General

# Advances in Autism: a bibliometric analysis

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This paper provides a comprehensive overview of AI treatment research for Autism Spectrum Disorder (ASD) from 2007 to 2023, focusing on global contributions across countries, institutions, authors, and keywords. The United States leads with 164 documents and 4988 citations, highlighting its central role in advancing AI technologies for ASD therapies, followed by significant contributions from China (90 documents, 1190 citations) and India (65 documents, 564 citations). Institutions like Stanford University and McGill University demonstrate substantial research output, while authors such as Dennis Wall are prominent with contributions that make diagnosing Autism much more efficient with the use of AI. Keywords like “Machine learning”, “Autism spectrum disorder”, and “Children” dominate, reflecting ongoing efforts to leverage technology for ASD interventions. Overall, this analysis underscores a dynamic global effort to enhance ASD treatment methodologies through collaborative research and technological innovations.

## INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by challenges in social interaction, communication, and repetitive behaviors. It affects individuals differently, with symptoms ranging from mild to severe, hence the term “spectrum.” Globally, ASD prevalence estimates vary, but the World Health Organization suggests approximately one in 160 children worldwide have ASD (11).

Symptoms of Autism typically emerge within the first two years of life, with early signs observable in infants as young as 12 months. The current standard for ASD diagnosis relies heavily on behavioral observational tests conducted by clinicians, such as the Autism Diagnostic Observation Schedule (ADOS) or Autism Diagnostic Interview-Revised (ADI-R) (8). However, these methods are subjective and can be time-consuming. Therefore, achieving an early and accurate diagnosis is essential to mitigate the progression of the condition and enhance long-term prognostic outcomes.

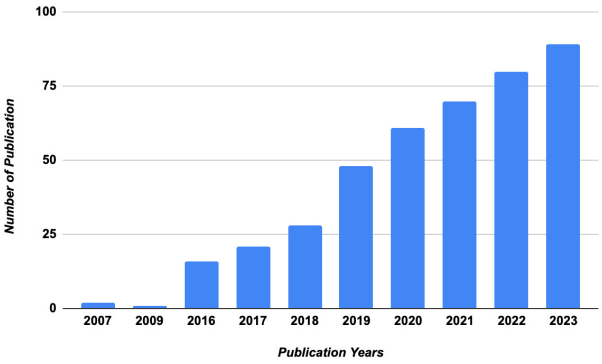
In recent years, artificial intelligence (AI) has shown promise in aiding the diagnosis of Autism Spectrum Disorder (ASD), complementing traditional methods. AI algorithms analyze behavioral patterns, speech, and language characteristics to identify potential markers of ASD. This technology has the potential to improve diagnostic accuracy, especially in cases where symptoms are subtle or vary widely. Research and development in AI-based diagnostic tools are ongoing, aiming to create more accessible and efficient screening processes that can be integrated into clinical settings.

Machine learning (ML) plays a significant role by analyzing extensive datasets encompassing behavioral, genetic, and neuroimaging data to detect patterns indicative of ASD (9). ML models can also predict the likelihood of ASD based on diverse inputs, enhancing diagnostic accuracy. Natural language processing (NLP) is another pivotal AI tool, analyzing verbal communication through speech patterns or interviews to identify linguistic traits associated with ASD, such as pragmatic language impairments (6). Additionally, NLP-powered chatbots or automated systems interact with individuals to screen for ASD based on text-based interactions, facilitating early detection and intervention. These AI technologies collectively contribute to more efficient and precise ASD diagnosis, improving outcomes for individuals and enhancing clinical decision-making processes.

We gathered and compiled research literature on various AI tools from the Web of Science, and employed CiteSpace and VOS viewer to comprehensively analyze and visualize this literature from different sources. This paper reveals emerging technologies in autism diagnosis, offering new insights into autism research. The findings from these analyses are poised to assist future researchers in comprehending the overall advancements in this field.

## METHODS

1. Analyze the number of articles published on AI technologies in diagnosing ASD using the Web of Science website
2. Identify authors and collaborations within the AI and ASD intersection provides insights into the research landscape’s key contributors.




Analyzing institutions involved in AI-based ASD research highlights centers of excellence and collaborative networks shaping the field.
Countries: Mapping the geographic distribution of research in AI-based ASD diagnosis reveals global trends, regional disparities, and emerging hotspots in this specialized area.

3. Examining where AI-driven ASD diagnosis research is published (high-impact journals, specialized AI or medical journals) indicates the field's visibility, credibility, and interdisciplinary nature.
   Analyzing the references cited in these publications reveals foundational works, influential studies, and methodological approaches shaping current research directions.
4. Identifying key terms related to AI technologies in ASD diagnosis since 1998 reveals evolving research interests, such as machine learning, deep learning, computer vision, and natural language processing applied to ASD diagnostics.

## RESULTS

### ANNUAL PUBLISHING TRENDS

A total of 501 articles was included with a continually increasing trend ranging from years 2007 to 2023.

### ANALYSIS OF AUTHORS, INSTITUTIONS, AND COUNTRIES/REGIONS

The collaboration network involves authors, institutions, and countries. In this network, each node symbolizes an individual researcher, with the node's size indicating the number of papers authored. Connections between nodes denote collaborative relationships among individuals. Nodes and connections are depicted in varying colors to signify different years, with a gradient from cool to warm indicating chronological proximity.

### COUNTRIES

Leading in document production is the United States with 164 publications, followed by China with 90 and India with 65. In terms of citations received, the United States leads significantly with 4988 citations, emphasizing its strong influence in the global research community, followed by England with 1089 citations. Both the USA and England also excel in total link strength, each registering 113 units, indicating robust collaboration networks and impactful research partnerships. Meanwhile, countries like Italy, Canada, and Australia demonstrate moderate levels of research activity and impact, while Saudi Arabia, United Arab Emirates, and France exhibit fewer documents and citations [Table 1].

### INSTITUTIONS

Institutions such as Stanford University lead in research output with 22 documents and 912 citations, emphasizing their pivotal role in advancing AI technologies for ASD therapies. McGill University follows closely with 9 documents and 424 citations, reflecting its substantial academic influence in the field. Notably, institutions from diverse geographical regions, including Abu Dhabi University and the Chinese Academy of Sciences, contribute significantly to the global research network, further enriching international discourse on AI treatment for ASD [Table 2] [Figure 1].

### AUTHORS

Among the top authors, Dennis Wall stands out with 13 documents and 474 citations, indicating substantial scholarly contributions and influence in the field. Authors like Ayman El-Baz and Ahmed Shalaby also contribute significantly, each with impactful research outputs and citation frequencies, demonstrating a collaborative and expansive research landscape. The analysis shows that while certain authors have high publication counts, academic influence and centrality are influenced by various factors beyond sheer publication volume, reflecting the diverse and interdisciplinary nature of AI treatment research for ASD [Table 3][Figure 2].

### KEYWORDS

Keywords such as "Machine learning" and "Autism Spectrum disorder" dominate the research landscape, with high occurrence frequencies and significant link strengths, highlighting their pivotal roles in shaping research directions and innovations. These keywords underscore the persistent focus on leveraging advanced technologies to understand and address ASD challenges effectively. The findings suggest a dynamic research environment where multidisciplinary approaches and technological advancements converge to foster new insights and therapeutic strategies for ASD [Table 4] [Figure 3].

## DISCUSSION

The application of artificial intelligence (AI) in medical diagnostics is rapidly expanding, with growing attention towards its utilization for diagnosing autism spectrum disor-

**Table 1. Number of documents, citations, and link strength for the top 10 countries publishing in autism.**

| Countries | Documents | Citations | Total link strength |
|---|---|---|---|
| USA | 164 | 4988 | 113 |
| China | 90 | 1190 | 46 |
| India | 65 | 564 | 48 |
| England | 37 | 1089 | 113 |
| Italy | 28 | 662 | 15 |
| Canada | 27 | 965 | 30 |
| Saudi Arabia | 25 | 374 | 32 |
| Australia | 24 | 363 | 38 |
| United Arab Emirates | 21 | 307 | 30 |
| France | 31 | 318 | 25 |

**Table 2. Number of documents, citations, and link strength for the top institutions publishing in autism.**

| Institution | Documents | Citations | Total link strength |
|---|---|---|---|
| Stanford University | 22 | 912 | 7 |
| University Louisville | 13 | 152 | 15 |
| Abu Dhabi University | 11 | 143 | 15 |
| Chinese ACAD Sci | 10 | 157 | 8 |
| Mcgill University | 9 | 424 | 12 |
| Kings Coll London | 9 | 276 | 11 |
| Alberta University | 7 | 450 | 9 |
| Columbia University | 7 | 81 | 4 |
| University of Minnesota | 6 | 559 | 9 |
| Vanderbilt University | 6 | 443 | 3 |

**Table 3. Number of documents, citations, and link strength for the top authors publishing in autism.**

| Author | Documents | Citations | Total link strength |
|---|---|---|---|
| Dennis Wall | 13 | 474 | 23 |
| Ayman El-Baz | 12 | 152 | 58 |
| Ahmed Shalaby | 11 | 145 | 59 |
| Peter Washington | 11 | 364 | 25 |
| Fadi Thatbtah | 10 | 367 | 0 |
| Ali Mahmoud | 9 | 95 | 50 |
| Mohammed Ghazal | 9 | 93 | 44 |
| Gregory Barnes | 7 | 69 | 40 |
| Aaron Kline | 7 | 219 | 21 |
| Kaitlyn Dunlap | 7 | 138 | 19 |

der (ASD). This paper analyzed 501 research articles about AI treatment research for Autism Spectrum Disorder (ASD) from 2007 to 2023. Based on the results above, it is clear that there has been a significant increase in publications focusing on AI in ASD in the past 16 years. This trend highlights the increasing popularity of this research area in recent times. Machine learning and deep learning integrated into computational intelligence systems, alongside other AI tools, are increasingly being employed in the medical domain.

Current ASD screening methods are critiqued for their reliance on extensive item-based assessments and subjective scoring by domain experts. To address these limitations, there is a growing interest in leveraging artificial intelligence (AI) to develop more efficient and accurate screening tools.

**Table 4. Number of occurrences, and link strength for the top keywords in autism.**

| Keywords | Occurrences | Total link strength |
|---|---|---|
| Machine learning | 216 | 1115 |
| autism spectrum disorder | 190 | 867 |
| children | 178 | 944 |
| classification | 119 | 692 |
| diagnosis | 110 | 610 |
| autism | 107 | 514 |
| spectrum disorder | 64 | 344 |
| deep learning | 64 | 344 |
| artificial intelligence | 42 | 191 |
| fmri | 38 | 230 |

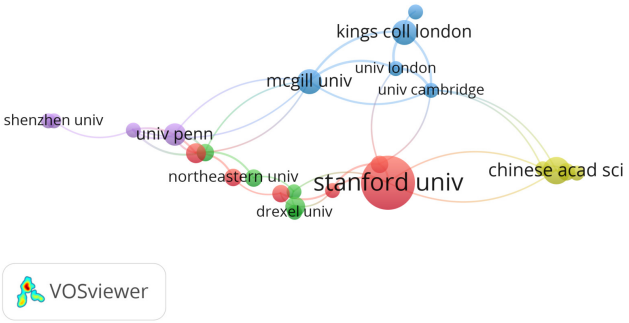



**Figure 1. Top institutions**

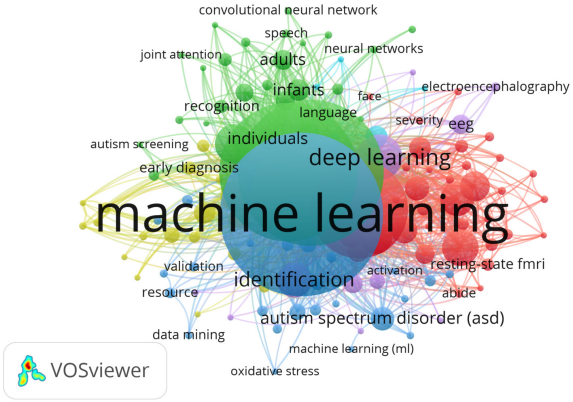



**Figure 3. Top keywords in autism**

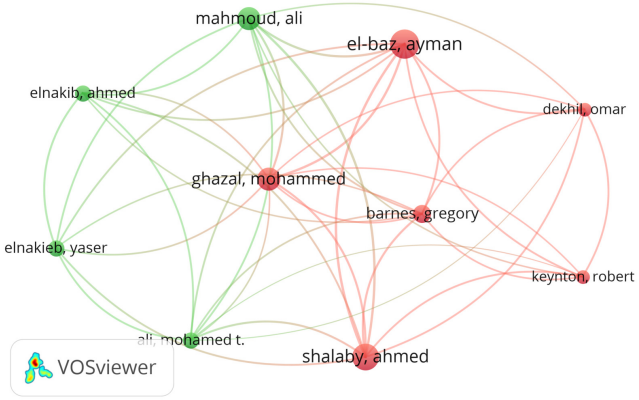



**Figure 2. Top authors**

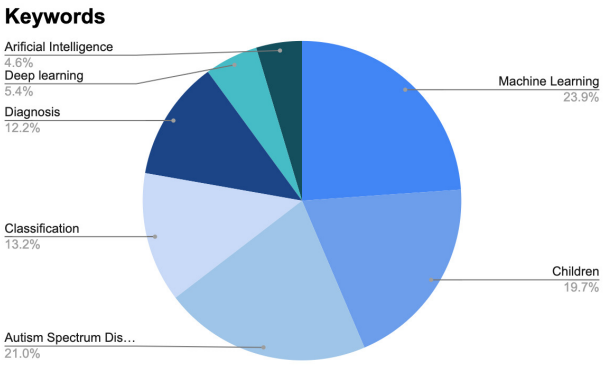



**Figure 4. Keyword categories**

One promising approach is the integration of deep learning (DL) algorithms into ASD screening systems. For instance, a recent study introduced a novel AI-driven screening system utilizing a Convolutional Neural Network (CNN) (10). This system features a mobile application for user interface and data collection, an intelligent ASD detection web service interfacing with the CNN, and a dynamic database for continuous learning from new data. Evaluation against a diverse dataset including adult, adolescent, child, and toddler cases demonstrated superior performance of the CNN over traditional screening methods, showcasing enhanced accuracy, sensitivity, and specificity. DL techniques have been applied to neuroimaging data, particularly using diffusion tensor imaging (DTI) and functional MRI (fMRI) modalities (2). These techniques offer non-invasive insights into brain structure and function, aiding in early and objective ASD diagnosis. The integration of

DL networks has shown promising results in automating ASD diagnosis and supporting rehabilitation efforts for ASD patients. NL (Natural Language) models processes natural language text from parents' dialogues to detect ASD symptoms (13). It employs sentiment analysis techniques to classify sentences based on their positive or negative sentiments towards ASD symptoms, utilizing BERT and ChatGPT models trained on a specific dataset. A significant advantage of this approach is its reliance on text-based analysis, making it cost-effective and accessible. This method has the potential to improve ASD detection and support, especially in underserved regions, thereby bridging gaps in ASD diagnosis and intervention efforts.

The distribution of research output and impact across different countries reflects a variety of factors shaping their positions in the global scientific community. Leading this is the United States, which stands out with 164 publications and a substantial 4988 citations, underscoring its significant influence driven by extensive research funding, robust infrastructure, and a culture that values academic excellence. England follows closely with 90 publications and 1089 citations, also demonstrating strong collaboration networks and impactful research partnerships, as evidenced by their total link strength of 113 units each. Both countries benefit from longstanding traditions of scientific innovation and a high concentration of prestigious universities that attract top researchers worldwide. In contrast, countries like Italy, Canada, and Australia exhibit moderate levels of research activity and impact, contributing steadily to global scientific advancements. Meanwhile, Saudi Arabia, United Arab Emirates, and France show fewer documents and citations, suggesting varying degrees of investment in research and differing priorities within their research landscapes.

Leading institutions like Stanford University, renowned for its substantial research funding, advanced infrastructure, and a culture of innovation, consistently produce a significant volume of influential research. This leadership position enables them to attract top researchers and students, driving advancements in AI technologies aimed at enhancing therapies for ASD. Similarly, McGill University's strong academic reputation contributes to its notable research output in the field, supported by rigorous academic standards and collaborations with leading experts. Furthermore, the global research landscape benefits from contributions by institutions from diverse geographical regions. Institutions like Abu Dhabi University and the Chinese Academy of Sciences enrich international discourse on AI applications for ASD by bringing unique perspectives and expertise to the forefront. This collaborative effort underscores a global commitment to leveraging AI innovations to improve outcomes for individuals affected by ASD, fostering a dynamic and inclusive research environment.

Dennis Wall emerges as a prominent figure in autism research, credited with 13 documents and 474 citations, indicating significant scholarly contributions and influence within the field. Additionally, Wall founded Cognoa, a company focused on autism diagnosis via a smartphone app for parents, securing over $20 million in venture capital and pursuing FDA approval.

Keywords such as "Machine learning" and "Autism spectrum disorder" command substantial attention within the research community, characterized by frequent appearance and strong linkages, signaling their central roles in driving innovative research directions. These keywords reflect a concerted effort to use emerging technologies, particularly machine learning, in tackling the complexities of ASD. The research landscape is dynamic, emphasizing various approaches that integrate technological advancements to yield deeper insights into ASD's nuances and to develop more effective therapeutic interventions. This intersection of machine learning and ASD research highlights ongoing efforts to enhance understanding and improve outcomes for individuals affected by autism spectrum disorder.

## ETHICAL APPROVAL

The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The Orlando College of Osteopathic Medicine's Research Committee determined this study to be exempt.

## CONSENT TO PARTICIPATE

Not applicable

## AVAILABILITY OF DATA AND MATERIALS

Not applicable.

## AUTHOR CONTRIBUTIONS

MC drafted the initial manuscript. MG and LG edited and critically revised the manuscript. All authors read and approved the final manuscript.

## COMPETING INTERESTS

Dr. Latha Ganti has an editorial role at Springer.

## CORRESPONDING AUTHOR

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## CONFLICTS OF INTEREST

None of the authors have any conflicts of interest.

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