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Review

Trends in The Use of Virtual Reality in Autistic Children and Adults: A Bibliometric Analysis on Web of Science

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Background

Autism spectrum disorder (ASD) is characterized by persistent difficulties in social communication and interaction, alongside restrictive and repetitive patterns of behavior. Virtual reality (VR) has emerged as a promising tool to enhance participation and engagement in individuals with ASD.

Objective

This bibliometric study aims to map the current research landscape on the intersection between ASD and VR, identifying trends in authorship, publication, geographic distribution, thematic focus, and keyword evolution.

Methods

A bibliometric analysis was conducted using the Web of Science Core Collection. Classic bibliometric laws and indicators (e.g., Bradford's, Lotka's, and Zipf's laws) were applied to analyze publication volume, citation impact, author productivity, and thematic clustering.

Results

A total of 398 publications were identified between 2007 and 2024, showing an exponential growth trend (R^2 = 0.97). The United States led in total output. Sarkar and Warren were among the most productive authors. The *Journal of Autism and Developmental Disorders* and *IEEE Transactions on Neural Systems and Rehabilitation Engineering* published the highest number of relevant articles. Fifty-six articles received 58 or more citations. Thematic clusters revealed emphasis on social skills training, immersive environments, and technological applications in ASD interventions.

Conclusion

Research on VR applications in ASD has increased exponentially, reflecting growing scientific and clinical interest. These findings provide a foundation for future interdisciplinary investigations and intervention development in developmental disabilities research.

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1. INTRODUCTION

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by distinctive patterns in social reciprocity, pragmatic communication, and behavioral flexibility.[1] These features often coexist with restricted or highly focused interests, repetitive behaviors, and atypical sensory responses.[2] As outlined in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders,[3] the presentation of these characteristics varies widely in both form and intensity, underscoring the substantial heterogeneity of the autism spectrum and the current lack of validated biological markers for diagnosis.

This section represents a medical-paradigm perspective on autism and may not capture the lived experiences or strengths of autistic individuals.[4] In recent years, there has been a shift toward a biopsychosocial understanding of autism. Recent research views autism through the lens of neurodiversity, in which autistic individuals have a different way of processing sensory information and experiencing the world.[5] Currently, approximately 1 in 100 children worldwide is identified as autistic,[6,7] though prevalence and recognition vary globally. Autistic individuals may encounter barriers in social participation, education, and employment, and this can have a significant impact on their quality of life, especially when the environment is not adapted to support diverse forms of communication, interaction, and sensory processing.[8] However, they often possess strengths such as increased attention to detail, pattern recognition, or concentration on areas of interest.[4] Due to these barriers, autistic individuals may experience social isolation and difficulties in maintaining employment, particularly in the adult population, which can impact their mental health.[9]

These challenges are often exacerbated by a lack of appropriate support systems rather than by autism itself. This recognition has generated a growing interest and need for individualized, accessible support tailored to each person's unique profile. In recent years, the development of autistic support interventions has advanced considerably, with a notable increase in research focusing specifically on interventions tailored to autistic children.[11,11]

Based on this evidence, the current approach to providing the necessary support to autistic individuals usually involves early and intensive interventions supervised by specialized health or educational professionals in this field.[12] However, many families or individuals themselves do not have access to these care interventions due to their high cost and the limited availability of qualified therapists. Among the possible solutions, the development of effective and accessible therapeutic interventions is essential to allow more autistic people to receive early care and to promote participation and well-being in different social contexts.[7,9,13]

The use of technology in educational contexts helps people with ASD develop various skills and has obtained the support of the National Autism Spectrum Disorders Professional Centre.[14] These approaches consider user experience, usability, and accessibility, and use game elements to enrich learning environments.[14-16] The development and evaluation of systems and applications for autistic users is very promising.[17]

In this regard, in recent years, virtual reality (VR)-based interventions have gained popularity as a therapeutic option, as they are stimulating and motivating for autistic individuals.[14-16,18,19]

Virtual reality is classified into three types: non-immersive VR involves virtual environments displayed on a screen or console, controlled with keyboards, mice, and/or controllers; semi-immersive VR includes partially virtual environments with sensors and powerful graphics, maintaining a connection with the physical environment; and immersive VR offers a realistic experience with VR glasses that create a stereoscopic three-dimensional effect and input tracking.[20]

In particular, VR technologies facilitate the active participation of children with ASD in interactive and engaging situations.[21] Additionally, they offer affordable and versatile options for educational and interventional use.[22] VR is also gaining popularity in the medical and healthcare fields because it provides interactive three-dimensional simulations of real-world environments and effective cognitive and performance training tools, including social and interaction skills.[23,24] A meta-analysis conducted in 2021 examined the application of VR for therapeutic purposes in people with ASD, and concluded that there is a significant improvement in daily living skills and a moderate improvement in cognitive, regulation, emotional recognition, and social and communication skills.[25] A systematic review highlighted limitations in determining the real impact of VR on autistic individuals, partly due to the lack of consensus among researchers regarding the definition of VR. In addition, the review showed that there is no clear guidance on designing VR-based interventions to ensure the application of the trained skills in real life due to variations in the target population, skills addressed, and types of VR.[9] Furthermore, adverse symptoms such as dizziness, visual fatigue, or nausea have also been reported. In particular, up to 80% of autistic young people who have used immersive VR systems have been reported to experience some of these symptoms.

In summary, the effectiveness of VR in this population is still under debate, as the recent systematic reviews or meta-analyses detect a moderate effect of these interventions in autistic individuals. Such controversies found in the literature are believed to be due to methodological limitations, such as small sample sizes, lack of controlled studies, or longitudinal studies.[9,26]

Given methodological heterogeneity, inconsistent outcome measures, and ongoing debate regarding the effectiveness of VR-based interventions in ASD, the current body of research presents a fragmented and rapidly expanding landscape. In this context, bibliometric analyses offer a valuable methodological approach to systematically map research activity, identify dominant trends, and contextualize the development of specific intervention lines. ASD research has been extensively examined through bibliometric analyses based on Web of Science (WoS) data across multiple research domains. Recent studies have mapped global research trends in areas such as neuroscience and artificial intelligence applied to diagnosis.[27,28] These investigations highlight the cumulative and interdisciplinary nature of ASD research, within which VR-based studies should be understood as part of a shared scientific effort. From this perspective, VR research represents a translational extension of broader advances in ASD knowledge, linking foundational research with applied and rehabilitative approaches.

In parallel, numerous previous publications highlight the ongoing interest in exploring the use of VR for individuals with ASD. Many of these articles primarily focus on social communication, including social functioning, emotion recognition, and speech and language.[14,16,18,22,29] The most recent systematic review addressed the use of VR in behavioral interventions for people with ASD.[25] Additionally, a bibliometric review focused on the educational aspect in

high-functioning children,[30] while another bibliometric analysis explored the educational application of VR in individuals with ASD.[31]

Based on the above, it is relevant to conduct an updated mapping of the scientific literature on the use of VR in autistic individuals, both children and adults, to identify and analyze current research trends and patterns within the field through a bibliometric analysis based on the traditional laws of bibliometrics. Therefore, this study aims to explore this topic in depth, examine the growing interest in the field, assess annual publication trends, and identify the categories, journals, and countries with the highest number of publications. In addition, the study aims to determine the most productive and prominent authors, highlighting the most cited articles and detailing the number and types of keywords and Keywords Plus® that were most used by the authors.

2. MATERIALS AND METHODS

2.1. DATA SOURCE

A bibliometric analysis was conducted based on the traditional laws of bibliometrics. These include Bradford's law of dispersion, Zipf's, and Lotka's laws. These laws are based on well-established scientific formulas, and their scientific validity can be tested empirically.[32-36] The WoS Core Collection (WoSCC) was consulted and searched.[37] The WoS provides access to several citation databases, which are particularly beneficial for researchers interested in understanding the impact of their work. In addition, WoS has high data integrity, as it can exclude self-citations and duplicate articles to ensure a more accurate representation of citations. The WoSCC is one of the most prestigious databases for the scientific community.[38] The WoSCC allows users to find high-impact articles, discover research areas, and identify trends. Moreover, WoSCC provides a large amount of information on documents and is, therefore, one of the most widely used databases by researchers for bibliometric analysis.[39]

2.2. SEARCH STRATEGY

The search was conducted on April 30, 2025, in the WoSCC, including papers published in three citation indexes/collections: Science Citation Index Expanded, Social Science Citation Index, and Emerging Sources Citation Index. To increase the accuracy and precision of the search, the tags "TI" and "AB" (for searching titles and abstracts, respectively) were used with two Boolean operators (AND/OR), including the concepts "Autism" or "Autistic" (using the truncation "autis*" to capture related variations with both concepts) and "Virtual Reality" or "Virtual Environment." Therefore, the search equation was as follows: TI= (autis* AND ["virtual realit*" or "virtual environment"]) OR AB= (autis* AND ["virtual realit*" or "virtual environment"]).

Studies focused on VR in autistic individuals, and publications that were articles or reviews of articles were included. No language or publication-date restrictions were applied to obtain as many publications as possible. We employed strict control mechanisms, such as the Preferred Reporting Items for Systematic reviews and Meta-Analyses method, to minimize bias in the filter and selection process.[40] In all included studies, VR was examined in relation to domains connected to core ASD characteristics.

Three researchers (S.L.-J., D.S.-G., and A.D.-Z.) searched independently to ensure that the search query was applied correctly and that the same documents were obtained. The titles and abstracts of the publications were reviewed by S.L.-J and D.S.-G to ensure that they met the inclusion criteria. Subsequently, data extraction was conducted using plain text and Microsoft Excel.

2.3. DATA ANALYSIS

Network visualizations were generated using VOSviewer (version 1.6.20), a software tool designed for constructing and exploring bibliometric maps.[41]

The Price/Dobrov law was applied to assess publication growth on autism and VR according to the trend of annual publications.[32,34] An exponential model was fitted to publication counts, and model fit was evaluated using the adjusted coefficient of determination (R^2),[42,43] calculated in Microsoft Excel. Analyses were performed using publications from 2007 to 2024. Earlier years (1996, 1999, 2002, 2004) were excluded from the analysis because publication output was sporadic, and 2025 was excluded as it was incomplete at the time of data extraction. A graph was plotted with Excel to represent the temporal trend in publications. A descriptive analysis was carried out with the distribution of the documents by WoS thematic categories.

Bradford's law was used to identify the journals with the most publications.[44-46] Following this distribution, we defined the core zone as the set of journals accounting for approximately the first tercile of all publications in the dataset. The Hirsch index (h-index) was used to identify the most relevant documents, defined as the h documents with h or more citations.[33] A distribution graph of papers and citations was used to establish the cut-off point based on the h-index. In addition, an analysis, using the h-index, was carried out to detect the documents that had received the highest number of usage counts in the last 180 days in WoS. This metric, provided by WoS, based on the number of clicks on links to the full article on the publisher's website or the number of downloads, has a direct relationship with the number of future citations of a document.[47]

Duplicate authors were eliminated, and the authors' names were standardized. Subsequently, Lotka's law was applied to estimate the number of authors to be considered prolific.[48] Lotka's law is calculated as the square root of the total number of authors. A graph with the distribution of documents by authors was generated to corroborate the correct application of Lotka's law. Co-authorship graphs were constructed in the VOSviewer software with the resulting authors.[49] To identify prominent authors, we cross-referenced the list of prolific authors with the authors of the most cited papers.[50] This distinction allowed us to differentiate authors with high productivity from those exerting greater citation influence within the field.

We examined co-authored countries by assessing the number of papers and citations per country. Charts were created in Microsoft Excel with the co-authored countries, presented according to the number of documents and the number of citations. Additionally, a country co-authorship analysis in VOSviewer illustrated the global production network, where node size represented the number of papers and links indicated the connections between co-authoring countries.

Finally, Zipf's law was applied to the author keywords and Keywords Plus® to identify the concepts with the highest occurrence in the documents.[51] Author keywords refer to

the terms selected by the authors of each article to describe the main topics of their work. In contrast, Keywords Plus are automatically generated by the Web of Science algorithm based on words or phrases that appear frequently in the titles of the cited references, even if these terms do not appear in the article's own title or in the author keywords.[52] Co-occurrence graphs were constructed with VOSviewer to analyze the temporal evolution of these concepts and identify thematic clusters.

3. RESULTS

A total of 417 documents were identified. The titles and abstracts were screened to ensure that they met the inclusion criteria. Following full-text review, 19 records were excluded as they were unrelated to the topic or the target population. For the main analyses, 398 documents published were analyzed (301 articles and 97 reviews) (Figure S1, Table S1). The first two papers found were published in 1996.

From 2007 to the present, there has been continuity in annual publications. From 2007 to 2024, there was a phase of exponential growth in annual publications (R^2=0.97). The total number of publications doubled in the last four years (since 2021), accumulating 55.3% of the papers (220 papers) in this period. Figure 1 shows the trends followed by annual publications.

The WoS database assigned the documents to 65 thematic categories. The five thematic categories with the highest number, accounting for 65% of documents, were psychology developmental (74), rehabilitation (73), educational research (48), education special (34), and psychiatry (31). Table 1 summarizes the five main categories of WoS, with the number of documents in each. The journal with the highest number of publications in each category is also presented, as well as the publisher and the number of publications corresponding to the publisher.

3.1. JOURNALS AND CITATIONS

As reported in Table 2, the core of publications comprised 15 journals (8% of the total journals), which contained 142 documents (35.7% of the total publications). Zone 1 included 44 journals, representing 22% of the journals with 119 papers (29.9% of the total publications). Zone 2 comprised 137 journals (70% of the journals) that each published a single paper. Table 2 presents the Bradford zones, illustrating the distribution of documents and journals within each zone, as well as the fit of the observed distribution to the theoretical Bradford model (% error = −0.7%).

The papers were published in 196 journals with a publication range between 1 and 38 papers, with the *Journal of Autism and Developmental Disorders* having the highest number of publications. To be part of the publication nucleus, it was necessary to have at least five or more published documents related to the object of study. Table 3 presents the set of journals that constitute this Bradford core.

The h-index was used to identify the most cited documents. Thus, 56 papers were found with 58 or more citations, which was used as the cut-off point identified to catalog the referenced documents (Figure 2). The article entitled "Virtual Reality Social Cognition Training for Young Adults with High-Functioning Autism" by Kandalaft *et al.*,[53] published in the *Journal of Autism and Developmental Disorders*, was the most cited article with 378 citations. The second most cited article, with 300 citations, was a meta-analysis by Grynszpan *et al.*,[54] entitled "Innovative

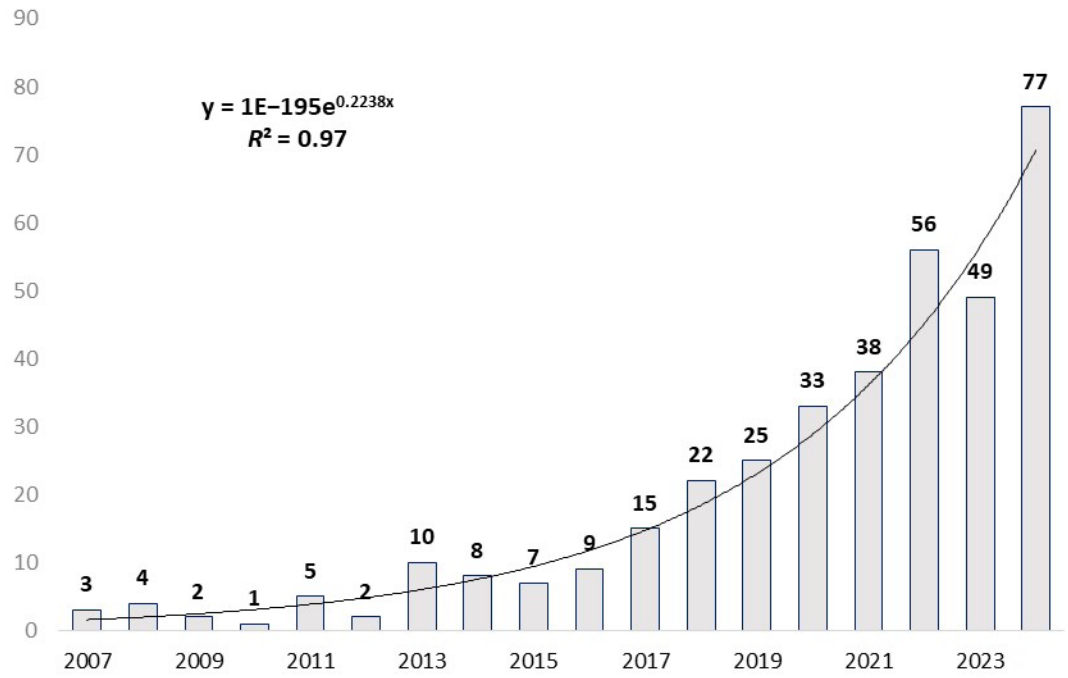

Figure 1. Annual publication trends. Bars illustrate the yearly volume of published documents (x-axis), and the black line shows the exponential model fitted to the distribution.

Table 1. The top five thematic categories in Web of Science

Web of Science categories	Documents of thematic category	Journals	Number of documents in the journal	Publishers	Number of documents by the publisher
Psychology developmental	74	*Journal of Autism and Developmental Disorders*	38	Springer Nature	92
Rehabilitation	73	*IEEE Transactions on Neural Systems and Rehabilitation Engineering*	14	IEEE	35
Education educational research	48	*Interactive Learning Environments*	10	Taylor & Francis	30
Education Special	34	*Research in Autism Spectrum Disorders*	9	Elsevier	41
Psychiatry	31	*Research in Autism Spectrum Disorders*	9	Elsevier	41

Table 2. Bradford's zones for autism and virtual reality-related research

Zone	Number of documents on thirds (%)		Journals (%)		Bradford multipliers	Journals (Theoretical series)	
Nucleus	142	35.7%	15	8%	-	16 × (n0)	15
Zone 1	119	29.9%	44	22%	2.9	16 × (n1)	45
Zone 2	137	34.4%	137	70%	3.1	16 × (n2)	137
Total	398	100%	196	100%	3.0	-	197
-						% Error	−0.7%

Note: Number of documents on thirds (%) refers to the percentage of total documents distributed across the three Bradford zones.

Table 3. Core journals for autism and virtual reality-related research

Journal titles	Number of documents	Citations	Normalized citations	Journal impact factor	Quartile	% Open access
Journal of Autism and Developmental Disorders	38	2,400	63	3.1	Q1	30.3
IEEE Transactions on Neural Systems and Rehabilitation Engineering	14	382	27	4.8	Q1	98.6
Interactive Learning Environments	10	186	19	3.7	Q1	6.4
Autism	9	570	63	5.2	Q1	36.0
Education and Information Technologies	9	213	24	4.8	Q1	21.2
Research in Autism Spectrum Disorders	9	250	28	2.2	Q1	20.7
Frontiers in Psychology	8	65	8	2.6	Q2	99.5
Autism Research	7	180	26	5.3	Q1	29.8
Journal of Enabling Technologies	7	55	8	1.7	Q2	10.2
Frontiers in Psychiatry	6	343	57	3.2	Q2	99.4
Applied Sciences-Basel	5	63	13	2.5	Q1	99.5
Frontiers in Virtual Reality	5	31	6	3.2	Q2	99.8
IEEE Transactions on Learning Technologies	5	120	24	2.9	Q1	12.4
International Journal of Environmental Research and Public Health	5	235	47	-	-	99.6
Sensors	5	345	69	3.4	Q2	99.6

technology-based interventions for autism spectrum disorders: A meta-analysis" published in *Autism*. The complete list and details of the most cited papers are presented in Table S2. In relation to the most visited documents in the last 180 days, 22 documents with 24 or more visits in WoS were identified (Table S3). Of these documents, only eight were among the 56 most cited.

3.2. CO-AUTHORS

All this scientific production was generated by 1,505 co-authors, comprising a publication range between 1 and 16 papers, with a power fit of 75%. As shown in Figure 3, 1,254 of the 1,505 authors were authors of only one paper, which allows us to estimate that there is a small group of prolific authors who are committed to the study of autism and VR.

3.2.1. PROLIFIC CO-AUTHORS

The number of prolific co-authors applying Lotka's law was 39 (≈39). A total of 25 authors were classified as prolific, with five or more papers (Figure 3).

The co-authors with the highest number of publications were Sarkar N (16 documents), Lahiri U (14 papers), Warren ZE and Alcaniz M (13 papers), and Schmidt M (12 papers) (Table S4). The VOSviewer analysis identified several collaborative clusters, each represented by a distinct color. These clusters reflect groups of authors who maintain strong co-authorship links within the dataset: blue cluster (Lahiri U and Sarkar N), red cluster (Alcaniz M and Abad L), and green cluster (Schmidt M and Newbutt N). In addition, three clusters were formed by two or three co-authors: purple cluster (Castelo-Blanco M and Simoes MA), sky blue cluster (Ke F and Moon J), and yellow cluster (Smith MJ, Smith JD, and Humm L). Between the green cluster formed by researchers such as Schmidt M or Newbutt N, a connection was observed with the sky blue cluster formed by Ke F or Moon J (Figure S2). Figure 4 shows the temporality in publications, aiming to identify authors with the most current works related to the topic. Schmidt M, Moon J, Glaser N, Alcaniz M, Sirera M, Marin-Morales J, and Minissi ME showed an average publication date closest to 2024. In contrast, Sarkar N, Warren Z, Humm L, Chapman SB, Lahiri U, Simoes M, and Parsons S showed sustained publication activity over a longer period (Figure 4).

3.2.2. PROMINENT CO-AUTHORS

Matching the prolific co-authors with the co-authors of the 56 most cited papers identified the most prominent co-authors. Sarkar N is one of the most prominent co-authors with 16 papers, 729 citations, and seven papers among the most cited. Warren Z is also a prominent co-author with 13 papers, 706 citations, and seven papers among the most cited. Up to 17 prominent co-authors were identified. Next to Sarkar N and Warren Z, Swanson A and Lorenzo G (4 and 3 top-cited papers, respectively) were also prominent co-authors (Table S4). Among the 56 most cited authors (according to the H-index), the four with the highest number of papers included three from the blue cluster and one (Lorenzo G) from the green cluster (Table S4).

3.3. COUNTRIES

Large international collaborative networks comprising 57 countries/regions were found, with collaborative networks formed between them. The United States of America (USA) (143 papers and 4,982 citations) contributed the largest number of papers, followed by the United Kingdom (44 papers and 2,022 citations), China (38 papers and 517 citations), and Spain (38 papers and 1,085 citations) on the topic of autism and VR. Figure 5 shows the geographical distribution of publications, with the predominance of the USA in terms of document number. Figure S3 shows the

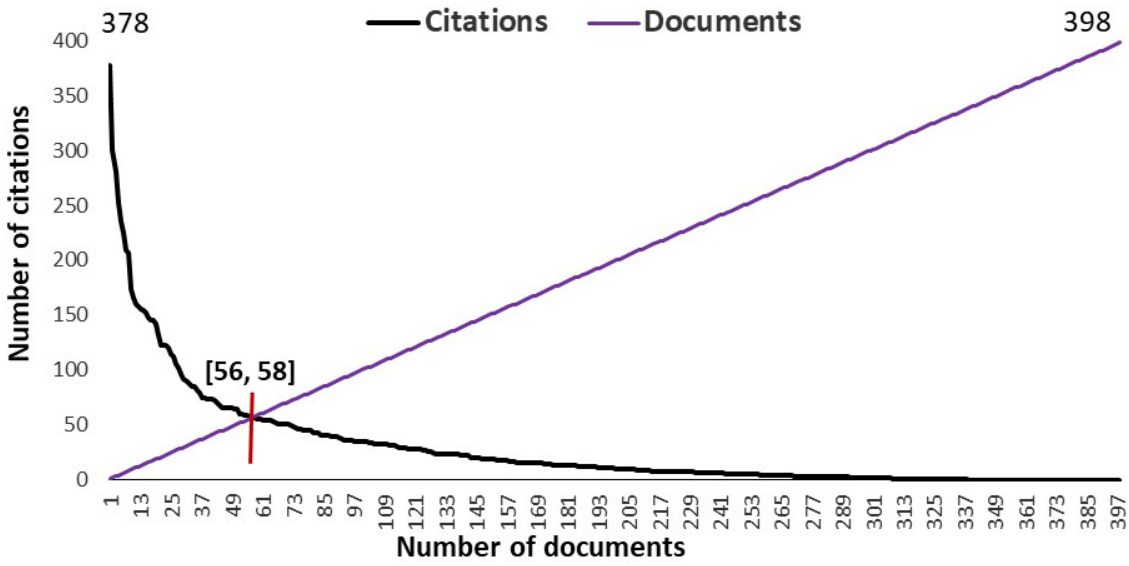

Figure 2. H-index graph. The cut-off point applied was 58 citations, a requirement for a paper to be considered among the most cited. The black line represents the citation frequency, and the purple line represents the paper count. The number 56 represents number of papers.

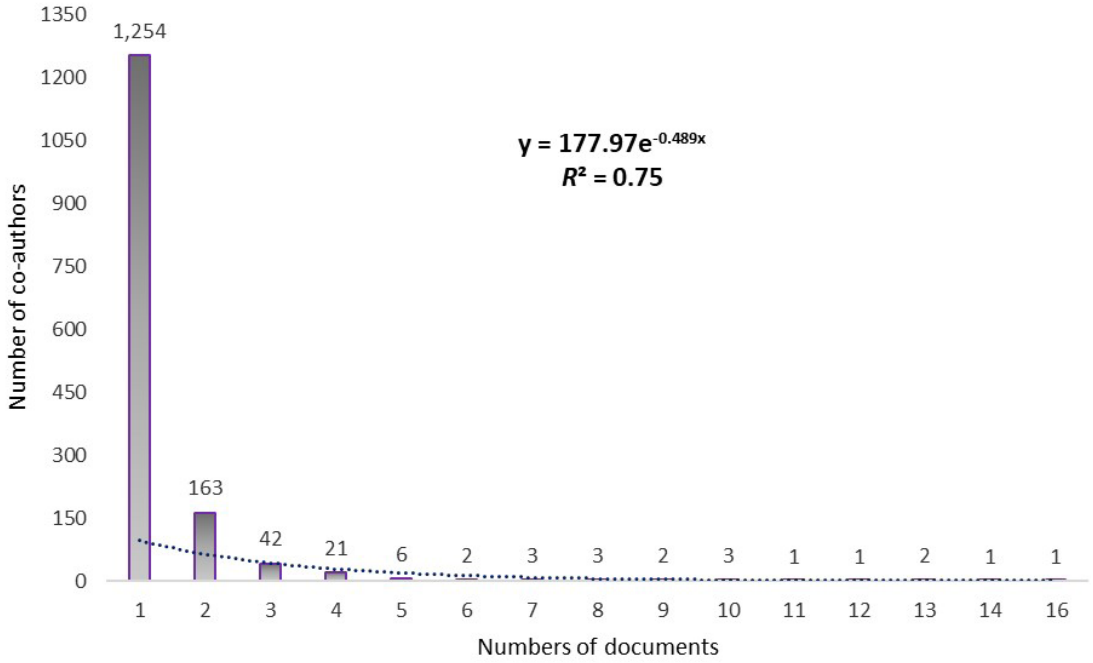

Figure 3. Relationship between scientific productivity and authorship. The bars represent the number of authors who have published 1, 2, 3, … documents within the dataset (y-axis). The dotted line depicts the fitted power-law trend.

Figure 4. Prolific co-authors' collaboration graph. Node size: citations; horizontal bar: average of all publication years.

geographical distribution of publications, with the predominance of the USA in the number of citations.

3.4. AUTHOR KEYWORDS AND KEYWORDS PLUS®

A total of 1,055 author keywords and 750 Keywords Plus® were found. Applying Zipf's law, the most relevant keywords and Keywords Plus® were estimated at 30 and 28, respectively. Figure 6 shows that, in the set of documents, 606 author keywords and 489 Keywords Plus® were used only once. In contrast, subsamples of words with a high frequency of occurrence were found in both cases, which were analyzed in more detail.

Thirty author keywords were identified as most relevant to the authors. Virtual reality (212), autism (129), autism spectrum disorder (116), ASD (26), social skills (23), and children (22) were the most frequently used keywords. Figure 7 shows the 30 most used keywords and the thematic

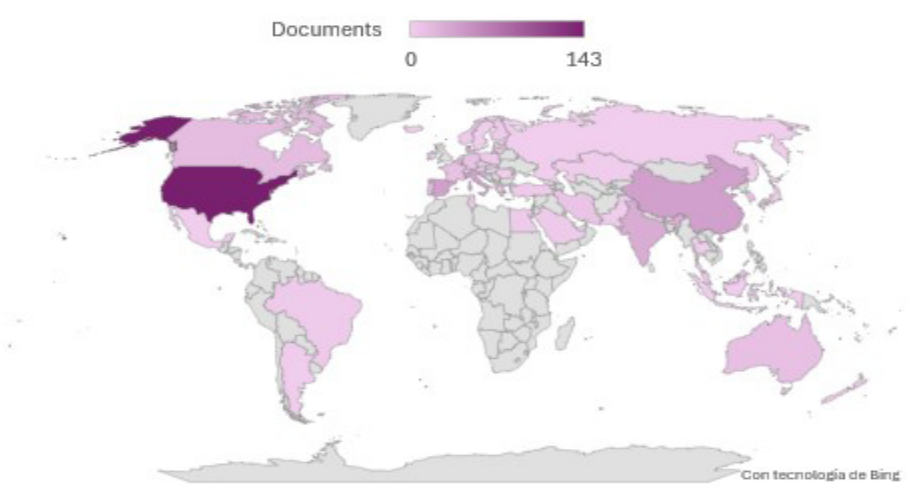

Figure 5. Geographical distribution of publications by document number. The map displays the number of documents published by country. Color intensity reflects publication volume, with darker shades indicating a higher number of documents.

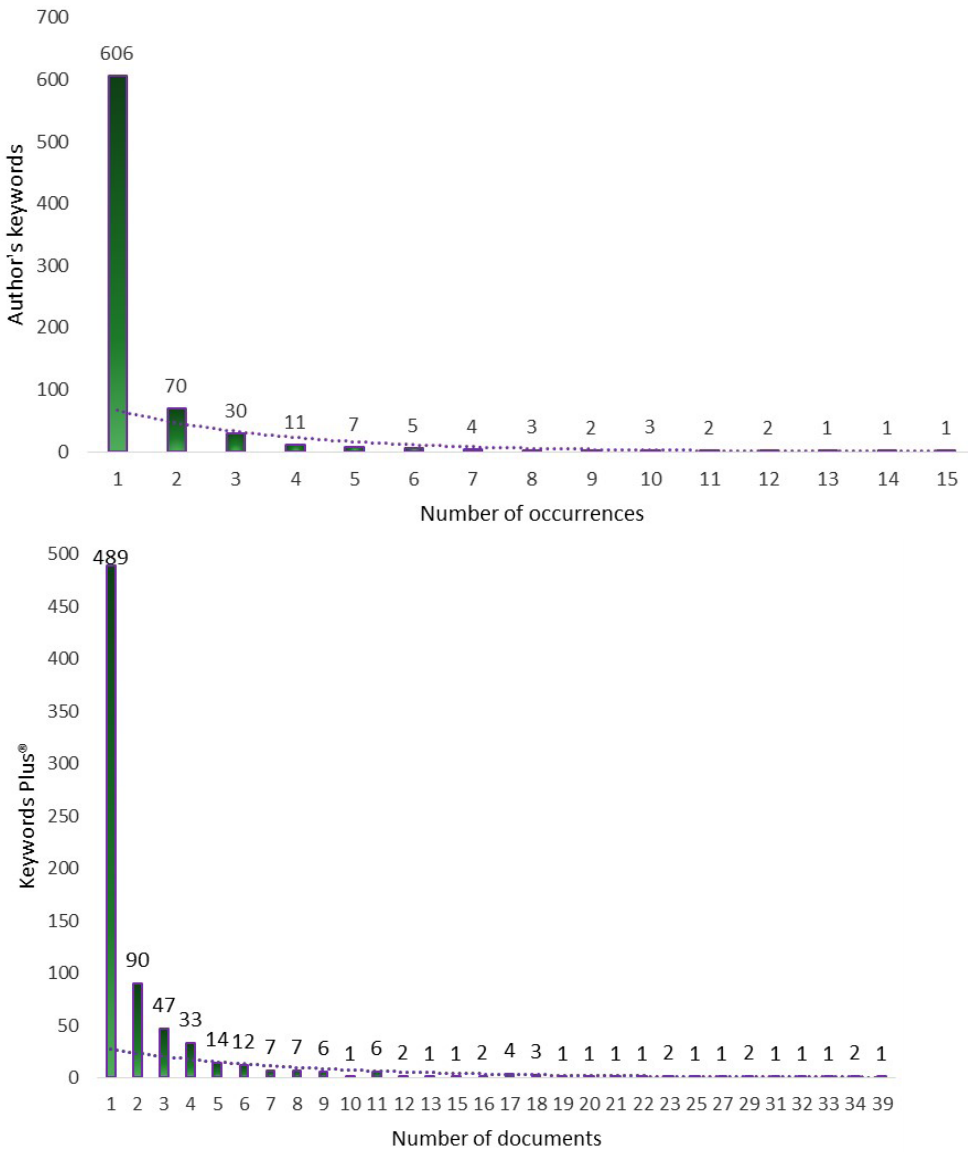

Figure 6. Relationship between the frequency of occurrence and the set of (A) author keywords and (B) Keywords Plus®. The figure displays the number of distinct keywords according to how many times they appeared across the dataset.

clusters formed. Figure S4 shows the average year of publication of the papers for each word.

A total of 28 Keywords Plus® were identified as the most relevant. Among them, the following stood out by number of occurrences: children (175), adolescents (113), adults (66), individuals (64), skills (60), and environments (47). Figure 8 shows the 28 most prominent Keywords Plus® and the thematic clusters formed. In addition, Figure S5 shows the concurrence of Keywords Plus® by year.

4. DISCUSSION

This study focused on mapping scientific literature on the use of VR in autistic individuals, aiming to evaluate research trends and patterns related to this topic. Therefore, a quantitative bibliometric analysis was conducted, applying the classical laws of Price, Bradford, Zipf, and Lotka, in addition to the h-index. Annual publication trends were analyzed, identifying the journals with the highest number of

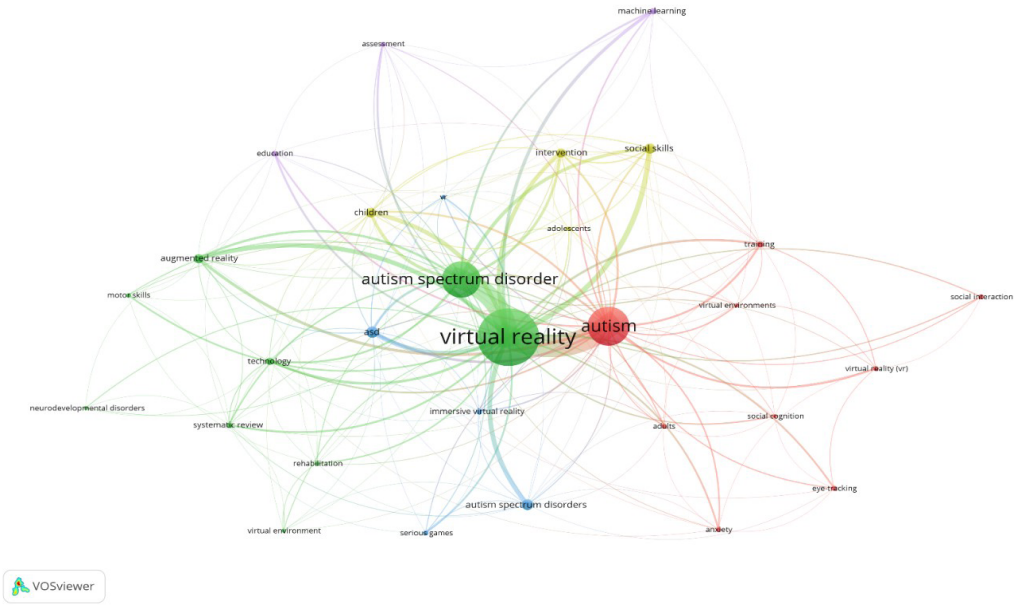

Figure 7. Author keywords graph. Node size: occurrences; color: cluster; analysis: association strength

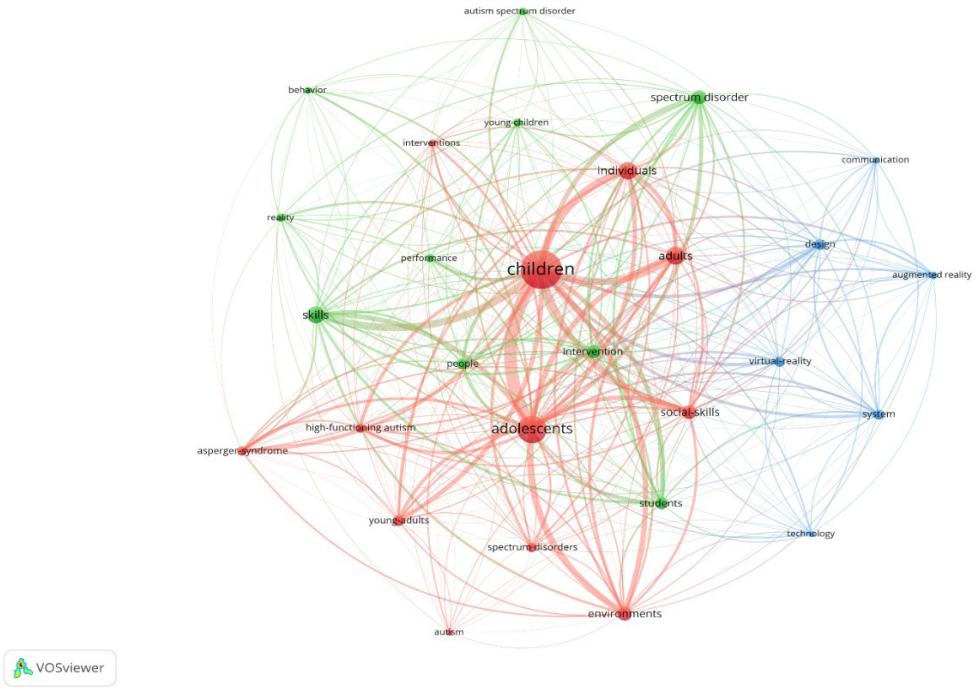

Figure 8. Author keywords graph. Node size: occurrences; color: cluster; analysis: association strength

documents, as well as the most productive and prominent authors. Finally, the most cited articles and the most frequently used keywords and Keywords Plus® were presented.

While there have been valuable previous contributions through systematic reviews and bibliometric analysis, the constant evolution of trends and the increase in publications made it relevant to update the literature with a new bibliometric analysis, identify emerging patterns, and provide an updated view of the main lines of research.[9,19,20,30,31]

4.1. DOCUMENTS AND PUBLICATION TRENDS

A total of 398 publications were obtained, with the first document related to this topic published in 1996.[55,56] However, upon analyzing the publication years, we observed that there was no continuity in the subsequent years. It was not until 2007 that a consistent year-to-year publication pattern emerged. From 2007 to 2024, there was an exponential growth in publications with an R^2 of 0.97. Therefore, the year 2007 confirmed the exponential growth of interest in the study of VR in autistic individuals. Considering these results and the implications of Price's law, the findings indicate a consolidated and actively expanding body of research on this topic, which stands to benefit from the insights generated in the present analysis.[32] Similar evidence of an exponential growth in publications has been reported in previous bibliometric analyses, although those studies included a smaller number of documents as they focused exclusively on educational research and on samples of high-functioning children with ASD.[30] In recent years, with high scientific production, 2017 stood out as the year when publications related to both VR and autism began to emerge, as reported by other authors.[31] In line with our results, other bibliometric analyses with VR as the study topic have shown similar exponential growth.[9,57] In addition, another bibliometric analysis showed an exponential growth of 0.97 in publications (1,556 publications) on the use of VR in neurorehabilitation.[58] All this evidence demonstrates the growing interest in this topic among researchers, institutions, and journals engaging with these new and promising technologies.

This more marked growth in recent years could also be related to the exponential increase in the prevalence of autism cases worldwide. Specifically, in 2021, it was estimated that 1 in 44 children was diagnosed with ASD in the USA, compared to 1 in 166 in 2004,[59] which also generates greater scientific interest in addressing individuals with ASD and the challenges they face.

4.2. THEMATIC WEB OF SCIENCE CATEGORIES

Individuals on the autism spectrum exhibit distinctive patterns in social reciprocity, communicative functioning, and behavioral flexibility, often accompanied by restricted interests and recurrent motor or behavioral routines.[60] Due to these difficulties, their quality of life is affected, although it is not always possible to directly assess this metric.[61] Therefore, many researchers have taken an interest in this condition from various fields of knowledge, leading to significant development in the study area, including high-impact documents on diverse topics. This is a cross-cutting research area and has been approached from multidisciplinary areas. A clear example of this is the disparity in the scope of the thematic categories with the largest number of papers, or the journals with the most publications. The two categories with the most publications are developmental psychology, with 74 publications, including the *Journal of Autism and Developmental Disorders*, which has 38 documents and is the first core journal to publish papers on this topic. The second category with the most documents is rehabilitation, with 73 documents. This category includes the journal *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, which has 14 articles and is the second core journal to publish papers on this topic. Together, these two journals account for 52 of the 142 core publications, underscoring the marked engagement of the research community with VR applications in psychological development and rehabilitation for autistic populations. Specifically, the use of these technologies in rehabilitation has been identified in various studies across different populations, such as Parkinson's disease.[62-65] In this sense, a previous bibliometric analysis in VR highlighted the WoS category of rehabilitation as having the highest number of publications, being the main area of interest in the use of VR.[49] Similarly, Lorenzo *et al.*,[31] one of the prominent co-authors, in the bibliometric study on the use of VR from an educational perspective in autistic individuals, also detected that developmental psychology and rehabilitation were the most prominent areas in WoS.[31] This reflects the continuous and growing interest of researchers in exploring the application of VR in these fields. In addition, these categories included publications, such as "Virtual Reality Social Cognition Training for Young Adults with High-Functioning Autism," which is the most cited paper.[53] Additionally, the study entitled "The potential of virtual reality in social skills training for people with autistic spectrum disorders"[66] is also included. In particular, the study by Kandalaft *et al.*[53] is the most cited, and Chapman SB is one of the prominent co-authors. These authors address the treatment of young adults with high-functioning autism, where evidence is still limited. This publication focuses on the use of VR to improve social skills, social cognition, and social functioning, with results suggesting that VR is a promising tool for enhancing these variables.[53] In contrast to our findings, Lorenzo *et al*.[31] identified the study as the sixth most cited in their bibliometric analysis, with 99 citations in 2018.

The study by Parsons *et al*.[66] is the third most cited article with 281 cites. This study is a comprehensive review of the literature, which concludes that VR can be a valuable tool for practicing behaviors in role-play situations, providing a safe environment for learning and repetition of tasks.[66] Previous bibliometric studies show similar results, with this article being the second most cited article, with 133 citations in 2018.[31] These virtual environments can improve understanding of social events and promote a flexible approach to solving social problems, introducing an alternative approach to fostering social competence for autistic individuals.[53,67]

In addition, all contributions covered fields such as psychology, education, rehabilitation, psychiatry, neuroscience, linguistics, communication, and pediatrics, all related to the most common keywords. When analyzing the keywords and Keywords Plus® in the set of documents, it was found that there was a group of terms that stood out from the rest in terms of their frequency of use. Among the concepts most frequently used by the authors, several thematic groupings stood out that can be used to identify research trends. The keywords were grouped into themes such as: virtual reality, autism, autism spectrum disorder, ASD, augmented reality, technology, children, intervention, social skills, immersive virtual reality, adults, eye tracking, rehabilitation, and

anxiety. All of this reflects the areas of interest in the use of VR interventions. In this regard, a recent systematic review showed that people with ASD experience severe social anxiety due to difficulties in understanding social cues, interpreting facial expressions, maintaining eye contact, and participating in two-way conversations.[68] In this regard, treatment on VR platforms is less stressful and less likely to increase anxiety or distress.[22] In relation to the temporality of the use of these terms, terms such as interventions, autism spectrum disorder, social skills, machine learning, and augmented reality are currently used around these topics.

Beyond VR-focused studies, ASD research has traditionally employed a wide range of methodological approaches, including behavioral and observational assessments, eye-tracking techniques, wearable sensors, and artificial intelligence.[27,29,69,70] Rather than constituting independent research lines, such methodologies increasingly inform the design, evaluation, and personalization of VR-based environments. In this sense, VR research can be understood as part of an integrative methodological framework, where insights derived from complementary approaches help guide target skill selection, outcome measures, and adaptive system development.

4.3. JOURNALS AND DOCUMENTS

Interest in thematic publications was also reflected in the high impact factor of the journals. The three journals with the highest number of publications were the *Journal of Autism and Developmental Disorders*, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, and *Interactive Learning Environments*, all of which are journals in the first quartile for their thematic categories. It is worth noting that the journal *Autism*, although with a smaller number of documents than the previous journals (9), accumulated 570 citations, more citations than the second journal in the core. These 15 core journals focused on topics related to autism and developmental disabilities, rehabilitation engineering, interactive learning environments, psychiatry, enabling technologies, autism research, psychology, brain science, and the use of VR.

4.4. AUTHORS AND CO-AUTHORS

In terms of authors, 25 co-authors were identified as prolific and 17 as prominent. Among them, the co-authors with the highest number of publications were Sarkar N and Lahiri U, among others, who published their work mainly in the WoS category "Rehabilitation," the second WoS category with the highest number of articles. In line with our results, the bibliometric analysis by Lorenzo *et al*.[31] identified the authors from Vanderbilt University (Sarkar N and Warren Z) as the top producers, having authored more than 10 articles on the topic until 2018.

These co-authors were grouped into eight clusters: the blue cluster, led by Sarkar and Lahiri and other researchers from the USA, formed a collaborative group with research related to engineering, biomedical, rehabilitation, computer science, software engineering, artificial intelligence, cybernetics, psychology, and development. The results of this cluster include important research, such as "Design of a Gaze-Sensitive Virtual Social Interactive System for Children With Autism"[71] and "Assessing the Utility of a Virtual Environment for Enhancing Facial Affect Recognition in Adolescents with Autism".[72] Alcaniz M was in the red cluster, mainly formed by Spanish researchers with papers such as "Machine Learning and Virtual Reality on Body Movements' Behaviors to Classify Children with Autism Spectrum Disorder"[73] and "Eye gaze as a biomarker in the recognition of autism spectrum disorder using virtual reality and machine learning: A proof of concept for diagnosis",[74] making important contributions focused on the use of VR and matching learning techniques to improve the detection and classification of autism. The latter in particular aimed to distinguish between typically developing and autistic children in visual attention behaviors using an eye-tracking paradigm in a virtual environment.[74] Schmidt MM and other researchers from the USA were in the green cluster with papers such as "Evaluation of a spherical video-based virtual reality intervention designed to teach adaptive skills for adults with autism: a preliminary report".[19] Collaboration networks were observed between researchers from the green and sky blue clusters, highlighting the integration of various disciplines to advance technological interventions in the field of autism.

Among the prolific authors, Sarkar N and Warren Z stood out as prominent authors, as they both have seven articles among the 56 most cited articles following the h-index, with cumulative citations of 729 and 706, respectively. In particular, both are co-authors of the paper "EEG-Based Affect and Workload Recognition in a Virtual Driving Environment for ASD Intervention".[75] The study focused on developing group classification models to detect affect states and mental workload in people with ASD during driving training. It concluded that electroencephalogram-based models are feasible for identifying affect intensity and workload in this context.[75] Sarkar also has other publications, such as "Design of a Virtual Reality-Based Adaptive Response Technology for Children With Autism",[77] "Understanding how Adolescents with Autism Respond to Facial Expressions in Virtual Reality Environments",[77] and "Cognitive Load Measurement in a Virtual Reality-Based Driving System for Autism Intervention",[78] among others, framed in the thematic categories of engineering, biomedical, rehabilitation (the second category with the most papers), computer science, and artificial intelligence.

4.5. COUNTRIES

The USA was the country with the highest number of documents and citations, driven mainly by researchers such as Sarkar N, Warren Z, or Chapman SB, all prominent co-authors with between two and seven articles among the most cited. Spain was the fourth country with the highest number of publications, with co-authors such as Lorenzo LG from the University of Alicante and Marian Sierra, Luis Abad, or Mariano Alcaniz from the University of Valencia standing out. Previous bibliometric studies on this topic also identified the USA as the country with the most publications in this field.[31,79] Additionally, other bibliometric studies have similarly reported that countries such as the USA, Italy, Canada, the United Kingdom, and Spain led research in VR-related neurorehabilitation.[58] These authors attribute this pattern to structural factors such as higher national Gross Domestic Product, which enables greater investment in clinical and technological research, as well as the higher prevalence of neurological conditions in Western Europe and North America.[58] The limited contribution observed from Africa and some other regions likely reflects disparities in research infrastructure, funding availability, and

diagnostic resources, rather than differences in the prevalence of ASD.[79,80,81]

4.6. PRACTICAL IMPLICATIONS

The analysis provides valuable information for editors, new researchers, and senior researchers, helping them to make informed decisions, identify key collaborators and references, and expand their collaborative networks. The practical implications of a bibliometric review on autism and VR cover several areas, including the identification of research trends that guide researchers toward high-impact topics and highlight gaps in exploration. From a clinical perspective, the identification of consolidated thematic clusters and emerging intervention-oriented trends offers concrete guidance for the development of VR-based therapeutic interventions. The study also supports the development of therapeutic interventions by pinpointing virtual reality approaches that have shown promise in enhancing social skills, emotional regulation, and specific skill learning for individuals with ASD. Additionally, it provides clinical and educational centers with insights to efficiently allocate resources, prioritizing scientifically backed VR tools.

Future lines of research could include a deeper analysis of the influence of the most cited article and the temporal relationship between topic development and factors such as changes in global strategies and research funding. Furthermore, the limited number of studies focusing on adults and individuals with greater support needs highlights an opportunity for the design of more accessible and scalable VR-based interventions.

Additionally, as a future direction, it is recommended that complementary studies be conducted to delve deeper into the technological and sensory aspects involved in the application of VR for autistic individuals, to optimize its effectiveness and adaptability in this context. Additionally, future research should focus on analyzing the differences in disciplinary approaches, such as technological and psychological, to better understand the complementary and divergent perspectives these fields contribute to the study of this area.

4.7. LIMITATIONS

Although this type of methodology is useful for obtaining an overview of the field of knowledge and can serve as a starting point for future research, it can also identify areas that require further investigation, highlighting the few studies conducted on the adult population. This study has certain limitations that should be acknowledged. Although we used databases indexed in the WoSCC, one of the most prestigious and widely used in the scientific community for bibliometric studies, this introduces a selection bias by not including research published in journals indexed in other databases. However, this decision was taken to ensure the homogeneity of the bibliometric index.

5. CONCLUSION

Research on ASD and VR is in an exponential growth phase. This topic of study has been approached from numerous thematic areas, finding articles related to up to 65 WoS thematic categories. Among the 1,505 authors found, Sarkar N, Warren Z, and Lahiri U stood out as prolific and prominent authors. Twenty-five authors with five or more papers were found as prolific authors, although only 17 of them were considered prominent authors.

Fifty-six documents had 58 or more citations, representing the most-cited papers in this field. The USA and the United Kingdom were the leading contributors in terms of publication volume, and the *Journal of Autism and Developmental Disorders* was the journal with the most publications. In terms of keywords, a differentiation was found between author keywords and Keywords Plus®. Both identified various thematic clusters related to different types of VR, ranges of age, and areas and fields affected.

The actual trends reveal a substantial critical mass that continues to grow, reflected in a high volume of annual publications, with research areas evolving over time from developmental psychology, rehabilitation, and special education to educational research and psychiatry.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

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CONSENT FOR PUBLICATION

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DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

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