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A Global Bibliometric Analysis of Sign Language Research: Trends and Technological Evolution*

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Lee, Sunghwa & Jhang, Se-Eun. 2024. A Global Bibliometric Analysis of Sign Language Research: Trends and Technological Evolution. ***Sign Languages and Linguistics Convergence Research,*** *1*(2), 371-404. This study presents a comprehensive bibliometric analysis of global sign language research, focusing on key contributors, thematic trends, and the integration of technology over time. Based on 8,784 records from the Web of Science database and analyzed using Biblioshiny, the study identifies key authors, including Karen Emmorey, Bencie Woll, and Susan Goldin-Meadow, as well as leading institutions such as the University of California system and the Rochester Institute of Technology. The results reveal three distinct research phases: the founding phase (1989-2001), the growth and expansion phase (2002-2015), and the maturity and technology integration phase (2016-2024). These phases mark a progression from early linguistic research to interdisciplinary and technology-driven studies. A comparative analysis of authors' keywords and Keywords Plus indicates that Keywords Plus offers a broader perspective, capturing emerging trends, particularly in machine learning and sign language recognition technologies. Furthermore, the study highlights increasing contributions from countries such as China, India, and Korea, reflecting greater diversity and international collaboration. Thematic mapping illustrates a shift from foundational topics, such as accessibility and language structure, to contemporary themes emphasizing cognitive science and technological applications. These findings provide a

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roadmap for future research, particularly in promoting accessibility through technology and fostering inclusive global collaboration in sign language research.

Key Words: Global Sign Language Research, Bibliometric Analysis, Author Keywords, Keywords Plus, Thematic Evolution, Trend Topics

1. Introduction

Sign language research has grown considerably over the last few decades, reflecting an expanding academic interest that spans linguistics, accessibility, education, and cognitive science. The recognition of sign languages as fully developed linguistic systems has increased, leading to a broader scope of research that now includes the intersections of technology, education, and social inclusion (De Vos & Pfau, 2015). Studies on sign languages-particularly American Sign Language (ASL)-have documented this growth, with bibliometric analyses identifying key contributors, trends, and shifts in research focus (Zaidman-Zait & Jamieson, 2007; Chen & Deng, 2021). However, the influence of sign language studies beyond the Western context, along with the role of emerging technologies such as machine learning and sign language recognition systems, has not been fully captured in existing literature.

Bibliometric analysis, which examines academic literature through quantitative methods like citation and keyword analysis, provides a powerful framework for understanding the development of a research field (Aria & Cuccurullo, 2017; González-Alcaide & Valderrama-Zurián, 2015). By mapping relationships among key authors, topics, and institutions, bibliometric methods can reveal thematic trends and illustrate how interdisciplinary fields influence research (Zhang et al., 2016). In particular, authors' keywords and keywords plus are invaluable in these analyses, enabling researchers to track author-selected themes, which reflect the specific focus of individual studies, alongside broader trends derived from cited references (Garfield & Sher, 1993). Studies in related fields, such as deaf education, bilingualism, and second language acquisition, underscore the importance of these methods in highlighting interdisciplinary collaboration and

emerging technologies that shape language research (Chen & Deng, 2021; González-Alcaide & Valderrama-Zurián, 2015; Khodadadian & Marashi, 2019).

Despite the insights offered by previous bibliometric studies, a comprehensive bibliometric analysis focused solely on sign language research remains limited. The rise of global sign language studies and advances in artificial intelligence and language recognition technology indicate a need for a broader and more current bibliometric examination. Addressing this gap, this study provides a global bibliometric analysis of sign language research, examining its evolution, key contributors, and emerging trends. Specifically, the study addresses the following research questions:

(i) How have key authors, institutions, and countries influenced the landscape of global sign language research over time?
(ii) What major trends in research output, citation patterns, and thematic periods define the evolution of sign language studies?
(iii) How have thematic trends and research focuses in sign language studies evolved over time, as revealed through keyword analysis and thematic mapping?

By addressing these questions, this study provides a detailed overview of the current state and potential future directions of sign language research, underscoring key areas for further exploration and international collaboration.

The following sections are structured as follows: Section 2 reviews prior bibliometric studies in the field of sign language research, identifying key contributions and gaps that this study seeks to address. Section 3 details the methodology, describing the data collection and processing methods used for this bibliometric analysis. Section 4 presents the main findings, including an analysis of influential authors, institutions, and countries; identification of major trends in research output across distinct thematic periods; and insights into thematic dynamics through a comparative analysis of authors' keywords and keywords plus. Section 5 summarizes these findings by addressing critical issues raised in the three research questions and discussing implications for the field. This final section concludes the study by outlining key contributions and offering directions for future research in sign language studies.

2. Literature Review

Bibliometric analyses have been increasingly applied to examine trends, key contributors, and thematic shifts in academic research fields, including sign language studies. This quantitative method involves the statistical analysis of publication metadata, such as keywords, authorship, citations, and institutional affiliations, to uncover patterns and relationships within a body of literature (Garfield, 1979; Small, 1999; Donthu et al., 2021). By leveraging tools like trend topics analysis, thematic map analysis, and thematic evolution analysis, bibliometric studies uncover patterns and relationships within the literature, enabling researchers to identify thematic trends, key contributors, and the evolution of research fields over time.

However, the use of bibliometric methods specifically in the area of sign language remains relatively limited. Existing studies have primarily focused on linguistic, educational, and cognitive aspects of sign language but lack a comprehensive examination of thematic trends over time using bibliometric techniques (Chen & Deng, 2021; Garfield & Sher, 1993). This section provides an overview of existing research on bibliometrics in sign language, highlighting the gaps in the literature, and reviews key studies that have examined the comparison between authors' keywords and keywords plus in bibliometric analyses. The inclusion of both keyword datasets is particularly valuable, as it enables researchers to analyze both author-selected themes and broader interdisciplinary trends derived from cited references (Zaidman-Zait & Jamieson, 2007; Garfield & Sher, 1993).

2.1. Bibliometric Analyses on Sign Language Research

One of the earliest and most comprehensive bibliometric studies on sign language research was conducted by Zaidman-Zait and Jamieson (2007). Their analysis focused on identifying key authors, institutions, and thematic areas that had shaped the academic discourse around sign language up to that point. By examining trends in sign language studies over several decades, they identified that North America and Europe dominated the research landscape, with ASL

being the most frequently studied language. While this study provided foundational insights, it was limited by the scope of its data, which did not capture more recent technological advancements and interdisciplinary trends.

A subsequent study by De Vos and Pfau (2015) examined the typological diversity of sign languages. This study applied bibliometric methods to map research on various sign languages worldwide, offering important insights into cross-linguistic research within the field. However, like Zaidman-Zait and Jamieson, this study did not explore the more recent interdisciplinary trends involving technology, education, or the growing global collaborations in sign language studies. These gaps in both foundational studies underscore the need for updated bibliometric analyses that capture the evolution of research over time, particularly in light of technological advancements like machine learning and sign language recognition systems.

2.2. Bibliometric Analyses in Related Fields

In addition to bibliometric research focused on sign language, studies from adjacent fields such as deaf education, cognitive science, and applied linguistics offer valuable insights. For example, Chen and Deng (2021) conducted a bibliometric analysis on research related to deaf education, providing an overview of key themes, collaboration networks, and global trends. Their work revealed a strong emphasis on educational practices and policies for Deaf students, though it did not delve deeply into the linguistic aspects of sign language.

Bibliometric research in second language acquisition and bilingualism, such as the work by González-Alcaide and Valderrama-Zurián (2015) and Khodadadian and Marashi (2019), provides useful comparative frameworks for sign language studies. These studies highlight the importance of interdisciplinary collaboration and the impact of emerging technologies on language research. However, bibliometric research specifically addressing sign language within these broader contexts remains limited, indicating a gap in the literature.

A noteworthy bibliometric analysis by Liu et al. (2024) on gender equality in the maritime industry demonstrates the potential of bibliometric methods to reveal thematic evolution, research trends, and gaps in underexplored domains.

Their study spans 2003 to 2024 and tracks the progression of gender equality research in a male-dominated field, using tools like R and VOSviewer to analyze thematic shifts. The study identified a transition from broad topics such as “gender equality” to specific areas like “women’s empowerment” and “marine conservation,” emphasizing the importance of targeted policies and interdisciplinary approaches. This work highlights how bibliometric analyses can not only map research landscapes but also identify critical areas for scholarly and policy intervention, offering valuable parallels for exploring sign language research trends.

These studies collectively underline the relevance of bibliometric analyses across diverse fields while exposing a need for more focused bibliometric exploration of sign language, particularly in linguistic and cross-disciplinary contexts.

2.3. Comparison of Authors’ Keywords and Keywords Plus

In bibliometric research, the comparison between authors’ keywords and keywords plus is crucial for understanding the thematic landscape of a field. Authors' keywords are selected by researchers to directly reflect the focus of their studies, whereas keywords plus are automatically generated from the references cited in the articles, offering a broader and often more generalized set of terms.

A significant study by Zhang et al. (2016) conducted in the field of patient adherence research revealed that keywords plus generated a broader set of terms, often related to methodologies or interdisciplinary themes not explicitly captured by authors' keywords. In contrast, authors’ keywords terms were more focused and specific, reflecting the primary focus of the study. This comparison suggested that keywords plus was more effective in identifying emerging interdisciplinary trends, while authors’ keywords provided a more precise and concentrated view of the research’s core themes (Zhang et al., 2016).

Similarly, Garfield and Sher (1993) found that using keywords plus alongside authors’ keywords significantly expanded the thematic scope of bibliometric analyses, retrieving more articles and revealing broader interdisciplinary

connections. Their research emphasized that keywords plus captured topics that were not necessarily defined by the authors but were still highly relevant to the broader research network.

These studies highlight the complementary nature of authors' keywords and keywords plus in bibliometric analysis. keywords plus is particularly effective for identifying broad trends and emerging interdisciplinary connections, while authors' keywords provide specificity, reflecting the core intent of the research. The broader reach of keywords plus makes it a valuable tool for bibliometric analyses seeking to map out the full thematic scope of a field. Based on these insights, the present study uses both authors' keywords and keywords plus to conduct a comprehensive analysis of thematic trends in sign language research, aiming to identify both specific and emerging themes.

3. Data and Methodology

This section outlines the methods used to collect and process the data for the bibliometric analysis of sign language research. The process involved two main stages: Data Collection and Data Processing. These stages were conducted using the Web of Science platform for data extraction and the Biblioshiny application in R for data processing and analysis.

3.1. Data Collection: Web of Science

The dataset for this analysis was collected from the Web of Science database (www.webofscience.com) on October 14, 2024, using the search term "sign language". To ensure a focused and relevant dataset, the search was filtered by language (English) and limited to the following document types: articles, proceeding papers, review articles, book reviews, and early access publications. The time period for the search was set to 1989-2025. These criteria resulted in an initial retrieval of 8,845 records, encompassing a broad range of scholarly publications relevant to sign language research.

The data was exported in plain text format, including the full record and

cited references. This export provided key metadata fields such as author names, publication titles, abstracts, authors' keywords, keywords plus, and citation data. Keywords plus, which is automatically generated from the titles of cited references, complements authors' keywords by capturing broader thematic trends within the field. Together, these datasets enabled a comparative analysis of trends and thematic patterns in sign language research.

The metadata cleaning for citation analysis included duplicate removal to address inconsistencies or incomplete entries. Following this step, the final dataset consisted of 8,784 records, ensuring consistency and accuracy for analysis. After this step, lemmatization for authors' keywords, abstracts and keywords plus is needed to prepare the data for bibliometric analysis. The dataset underwent lemmatization using spaCy, a Python-based natural language processing library, to standardize terms by reducing different word forms (e.g., singular and plural) to their root forms.

It is important to acknowledge the limitations of the dataset. While Web of Science provides robust coverage of high-impact journals, it has inherent biases, such as favoring publications in English and potentially underrepresenting research from regions or institutions not well-covered by the database. These limitations should be considered when interpreting the findings, as the dataset may not fully capture the diversity of global research on sign language.

3.2. Data Processing: Biblioshiny

The preprocessed dataset of 8,784 records was uploaded to Biblioshiny, a web interface for the R-based Bibliometrix package, for bibliometric analysis. Biblioshiny is recognized as a reliable and effective tool for bibliometric studies due to its integration with the Bibliometrix R package, which has been extensively validated in the field (Aria & Cuccurullo, 2017). The tool provides researchers with a comprehensive suite of analytical and visualization capabilities, including the ability to examine productivity, impact, and thematic trends across large datasets. Its reliability is further underscored by its use in numerous bibliometric studies across disciplines, demonstrating its adaptability and accuracy in handling diverse datasets.

Key analyses conducted in Biblioshiny included Annual Scientific Production, Average Citations per Year, trends in Authors' Keywords and Keywords Plus, Trend Topics Analysis, Thematic Map Analysis, and Thematic Evolution Analysis. These analyses offered a detailed understanding of the productivity, impact, and thematic developments in sign language research. For example, Annual Scientific Production was calculated by aggregating the number of publications per year, providing insights into temporal trends in the field. Average Citations per Year was computed by dividing the total citations by the number of years since publication, offering a measure of the long-term academic impact of individual publications.

The primary focus of the analysis was on trending topics and thematic evolution, which examined how research themes have developed over time. These analyses used both authors' keywords and keywords plus, enabling a comparative perspective on emerging trends and established themes. Trend Topics Analysis identified frequently discussed terms across time periods, offering a snapshot of the field's evolving interests. Thematic Map Analysis categorized topics into clusters based on their centrality and density, highlighting their significance and relationships. Finally, Thematic Evolution Analysis tracked the progression of these themes across defined periods, providing a visual narrative of how sign language research has evolved.

Biblioshiny's reliability lies in its robust data processing and analytical algorithms, which ensure accurate computation of indices and visualization of trends. Indices such as the h-index and citation counts are computed using well-established bibliometric standards. For instance, the h-index reflects an author's impact by quantifying the number of papers (h) with at least h citations each, while citation counts aggregate the total number of citations received by publications or authors. These metrics provide valuable insights into the influence of researchers and publications within the field.

While Biblioshiny is a powerful tool for analysis and visualization, it does not include features for preprocessing metadata, such as duplicate removal or metadata cleaning. These preprocessing steps were completed during the earlier data collection phase to ensure the dataset's quality and consistency. Additionally, since Biblioshiny does not offer a cloud-saving option, the processed dataset was

saved in R data format using the Export Collection option. This ensured that the analysis could be revisited and extended without requiring the data to be reprocessed.

4. Results and Discussion

4.1. Key Authors, Institutions, and Countries in Sign Language Research

The following section provides a detailed bibliometric analysis of key contributions to the field of sign language research. This analysis focuses on the top 50 authors ranked by their h-index and productivity trends over time, as well as the 20 most significant institutional and national influences. By examining these metrics, the section highlights the individuals, institutions, and countries that have shaped the academic discourse surrounding sign language.

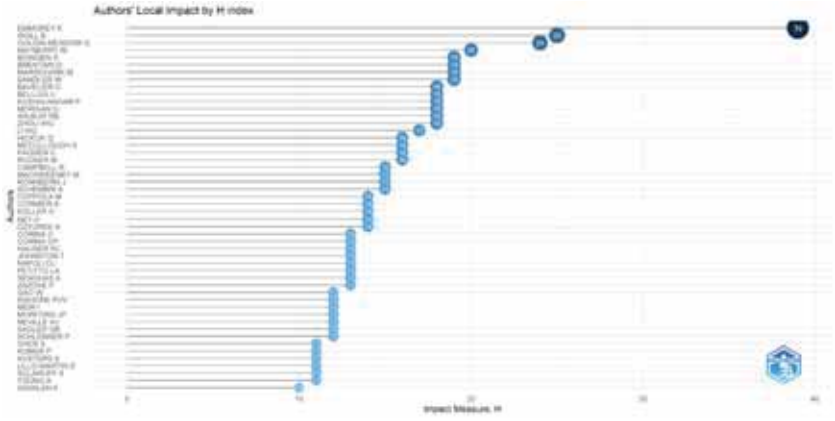
The dataset consisted of 8,784 documents, with 17,486 individual author entries. Notably, one document lacked author information, resulting in 8,783 records with valid author data. To ensure consistency and accuracy, authority control was automatically applied using Biblioshiny, standardizing author names by unifying variations such as initials, alternate spellings, and formatting (e.g., J. Kim and Kim, Jinsoo). This process minimized duplication errors and enhanced the reliability of the analysis.

These standardized data enabled a robust assessment of the most productive researchers and their contributions to the evolution of sign language research over time.

4.1.1. Authors' Local Impact by h-Index

The local h-index is a measure of both an author's productivity and the citation impact of their work within the dataset. As shown in Figure 1, Karen Emmorey leads with an h-index of 39, followed by Bencie Woll and Susan Goldin-Meadow, with h-indices of 24 and 23, respectively. These authors' high h-index values reflect their sustained contributions and the influence of their publications within the field of sign language research. Other prominent authors

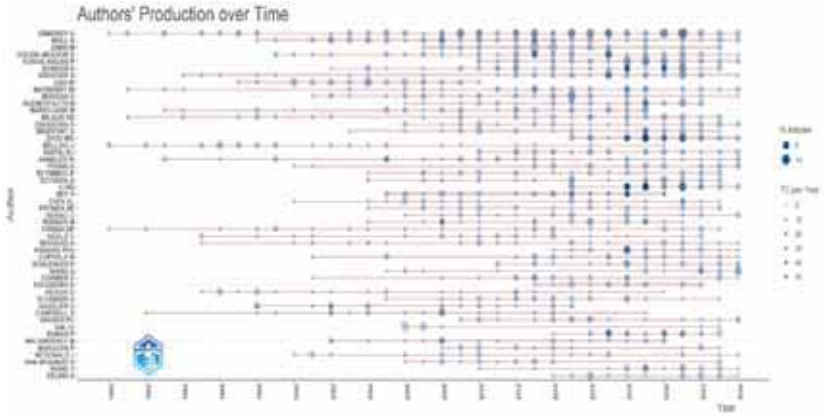
include Rachel I. Mayberry, Diane Brentari, and Marc Marschark, each with an h-index of 18 or higher, further demonstrating their importance in advancing the field. This metric highlights authors whose research has had a lasting and widespread impact, not only in terms of volume but also in terms of citations received from their peers.



[Figure 1] Authors' Local Impact by h-Index

4.1.2. Authors' Production over Time

The publication timeline of authors, as presented in Figure 2 below, reveals that Karen Emmorey and Bencie Woll have been consistently productive over the past 30 years. This continuous publication activity underscores their long-term commitment to the development of sign language research. In contrast, more recent contributors, such as Jenmi and Huerfarth, have emerged as new, significant voices in the field, contributing to its expansion in recent years. The darker, larger circles on the graph represent authors whose work has garnered high citation counts, indicating not only consistent publication activity but also substantial academic influence. For example, Karen Emmorey's publications are not only numerous but also widely cited, reinforcing her leadership role in the field.

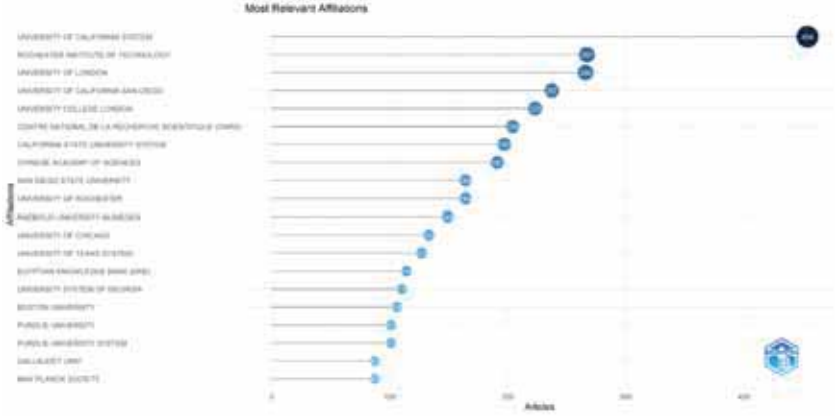


[Figure 2] Authors' Production Over Time

4.1.3. Most Relevant Affiliations

Institutional ccontributions to sign language research are also a critical factor in understanding the field's development. Using Python, we extracted and cleaned a total of 16,230 unique affiliations from the dataset by processing semicolon-separated metadata across multiple columns (C1, C3, and CA). These columns captured a variety of affiliations, including primary institutions, secondary affiliations, and corresponding author affiliations, offering a comprehensive view of the institutional landscape in sign language research. The subsequent analysis of these affiliations was conducted in Biblioshiny to identify key institutional contributors.

Figure 3 shows that the University of California System is the leading institution, with 454 publications, followed by the Rochester Institute of Technology and the University of London, with 267 and 266 publications, respectively. These institutions are recognized for their strong research programs in linguistics, cognitive science, and Deaf studies. In particular, Gallaudet University, known for its specialization in Deaf education, contributes significantly to the field. The dominance of institutions in North America and Europe illustrates the geographical concentration of expertise and resources in sign language research.



[Figure 3] Most Relevant Affiliations

4.1.4. Corresponding Authors' Countries

An analysis of the geographical distribution of corresponding authors reveals a total of 1,104 unique countries, extracted using Python by processing semicolon-separated metadata from the CL column. The subsequent analysis was conducted in Biblioshiny to identify the most significant contributing countries, as shown in Figure 4.

The USA stands out as the dominant country in terms of research output, contributing a substantial number of Single Country Publications (SCP) while also actively engaging in Multiple Country Publications (MCP). This balance reflects its central role in both domestic research productivity and international collaborations. Other major contributors include China, India, and the United Kingdom, all of which have produced significant numbers of both single-country and multi-country publications. The growing research output from these countries indicates an increasing global interest in sign language studies.

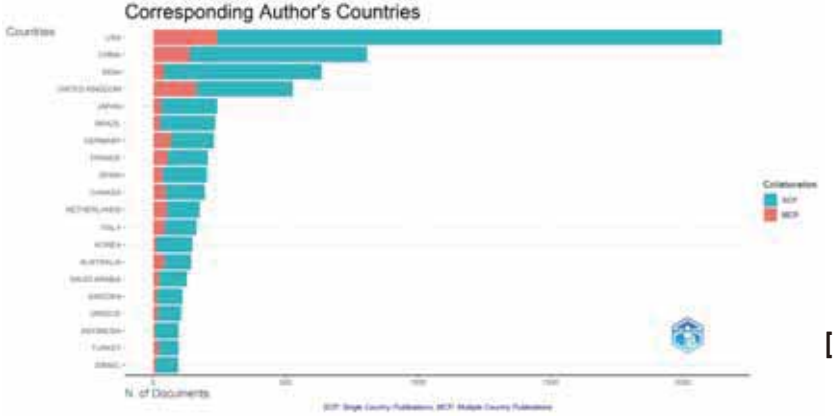
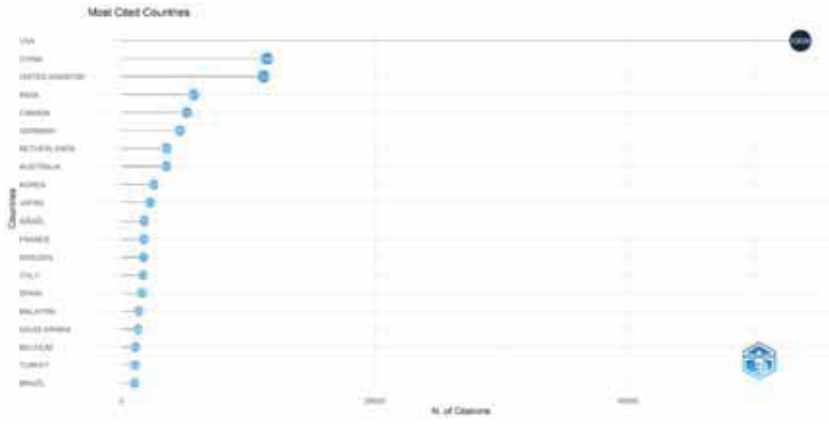


Figure 4] Corresponding Authors' Countries

4.1.5. Most Cited Countries

The citation impact of countries involved in sign language research is presented in Figure 5. The USA leads by a large margin, with over 53,000 citations, far surpassing other countries. This result confirms the USA's role as a global leader in sign language research, contributing both foundational and cutting-edge work to the field. Other countries, such as China and the United Kingdom, follow with 148 and 120 citations, respectively, reflecting their growing academic influence. Countries like India, Canada, and Germany also contribute to the global citation network, but their impact is comparatively lower, further emphasizing the USA's dominance in shaping the field's discourse.

Of particular note, Korea has also made notable strides in sign language research. While Korea's overall output is still growing, its contributions reflect an increasing focus on both linguistic studies of KSL and its integration into broader sign language research, particularly with regard to accessibility and education in Deaf communities. This emerging research trajectory offers valuable cultural and linguistic insights that enrich the global discourse on sign language.



[Figure 5] Most Cited Countries

4.1.6. Discussion and Implications

This bibliometric analysis provides key insights into the global development of sign language research, highlighting the dominant role of certain countries, institutions, and authors. The USA leads both in research output and citation impact, underscoring its leadership in shaping the academic discourse on sign language. Institutions such as the University of California System and Rochester Institute of Technology have been central to driving much of the innovation and scholarly conversation in the field.

Prominent authors such as Bencie Woll, Karen Emmorey, and Susan Goldin-Meadow stand out for their significant and sustained contributions. Their high h-index values reflect not only their productivity but also the far-reaching impact of their research, which has consistently shaped key areas of sign language studies, including linguistics, cognitive science, and language acquisition. These scholars have been pivotal in advancing both theoretical frameworks and practical applications, such as sign language education and recognition technologies.

While the USA maintains its leading position, the increasing contributions from countries such as China and India suggest a shift towards a more globally diverse research landscape. Although these countries currently lag behind the

USA in citation impact, their growing volume of publications and involvement in multi-country collaborations indicate an expanding influence that will likely diversify the field further. This rise in Multiple Country Publications (MCPs) points to a growing trend of international collaboration, which promises to bring cross-cultural perspectives and foster joint projects that could drive innovation in sign language studies.

Korea is also emerging as an important player, particularly in research on KSL and educational practices for Deaf communities. With Korea's increasing research output, particularly in KSL studies, it is positioned to contribute unique insights into cultural and linguistic diversity within the global discourse on sign language. As Korea continues to engage in international collaborations and deepen its research efforts, its influence in the global research landscape is expected to grow, providing valuable contributions to areas such as language accessibility and Deaf education.

The role of specialized institutions such as Gallaudet University is crucial in advancing both theoretical and applied research on sign language. These institutions provide a platform for scholars who are dedicated to the Deaf community, supporting research that spans linguistics, education, and technology. Continued investment in such institutions will be vital for pushing the field forward, particularly in addressing key challenges related to communication accessibility and the integration of sign language into educational frameworks.

The emergence of new contributors from regions like Asia is further diversifying the research landscape. As Korea, China, and other countries expand their contributions, we are seeing the introduction of new cultural and linguistic perspectives that are enriching the field. In particular, Korea’s research on KSL is set to play a prominent role in influencing global perspectives on sign language linguistics and Deaf education.

The dominance of a small group of authors and institutions remains, but the rise of new contributors suggests that the future of sign language research will be more collaborative and globally diverse. The evolving research landscape holds great promise for innovation and cross-cultural insights, which will further deepen our understanding of sign language's role in society and its impact on education, technology, and communication.

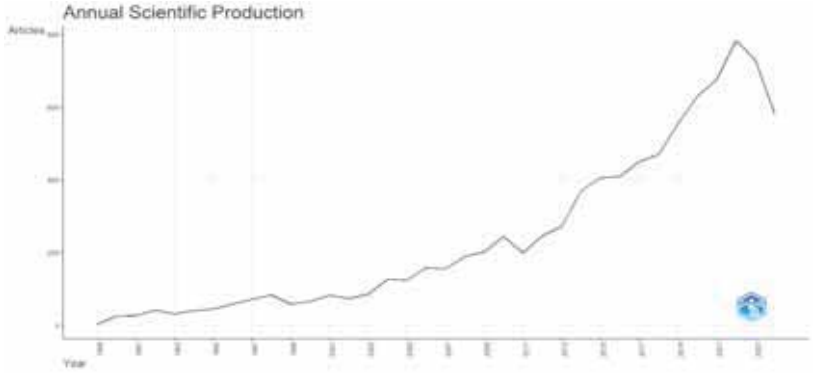
4.2. Trends in Research Output, Citation Patterns, and Thematic Periods

This section examines the research output in sign language studies by analyzing ASP and ACPY to understand trends in publication volume and academic influence. Based on these findings, three distinct research periods are proposed to capture the thematic evolution of the field and its shifting research priorities over time.

4.2.1. Annual Scientific Production and Average Citations per Year: A Comparative Analysis

This section provides a comprehensive analysis of the trends in ASP and ACPY offering insights into both the quantity of research output and the impact of these publications over time (see Figure 6 and Figure 7).

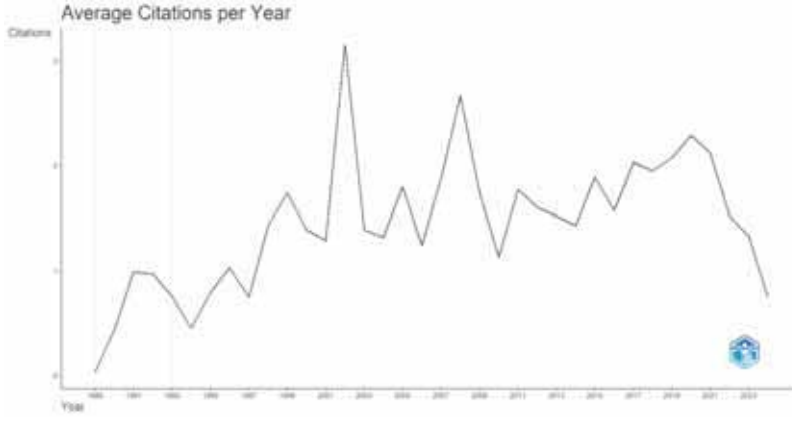
The ASP graph highlights a significant growth in research output from 1989 to 2022, particularly after 2010 when the number of published articles rose sharply. This period of expansion reflects the increasing academic interest in the field, likely driven by technological advancements, increased interdisciplinary collaborations, and rising awareness of the importance of the subject. By 2021, the annual number of articles exceeded 700, showcasing the field's rapid development and expanding global research community.



[Figure 6] Annual Scientific Production from 1989 to 2024

(as of September 27, 2024)

On the other hand, the ACPY graph displays a more fluctuating pattern. Peaks are observed in 2002, 2009, and 2020, indicating that certain key publications during these years attracted significant academic attention. These peaks suggest that while a growing number of articles were being published, a few influential studies contributed disproportionately to the citation impact, elevating the overall citation averages for those years. The 2002 and 2009 peaks may correspond to seminal works or significant breakthroughs that gained widespread recognition, influencing subsequent research.



[Figure 7] Average Citations per Year from 1989 to 2024

The discrepancy between the steady rise in ASP and the fluctuating ACPY suggests that although more articles were being published, not all of them were equally impactful in terms of citations. The steady decline in ACPY after 2020 could be attributed to several factors, including the natural citation lag for newly published articles and the sheer volume of articles diluting the overall citation impact. As more articles are published, citations are spread across a larger number of works, reducing the average citation count per article.

Both ASP and ACPY show a decline after 2021, likely due to the effects of the COVID-19 pandemic, which disrupted global research activities. The pandemic may have impacted not only the production of new research but also the ability of recent publications to accumulate citations as academic priorities

shifted and access to research resources was limited.

In summary, while ASP reflects a steady increase in the number of published articles, the ACPY indicates that the citation impact of these publications has been more variable. Peaks in citation rates during key years highlight the influence of groundbreaking studies, while the overall decline in ACPY after 2015 underscores the challenge of maintaining citation impact in an expanding research field.

4.2.2. Three Proposed Research Periods

The analysis of ASP and ACPY in Section 5.1 revealed distinct trends in both research output and citation impact over time. These trends allow us to divide the development of the field into three key periods, each characterized by shifts in research focus, volume of publications, and academic influence. Based on these insights, the field can be divided into the following periods: Foundational Stage (1989-2001), Growth and Expansion (2002-2015), and Maturity and Recent Trends (2016-2024).

(1) 1989-2001: Foundational Stage

During this period, research in the field experienced gradual growth, as indicated by a steady but modest increase in the number of published articles. This foundational period was marked by influential studies, with a significant ACPY peak around 2002, which helped shape the early theoretical frameworks of the field. There latively low research output during these years suggests that the field was still emerging, building its academic foundations.

(2) 2002-2015: Growth and Expansion

This period marks a significant increase in research activity, with ASP showing steady growth in publications. The citation impact also shows variability, with a notable peak in ACPY around 2008, reflecting the publication of impactful studies that attracted significant academic attention. The expansion of

research during these years suggests growing interdisciplinary engagement and heightened interest in the field from both academic and applied perspectives.

(3) 2016-2024: Maturity and Recent Trends

The final period is characterized by high productivity, with research output peaking around 2021 before experiencing a slight decline, likely influenced by the COVID-19 pandemic. ACPY during this period shows a peak around 2020, followed by a decline, reflecting the challenges newer publications face in rapidly accumulating citations due to the citation lag and the dilution effect of a high volume of publications.

These three periods provide a framework for conducting the thematic evolution analysis in subsequent sections, where shifts in research themes and their development over time will be examined in detail.

4.3. Technological Advancements and Emerging Interdisciplinary Themes in Sign Language Research

This section explores the evolution of research themes in sign language studies through four analyses: Trend Topics Analysis, Thematic Map Analysis, Comparative Evaluation of Authors' Keywords and Keywords Plus, and Thematic Evolution Analysis. The dataset includes 6,563 Authors' Keywords and 4,947 Keywords Plus, which were lemmatized prior to processing in Biblioshiny to standardize word forms and ensure consistency.

Trend Topics Analysis identifies frequently discussed terms over time, highlighting popular themes, while Thematic Map Analysis examines the relationships between these topics, categorizing them based on their significance and interconnectedness. The Comparative Evaluation assesses the strengths of Authors' Keywords versus Keywords Plus in capturing thematic trends. Although Biblioshiny processes metadata for visualization, it does not perform additional authority control to unify synonyms or variations; therefore, the analysis reflects the keywords as provided in the dataset following lemmatization. Finally,

Thematic Evolution Analysis tracks the development of topics across periods, illustrating shifts and changes in research focus. Together, these analyses provide a comprehensive view of the field's current state, its historical development, and emerging trends in sign language research.

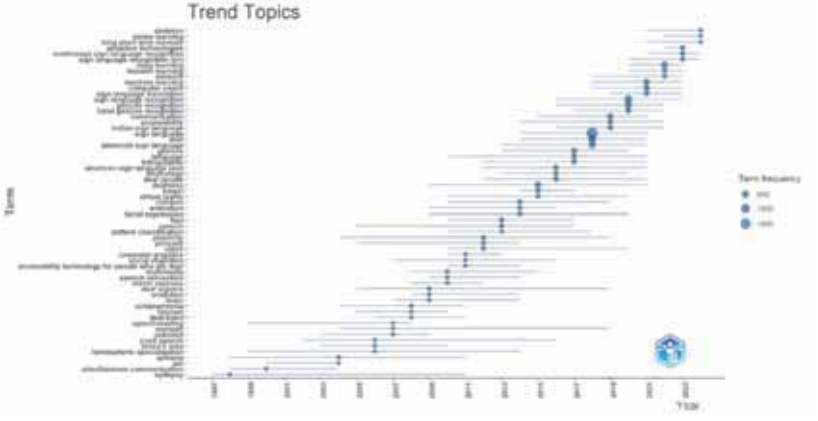
4.3.1 Comparative Analysis of Trend Topics: Author Keywords vs. Keywords Plus

This subsection provides a comparative analysis of the trend topics derived from two different keyword datasets: authors' keywords and keywords plus. Authors' keywords are chosen by the authors to represent the specific content and themes of their papers, while keywords plus are generated automatically from the titles and references of cited papers, capturing a broader, more interconnected set of terms related to the overall field of study. Studies have shown that keywords plus tends to generate a significantly larger and more comprehensive set of terms compared to Authors' Keywords (Zaidman-Zait & Jamieson, 2007; Chen & Deng, 2021; Garfield & Sher, 1993). However, in this analysis, the total number of authors' keywords (6,563) exceeded the number of keywords plus (4,947), which is an interesting result that highlights how authors' keywords may capture a wider range of specific research themes while keywords plus focuses on more interconnected topics.

The Trend Topics Analysis was conducted in Biblioshiny with the following parameters applied to both datasets: a timespan of 1989−2024, a word minimum frequency of 5, and a maximum of 3 words per year to highlight the most prominent topics. No additional text editing, such as removing specific terms or loading synonym lists, was applied, ensuring that the data were analyzed in their standardized, lemmatized form.

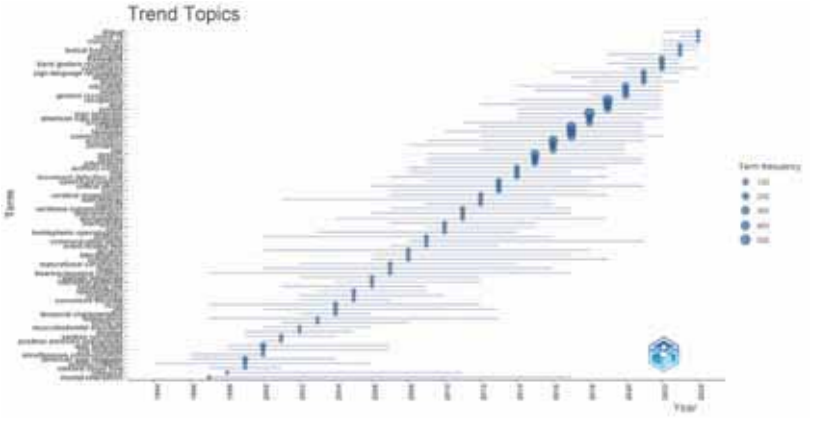
The trend topics based on author keywords emphasize themes that researchers explicitly define as central to their work. These include terms such as "sign language recognition", "gesture recognition", "machine learning", and "deafness", which highlight a strong focus on technological advancements and applied research in sign language studies (see Figure 8). The frequent appearance of terms like "American Sign Language (ASL)" and "deaf people" underscores

the continued importance of cultural and linguistic aspects within the field. Additionally, more recent terms like “sensors” and “online learning” reflect the growing integration of AI and virtual platforms in addressing the needs of Deaf communities.



[Figure 8] Trend Topics by Author Keywords

In contrast, the trend topics derived from keywords plus offer a broader view of the research landscape, encompassing not only specific study foci but also related disciplines such as neuroscience and cognitive science. Frequently occurring terms in this dataset include “deaf”, “sign language”, “children”, and “language acquisition” (see Figure 9). These topics indicate a sustained focus on educational and cognitive development within the Deaf community, as well as on the neurological and cognitive aspects of sign language processing. The presence of terms like “cerebral organization” and “speech perception” highlights the interdisciplinary connections between sign language research and broader studies in brain function and language cognition.



[Figure 9] Trend Topics by Keywords Plus

The comparison between the two datasets reveals key differences in the scope of thematic focus. Author keywords tend to highlight emerging technological themes and specific linguistic studies, whereas keywords plus captures a wider array of topics, including neurological, educational, and cognitive dimensions. This distinction is important because it reflects the different ways in which researchers and citation data define the field's boundaries. While author keywords focus on the specificities of individual studies, keywords plus highlights the interconnectedness of sign language research with adjacent disciplines.

Together, these analyses provide a comprehensive picture of the thematic evolution of sign language research. The author keyword dataset emphasizes technology-driven research and specific linguistic phenomena, while keywords plus broadens the scope to include interdisciplinary links with cognitive and neurological studies. This dual perspective enables a more nuanced understanding of the dynamic development of the field.

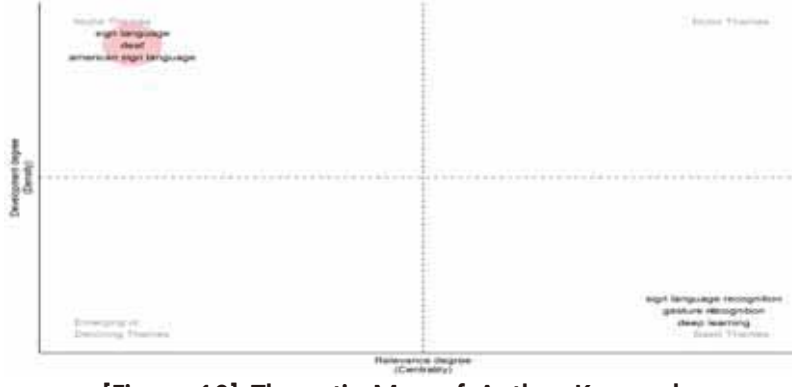
4.3.2. Thematic Map Analysis: Author Keywords vs. Keywords Plus

This subsection provides an analysis of the thematic maps derived from author keywords and keywords plus, offering insights into different aspects of

the research landscape. Thematic maps group research topics into four distinct categories: niche themes, basic themes, motor themes, and emerging or declining themes, each representing unique aspects of how research evolves within the field.

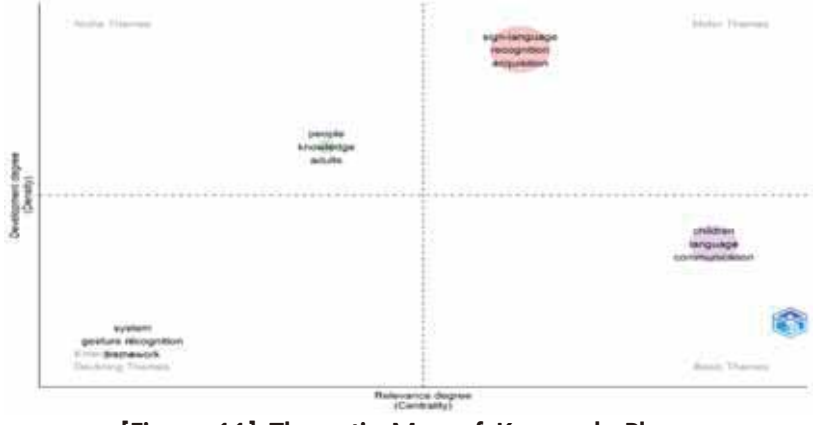
The thematic map based on author keywords reveals a strong emphasis on basic themes, particularly those related to cultural and linguistic dimensions. Dominant terms such as “sign language”, “deaf”, and “American Sign Language (ASL)” underscore the ongoing scholarly focus on cultural identity and the recognition of sign languages as legitimate linguistic systems (see Figure 1). This concentration on basic themes reflects a long-standing interest in the social and linguistic foundations of sign language, with particular attention to the Deaf community’s cultural heritage and the legitimization of sign languages within broader linguistic discourse.

Interestingly, in Figure 10, there are no terms represented in the motor themes or emerging/declining themes quadrants. This absence suggests that author-selected keywords are predominantly focused on established, foundational aspects of sign language rather than on innovation or emerging areas of research. The lack of terms in these thematic sections implies that authors prioritize foundational studies over more technology-driven or emerging topics, indicating a potential gap in research related to newer developments and interdisciplinary innovations.



[Figure 10] Thematic Map of Author Keywords

In contrast, the thematic map derived from keywords plus showcases a broader range of research topics, with frequent terms like “recognition”, “gesture”, and “acquisition” suggesting a growing focus on motor themes related to technological advancements and their practical applications (see Figure 11). This thematic structure highlights the increasing interest in how technology, particularly in areas such as gesture recognition and sign language acquisition, is being integrated into the field. These motor themes point to active engagement with machine learning and recognition software, reflecting the field’s growing emphasis on using technology to improve communication accessibility and educational methods for the Deaf community.



[Figure 11] Thematic Map of Keywords Plus

The two thematic maps reveal distinct priorities within the research landscape. The author keywords map emphasizes basic themes related to the linguistic and cultural foundations of sign language research, suggesting a deep engagement with the historical and social dimensions of the field. Meanwhile, the keywords plus map highlights motor themes associated with technological solutions and educational innovations, reflecting the field’s evolving focus on practical applications that leverage technological advancements.

4.3.3. Comparative Evaluation of Author Keywords and Keywords Plus in Thematic Analysis

Based on the analyses in 4.1 and 4.2, both author keywords and keywords plus offer distinct insights into thematic trends in sign language research. Each approach has its advantages and limitations, influencing how effectively they reveal the thematic evolution of the field.

Author keywords provide a more focused and specific representation of a paper's central themes. Since these keywords are selected by the authors themselves, they offer precise insights into the main focus of the research. This makes author keywords especially useful for capturing specific research areas, such as the cultural and linguistic dimensions of sign language, as demonstrated in 4.2. However, this focus can be limiting, as author keywords may overlook broader thematic trends or emerging interdisciplinary connections. The absence of motor and emerging/declining themes in Figure 1 highlights how author keywords may miss newer developments in the field.

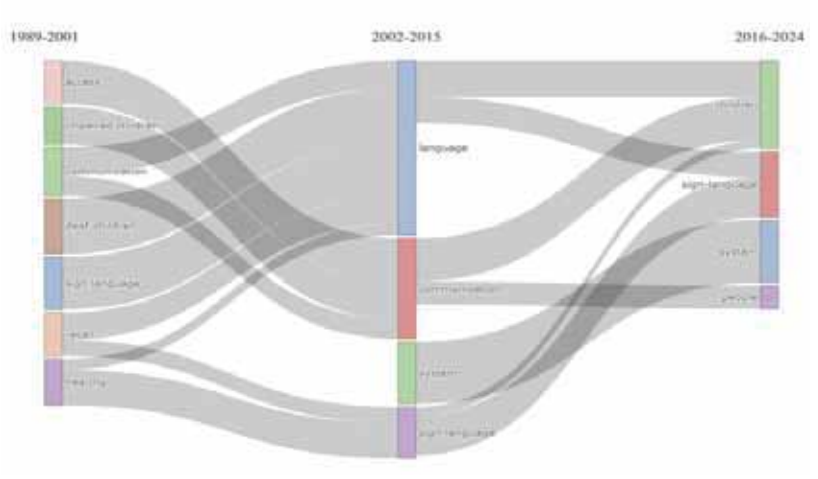
In contrast, keywords plus, which is generated automatically from article titles and cited references, provides a broader range of topics. It captures interdisciplinary connections and reveals emerging areasthat may not be explicitly highlighted by authors but are influential across the field. In 4.2, keywords plus uncovered motor themes such as gesture recognition and sign language acquisition, reflecting the growing role of technology and innovation in sign language research. The strength of keywords plus lies in its ability to identify emerging trends and interdisciplinary shifts, providing a more comprehensive view of thematic evolution. However, its broader scope can sometimes result in less precise representations of specific research focuses.

Considering these factors, keywords pluse merges as the more effective tool for tracking thematic trends and evolving areas in sign language research. It offers a more holistic understanding of the research landscape by capturing a wider array of topics, including technological advancements and interdisciplinary influences. While author keywords remain useful for gaining precise insights into specific topics, keywords plus provides the depth needed to track the dynamic shifts within the field.

In light of this, keywords plus will be used exclusively in the following section 4.3.4 Thematic Evolution Analysis, to explore the evolution of research themes over time, revealing how the field has progressed and identifying key trends that have emerged across distinct periods.

4.3.4 Thematic Evolution in Sign Language Research

The thematic evolution diagram based on keywords plus highlights the changing focus and trends in sign language research across three distinct periods: 1989-2001, 2002-2015, and 2016-2024. As discussed earlier, using keywords plus allows for capturing a broader spectrum of themes that reflect the dynamic nature of the research landscape. Figure 12 illustrates the transition in research priorities and the emergence of new themes, offering a deeper understanding of how sign language studies have evolved over time.



[Figure 12] Thematic Evolution Analysis with Keywords Plus

(i) Foundational Stage (1989-2001)

During the foundational period from 1989 to 2001, the primary themes were access, impaired children, communication, deaf children, sign language, recall,

and hearing. These keywords suggest that early research was largely focused on issues of communication accessibility for individuals with hearing impairments, particularly children. This foundational interest underscores a period when researchers concentrated on establishing basic understanding and frameworks to address the communicative needs of people with auditory impairments. The inclusion of sign language as a significant theme reflects an early acknowledgment of non-verbal modes of communication, although it was approached within a broader context of accessibility and basic communicative support. This foundational period laid the groundwork for later, more specialized studies, setting essential theoretical and practical bases for future research.

(ii) Growth and Expansion (2002-2015)

The period from 2002 to 2015 marks a phase of growth and expansion within the field, as research activity increased, and thematic interests broadened. The most prominent themes in this period were language, communication, system, and sign language. The centrality of language indicates a shift toward more generalized linguistic inquiries, suggesting that researchers had started to explore communication beyond the specific context of sign language and hearing impairments. The continued focus on communication shows sustained interest in interaction and accessibility, yet at a more systemic or theoretical level compared to the foundational period. The emergence of system as a key theme implies an increased interest in understanding communication within structured frameworks, potentially incorporating perspectives from cognitive science or educational studies. The enduring presence of sign language reflects its ongoing importance within the field, signifying that while the scope of research was broadening, the study of sign language remained a core area of interest.

(iii) Maturity and Recent Trends (2016-2024)

The most recent period, from 2016 to 2024, represents the field's maturity and the emergence of recent trends. During this phase, children, sign language, system, communication, and people emerged as central themes. The prominence

of children suggests a renewed focus on developmental and educational aspects, particularly in the context of sign language and communication. This emphasis may indicate an increasing concern with how early language exposure and accessibility impact language development and learning outcomes among children. Sign language remains a core theme, illustrating its sustained significance as a research focus across all three periods. The themes of system and communication continue to be relevant, indicating ongoing interest in structured analyses and communication accessibility within formal systems. The introduction of people as a theme highlights a shift toward studying the social dimensions of communication, suggesting that recent research is increasingly concerned with how sign language interacts with broader societal factors.

To summarize, the thematic evolution observed across these periods highlights a gradual yet profound transformation within the field. Initially, research focused on foundational issues related to accessibility and basic communication needs, particularly for children with hearing impairments. Over time, the field expanded to explore systemic and theoretical aspects of language and communication, demonstrating growing interdisciplinary engagement. In recent years, the field has matured to encompass social and developmental contexts, reflecting a comprehensive understanding of communication that considers both individual and societal factors. Throughout this evolution, sign language has remained a central focus, emphasizing its pivotal role in the field's progression and its importance as a consistent area of scholarly inquiry.

This thematic evolution provides valuable insights into how research in this field has developed over time, moving from foundational frameworks to a mature phase characterized by nuanced social, developmental, and systemic perspectives. These insights lay the foundation for further exploration of thematic trends and their implications in subsequent sections of this paper.

5. Conclusion

This study offers a comprehensive bibliometric analysis of global sign language research, examining influential contributors, thematic shifts, and the growing role of technology. The findings reveal that the landscape of sign language research has been substantially shaped by key scholars, including Karen Emmorey, Bencie Woll, and Susan Goldin-Meadow, whose contributions have driven both foundational and applied research within the field. Prominent institutions, such as the University of California System and the Rochester Institute of Technology, have played significant roles in fostering research growth and innovation. Regionally, North America has long been the primary contributor in terms of both research output and impact; however, recent and rising contributions from countries like China, India, and Korea point to an increasingly diverse and collaborative global research landscape in sign language studies.

Examining the evolution of sign language research, this study identifies three major periods: the Foundational Stage (1989－2001), the Growth and Expansion Period (2002－2015), and the Maturity and Technological Integration Period (2016－2024). The Foundational Stage was characterized by the establishment of theoretical frameworks and steady, incremental growth in research output. In contrast, the Growth and Expansion Period marked a notable increase in interdisciplinary engagement, with research productivity significantly rising during this time. The most recent period, Maturity and Technological Integration, has been defined by the application of technological tools and methodologies, such as machine learning, to address practical needs within sign language research, underscoring the field's maturation and transition into a robust, interdisciplinary domain.

Thematic analysis highlights how research trends in sign language studies have progressed from early focuses on accessibility and linguistic structure to more sophisticated, technology-driven applications. The analysis of keywords indicates a thematic shift from cultural and linguistic topics to interdisciplinary connections with cognitive science and technological innovation. Contemporary research now includes both foundational areas, such as Deaf education and sign language recognition, and emerging themes, such as machine learning and

assistive technologies. This evolution reflects the dynamic nature of the field, which is increasingly responsive to both academic advancements and the societal needs of the Deaf community.

While this study provides valuable insights, it is important to acknowledge its limitations. The dataset, sourced exclusively from the Web of Science, focuses primarily on English-language and high-impact publications, potentially underrepresenting research in other languages or from less prominent regions. Additionally, some metadata inconsistencies, such as unstandardized author names or affiliations, may have affected the precision of certain analyses despite preprocessing efforts. The reliance on Keywords Plus, which is automatically generated, could also result in missed nuances compared to fully curated metadata.

Future research could address these limitations by incorporating datasets from additional bibliometric platforms, such as Scopus or Google Scholar, to capture a broader range of publications and perspectives. Expanding the dataset to include non-English publications would also provide a more inclusive view of global research trends. Additionally, future studies could leverage advanced natural language processing techniques to enhance metadata standardization and improve the accuracy of thematic analyses. Exploring emerging topics, such as the role of AI and virtual platforms in sign language research, and conducting longitudinal studies on the societal impacts of these advancements could further enrich our understanding of the field.

In conclusion, this bibliometric study provides valuable insights into the growth and thematic progression of sign language research, outlining the roles of influential contributors, key thematic trends, and the impact of technology. These findings contribute a roadmap for future studies, especially in leveraging technology to enhance accessibility and foster inclusive, global collaboration. Continued bibliometric tracking will be essential to sustain innovation and inclusivity, promoting a more accessible and equitable world for the Deaf community.

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