Landscape of Syntactic Complexity Research (2000–2023): A Bibliometric Review

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This study centers on syntactic complexity from a bibliometric perspective to explore the evolving landscape within this domain. The Bibliometrix R package and VOSviewer were used as bibliometric tools in this study to obtain an overview of syntactic complexity and gain an understanding of current research priorities. Data were collected primarily from the Web of Science core collection database. A compilation of 2,935 documents spanning from 2000 to 2023 forms the database of this investigation. This study provides a comprehensive overview of the current research landscape in the field of syntactic complexity and reports the following findings: (1) Current research themes in syntactic complexity encompass cognition and language processing, child language development, second language writing, speech pathology, and natural language processing (NLP). (2) NLP and computer-based methods have emerged as prominent and enduring research methodologies in the present and future. (3) Future research directions may focus on syntax-related themes, complexity, accuracy, fluency (CAF), and individual differences.

Keywords: syntactic complexity, bibliometric analysis, WoS core collection, VOSviewer, Biblioshiny

Syntactic complexity, a subset of linguistic complexity, involves the diversity of syntactic structures and their varying degrees of sophistication (Ortega, 2003). In the realm of linguistic inquiry, syntactic complexity emerges as a pivotal area of study that traverses the domains of linguistics, neuroscience, education, and beyond (Casal & Lee, 2019; Friederici et al., 2002; Kemper, 1987). Its significance lies in its capacity to unravel the intricate structures that underlie language comprehension and production.

The study of syntactic complexity covers a diverse array of dimensions, spanning across varying aspects of linguistic structures and their intricate interplay with cognition, processing, and acquisition (Housen & Kuiken, 2009). Scholars can investigate syntactic complexity through a multitude of perspectives and methodological approaches, thereby facilitating a profound elucidation of the relationship between linguistic structure and cognitive mechanisms.

However, despite the wealth of individual studies on syntactic complexity, there is a noticeable lack of comprehensive reviews specifically focused on this area of research. Some literature reviews incorporate syntax as one of the research components, but it generally assumes a subordinate role rather than constituting the primary focus (Grevisse et al., 2023; Jackson & Suethanapornkul, 2013; Norhan et al., 2023). A comprehensive analysis of the overall publication landscape and developmental trends involved in syntactic complexity remains lacking. Undertaking a bibliometric study on syntactic complexity holds the potential to provide invaluable insights into navigating the trajectory of this field, allowing for timely realignment of research interests and the tracking of emerging investigative directions.

Recognizing this void, we embark upon a comprehensive bibliometric study to address this dearth. This study collects a database comprising 2,935 documents published between 2000 and 2023 from the Web of Science core collection database. By employing bibliometric analysis software, we investigate the dynamic trajectories evident in publications and citations over time. Our inquiry involves the identification of paramount sources, influential articles, distinguished researchers, and

notable affiliations. Furthermore, we illuminate the social structures that interlink authors, showcasing the complex web of connections within this scholarly context. Additionally, a comprehensive exploration of global academic contributions is undertaken, spanning across various nations. Simultaneously, we engage in an analysis of keywords, delving into emergent thematic domains that shape the scholarly landscape. The analysis of the literature equips us to pinpoint research gaps and discern the frontier issues within the domain of syntactic complexity.

Relevant Studies

Scholars have endeavored to compile and synthesize research on syntactic complexity. Numerous academic journals have disseminated research articles on diverse facets of this topic (Friederici et al., 2002; Housen & Kuiken, 2009; Norhan et al., 2023; Ortega, 2003). These articles delve into themes such as the interplay of semantics and syntax (Gunter, 1997), cognitive load and language processing (Seeber, 2011), second language acquisition (Bulté & Housen, 2014), cross-linguistic comparisons (Phillips, 2010), individual differences (Just & Carpenter, 1992), and educational implications (Lu, 2011).

Moreover, scholars have conducted reviews, albeit a minor portion, that meticulously assess the existing scholarly landscape. From an educational and grammatical perspective, Frantz et al. (2015) distilled insights gleaned from linguistic research centered on academic English to advocate for the explicit incorporation of syntactic complexity at the sentence level as a distinct and discernible component within a model for gauging text complexity. Based on the author's comprehensive review, it has been observed that certain linguistic characteristics might have commonalities across various academic disciplines, while others exhibit specificity unique to a particular field of study. Jagaiah et al. (2020) classified diverse syntactic complexity metrics (SCMs) selected from 36 studies into six discrete categories. In this review, an examination was conducted to assess the diverse utilization of SCMs based on factors such as genre, grade level, writing proficiency, and writing quality. The author suggests that to effectively analyze a substantial dataset and multiple SCM categorizations, the implementation of an automated scoring system is essential. Adopting a vantage point centered on language acquisition and linguistic impairment, Patel (2003) explored syntax intricacies, utilizing contemporary

neuroimaging data and robust theoretical frameworks to propose a distinct convergence between syntactic processing in language and music. This gives rise to hypotheses that can be empirically tested, including the hypothesis that syntactic comprehension difficulties observed in individuals with Broca's aphasia do not exclusively affect language but also have an impact on music perception. Concurrently, Klieve et al. (2023) analyzed syntactic utilization in children with hearing loss (CHL) who use spoken language. This scrutiny drew from a comprehensive review of 42 relevant studies. The results underscore the importance of developing assessment protocols and analytical approaches that more effectively facilitate the characterization of intricate syntax profiles in CHL. Undoubtedly, these relevant studies hold value as they have identified observable characteristics inherent in syntactic complexity. However, syntactic complexity is a subject of interdisciplinary research that encompasses fields such as second language writing, psychology, speech pathology, cognitive science, among others. Existing reviews primarily focus on individual disciplinary applications of syntactic complexity without offering a comprehensive, interdisciplinary analysis. Furthermore, summarizing and quantitatively analyzing the evolution of an interdisciplinary field over an extended timeframe in traditional review articles can be challenging. Given the exponential growth in literature within this field, there is a pressing requirement for effective tools to manage this extensive body of work and gain a precise understanding of emerging research trends and directions.

The selection of review methodologies is contingent upon the specific objectives underpinning the review. Given the current study's objective of comprehensively elucidating and evaluating existing scholarship related to syntactic complexity, employing bibliometric analysis is justified. This approach aims to cover a broad range of scholarly investigations, with the primary goal of enhancing research accuracy. Bibliometric analysis serves as a cogent instrument facilitating the quantification of scholarly output within a given domain. This encompasses the chronologically sequenced production, identification of seminal authors, affiliations and national origins of scholarly contributors, prominently referenced sources, interlinked networks of co-cited works, collaborative frameworks, and recurrently explored themes. These multifaceted aspects are amenable to quantitative representation and visual presentation (Paul & Criado, 2020). Furthermore, the key advantage of bibliometric analysis over traditional review methods lies in its ability to generate precise, impartial, and comprehensive visualizations

of scientific knowledge (Rejeb et al., 2022).

Therefore, utilizing a bibliometric framework, we compiled a dataset comprising 2,935 scholarly publications focused on syntactic complexity. These sources, spanning from January 2000 to June 2023, were curated from the WoS core collection. It is important to underscore that, to the best of our knowledge, our investigation represents the first study into the realm of syntactic complexity research using bibliometric analysis. More precisely, our investigation is steered by the subsequent research inquiries:

1. What is the current research status of syntactic complexity, encompassing publication and citation trends, the most influential sources, the social structure among researchers, and the global collaboration networks?

2. What dominant themes emerge in syntactic complexity research, as evidenced by the co-occurrence of keywords?

3. How does the trend of syntactic complexity research unfold, as revealed by topic evolution analysis and strategic mapping, and what implications does it hold for future research?

Methodology

Bibliometric Analysis

Bibliometrics is a branch of information science that applies quantitative analysis and statistical methods to study various types of scholarly publications, including academic articles, reviews, books, and other forms of literature. This study utilizes the Bibliometrix R package to facilitate the systematic collection and comprehensive analysis of data, wherein the package incorporates the graphical interface referred to as Biblioshiny (Aria & Cuccurullo, 2017). To construct visualization networks, we employed VOSviewer 1.6.19, renowned for its proficiency in this domain (Bretas & Alon, 2021; Chen et al., 2022; Khan et al., 2022). Both of these software tools hold a prominent status within the field and enjoy widespread adoption, particularly for the purpose of scrutinizing and interpreting bibliometric data.

Data Extraction

In this study, Web of Science Core Collection was utilized as database to ensure the quality of the materials. We first used Advanced Search Query Builder in the WoS database to develop a keyword search to retrieve data on July 22, 2023. The keywords ["syntactic complexity" OR "syntactic

sophistication"] were searched in the WoS core collection without limiting the data range, categories or fields. Then the full records and cited references of 3,055 documents were collected in plain text file format. We further refined the documents written in English to make sure the full comprehension of the materials so that the relevance of the documents can be confirmed. As this is a thematic study, document types have been preserved to include research articles, proceeding papers, review articles, book reviews, and book chapters in order to extract a comprehensive range of themes. The data of 2,935 documents published during 2000–2023 was retrieved from the WoS core collection. (The first article collected in WoS is published in 1970). These documents were then extracted and analyzed in Biblioshiny and VOSviewer.

Results

Current Status of Syntactic Complexity Research

Dynamics of Publications and Citations

To answer RQ1, we report the annual trends of publications and citations, the most influential sources, social structure analysis among researchers, and global academic contributions among countries. The annual citation trends and scientific outputs from the year 2000 to 2023 are illustrated in Figure 1, illuminating the dynamic fluctuations in scholarly impact and research productivity. The trend of annual scientific production indicates a gradual increase in the number of research publications within the field. Over the period, the annual scientific outputs display consistent growth, commencing at 39 publications in 2000 and culminating at its zenith of 302 publications in 2022. This suggests a continuous expansion of research activity and scholarly output in the past two decades.
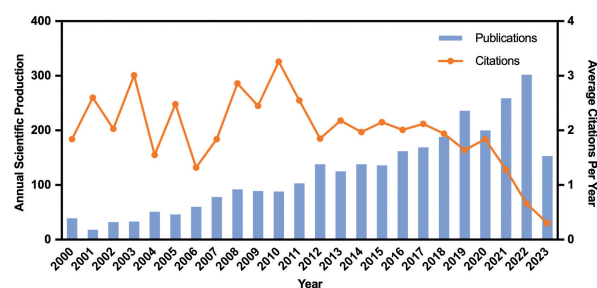

Figure 1. Annual Citation Trends and Scientific Output

In contrast, the average number of citations received by papers each year exhibit a divergent pattern compared to publications. Notably, the average citations per year demonstrated significant fluctuations with an overall upward trajectory before 2010. It gradually increased from 1.84 citations per paper in 2000 to a peak of 3.26 citations per paper in 2010, indicating substantial attention and recognition of research output during that period. However, there has been a gradual decline in this indicator since its peak in 2010. Possible reasons for this trend include the following: First, research in a specific topic area may have become saturated, making it challenging for new studies to garner citations. Researchers might be more inclined to cite earlier or classic studies rather than the most recent ones. Second, as the academic research field expands and research output increases, a larger number of papers are vying for a limited pool of citations. This may lead to citations being dispersed among a greater number of papers, consequently reducing the average number of citations per paper. Third, research papers typically require some time to undergo peer review, be published, and attract widespread citations. Recent studies may not have had sufficient time to accumulate a substantial number of citations.

Most Influential Sources

The documents with the theme of syntactic complexity in Table 1 present key metrics for various sources in the field of language and cognitive sciences, including their H-index, total citations, number of documents, and the year of the first publication (PY_Start). These metrics offer insights into the scholarly impact and productivity of each source. The H-index, which represents the number of articles that have been cited at least h times, serves as an indicator of the sources' academic influence (Bornmann & Daniel, 2007). Among the listed sources, *Brain and Language* has the highest H-index of 27, followed by *Journal of Second Language Writing* with an H-index of 21. The number of documents reflects the total number of publications from each source. *Frontiers in Psychology* has the most substantial publication output, with 77 documents, followed by *Journal of Speech Language and Hearing Research* and *Aphasiology* with 57 and 46 documents, respectively. Additionally, the year of the first publication provides insights into the longevity of each source's scholarly contribution. Some sources, such as *Brain and Language*, *Journal of Memory and Language*, and *Neuropsychologia* have their first publications dating back

to the year 2000, indicating their established presence in the field.

Table 1

Top 10 Publication Sources (Ranked by H-index)

Sources	H-index	TC	NP	PY_Start
Brain and Language	27	2521	47	2000
Journal of Second Language Writing	21	1684	40	2008
Journal of Speech Language and Hearing Research	20	1230	57	2004
Journal of Memory and Language	18	1708	23	2000
Aphasiology	17	987	46	2000
Neuroimage	16	1098	20	2002
Frontiers in Psychology	15	933	77	2011
Lingua	14	877	31	2007
Neuropsychologia	14	724	22	2000
Cognition	13	1649	19	2007

Note. TC: Total citations, NP: Number of publications, PY_Start: The year of the first publication.
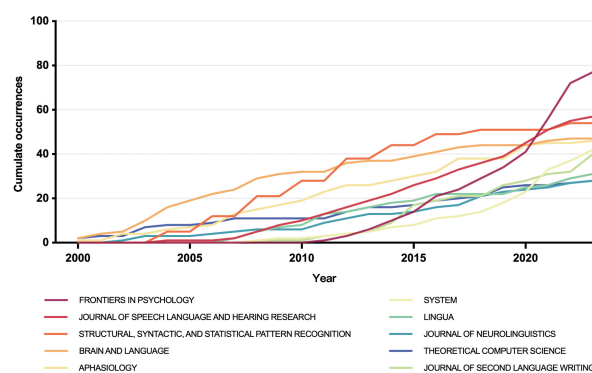

Figure 2. Source Growth

For enhanced visual clarity, Figure 2 displays the growth patterns over the past two decades for the ten journals that have published the most relevant articles involving syntactic complexity. A thorough analysis of the data reveals distinct growth patterns over the years. Specifically, certain journals, such as *Frontiers in Psychology* and *Journal of Speech Language and Hearing Research*, demonstrate consistent and substantial growth in publications, indicating increasing research interest and impact. On the other hand, some journals, like *Brain and Language* and *Aphasiology*, maintain relatively stable publication rates. In addition, moderate growth is observed in journals like *Journal of Second Language Writing* and *Lingua*. Among the listed journals in Figure 2, *Frontiers in Psychology* exhibits the

highest growth rate in recent years.

Social Structure Analysis Among Researchers

Figure 3 depicts the collaborative network of scholars actively involved in investigating syntactic complexity, wherein 98 researchers are classified into 11 principal research communities. The red cluster, represented by Shravan Vasishth, John Hale, and Nicole Stadie, encompasses the largest number of authors, consisting of 15 scholars. Their research is predominantly centered on psycholinguistics and neurolinguistics. On the other hand, the green cluster, epitomized by eminent Japanese academics, Masatoshi Koizumi and Hajime Ono, comprises 13 researchers. Their scholarly endeavors chiefly revolve around the realm of cognitive linguistics and neurolinguistics. Authors affiliated with the yellow cluster demonstrate stronger partnerships with their counterparts in the purple, orange, and brown clusters, while those within the blue cluster exhibit
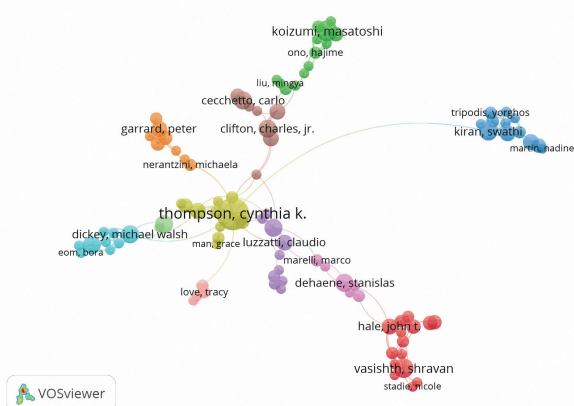
comparatively weaker associations with other researchers. Of significance, a total of 998 authors were calculated in the collaborative analysis. However, only 98 scholars partake in the collaborative network concerning research on syntactic complexity, indicating relatively limited collaboration among researchers in this field.

Figure 4 illustrates the construction of the authors' co-citation network of syntactic complexity. A collective link strength of 585,290 was calculated from a network of 81,121 links. Furthermore, 787 citations were categorized into five distinct clusters, with the green, purple, blue, and yellow clusters displaying stronger interconnections, followed by the red cluster. Within each cluster, the nodes with the highest degree include Friederici AD, Gibson E, Thompson CK, and XF Lu. Particularly noteworthy is the research focus of the first three scholars, primarily revolving around psycholinguistics, neurolinguistics, and language processing, which explains the close proximity of their nodes in the network due to the alignment of their research domains.

In contrast, XF Lu's scholarly outputs in corpus linguistics and second language acquisition result in a relatively greater distance between his node and others within the network. As the most cited author in the field, XF Lu's article titled *Automatic Analysis of Syntactic Complexity in Second Language Writing* has garnered 959 citations. This widespread citation can be attributed to the fact that the author developed the L2 Syntactic Complexity Analyzer, a tool designed to automate the analysis of syntactic complexity in written English language samples. Consequently, many scholars utilize this software as a benchmark for measuring syntactic
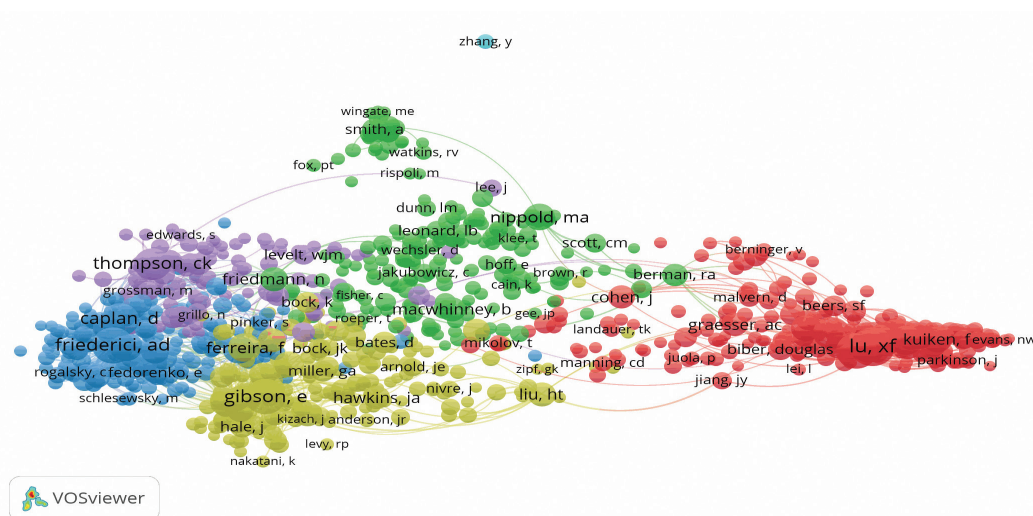

Figure 3. Authors' Collaboration Network

Figure 4. Authors' Co-citation Network

complexity.

Furthermore, the presence of structural holes, represented as gaps between clusters, suggests instances where specific academic works facilitate connections across diverse research clusters, thereby fostering potential knowledge flow between distinct domains (Rejeb et al., 2022). These structural holes play a critical role in linking separate areas of research and promoting interdisciplinary collaboration and intellectual exchange. Figure 4 illustrates the presence of structural holes between the red cluster, which signifies the domain of second language acquisition, and the fields of neurolinguistics and psycholinguistics. This observation implies the potential for enhanced integration of research efforts across these domains to attain a more holistic comprehension. For instance, neuro-linguistics could leverage neuroimaging methodologies to explore the neurophysiological underpinnings of second language acquisition, while psycholinguistics could investigate the cognitive processes of language learners, thus affording a more profound understanding of their learning requisites.

The co-citation network of authors (Figure 4) represents the simultaneous citation of two authors' papers by other documents. This network serves as a tool to discern researchers who possess reciprocal influence within the academic community and facilitates an investigation of their research associations and collaborative endeavors. In contrast, the bibliographic coupling network of authors (Figure 5) signifies a situation where two researchers share common references within their respective paper citation lists.

Figure 5 provides an illustrative depiction of the bibliographic coupling network of authors, with connections between them being weighted according to the total link strength. The network shows the existence of five distinct clusters. Particularly noteworthy are the red and green clusters, which stand out as the most dominant elements in the network. Such dominance suggests that authors within these clusters exhibit a significant convergence of common references in their citation lists, thereby implying a considerable degree of similarity in their research interests or thematic pursuits. On the other hand, the remaining clusters appear relatively smaller in proportion, indicating less pronounced connections between authors operating within these research areas. This observation could be attributed to their research interests being comparatively more independent, or it may signify a scarcity of cross-references in their citation patterns.

Global Academic Contributions Among Countries

A comprehensive overview of the global academic contributions to syntactic complexity research is presented in Figure 6, encompassing data from 78 countries. The United States emerges as the most prominent player in the field, leading with a substantial number of publications (1,744) and a significantly high total citation count (24,323). Following closely, China demonstrates a noteworthy number of publications (629), indicating its growing engagement in syntactic complexity research. However, the relatively lower total citation count (1,712) suggests the need for the research findings to gain recognition within the academic community.

Among the European countries in the dataset, Germany stands out with 432 publications and 4,733 citations, followed closely by the United Kingdom with 417 publications and 4,948 citations. France has 292 publications and 1,296 citations, while Italy contributed 222 publications and received 1,300 citations. These numbers highlight the research productivity and impact of these European nations in the academic landscape, underscoring their significant contributions to advancing knowledge in syntactic complexity
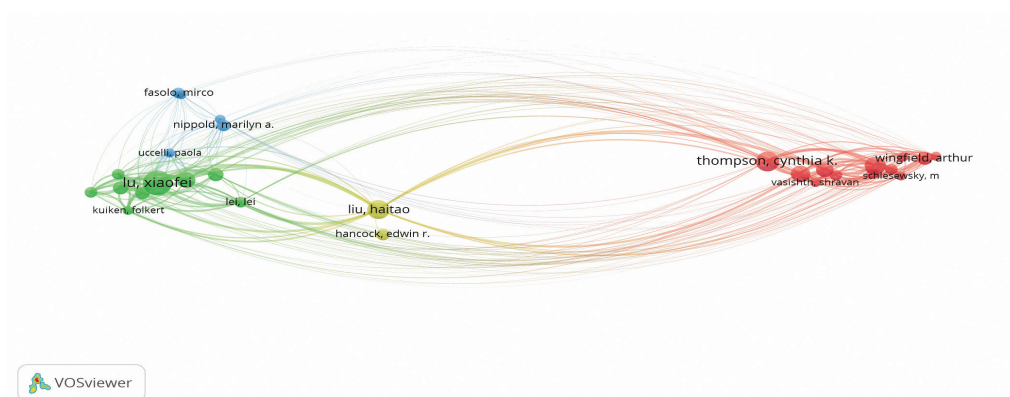

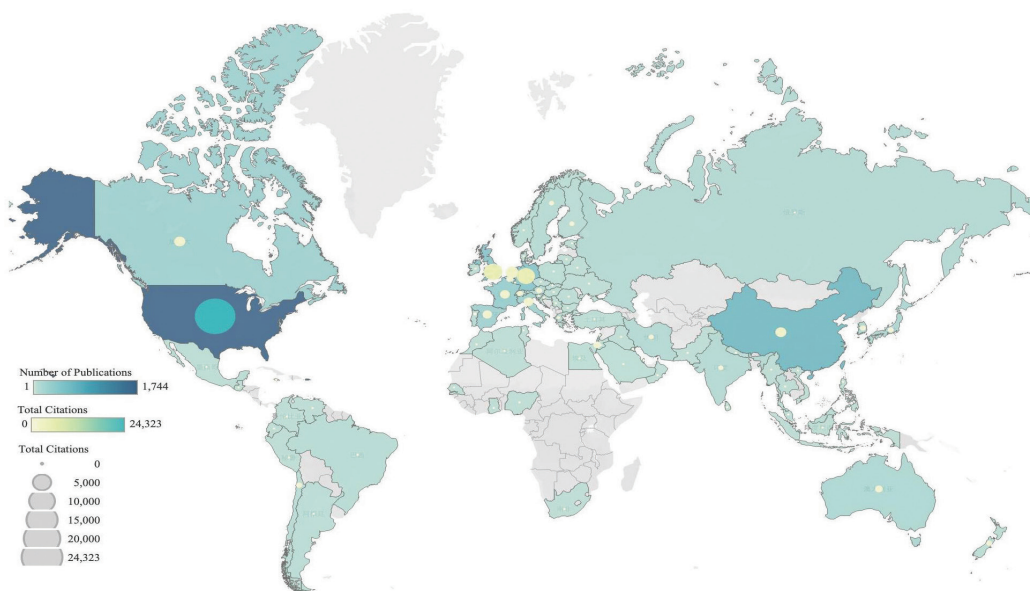*Figure 5.* Authors' Bibliographic Coupling Network

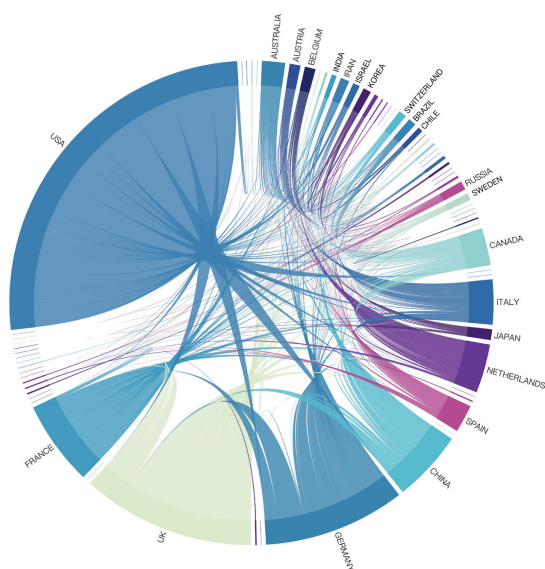*Figure 6.* Countries' Publications and Citations

research.

Figure 7. Collaboration Map of Countries

The world's collaboration networks are visually showed in Figure 7, in which the shaded area can reflect the level of academic exchange and collaboration between 71 countries. The countries with larger shaded areas in the chord diagram have their names displayed in the figure. Conversely, countries without labeled names indicate relatively fewer connections in terms of academic cooperation concerning syntactic complexity. By observing the shaded area in the chord diagram, it becomes evident that the United States has

the closest and most extensive collaborations with almost a quarter of all the countries. Following closely are the United Kingdom, Germany, France, China, the Netherlands, Italy, and Canada, among others. This trend of collaboration aligns closely with the number of publication and citation of the various countries as depicted in Figure 6.

Dominant Themes in Syntactic Complexity Research

RQ2 addresses the prevailing thematic patterns that arise in syntactic complexity research. Accordingly, this section analyzes both network visualization and overlay visualization of keywords. These methodologies are employed to present the interconnections and temporal dynamics of research keywords, thereby shedding light on the evolving associations and shifts in themes.

VOSviewer 1.6.19 is applied to generate a keyword co-occurrence network based on the co-occurrence data in the literature. In this network visualization, each keyword is represented as a node, and the co-occurrence relationships between keywords are represented by edges connecting the nodes. The thickness or color of the edges often represents the frequency or strength of co-occurrence between keywords. In Figure 8, 357 keywords are divided into 5 clusters.

The red cluster contains the highest number of items with 97, and the keywords "working memory" and "comprehension" receive the most attention within this

Figure 8. Network Visualization of Keywords

Figure 9. Overlay Visualization of Keywords

cluster. This cluster's keywords illustrate that scholars employ syntactic complexity to assess its impact on cognition and language processing. This includes investigating how sentence structure influences working memory load (Vos et al., 2001), understanding the language comprehension demands of different syntactic structures (Xiao et al., 2016), examining the role of syntactic constraints in sentence processing (Fiebach et al., 2005), and utilizing techniques such as eye-tracking to study how syntactic complexity affects attention and reading speed (Lenzner et al., 2011).

The green cluster ranks second with 81 items, and the keywords "acquisition," "speech," and "children" appear

most frequently. This cluster encompasses topics related to child language development. The primary research areas within this cluster involve the analysis of language samples from individuals with language disorders to assess differences in syntactic complexity compared to typically developing children (Marinellie, 2004; Zebib et al., 2020). Additionally, it explores the impact of syntactic complexity on children's language comprehension and expressive abilities (Leikin & Bouskila, 2004), aiming to aid in the identification and treatment of language disorders.

The blue cluster ranks third with 71 items, with "accuracy," "fluency," "English," and "proficiency" being the most prevalent keywords. These keywords indicate that the content within this field is related to second language writing. In the field of second language writing, syntactic complexity finds primary application in the investigation of writing quality, L2 proficiency, and genres (Kyle & Crossley, 2018; Norris & Ortega, 2009). Moreover, a range of syntactic complexity measures (SCMs) have been utilized to evaluate aspects such as writing quality, second language (L2) proficiency, readability, and formality (Lu, 2010, 2011). This cluster appears relatively independent compared to other fields, which is also reflected in the authors' co-citation network.

The yellow cluster comes in fourth with 64 items and primarily focuses on cognitive linguistics and neurolinguistics, such as "sentence comprehension," "aphasia," "Broca's area," and so on. This cluster pertains to the field of speech pathology. Syntactic complexity is commonly used to assess and study reading disorders (Shankweiler & Crain, 1986), autism spectrum disorders (Durrleman et al., 2016), aphasia (Thompson et al., 2003), and Alzheimer's Disease (Pakhomov, 2011), among others. The utilization of syntactic complexity as a metric enables researchers to gain deeper insights into the linguistic manifestations and impacts of these disorders, ultimately facilitating the improvement of interventions and treatment approaches.

The purple cluster has the fewest number of items, totaling only 44, with the most commonly occurring keywords being "complexity," "knowledge," "algorithm," "deep learning," and "models." It is worth noting that this cluster includes a significant number of keywords related to natural language processing (NLP). These computational methods find extensive applications across the four categories mentioned above, including automatic assessment metrics (e.g., Bulté & Housen, 2014; Lu, 2010; Norris & Ortega, 2009), corpus analysis (e.g., Díez-Bedmar & Pérez-Paredes, 2020; Lu, 2017), and machine learning algorithms (e.g., Lei & Shi,

2023).

The overlay visualization of keywords, depicted in Figure 9, was concurrently generated with Figure 8. The color gradation along the lines signifies the temporal trends, where darker (purple) lines denote research topics that have been prominent in the past, while lighter (yellow) lines indicate more recent and current topics. In contrast to the timeframe selected for Figure 8 (2000–2023), Figure 9 adopts a narrower temporal scope to showcase the latest research trends. It employs literature data spanning the last decade (2012–2022) to delineate the chronological evolution of keyword research. The omission of the year 2023 is attributed to the absence of a clear co-occurrence trend among keywords during this year.

Figure 9 reveals that from 2012 to 2016, the main research hotspots were centered on language processing and comprehension, including "working memory," "language comprehension," "cognitive control," "sentence processing," and "brain." A noticeable shift in research focus occurred after 2016, with a gradual transition towards the realms of grammar and education. Themes such as "writing proficiency," "accuracy," "task complexity," "L2 writing," and "writing quality" gained prominence during this phase. Additionally, with the continuous development of big data, new research approaches like natural language processing and corpora analysis also emerged as recent hotspots. This overlay visualization of keywords provides valuable insights into the evolution of research interests in syntactic complexity over the years. It shows how the focus has shifted from language processing and comprehension to more specific grammar-related and educational aspects. The emergence of new research methods reflects the evolving trends and technological advancements in the field of linguistics and language research.

Trends of Syntactic Complexity Research

Topic Evolution Process

The inquiries presented in RQ3 are tackled within this section through a comprehensive analysis of the alterations in both the topic evolution and the strategic map of syntactic complexity. The thematic evolution Sankey diagram can incorporate both "keywords plus" and "author's keywords" as variables, illustrating the changing trends of topics over different years. "Keywords plus" are additional keyword lists generated by literature databases or publishers through content analysis and mining of the documents. These keywords are usually extracted from the literature but not necessarily
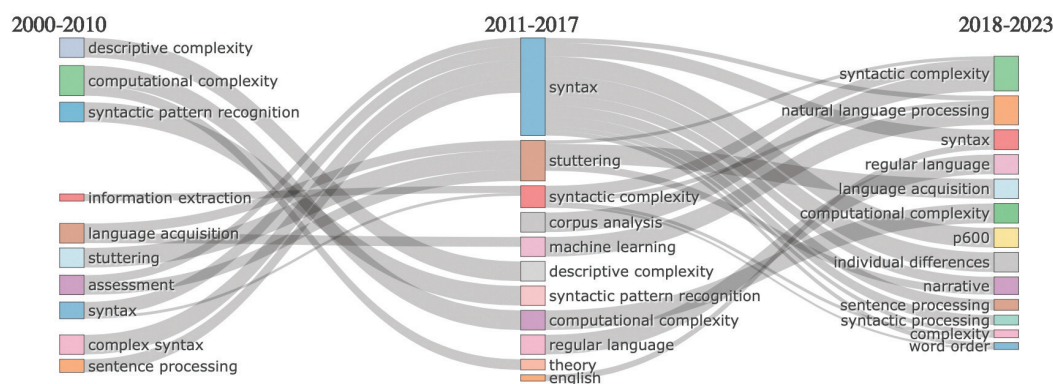
Figure 10. Topic Evolution Process of Syntactic Complexity

provided by the original authors. While "author's keywords" represent the keyword lists provided by the original authors to describe the main themes and content of the literature, which are typically selected by the authors themselves when submitting articles, and often reflect the authors' perception of the most crucial topics and focal points of their work. After comparing Sankey diagrams generated from both variables, this study utilizes "author's keywords" as the variable, as it yields a more extensive and relevant set of keywords closely aligned with the research content of syntactic analysis. Therefore, the thematic evolution of syntactic complexity from 2000 to 2023 was analyzed, and Figure 10 presents a three-stage map with 2010 and 2017 as the dividing points. This map illustrates the occurrences and transitions of various topics from 2000 to 2010, as well as their evolution from 2011 to 2017 and from 2018 to 2023.

During the initial decade spanning from 2000 to 2010, syntactic complexity did not emerge as a predominant subject of inquiry. Instead, the field featured related concepts such as "syntax" and "complex syntax," indicative of its nascent developmental phase. During this epoch, the thematic concerns associated with syntactic complexity may be distilled into three principal domains: computer science and information processing, language acquisition, and language assessment. Within these domains, the terminological focus centered predominantly on computer science and information processing as a methodological approach for investigating syntactic complexity. Notably, terminology pertinent to this period encompassed "descriptive complexity," "computational complexity," "information extraction," "syntactic pattern recognition," and "information extraction," all situated within the ambit of research methodologies.

Descriptive complexity primarily focuses on delineating

how formalized languages can be employed to expound upon distinct syntactic structures and evaluates the degree of challenge associated with representing and processing information embedded within these structures. In contrast, computational complexity is more oriented toward scrutinizing the computational challenges intrinsic to syntactic complexity issues. It seeks to ascertain whether specific tasks related to syntactic analysis or processing can be feasibly accomplished within reasonable temporal constraints or necessitate substantial computational resources, as elucidated by Jakubowicz and Nash (2001). This endeavor proves instrumental in appraising the practicability of addressing syntactic complexity within real-world applications. In terms of research content, the inaugural phase of inquiry was characterized by a focal interest in the domains of first language (L1), second language (L2), third language (L3), and child language acquisition (Lu, 2009; Mayberry, 2007), alongside the realm of language assessment (Nation & Snowling, 2000).

In the second phase (2011–2017), syntactic complexity emerged as a new focal point, evolving from the groundwork laid in the initial stage of information extraction and syntax. This period witnessed a close interrelation between syntactic complexity and the research methodology of information extraction. Research endeavors during this time primarily concentrated on the handling of textual data with intricate grammatical structures (Evans, 2014). These studies aimed at simplifying the grammatical structures of sentences to facilitate easier information extraction. For instance, this was achieved by classifying potential coordinators in sentences (e.g., commas, and coordinating conjunctions) and subsequently employing recursive algorithms to transform sentences containing these coordinators into a series of simpler

sentences (Evans, 2011). Alternatively, through information extraction, sentences characterized by complex linguistic structures were converted into simplified, syntactically correct sentences, from which propositions were extracted in the form of core relationship tuples and accompanying contextual information (Cetto et al., 2018).

Furthermore, new topics that emerged from 2011 to 2017 included "corpus analysis," "machine learning," "regular language," "theory," and "English." Specifically, "corpus analysis," "machine learning," and "regular language" were novel method-related themes, signifying researchers' quest for more advanced computational tools and techniques to delve deeper into the study of syntactic complexity. "Theory" pertained specifically to computational complexity theory, indicating the continuation of research methods from the preceding phase. The appearance of "English" as a keyword underscored the language's prominence as the primary focus of investigation. Additionally, "syntax," serving as both the unit of study and a principal subject matter in the realm of syntactic complexity, experienced significant development. "Stuttering" also remained a research hotspot, intricately linked with language acquisition and assessment. Researchers frequently employed syntactic complexity as a pivotal metric to comprehensively understand the linguistic characteristics of individuals with stuttering disorders, assess their therapeutic needs, monitor language development, and evaluate treatment efficacy (Hollister et al., 2017; Usler et al., 2017).

In the third phase (2018–2023), several new themes have emerged, including "natural language processing," "P600," "individual differences," "narrative," "sentence processing," "syntactic processing," and "word order." In terms of research methodology, descriptive complexity, machine learning, and

syntactic pattern recognition have been supplanted by the field of natural language processing, marking a comprehensive evolution in the analytical approaches to syntactic complexity. Regarding research content, narrative texts have assumed a predominant role as the primary genre of investigation. The inclusion of the theme "individual differences" signifies researchers' growing interest in understanding individual variations in syntactic comprehension and processing. This interest may encompass factors such as individuals' linguistic backgrounds, cognitive abilities, and age, and their impact on syntactic understanding. Studies related to "P600" typically pertain to the domain of neurolinguistics, focusing on the relationship between language processing and brain activity. Keywords such as "sentence processing" and "syntactic processing" indicate that researchers have increasingly turned their attention to elucidating the neural mechanisms underlying grammar and syntactic processing at a neuroscientific level. The changes in research focal points during the third phase will be further analyzed in detail in the strategic map (Figure 11).

Recent Theme Analysis

The strategic map, a two-dimensional graph constructed with the *Density* as the vertical axis and the *Centrality* as the horizontal axis, is presented in Figure 11. According to Cobo et al. (2011), density represents the strength of connections between basic knowledge units within individual topics. A higher density value indicates a greater maturity level of the topic. Centrality, on the other hand, signifies the strength of connections between a particular topic and other topics. A higher centrality value implies closer associations with other topics, placing the topic at the core of all research subjects.
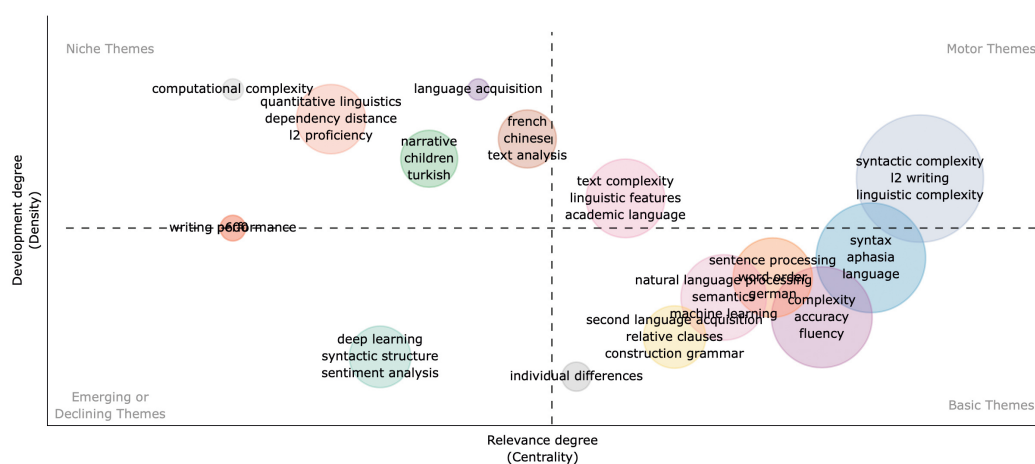

Figure 11. Strategic Map of Syntactic Complexity (2018–2023)

Based on the density and centrality values, the rectangular coordinate system is divided into four quadrants. In this section, we focus on a more detailed thematic analysis of the third phase, as depicted in Figure 10, covering the most recent five years (2018–2023), in order to ascertain the latest research themes and directions.

Motor themes, presented in the first quadrant, are highly mature and core topics. The theme of "syntactic complexity" encompasses various subjects, including "L2 writing," "linguistic complexity," "task complexity," "academic writing," and "corpus linguistics." From 2018 to 2023, researchers have made significant contributions to the analysis of syntactic complexity measures that impact writing level, particularly in investigations related to writing quality, L2 proficiency, and genre distinctions (Casal & Lee, 2019; Zhang & Lu, 2022). There is also a limited body of research that examines the development and variation of syntactic complexity in spoken language, as exemplified by Vercellotti (2019), who utilized productive complexity measures (such as AS-unit length, clause length, subordination) and three exploratory measures of structural complexity (namely, syntactic variety, weighted complexity scores, frequency of nonfinite clauses) to assess the variability of syntactic complexity in the speech of L2 learners enrolled in an intensive English program. "Text complexity" is another developed research topic. Studies involving the application of text complexity for detecting linguistic features have expanded significantly. Apart from academic writing, this includes areas like reading fluency and comprehension (Amendum et al., 2018), readability assessment (Vajjala & Lučić, 2018), fake news detection (Verma et al., 2021), and automatic essay scoring (Dasgupta et al., 2018), among others.

Niche themes, located in the second quadrant, represent topics that are highly developed but not particularly significant. "Quantitative linguistics" is one of these niche themes, encompassing concepts such as "dependency distance" and "L2 proficiency." Dependency distance refers to the lexical distance (typically measured in terms of word count or arc length) between a word and the other words it depends on within a sentence. This metric is employed to study sentence structure, complexity, and comprehension difficulty. Dependency distance is utilized as an indicator of syntactic complexity and applied to predict the difficulty of interpreting tasks (Jiang & Jiang, 2020), explore the impact of the dependency distance minimization constraint on word order preferences (Yadav et al., 2020), assess discourse complexity (Sun & Xiong, 2019), among other processes, predominantly

employing quantitative research methods. The theme of "narrative" signifies that a substantial amount of research has adopted narrative as a genre, primarily focusing on children as the study subjects. For instance, studies have investigated the developmental patterns of syntactic complexity in native language (L1) narrative writing among elementary school students (Huang et al., 2022) or examined how changes in task demands affect the language performance of children who stutter (CWS) using a narration task (Sasisekaran & Lei, 2023). In addition to these, themes like computational complexity, language acquisition, and text analysis also fall into the category of marginally important topics.

Emerging or declining themes, located in the third quadrant, encompass new or fading topics. The themes around the topic "deep learning" also include "syntactic structure" and "sentiment analysis." Within the domain of deep learning, the literature strives to leverage deep learning techniques for handling natural language tasks. Researchers aim to enhance model performance by constructing new deep algorithmic models or by extracting lexical semantic information for sentiment analysis in diverse domains. For instance, Bie et al. (2022) introduce an end-to-end Aspect-Based Sentiment Analysis (ABSA) model, SSi-LSi, which integrates both syntactic and semantic information to ameliorate performance, addressing shortcomings in existing approaches for aspect-based sentiment analysis. Tymoshenko & Moschitti (2018) investigate the utilization of syntactic and semantic structures derived from shallow and full syntactic parsers, augmented with Linked Open Data knowledge, to represent question-answer pairs. They encode these structures using tree kernels within learning-to-rank algorithms, highlighting the significance of relational syntactic structures for achieving superior performance in passage reranking. Xu & Jiang (2020) delve into the application of deep learning coupled with a BPSO algorithm-based context segmentation method for entity relationship classification within recommendation systems. In summary, these studies predominantly emphasize enhancing model performance in natural language processing tasks through algorithms and technology, rather than placing excessive emphasis on syntactic complexity or delving into an in-depth understanding of language structure itself. Although some research may involve the fusion of syntactic and semantic information, the primary objective typically revolves around addressing practical natural language processing challenges such as sentiment analysis, question answering, and sentence ranking, as opposed to delving into linguistics or syntax. These studies prioritize practical applications and

performance optimization.

Basic themes, presented in the first quadrant, are highly relevant but less mature foundational topics that may become future research hotspots or development trends. This quadrant encompasses various distinct research domains within the field of syntactic complexity. "Syntax," "complexity," "sentence processing," "natural language processing," "second language acquisition," and "individual differences" represent fundamental themes in the realm of syntactic complexity research. Under the theme of "syntax," two hot topics of investigation include "aphasia" and "language." This theme primarily delves into the adaptive linguistic behaviors of aphasia patients and their relationship with language proficiency (Gleichgerrcht et al., 2021). It also explores how aphasia patients cope with language disorders through various strategies, encompassing aspects of psycholinguistics and neurolinguistics (Dyson et al., 2022). Within the context of the "sentence processing" theme, the focal areas of interest pertain to "word order" and "German." A literature search using "sentence processing" and "word order" as keywords reveals research on brain networks associated with sentence comprehension and generation (Walenski et al., 2019), early effects of online incremental processes (Stowe et al., 2018), and the processing difficulty associated with context-based comprehension (Futrell et al., 2020). Furthermore, the dimensions of "complexity," "accuracy," and "fluency" constitute essential criteria for assessing language proficiency and performance (Barrot & Agdeppa, 2021). These dimensions are commonly referred to as the "CAF" framework in language assessment. Under the theme of "natural language processing," which encompasses machine learning, research methods indicate a continued trend towards studies utilizing computer-based natural language analysis methods, highlighting the significance of computational approaches in future research. Finally, "individual differences" emerges as a new theme between 2018 and 2023, with a primary focus on understanding variations in language acquisition, processing, and performance among different individuals.

Future Researches and Limitations

Based on a bibliometric analysis of the collected documents, this study conducts a comprehensive examination of the current research landscape within the domain of syntactic complexity. The examination uncovered the following significant themes and areas warranting further investigation

in the domain of syntactic complexity.

Syntax. In the basic themes from 2018 to 2023, research outcomes related to syntax have constituted the largest proportion. Syntax is concerned with the arrangement among words, phrases, and sentence constituents within a sentence, as well as how these arrangements and relationships impact the meaning and grammatical properties of sentences. Within the cluster of research topics related to syntax, there are subthemes such as "aphasia", "language", "grammar", "working memory", and "sentence comprehension." This indicates that future research will emphasize the assessment of aphasia, working memory, and the influence of syntactic complexity on sentence comprehension using metrics associated with syntax.

CAF. Complexity, accuracy, and fluency (CAF) have been utilized both as criteria for evaluating the performance of language learners in both oral and written assessments, as well as indicators of the learners' proficiency that underlies their performance. They have also served as metrics for assessing progress in language acquisition. It is noteworthy that within the clustering of CAF, two key terms, namely "collaborative writing" and "register," have emerged. This suggests that future research may consider employing CAF indicators for evaluating collaborative writing assessments and for comparing texts of different registers. These two themes potentially signify new directions in the field of L2 writing, with a particular focus on the dimensions of complexity, accuracy, and fluency in language expression.

Individual differences. There exists a complex relationship between individual differences and syntactic complexity, encompassing factors such as individual cognitive abilities, learning strategies, language backgrounds, and experiences. In recent years, research on individual differences has seen a gradual increase in the Web of Science (WoS), but it still remains underrepresented in this field. Thus, greater emphasis should be placed on examining the inter-individual variation in the progression of syntactic complexity, not only in second language acquisition (L2) but also in first language development (L1). This entails a more concentrated investigation into the diverse developmental trajectories exhibited by individual learners, aligning with the recommendations proposed by Kuiken et al. (2019).

In addition to research themes, the basic themes also encompass research methods that are likely to become focal points in the future, notably natural language processing. With the advent of computers and big data, research methods in the social sciences have assimilated theories and techniques from

computer science. This interdisciplinary fusion has endowed social sciences with enhanced capabilities and depth in data collection, analysis, and interpretation. Researchers have embraced the use of computers to process natural language. In strategic map (Figure 11), various computer-based methods for processing syntactic complexity are evident. NLP, a field that applies computer technology to process and comprehend natural language, aids in tasks such as syntactic analysis, semantic role labeling, and syntax tree construction in the study of syntactic complexity (McNamara et al., 2013; Vyatkina, 2013). The placement of NLP in the fourth quadrant indicates that there is still significant room for both utilization and research in the field of syntactic complexity.

Despite substantial advancements in syntactic complexity research, there remain certain limitations. To begin with, there exists a lack of consensus concerning the precise definition and measurement methods of "syntactic complexity." Various terms such as "syntactic complexity," "syntactic sophistication," and "grammatical complexity" are used in the literature, posing challenges when comparing and synthesizing findings across different studies. Moreover, researchers often utilize different sets of indices to assess syntactic complexity in writing, including Lu's (2017) 14 syntactic complexity indices, Bulté & Housen's (2014) 10 indices, and Norris & Ortega's (2009) 8 indices. However, this diversity of measurement methods may lead to discrepancies and hinder the comparability of research results. Second, data samples in syntactic complexity research frequently exhibit limitations. This field often relies on corpora or specific text samples for analysis. Nevertheless, the restricted scope of corpora or the specificity of text samples may impede the generalization of research findings to broader language usage contexts. Furthermore, there are constraints related to the linguistic and cultural diversity of research subjects. The majority of studies on syntactic complexity primarily focus on widely-used languages and cultures, resulting in a scarcity of research on non-dominant languages and cultures. This limitation restricts a comprehensive understanding of universal features and variations in syntactic complexity across a global context.

These identified concerns underscore the challenges and unresolved aspects in syntactic complexity research. In addition to the future research themes derived from the strategic map, researchers can engage in discussions regarding the definition of syntactic complexity and establish standardized terminology to ensure consistent usage across different studies. For example, to be precise, syntactic complexity and syntactic sophistication are two related

but distinct concepts. The term *sophistication* is employed to describe syntactic development from a usage-based perspective, whereas the term *complexity* is used to denote the formal characteristics of syntax, such as subordination (Kyle, 2016). In essence, *sophistication* can be roughly equated with *relative complexity*, while *complexity* falls within the realm of *absolute complexity* (Bulté & Housen, 2014). Consequently, when discussing similar concepts, it is advisable to consult multiple sources and identify the most accurate and widely accepted terminology.

In addition to existing measurement indices, researchers can explore and develop new metrics to comprehensively capture the multidimensional features of syntactic complexity, catering to diverse research objectives and subjects. Meanwhile, as reported by Polat et al. (2020), researchers in this field have utilized a wide range of diverse metrics and indices, and given the absence of replication studies, it becomes challenging to establish meaningful comparisons between different studies. Therefore, researchers may consider selecting a specific measure of syntactic complexity and endeavor to conduct in-depth investigations of this metric in various studies to gain a better understanding of its significance and implications.

Furthermore, researchers should bolster investigations into non-dominant languages and cultures to broaden our comprehension of features and variations in syntactic complexity on a global scale. In-depth investigations into the changes and influencing factors of syntactic complexity in different languages and cultures will facilitate a more profound understanding of language diversity and commonalities. Meanwhile, sustained interdisciplinary collaboration between linguistics and other fields, such as psychology, education, and computer science, will enable the exploration of cross-disciplinary relationships and impacts of syntactic complexity with other domains.

Conclusion

Drawing upon a dataset comprising 2,935 documents focused on syntactic complexity, sourced from the WoS core collection published between 2000 and 2023, the present study employs the bibliometrix R package and VOSviewer 1.6.19 to undertake a comprehensive bibliometric analysis. Based on the three research questions, we have thoroughly outlined the current research landscape concerning syntactic complexity, delineated the dominant emerging themes within syntactic complexity research, and scrutinized the

evolving trends in future research. Our review demonstrates that, through network visualization of keywords (Figure 8), five clusters representing current research areas have been identified, namely cognition and language processing, child language development and language disorders, second language writing, speech pathology, and natural language processing. Furthermore, utilizing a Sankey diagram (Figure 10), we have depicted the evolution of keywords from 2000 to 2023. Additionally, based on a strategic map analysis of the past five years (Figure 11), we have highlighted the future research directions in the field of syntactic complexity, including syntax-related themes, Complexity, accuracy, and fluency (CAF), and individual differences. Notably, natural language processing (NLP) and computer-based methods have emerged as prominent and enduring research methodologies in the present and future. These efforts have culminated in a comprehensive understanding of the prevailing research focal points in the domain of syntactic complexity.

These findings contribute to an elevated understanding of the trajectory of syntactic complexity research. However, certain limitations that warrant careful consideration still exist. Primarily, the bibliometric analysis hinges upon the utilization of documents from the WoS database, thereby potentially engendering an incomplete portrayal of the corpus. Furthermore, the concentration on articles authored in English could potentially engender an inadvertent neglect of relevant publications and scholarly networks that operate within different linguistic realms. It is noteworthy, however, that our data collection approach incorporates relevant publications, such as book reviews, book chapters, and review articles, aiming to augment the comprehensiveness of the analysis. In addition, a few studies opt for the term "grammatical complexity" interchangeably with "syntactic complexity," which could lead to discrepancies in the retrieval and analysis of outcomes. In view of this, future inquiries into syntactic complexity must extend beyond the broadening of the database and the embrace of linguistic diversity. It is imperative to establish a clear and standardized terminology for syntactic complexity.

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