of Neurolinguistics, Cognition, Trends in Cognitive Science). Figure 11C depicts the journal citation network. This includes "Brain and Language," "Journal of Neurolinguistics," and "Frontiers in Psychology."

Figure 8. Top 10 keywords with the strongest citation bursts.



Using the bibliometric data supplied by Scopus, WOS, and Lens, we exported the citations reports and reported the 10 most-cited publications. As indicated in Table 3, we consolidated the 30 most-cited documents in neurolinguistics, deleted the duplicates, and were left with 19 documents. As can be observed, this list and position vary depending on the database used. For example, the article "Neurolinguists, beware! The article titled "The bilingual is not two monolinguals in one" ranks first in Scopus and fifth in Lens but does not appear in the WOS. From monkey-like action recognition to human language: an evolutionary framework for neurolinguistics' is ranked second in Scopus, first in the WOS, and ninth in Lens. Figure 13D further illustrates the most frequently cited documents using a VOSviewer-created density representation.

3.3.2. Impact of research on neurolinguistics by clusters, citation counts, citation bursts, centrality, and Sigma

3.3.2.1. Clusters. The network is divided into sixteen co-citation clusters in the WOS data (See Table 4 for the list of all clusters.). The largest six clusters are summarized as follows. The largest cluster (#0) has 112 members and a silhouette value of 0.758. It is labelled as flexible word order language by LLR, language-ready brain by LSI, and discourse processing (1.11) by MI. The most relevant citer to the cluster is (Pulvermüller, 2018) "Neural reuse of action perception circuits for language, concepts and communication".

The network is divided into twelve co-citation clusters in the Scopus data. The largest four clusters are summarized as follows. The largest cluster (#0) has 315 members and a silhouette value of 0.507. It is labelled as linguistic theory by LLR, cognitive neuroscience by LSI, and inappropriate stress (3.02) by MI. The most relevant citer to the cluster is (Kemmerer, 2014) "Cognitive neuroscience of language".

3.3.2.2. Citation counts. In the WOS, the top ranked item by citation counts is (Friederici, 2003) in Cluster #0, with citation counts of 106. The second one is (Emmorey et al., 1998) in Cluster #5, with citation counts of 95. In Scopus, the top ranked item by citation counts is Chomsky N (1976) in Cluster #2, with citation counts of 149. The second one is (Friederici, 2003) in Cluster #0, with citation counts of 132. The remaining references with top citation counts are shown in Table 5.

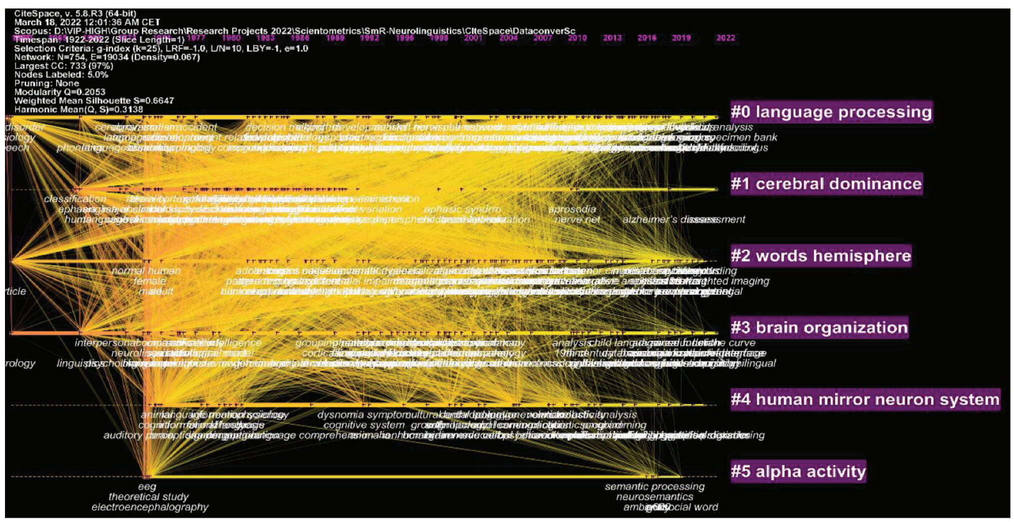
3.3.2.3. Bursts. In the WOS data, the top ranked item by bursts is (Coudry, 2018) in Cluster #15, with bursts of 7.97. The second one is (Y. O. S. E. F. Grodzinsky et al., 1985) in Cluster #2, with bursts of 6.51. In Scopus, the top ranked item by bursts is [Anonymous] (1974) in Cluster #1, with bursts of 34.34. The second one is (Emmorey et al., 1998) in Cluster #0, with bursts of 13.03. The remaining detected bursts in neurolinguistics are shown in Table 6 and Figure 14A-D.

3.3.2.4. Centrality. In the WOS, the top ranked item by centrality is (Hagoort, 2005) in Cluster #0, with centrality of 115. The second one is (Friederici, 2003) in Cluster #0, with centrality of 112. In Scopus, the top ranked item by centrality is (Chomsky, 2002) in Cluster #2, with centrality of 598. The second one is (Caramazza & Brones, 1979) in Cluster #2, with centrality of 514. The remaining central authors in neurolinguistics are shown in Table 7.

3.3.2.5. Sigma. In the WOS, the top ranked item by sigma is (Hagoort, 2005) in Cluster #0, with sigma of 0.00. The second one is (Friederici, 2003) in Cluster #0, with sigma of 0.00. In Scopus, the

Figure 9. Top keywords, cited references, and clusters.

A *(Scopus)*



B *(WOS)*

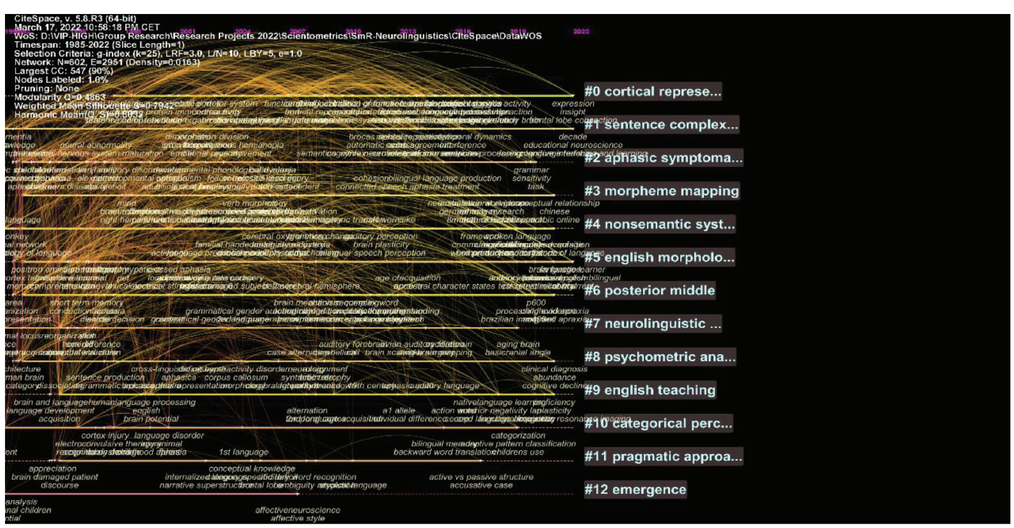
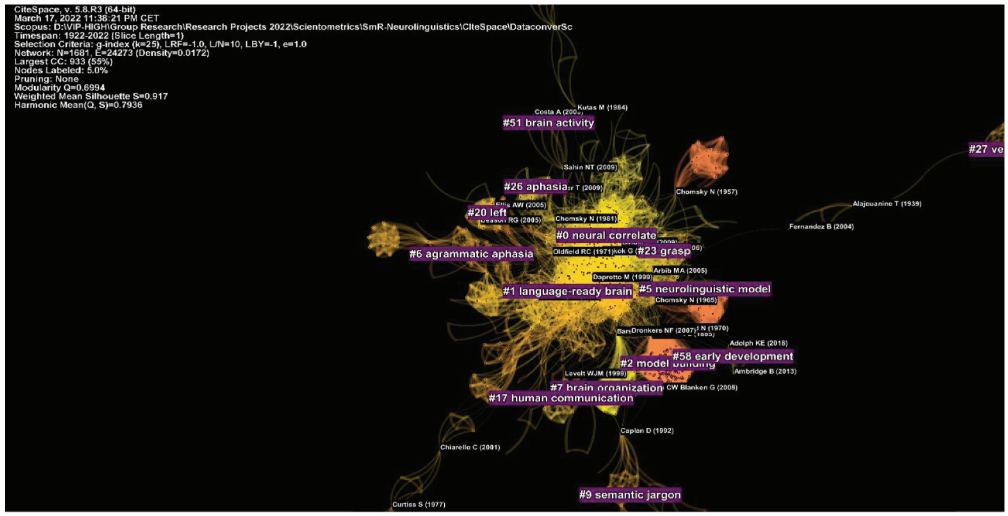
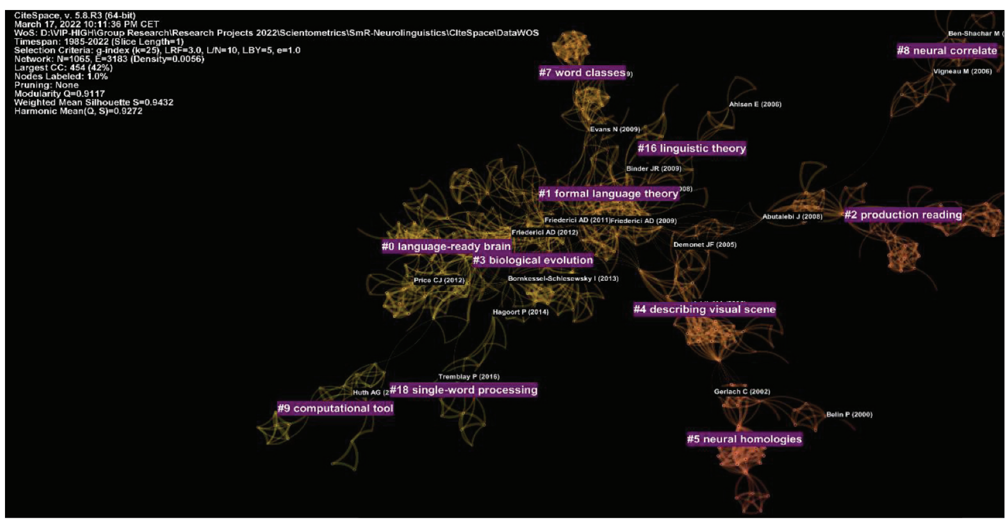


Figure 9. (Continued).

C *(Scopus: Cited References)*



D *(WOS)*



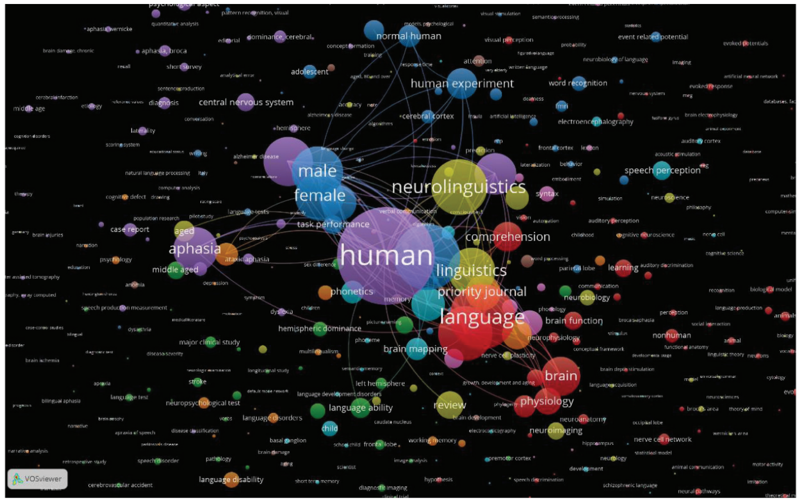
top ranked item by sigma is (Chomsky, 2002) in Cluster #2, with sigma of 0.00. The second one is (Caramazza & Brones, 1979) in Cluster #2, with sigma of 0.00. The remaining authors with possible citation growth in neurolinguistics are shown in Table 8.

4. Discussion

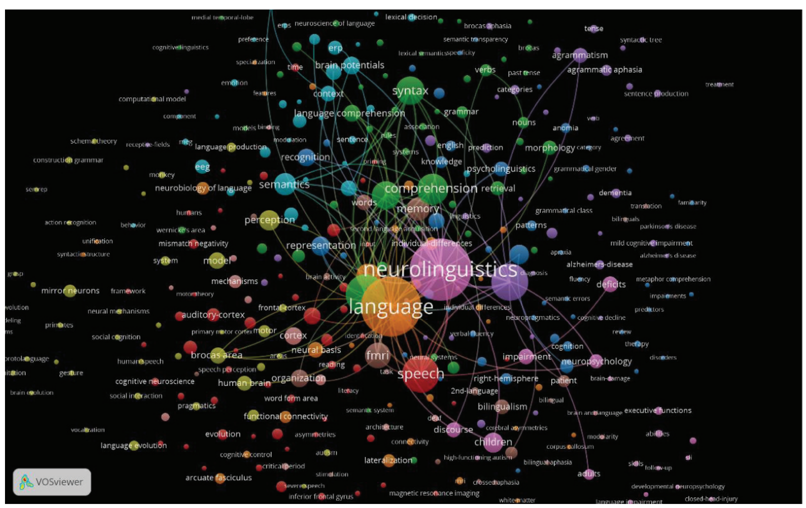
The current scientometric investigation aimed to map the interdisciplinary field of neurolinguistics in linguistics and provide a visual representation of its developmental process and structural relationships of scientific knowledge. The study utilized bibliometric and scientometric indicators to assess the knowledge created in neurolinguistics. The findings revealed two patterns. Firstly, bibliometric indicators were developed to examine the development of neurolinguistics using data from the Scopus, WOS, and Lens databases. These indicators consisted of publications by year, top regions, universities, journals, publishers, subject/research areas, and authors. The analysis revealed a significant increase in neurolinguistics knowledge output, with a peak of 64 articles in Scopus, 56 publications in WOS, and 197 publications in Lens in 2020. This growth indicates that the body of knowledge in neurolinguistics has increased over the

Figure 10. Cooccurrence by all keywords network visualization.

A *(Scopus)*



B *(WOS)*



C *(Lens)*

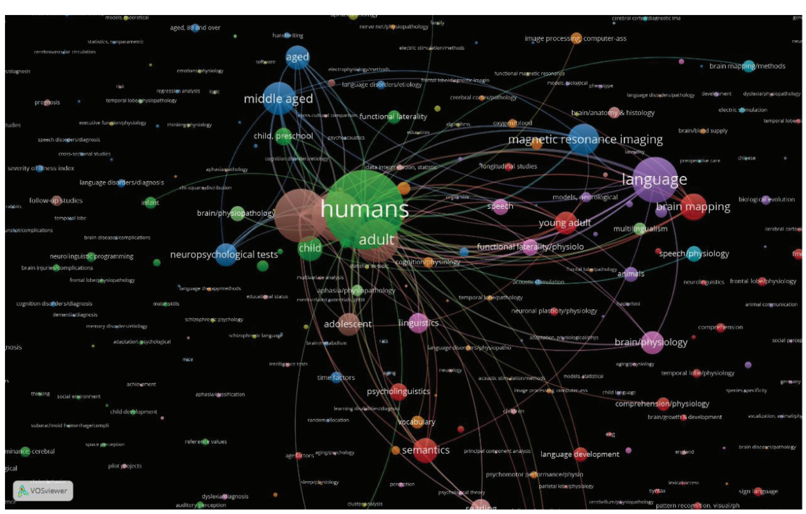
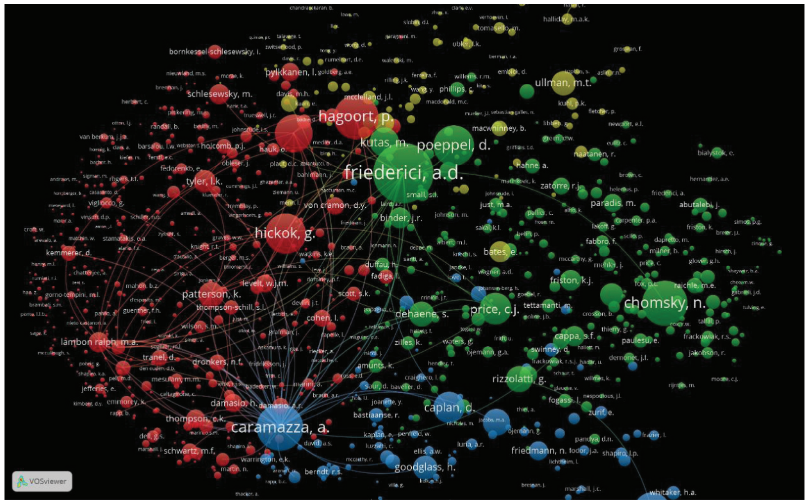
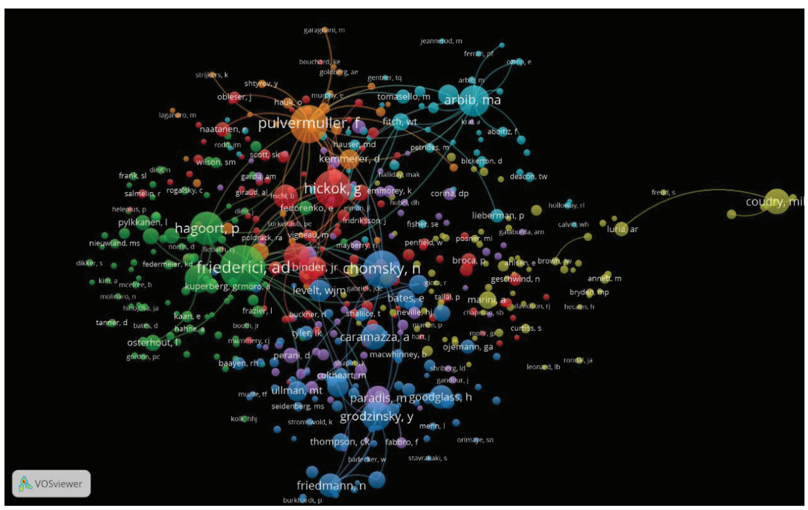


Figure 11. *(Co)-citation by cited author network visualization.*

A *(Scopus)*



B *(WOS)*



C *(Lens: Citation)*

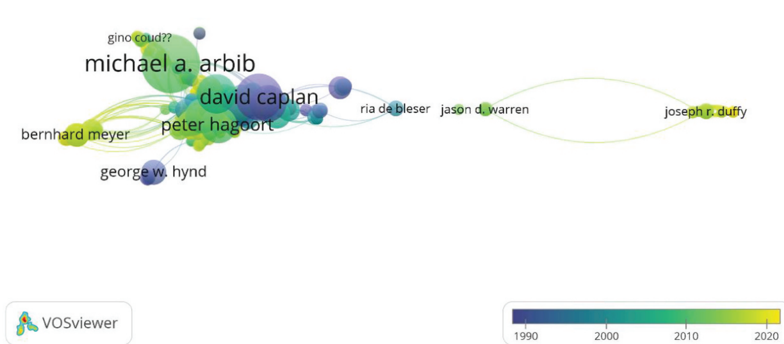


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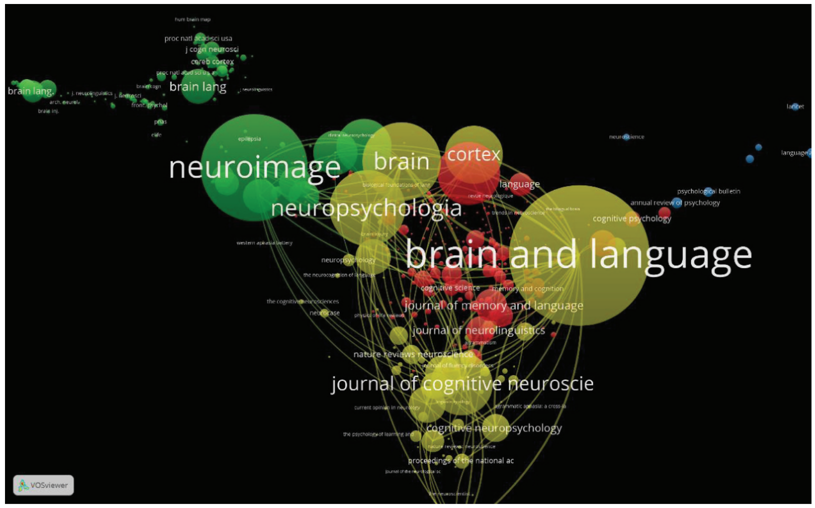
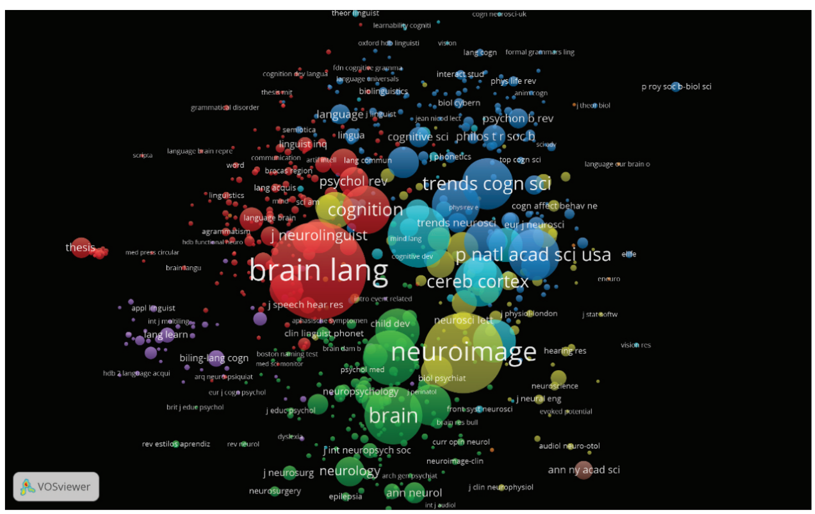
Figure 12. Co-citation by source network visualization.

A *(Scopus)*



B *(WOS)*



C *(Lens: Citation)*

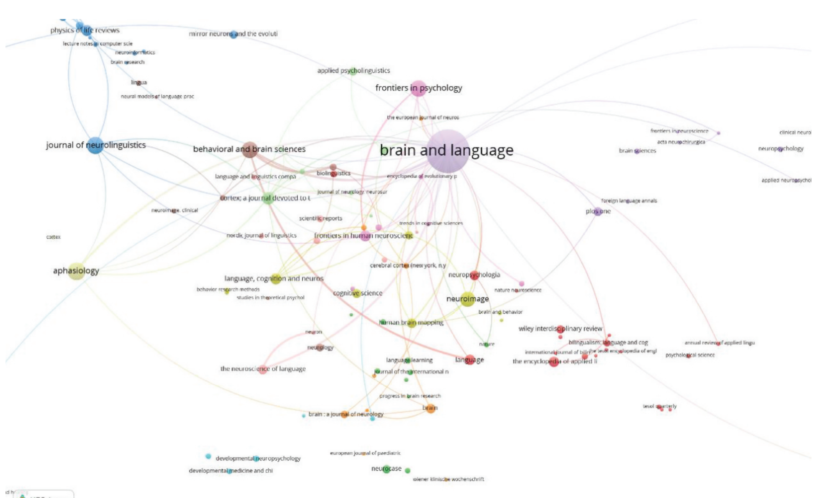


Table 3. Top cited documents of neurolinguistics from Scopus, WOS and Lens

No.	Source title	Citation	Citations by database		
			Scopus	WOS	Lens
1	Architectonic identification of the core region in auditory cortex of macaques, chimpanzees, and humans	(Hackett et al., 2001)	347	320	X
2	Distinctions between manipulation and function knowledge of objects: Evidence from functional magnetic resonance imaging	(Boronat et al., 2005)	209	195	X
3	Event-related potential indices of semantic priming using masked and unmasked words: Evidence that the N400 does not reflect a post-lexical process	(Deacon et al., 2000)	212	207	X
4	Foundations of Language: Brain, Meaning, Grammar, Evolution	(Jackendoff, 2002)	X	537	1303
5	From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics	(Arbib, 2005)	653	X	855
6	Handbook of clinical neuropsychology	(Susan & Thomas, 1981)	X	X	774
7	Learning Theories: An Educational Perspective	(Schunk, 2012)	X	X	2090
8	Lexical entries and rules of language: A multidisciplinary study of German inflection	(Clahsen, 1999)	357	332	X
9	MUC (Memory, Unification, Control) and beyond	(Hagoort, 2015)	X	183	X
10	Neural subsystems for object knowledge	(Hart & Gordon, 1992)	231	220	X
11	Neurolinguistics: Structural plasticity in the bilingual brain	(Mechelli et al., 2004)	633	X	809
12	Neurolinguists, beware! The bilingual is not two monolinguals in one person	(Grosjean, 1989)	699	X	1013
13	Renewal of the neurophysiology of language: Functional neuroimaging	(Démonet et al., 2005)	326	292	X

(*Continued*)

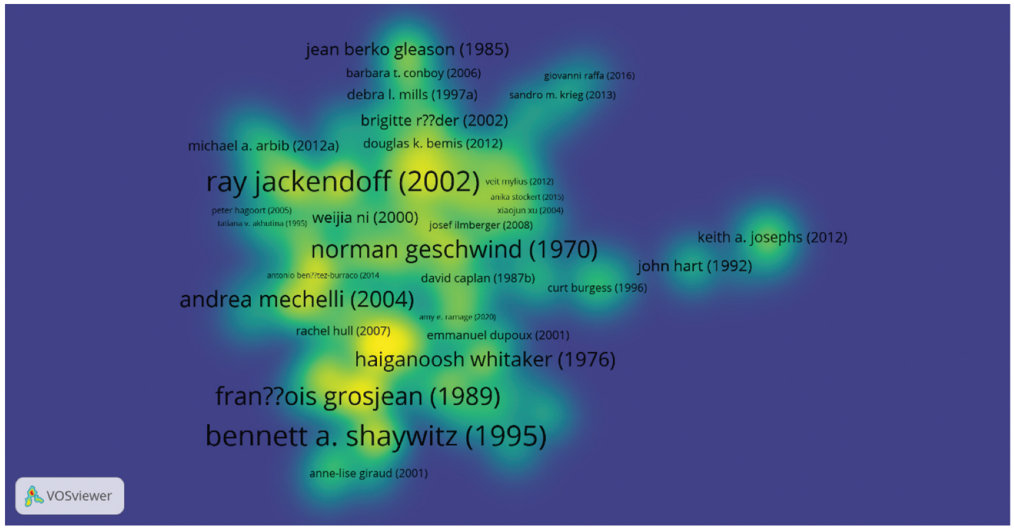
No.	Source title	Citation	Citations by database		
			Scopus	WOS	Lens
14	Reworking the language network	(Fedorenko & Thompson-Schill, 2014)	280	253	X
15	Second Language Acquisition: An Introductory Course	(Gass & Selinker, 1994)	X	X	1384
16	Sex differences in the functional organization of the brain for language	(Shaywitz et al., 1995)	X	X	1314
17	The Language Connectome: New Pathways, New Concepts	(Dick et al., 2014b)	X	158	X
18	The Organization of Language and the Brain	(Geschwind, 1970)	X	X	949
19	The Social Brain: Mind, Language, and Society in Evolutionary Perspective	(Dunbar, 2003)	X	X	756

past 22 years. Moreover, the top 10 nations contributing to neurolinguistics knowledge were in North and South America, Europe, and Australia, with China being the only Asian nation on the list. Similarly, the top 10 universities and/or research institutions were in Europe or the United States.

The scientometric findings were presented in the second pattern, which may be further broken down into five components that describe the scientometric features of neurolinguistics. First, we identified the most used words to search for knowledge related to neurolinguistics. These are elaborated as follows. The investigation into whether metaphors are processed in the right or left hemisphere in Chinese bilingual speakers, revealed a different pattern of brain responses in metaphor processing in L1 and L2, and that both metaphoricity and familiarity have an impact on the brain's response pattern when processing Chinese and English metaphors (Zhu et al., 2022). An investigation examining whether native French speakers (fixed- stress language) can learn to recognize stress differences in Spanish (free- stress language) found that French listeners could improve their ability to discriminate stress contrasts. According to the results, the discrimination of L2 stress contrasts is more strongly related to working memory than to auditory sensitivity (Schwab et al., 2020). Interestingly, it has been hypothesized that the left premotor activity in Kureru sentence comprehension represents not the processing of linguistic empathy per se, but rather the attentional shifting process of linguistic empathy (Yokoyama et al., 2009).

Research into alpha and beta power decreases associated with predictions in sentence comprehension, as well as their generality across different modalities of comprehension, indicated that constrained-related alpha power decreases could reflect richer and more accurate information representation in contexts that allow for strong lexical and/or semantic predictions (León-Cabrera et al., 2022). It has been discovered that switching between languages causes an increase in activity in regions linked with domain-general inhibitory processes in highly proficient bilinguals (Köpke et al., 2021). It was suggested that language switching recruits a neural network that is engaged in domain-general executive control functions and that proficiency, rather than age of acquisition, affects language representations (Köpke et al., 2021). Investigation on the effects of primes of different length on spoken word recognition using lexical decision and by three partial

Figure 13. Citation by document density visualization.



repetition priming experiments showed that priming increased with prime length and latencies decreased with increasing prime length but priming decreased only for complete words (Bölte & Uhe, 2004). Investigation on the neurocognitive mechanisms underlying bimodal language control measuring ERPs by examining language switching in American Sign Language (ASL)-English bilinguals found no ERP patterns related to control were observed with the spoken language (Declerck et al., 2021).

Investigation on the role of the left dorsolateral prefrontal cortex in language switching using theta burst stimulation (TBS) and electroencephalography in late bilinguals showed no differences between inhibitory and excitatory left DLPFC stimulation on response times during language and nonverbal switching (Pestalozzi et al., 2020). At both the group and individual patient levels, Roelof (Roelofs, 2022) demonstrated that WEAVER++/ARC model, which integrates behavioral psycholinguistic, functional neuroimaging, tractography, and aphasiology evidence, can capture patterns of impaired and spared naming, comprehension, and repetition performance (Roelofs, 2022). A computational study addressed some questions about the nature or functional role of perceptuo-motor interconnections of speech perception and speech production through the use of a computational perceptuo-motor model of speech perception, COSMO, as an integral model of speech communication that enables us to simulate both speech perception and speech production in a single computational architecture (Barnaud et al., 2018).

Another feature is that 5,104 documents were sorted into clusters. These clusters show the possible associated patterns among these documents. Investigation on the source of verb inflection errors in agrammatic individuals with mild-moderate Broca's aphasia showed that verb inflection errors observed in English- speaking agrammatic individuals are the most likely the consequence of a prephonological diacritical deficit, and less likely to be due to a failure of the phonological process of affixation (Faroqi-Shah & Thompson, 2004). In addition, examining the Argument Structure Complexity Hypothesis (ASCH) by investigating agrammatic aphasic comprehension and elicited production of two types of intransitive verbs (i.e., unergatives and unaccusatives) in sentence contexts showed that eight agrammatic aphasic subjects had production difficulty with unaccusative verb sentences, as compared to unergatives, in the face of near-normal comprehension of both sentence types (Lee & Thompson, 2004). An event-related functional MRI study showed different activated brain regions during the delay period in a versus semantic short-term memory as a left inferior parietal region overlapping the supramarginal gyrus was more activated in the phonological than the semantic task (Martin et al., 2003). Arbib sought to build the framework for a comprehensive theory of situated language processing in the human

Table 4. Summary of the largest clusters in neurolinguistics research

Cluster ID	Size	Silhouette	Label (LSI)	Label (LLR)	Label (MI)	Average Year
0	112	0.758	language-ready brain	flexible word order language (99.04, 1.0E-4)	discourse processing (1.11)	2015
1	89	0.78	cultural neurolinguistics	language talent (75.54, 1.0E-4)	discourse processing (0.99)	2008
2	89	0.699	agrammatic aphasia	agrammatic aphasia (129.85, 1.0E-4)	object knowledge (0.87)	2002
3	75	0.801	cerebral localization	cerebral localization (66.62, 1.0E-4)	early experience (0.55)	2006
4	69	0.788	autism spectrum disorder	autism spectrum disorder (118.26, 1.0E-4)	language (0.35)	2010
5	59	0.911	language evolution	language-ready brain (120.11, 1.0E-4)	cognitive adequacy (0.65)	2004
Scopus						
0	315	0.507	cognitive neuroscience	linguistic theory (194.5, 1.0E-4)	inappropriate stress (3.02)	2013
1	280	0.957	philosophy-based neurologies	Ethno-neurologies-the social science-based neurologies (192.75, 1.0E-4)	tachistoscopic language laterality task (0.24)	1985
2	260	0.564	unaccusative verb	words hemisphere (201.69, 1.0E-4)	Jakob wepfer (1.84)	2000
3	116	0.847	fMRI investigation	fMRI investigation (95.96, 1.0E-4)	inappropriate stress (2.36)	2008

Table 5. Citation Counts for top references in neurolinguistics

WoS			Scopus		
Citation	**Reference**	**Cluster ID**	**Citation**	**Reference**	**Cluster ID**
106	Friederici (Friederici, 2003)	0	149	Chomsky (Chomsky, 2002)	2
95	Hickok (Emmorey et al., 1998)	5	132	Friederici (Friederici, 2003)	0
86	Chomsky (Chomsky, 1986)	6	122	Hickok (Emmorey et al., 1998)	0
73	Hagoort (Hagoort, 2005)	0	104	[Anonymous], 1974	1
68	Caramazza (McCloskey et al., 1985)	2	98	Caramazza (Caramazza & Brones, 1979)	2
55	Pulvermuller (Pulvermüller et al., 2006)	1	94	Hagoort (Hagoort, 2005)	0
52	Price (Crinion et al., 2006)	1	92	Caplan (Caplan & Marshall, 1975)	2
50	Binder (Bellgowan et al., 1998)	3	87	Goodglass (Blumstein et al., 1977)	2
50	Kutas (Federmeier et al., 2007)	0	74	Bates (Bates & Rankin, 1979)	2
48	Bates (Bates Thal, D., Finlay, B., & Clancy, B., 2002)	6	71	Geschwind (Mesulam et al., 1976)	6

brain that encompasses dorsal and ventral streams for both vision and audition (Arbib, 2017). The researcher evaluated two accounts of language comprehension and one of language production. It is suggested that ventral processes feed much of syntactic and semantic processing, that both function at the level of words as signifiers, and that the dorsal pathway and its involvement in perception and production of words as articulatory activities play only a minor part in this processing (Arbib, 2017).

Another part of neurolinguistics research is identifying the authors who have contributed the most to the field and describing their research topics and themes. Arbib and Caplan discussed and classified a number of models that relate language function to neural processes (Arbib & Caplan, 1979). They did not report new observations, but they attempt to clarify conceptual issues in neurolinguistics by confronting classic neurological approaches with developments in psycholinguistics, artificial Intelligence, neuroscience, and cybernetic modelling (Arbib & Caplan, 1979). Research on the neural structures that are involved in sentence comprehension in 60 stroke patients with syntactic comprehension deficits showed that lesions in both the left and right hemispheres have an impact on sentence comprehension, with the former having a greater impact (Caplan et al., 1996). Regarding syntactic circuits or the role of the brain in creation of serial order in sentences, it has suggested that link neuroscientific evidence to linguistic facts is vital to better understand the brain mechanisms of syntax (Pulvermüller, 2000). Investigation on the syntactic priming and lexical boost effects on the neuronal activity in brain regions subserving syntactic processing showed repetition suppression in the left IFG and left MTG for sentences with repeated

Table 6. Detected bursts in neurolinguistics research

WoS			Scopus		
Burst	**Reference**	**Cluster ID**	**Burst**	**Reference**	**Cluster ID**
7.97	Coudry (Coudry, 2018)	15	34.34	[Anonymous], 1974	1
6.51	Grodzinsky (Y. O. S. E. F. Grodzinsky et al., 1985)	2	13.03	Hickok (Emmorey et al., 1998)	0
6.47	Bornkessel-Schlesewsky (Bornkessel-Schlesewsky et al., 2015)	0	9.56	Grodzinsky (Y. Grodzinsky, 2000)	0
6.34	Demonet (Paulesu et al., 2001)	3	9.48	Binder (Bellgowan et al., 1998)	0
6.14	Tyler (Wright et al., 2012)	2	8.85	Caramazza (Caramazza & Brones, 1979)	2
5.79	Rilling (Mascaro et al., 2017)	0	8.85	Tyler (Wright et al., 2012)	3
5.58	Fedorenko (Fedorenko & Thompson-Schill, 2014)	4	8.63	Pinker (Pinker, 2004)	0
5.56	Fitch (Wilkins et al., 2014)	0	8.44	Caplan (Caplan & Marshall, 1975)	2
5.51	Franchi (Costanzo et al., 2018)	15	8.19	Goodglass (Goodglass et al., 1974)	1
5.09	Kuhl (Zhang et al., 2009)	1	8.12	Hagoort (Hagoort, 2005)	0

syntax and for sentences with a repeated verb (Segaert et al., 2013). Research on whether brain activation topographies elicited by words are driven by lexical or semantic factors, or by both using event-related fMRI showed that topographical differences in brain activation, especially in the motor system and inferior frontal cortex, are driven by semantics and not by lexical class (Moseley & Pulvermüller, 2014). Study on whether Broca's area is relevant for syntactic integration processes, or it is associated with working memory mechanisms relevant for language processing, hemodynamic responses elicited while participants processed German indirect wh-questions were examined that results suggested that Broca's area plays a critical role in syntactic working memory during online sentence comprehension (Fiebach et al., 2005). According to neuroimaging studies, a complex neurofunctional organization based on the interconnection between shared and distinct neural circuits is involved in the languages mastered by bilingual speakers and several factors such as age of acquisition, proficiency level, modality of acquisition, and level of exposure implicate the exact pattern of such organization (Marini et al., 2012).

In addition, among 5,104 documents, we identified the most cited documents that have received the most attention from neurolinguistics researchers. Addressing various technical and methodological issues on neuroimaging techniques in the domain of normal and pathological language physiology showed that functional neuroimaging has become a fundamental approach and could be even more important in the future, by improving the precision of diagnosis, prognosis, and therapeutic interventions in brain-damaged patients (Démonet et al., 2005). A neurobiological model of language that addressed the inadequacies of the traditional Wernicke-Lichtheim-Geschwind model built on the division of language processing into three parts: Memory, Unification, and Control (Hagoort, 2013). In the field of the neurobiology of language, a paradigm shift occurred in which the predominant Broca—Wernicke–Geschwind language model was revised by the connectional anatomy of three putative processing streams—dorsal,

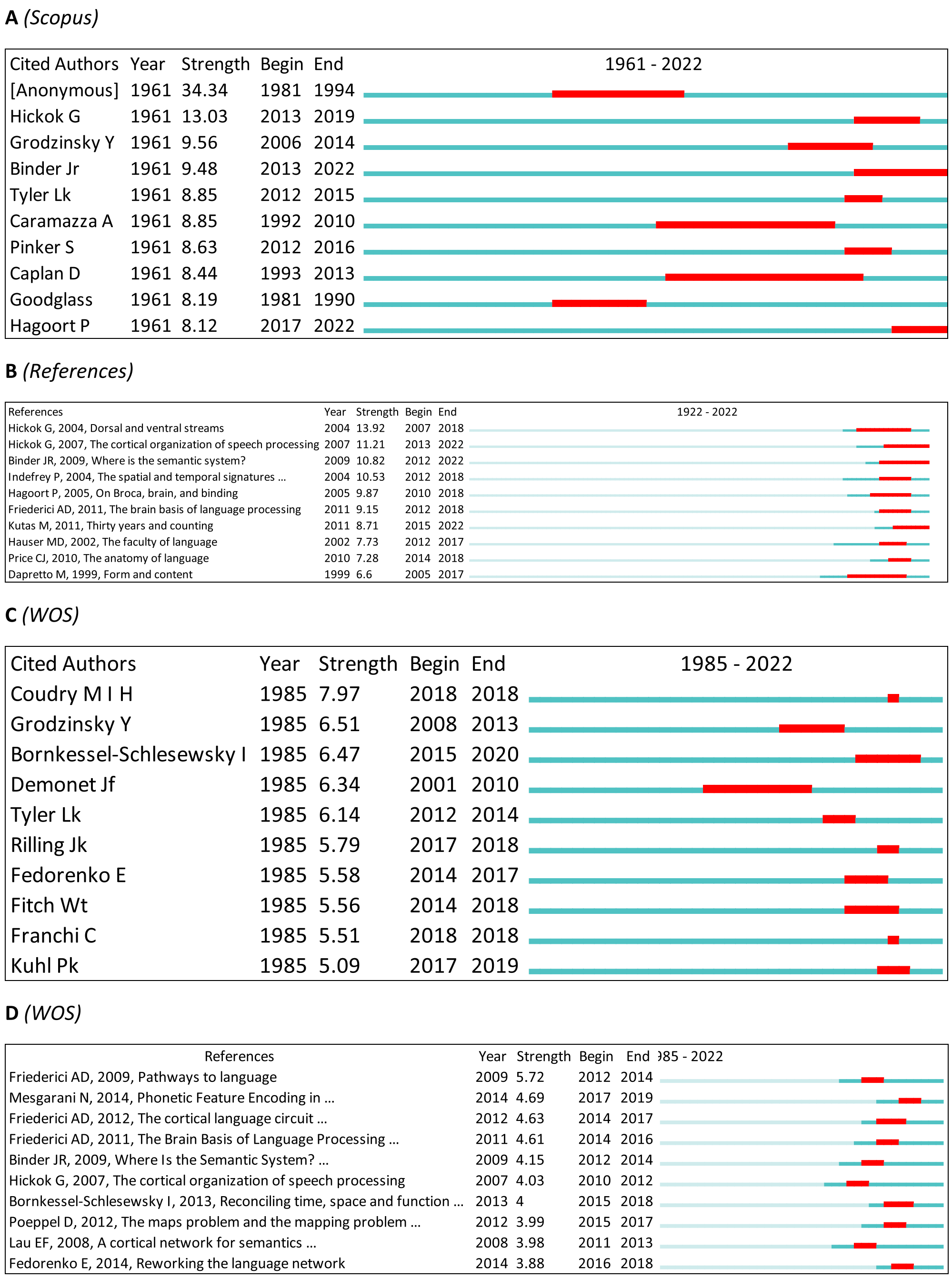


Figure 14. Top 10 authors and references with the strongest citation bursts.

ventral, and motor— suggesting that the classical language model is quickly being replaced with more comprehensive models influenced by advances in neuroimaging methodologies (Dick et al., 2014a). Arbib offered hypotheses on evolutionary changes within and outside the mirror system hypothesis which may have occurred to equip Homo sapiens with a language-ready brain (Arbib, 2005). To explain primates' exceptionally big brains, the social brain (or Machiavellian Intelligence) theory was proposed. It was proposed that the cognitive challenges of living in complexly connected social groupings were chosen for advances in executive brain function. Although there were some interpretation issues, the evidence supported the social brain concept (Dunbar, 2003).

Table 7. Between centrality for top central authors in neurolinguistics

WOS			Scopus		
Centrality	Reference	Cluster ID	Centrality	Reference	Cluster ID
115	Hagoort (Hagoort, 2005)	0	598	Chomsky (Chomsky, 2002)	2
112	Friederici (Friederici, 2003)	0	514	Caramazza (Caramazza & Brones, 1979)	2
104	Hickok (Emmorey et al., 1998)	5	496	[Anonymous], 1974	1
99	Caramazza (McCloskey et al., 1985)	2	483	Friederici (Friederici, 2003)	0
95	Chomsky (Chomsky, 1986)	6	469	Goodglass (Blumstein et al., 1977)	2
95	Binder (Bellgowan et al., 1998)	3	467	Bates (Bates & Rankin, 1979)	2
93	Grodzinsky (Y. O. S. E. F. Grodzinsky et al., 1985)	2	466	Caplan (Caplan & Marshall, 1975)	2
90	Caplan (Caplan et al., 1985)	2	456	Geschwind (Mesulam et al., 1976)	6
76	Bates (H. Liu et al., 1992)	6	437	Hickok (Emmorey et al., 1998)	0
68	Price (Crinion et al., 2006)	1	420	Hagoort (Hagoort, 2005)	0

Lastly, Sigma metric enabled us to identify authors and works with the potential for significant citation growth. Hagoort discussed about the role of Broca's area in neuroanatomical, neuropsychological, and cognitive neuroscience perspectives and concluded that Broca's area is not a natural kind at the level of either brain structure or cognitive function (Hagoort, 2005). He proposed to use the term "Broca's complex," to refer to a set of areas subserves more than one

Table 8. Sigma metrics for authors with potential growth in citations

WOS			Scopus		
Sigma	Reference	Cluster ID	Sigma	Reference	Cluster ID
0	Hagoort (Hagoort, 2005)	0	0	Chomsky (Chomsky, 2002)	2
0	Friederici (Friederici, 2003)	0	0	Caramazza (Caramazza & Brones, 1979)	2
0	Hickok (Emmorey et al., 1998)	5	0	[Anonymous], 1974	1
0	Caramazza (McCloskey et al., 1985)	2	0	Friederici (Friederici, 2003)	0
0	Chomsky (Chomsky, 1986)	6	0	Goodglass (Blumstein et al., 1977)	2
0	Binder (Bellgowan et al., 1998)	3	0	Bates (Bates & Rankin, 1979)	2
0	Grodzinsky (Y. O. S. E. F. Grodzinsky et al., 1985)	2	0	Caplan (Caplan & Marshall, 1975)	2
0	Caplan (Caplan et al., 1985)	2	0	Geschwind (Mesulam et al., 1976)	6
0	Bates (H. Liu et al., 1992)	6	0	Hickok (Emmorey et al., 1998)	0
0	Price (Crinion et al., 2006)	1	0	Hagoort (Hagoort, 2005)	0

function in the language domain and certainly other nonlanguage functions as well (Hagoort, 2005). Identifying the brain regions involved in the processing of sentence-level semantic and syntactic information using an event-related functional magnetic resonance imaging (fMRI) paradigm revealed that both semantic and syntactic processes are supported by a temporo-frontal network with distinct areas specialized for semantic and syntactic processes (Friederici, 2003). A significant degree of similarity has been shown in the neurobiology of signed and spoken languages, suggesting that the neural organization of language is largely modality-independent (Hickok et al., 1998). The dichotic listening paradigm was employed in Goodglass and Calderon's (Goodglass & Calderón, 1977) study to test the hypothesis that left hemisphere dominance for verbal content and right hemisphere dominance for tones coexist when tonal and verbal material were presented simultaneously. The results of the study support the idea that the two hemispheres independently process the preferred (verbal vs. tonal) elements of a complex input in parallel (Goodglass & Calderón, 1977).

5. Conclusions

5.1. Practical implications

Strict caution should be used while interpreting scientometric results (van Eck & Waltman, 2014) notwithstanding the the current popularity of these methodological approaches (Moral-Muñoz et al., 2020; van Eck et al., 2010). This begins with data retrieval from numerous sources and avoids the restriction to a single database unless justifiable (i.e., in this study we used Scopus, WOS and Lens). The subsequent stage should involve the use of various tools for the analysis to permit the incorporation of diverse scientometric indications (i.e., in this study we used both CiteSpace and VOSviewer).

5.2. Theoretical implications

This review offers valuable insights that have practical implications for decision-makers and policy-makers in academia. Specifically, it highlights the need to reconsider the university curriculum for language, linguistics, and associated humanities social studies degrees. While neurolinguistics is a topic taught in majors such as neuroscience, cognitive science, and medical sciences, none of these disciplines provide a comprehensive education on linguistics or the neurology of language. Therefore, universities should consider replacing traditional linguistics courses with interdisciplinary courses such as neurolinguistics, biolinguistics, or clinical linguistics, to produce graduates who are better equipped with skills and practical knowledge in response to the evolving needs of society. Furthermore, our study indicates that neurolinguistics knowledge generation is concentrated in North America, Russia, Europe, and Australia, while Asia (excluding China), Africa, and South America exhibit a relatively low level of research in this field. This suggests that it may be beneficial for these nations to modify their curriculum for higher education and incorporate more practical subjects, such as neurolinguistics, to enhance their research capabilities and promote scientific advancement.

5.3. Limitations and future directions

The results of this study highlight the significance of scientometric research in analysing the evolution of neurolinguistics research. However, it is essential to acknowledge the potential limitations of this study. Firstly, the search terms used were limited to "neurolinguistics" and its synonymous terms, which excluded other relevant concepts in the field. Future studies could expand their search strings to include more specific neurolinguistics themes. Although we were aware of publications like "Brain and Language" and "neurolinguistics" that might publish relevant research without using the term "neurolinguistics," we conducted a broad search without excluding these publications. To mitigate this limitation, the top journals found in our study could be analysed, and additional relevant documents from other journals could be added. Secondly, our analysis of the discovered themes and subjects was limited to classifying the 5,104 papers into several clusters. Examining these clusters in detail was beyond the scope of our study. Despite these limitations, our findings provide valuable insights into the development and trends of neurolinguistics research, paving the way for future research to delve deeper into these clusters and explore further themes in the field.

Further, there are several recommendations for future research in neurolinguistics. Firstly, further investigation could be carried out to explore the clusters identified in this study, particularly those related to discourse processing, object knowledge in agrammatic aphasia, and language in autism spectrum disorder. This could involve examining the underlying mechanisms and neural processes involved in these clusters. Secondly, future studies could extend the search terms used in this study to include a wider range of neurolinguistics themes and publications that may not explicitly use the term “neurolinguistics”.

5.4. Conclusions

The present study highlights the importance of scientometric research in guiding scholars in their exploration of past, present, and future directions of a particular topic or field of study, such as neurolinguistics. To this end, we conducted an analysis of the state of the art in neurolinguistics scholarship, utilizing both bibliometric and scientometric metrics. Our analysis included a total of 5,104 neurolinguistics documents published between 1913 and 2022 and revealed eight bibliometric and eight scientometric indices of the growth of neurolinguistics.

One of our key findings was the marked increase in neurolinguistics research during the past two decades, with 3,804 out of 5,104 articles published between 2000 and 2022. We also investigated the size of knowledge production in neurolinguistics by country, university, journal, publisher, research field, author, and most-cited papers, providing insight into the distribution of knowledge generation in this field. Furthermore, utilizing scientometric analysis, we identified the most important and influential authors in the field, as well as those likely to experience citation growth.

Our study also included visual maps of the most frequently occurring keywords in neurolinguistics and clustered the entire dataset, providing a comprehensive overview of the topics and themes that have received the most attention in this field. Overall, our findings demonstrate the utility of scientometric research in evaluating the trajectory of a particular field of study and provide valuable insights for scholars and decision-makers alike.

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Highlights

- A total of 5,104 documents related to neurolinguistics were analyzed in this study.
- The development of neurolinguistics was assessed using a combination of eight bibliometric and eight scientometric indicators.
- Visual maps and tables were used to represent the knowledge domains and growth of neurolinguistics.
- The study examined topics and themes in neurolinguistics through the use of cluster analysis.

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No potential conflict of interest was reported by the authors.

Data availability statement
The data used in this is incorporated in the paper and there is no additional data to be shared.

Contribution statement
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