



# Bibliometric Analysis of Research Themes and Trends of the Co-Occurrence of Autism and ADHD

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**Background:** In recent years, there has been a growing body of research suggesting that ASD and ADHD are two disorders that often co-exist. Despite the rapid development of research, little is known about their etiology, diagnostic markers, and interventions, which has led us to review and summarise the development of the field in the hope that this will provide an opportunity to look for future directions.

**Methods:** A bibliometric approach was used to analyse papers in the field of ASD co-morbidities in ADHD on Web of Science from 1991–2022, using CiteSpace and VOSview to map the country/institution, journal, author, co-citation, and keyword networks in the field and to visualise the results.

**Results:** A total of 3284 papers were included, showing an increasing trend in terms of posting trends. Research on co-morbidities of ASD has proven to be mainly focused on universities. The USA (1662) published the most relevant literature in this area, followed by the UK (651) and Sweden (388). Lichtenstein P is the most published author (84), and research into the pathogenesis of ASD co-occurring ADHD and related clinical diagnostics is currently at the forefront of the field.

**Conclusion:** This analysis identifies the most influential institutions and countries, cited journals, and authors in the field of ASD co-morbid ADHD research. The future direction of ASD co-occurring ADHD should be based on improving case identification, discovering the etiological and diagnostic markers of ASD and ADHD, and finding more effective clinical interventions.

**Keywords:** autism, hyperactivity, bibliometrics, VOSviewer, CiteSpace, visualization analysis

## Introduction

Autism Spectrum Disorder (ASD) is a common neurodevelopmental disorder that begins in childhood, along with Attention Deficit Hyperactivity Disorder (ADHD).<sup>1,2</sup> The core impairments of ASD are social interaction deficits and limited, narrow patterns of repetitive behaviour.<sup>3</sup> ADHD is characterised by symptoms of inattention, hyperactivity or impulsivity that are disproportionate to the level of development.<sup>4</sup> ADHD is characterized by symptoms of inattention, hyperactivity, or impulsivity that are incompatible with development. Although the two disorders are defined by their distinct core syndromes, they have a high degree of clinical overlap.<sup>5</sup> Currently, the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) diagnostic criteria consider a co-morbid diagnosis to be made if a person with ASD has significant ADHD symptoms.<sup>6</sup> The DSM-5 criteria suggest that a co-morbid diagnosis can be made if a person with ASD has significant ADHD symptoms. Studies have found that the prevalence rate of ADHD among children with ASD is 37%–85%. Similarly, about 13% of children with ADHD had ASD.<sup>7</sup> The prevalence of co-occurring ADHD in children with ASD has been increasing over time.

In recent years, there has been a growing body of research on the co-morbidity of ASD and ADHD. Researchers have found some overlap between ASD and ADHD in terms of disease characteristics. Firstly, in terms of clinical presentation, both children with ASD and children with ADHD may have symptoms such as attention deficit, hyperactivity and impulsivity, and difficulties with social interaction. The most common symptoms are attention deficit, hyperactivity, and impulsivity.<sup>8,9</sup> The most common symptoms are attention deficit, hyperactivity, and impulsivity, but the core symptoms

of ASD, such as social interaction difficulties, language difficulties, and stereotyped behavior, are also common in children with ADHD, especially in those with more severe ADHD.<sup>10</sup> The core symptoms of ASD are particularly evident in more severe cases of ADHD. Secondly, the prevalence of ASD and ADHD in boys is higher than that in girls.<sup>11</sup> In addition, both ASD and ADHD are associated with a higher prevalence of ASD than girls. In addition, both ASD and ADHD are strongly associated with genetic factors.<sup>12</sup> In addition, both ASD and ADHD are associated with genetic factors. Therefore, it is necessary to summarise the history of the field of ASD co-morbidities in ADHD research, to identify current hotspots and potential trends, and to provide new ideas for future research.

CiteSpace is an excellent bibliometric tool that provides an overview of the structure of research in a field by mapping relevant knowledge, thus helping researchers to grasp the current state of research in the field from multiple perspectives.<sup>13</sup> VOSviewer also has strengths in bibliometric analysis.<sup>14</sup> This study is based on CiteSpace and VOSviewer for bibliometric and visual analysis. To the best of our knowledge, this is the first bibliometric analysis in the field of ADHD research on co-morbidities with ASD. We fill this gap and visualise trends in postings, collaborative networks (country, institution and author), published journals, keyword clustering, and keyword emergence in this research area. The aim is to provide a comprehensive analysis of research hotspots, future trends, challenges, and prospects for ADHD in ASD co-morbidity.

## Methods

The bibliometrics research process is shown in [Figure 1](#). A subject search was conducted in the Science Citation Index Expanded (SCI-E) database on WoS. The search was conducted in the Science Citation Index Expanded (SCI-E) database on WoS. The search was conducted from the date of creation to 31 October 2022. Type of literature: Article and Review. enter the following search terms in the subject field: (“autism” OR “autism spectrum disorder” OR “ASD” OR “autistic spectrum disorder”) AND (“attention deficit hyperactivity disorder” OR “attention deficit disorder with hyperactivity” OR “ADHD”) AND language = English. exclude newspapers, conferences, advertisements, and literature with incomplete and duplicate information. In the end, A total of 4110 papers were retrieved. After manual screening, 3284 articles were included, and data on the following variables were extracted: title, publication year, country, institution, journal, author, and keywords.

This study used CiteSpace (version 6.1.R3) and VOSviewer (version 1.6.10) for bibliometric analysis and data visualisation. Literature data were downloaded in plain text format, including title, author, abstract, source publication, cited literature and keywords. The normalised data were imported into VOSviewer 1.6.10 software to generate keyword network co-occurrence maps; the data were then imported into CiteSpace 6.0.R3 software for country/institution, author, keyword clustering, and emergent analysis, setting the time span to 1991–2022, with a time slice of 1 year, and setting the data with a Top N threshold, N=50, using pathfinder, pruning sliced networks and pruning the merged network clipping method for network clipping, clustering by LLR method, and drawing keyword clustering maps.

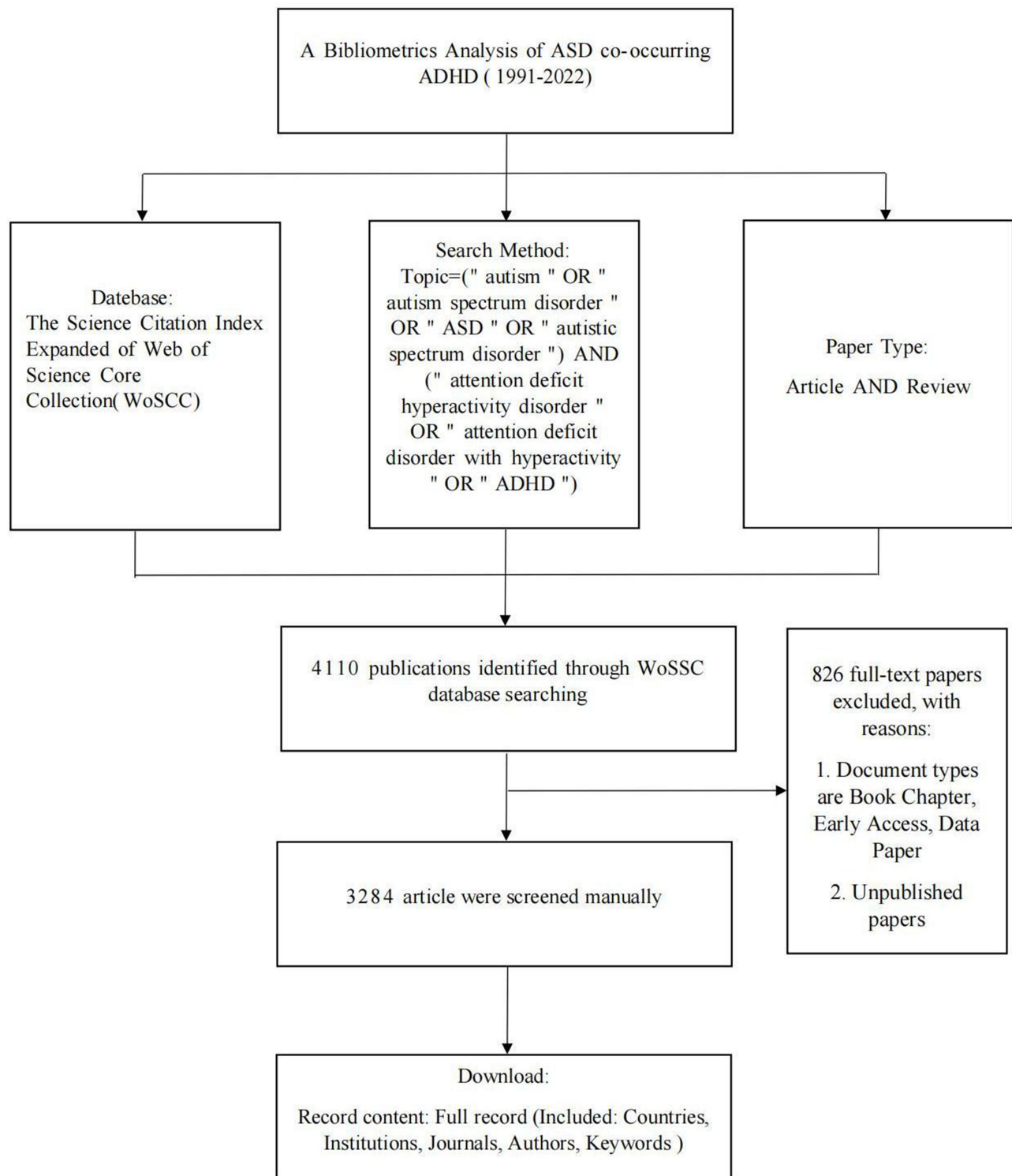
## Results

### Trends in Issuance

The search yielded a total of 3284 relevant articles. The number of articles published from 1991 to 2007 was low, with little change, and the research on ASD co-morbidities in ADHD was basically in its infancy during this period. In 2012, the number of articles exceeded 100 for the first time, after which the number of articles in this field increased exponentially and peaked in 2021. The number of articles published in 2022 is low as only the first 10 months of the literature are included in 2022. The overall trend shows that there has been significant research in the field in recent years and that there is great potential for future research (see [Figure 2](#)).

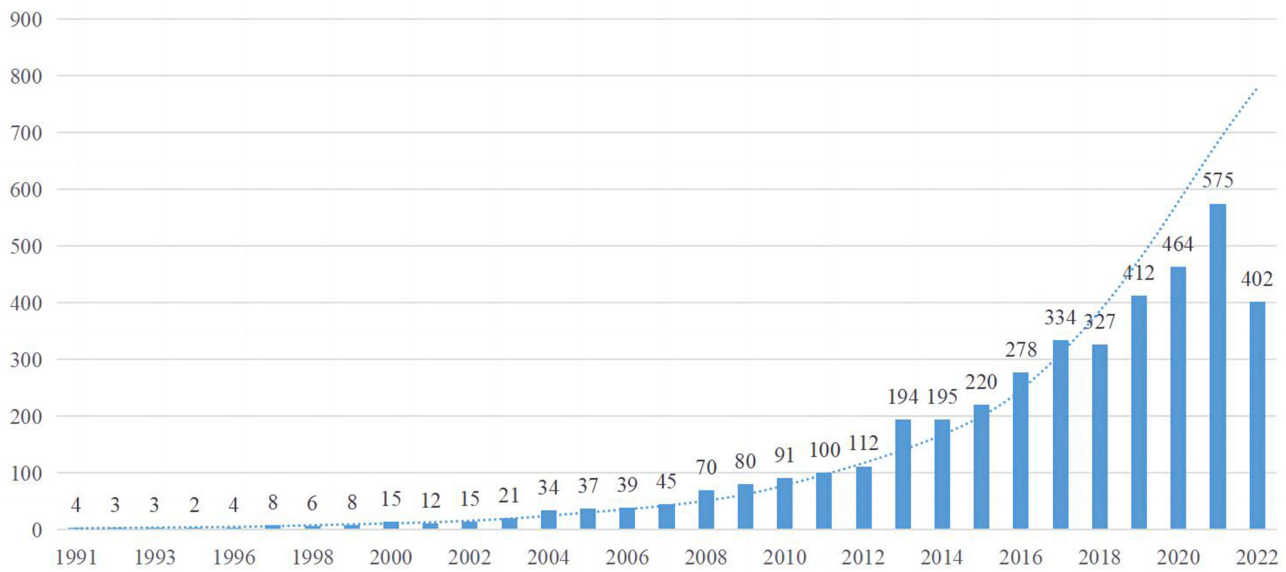
#### Countries / Regions and Institutions

A total of 93 countries/regions have published research on ADHD-related studies on co-morbidities in ASD (see [Figure 3](#)). The circles in the figure represent the number of studies published and the lines represent collaboration with each other. Larger circles indicate more relevant studies published, and thicker lines indicate closer collaboration. [Figure 4](#) shows the global distribution of publications in this area. The US has published the most relevant studies and



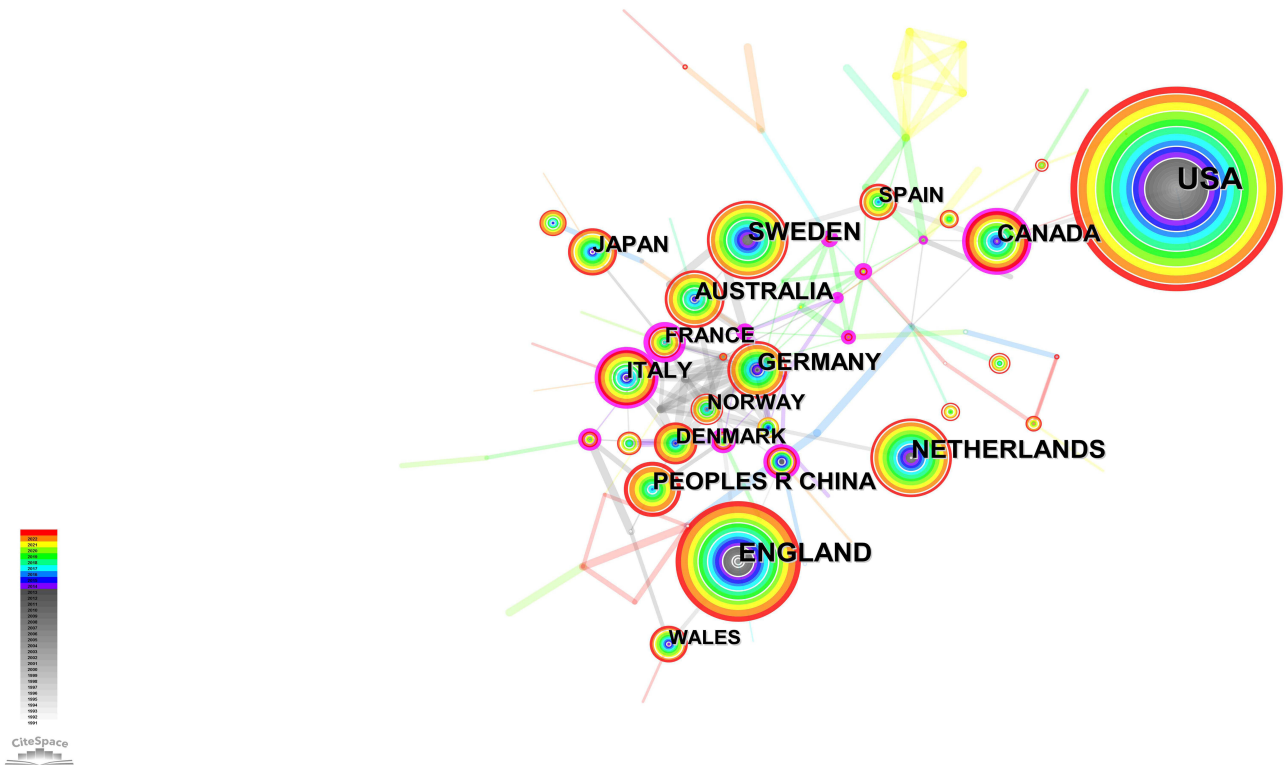
**Figure 1** Flow chart of bibliometrics analysis.

started the earliest, but it is not the most central (centrality = 0.04). This may be because since the US is dominated by inter-institutional collaboration within the country. This is followed by the UK, Sweden, the Netherlands and China. A total of 320 institutions are involved in this area of research (see [Figure 4](#)). The top 10 institutions with the most published articles are listed in [Table 1](#), with the Karolinska Institutet publishing the most articles, with 241 being



**Figure 2** The annual number of publications related to ASD co-occurring ADHD.

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 Network: N=93, E=154 (Density=0.036)  
 Largest CC: 84 (90%)  
 Nodes Labeled: 10%  
 Pruning: Pathfinder  
 Modularity Q=0.7716  
 Weighted Mean Silhouette S=0.9136  
 Harmonic Mean(Q, S)=0.8396



**Figure 3** The network of countries/regions publications and collaborations.

published from 2008 to 2022, followed by King’s College London (217), the University of Gothenburg (133), the Radboud University Nijmegen (132 articles), and the University of Toronto (108 articles). Notably all 10 institutions are now globally renowned universities, reflecting the fact that ASD co-occurring ADHD research continues to be dominated by universities with leading international research platforms and high levels of excellence.





**Figure 4** World map based on the total publications of different countries/regions.

## Journals and Cited Journals

Of the 3284 articles published in 201 journals, 49 journals (24.38%) had  $\geq 20$  articles, and those with  $\geq 100$  articles included the Journal of autism and developmental disorders (240 articles), Journal of child psychology and psychiatry and allied disciplines (113 articles), Research in developmental disabilities (109 articles), and European child adolescent psychiatry (104 articles). The impact factors of these journals are generally high, and the accepted articles mainly study the current status and etiology of ADHD in ASD from the perspectives of brain structure, genes, psychology and epidemiology, and other hot issues (Table 2).

**Table 1** Top 10 Institutions Published Analysis Concerning the Research of ASD Co-Occurring ADHD

Rank	Institutions	Country	Count	Centrality
1	Karolinska Institutet	Sweden	241	0.12
2	King's College London	England	217	0.04
3	University of Gothenburg	Sweden	133	0.03
4	Radboud University Nijmegen	Netherlands	132	0.06
5	University of Toronto	Canada	108	0
6	University College London	England	99	0.06
7	Cardiff University	Welsh	94	0.02
8	Harvard University	USA	87	0.02
9	University of Melbourne	Australian	77	0.06
10	Universitas Arhusiensis	Denmark	75	0.04

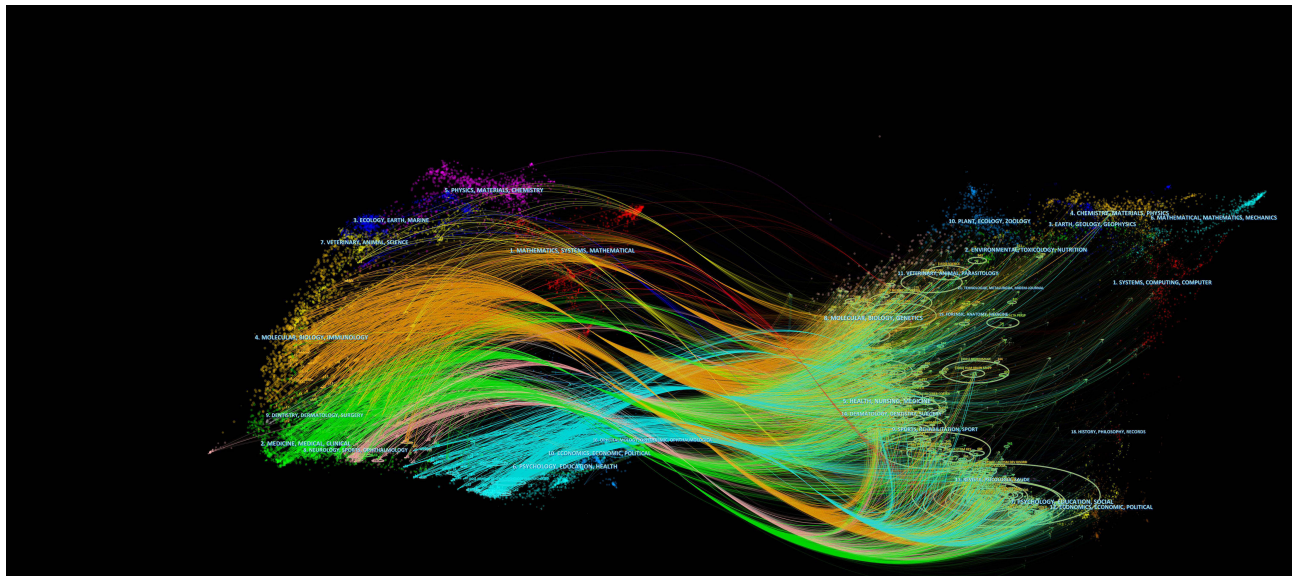
**Table 2** Top 10 Published Journal Analysis Concerning the Research of ASD Co-Occurring ADHD

Rank	Journal Title	Published Country	Count	IF (2022)	JCR (2022)	Research Area
1	Journal of Autism & Developmental Disorders	USA	240	4.35	Q3	Psychology
2	Journal of Child Psychology & Psychiatry & Allied Disciplines	USA	113	8.27	Q1	Psychology, Psychiatry
3	Research in Developmental Disabilities	England	109	3	Q2	Special Education, Rehabilitation
4	European Child & Adolescent Psychiatry	USA	104	5.35	Q2	Psychology, Psychiatry
5	Research in Autism Spectrum Disorders	England	91	3.29	Q3	Psychiatry, Special Education, Psychology, Rehabilitation
6	Journal of Attention Disorders	USA	85	3.19	Q2	Psychology, Psychiatry
7	Autism Research	USA	83	4.63	Q2	Behavioral Sciences, Psychology
8	Frontiers in Psychiatry	USA	76	5.44	Q3	Psychiatry
9	Autism	USA	73	6.68	Q2	Psychology
10	Translational Psychiatry	USA	62	7.99	Q2	Psychiatry

A total of 587 journals were cited for research related to ADHD in co-morbidities with ASD, and the 10 most frequently cited journals are shown in Table 3. Analysis by subject area was dominated by pediatrics, psychiatry and psychology. The Journal of autism and developmental disorders, the Journal of the American Academy of Child and Adolescent Psychiatry and the Journal of child psychology and psychiatry and allied disciplines were the most frequently cited journals, and the publishers of these journals were mainly based on the USA or the UK.

**Table 3** Top 10 Cited Journal Analysis Concerning the Research of ASD Co-Occurring ADHD

Rank	Journal Title	Cited Country	Frequency of Citations	IF (2022)	JCR (2022)	Research Area
1	Journal of Autism & Developmental Disorders	USA	2220	4.35	Q3	Psychology
2	Journal of the American Academy of Child & Adolescent Psychiatry	Netherlands	2158	13.11	Q1	Psychiatry, Pediatrics
3	Journal of Child Psychology & Psychiatry & Allied Disciplines	USA	1974	8.27	Q1	Psychology, Psychiatry
4	Biological Psychiatry	USA	1779	12.81	Q1	Neurosciences, Psychiatry
5	American Journal of Psychiatry	USA	1757	19.24	Q1	Psychiatry
6	BMC Pediatrics	England	1630	2.57	Q4	Pediatrics
7	Plos one	USA	1621	3.75	Q3	Multidisciplinary Sciences, Biology
8	Archives of General Psychiatry	USA	1366	13.77	Q1	Psychiatry
9	Molecular Psychiatry	England	1319	13.44	Q1	Biochemistry & Molecular Biology, Neurosciences
10	European Child & Adolescent Psychiatry	USA	1250	5.35	Q2	Psychology, Psychiatry



**Figure 5** A dual-map overlap of journals on ASD co-occurring ADHD carried out by Citespace.

Figure 5 shows the relationship between the citing and cited journals. We found that literature from the fields of psychiatry, psychology, and rehabilitation medicine had cross-citation relationships with literature from molecular biology, anatomy, genetics, etc. This indicates that the multidisciplinary culture of the field is effective, and researchers try to explain the pathogenesis of ADHD patients with ASD co-morbidities from the perspectives of molecular biology, genetics, and brain structure. And it is hoped that through rehabilitation and psychological intervention, patients can return to society sooner.

## Author

A total of 457 authors published articles on ADHD-related research with ASD co-morbidities (see Figure 6). The nodes and lines in the graph represent individual authors and their collaboration with each other, the size of the nodes and the thickness of the lines represent the number of articles published and the tightness of the collaboration, and the warm and cold colors represent the distance in time. Table 4 shows the top 10 authors in terms of the number of publications, with Lichtenstein P having published 84 articles, followed by Gillberg C 78 articles and Buitelaar J 70 articles. According to Price Law the minimum number of articles by core authors ( $M = 0.749 \times \sqrt{n_{\max}}$  ( $n_{\max}$  is the number of articles by the most productive authors)<sup>15</sup>  $M = 0.749 \times 9.2 \approx 6.89$ , taking the integer 7, ie the number of core authors' publications  $\geq 7$ . 85 core authors were screened out, with a total of 1418 publications, accounting for 43.18% of the total publications (1418/3284), not reaching 50% of the total literature, indicating that a significant core author group has not yet been formed.

## Co-Cited Literature

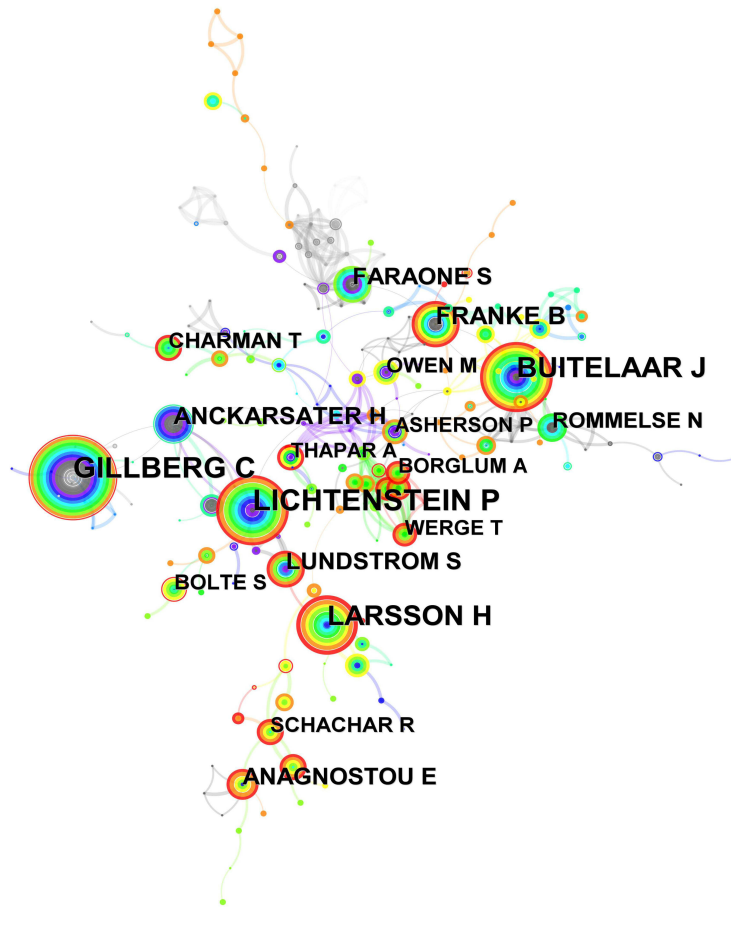
Analyzing the co-cited literature can help us to understand the research themes and the context in which the field has developed, and these co-citations form the knowledge base for the research. A total of 846 references were co-cited and the 10 most cited articles are listed in Table 5. The most frequently cited articles were those published by Demontis D, Grove J, and Baio J respectively. These articles mainly included studies on the pathogenesis, diagnostic criteria, and epidemiology of this area of co-morbid ADHD in ASD.

## Keywords

### Keyword Mapping Co-Occurrence Analysis

Keywords are highly condensed versions of relevant features of scientific research, reflecting hot spots in the field and links between them.<sup>16</sup> The keywords were extracted using VOSviewer and CiteSpace. VOSviewer and CiteSpace were used to extract

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 Network: N=57, E=758 (Density=0.0073)  
 Largest CC: 202 (44%)  
 Nodes Labeled: 1.0%  
 Pruning: Pathfinder



**Figure 6** The network of authors' publications and collaborations.

keywords from the articles and construct a visual mapping based on the links between different keywords (Figures 7 and 8). Figure 7 uses VOSviewer 1.6.10 software to analyse the keywords in the literature related to ASD co-morbid ADHD, and analyses the co-occurrence network into 8 clusters, mainly related to clinical disease research, pathogenesis, treatment methods, and common co-morbidities of ASD co-morbid ADHD. Each circle in Figure 8 represents a keyword; the larger the circle, the

**Table 4** Most Important Authors in the ASD Co-Occurring ADHD Research Field

Rank	Author	Count	Centrality
1	Lichtenstein P	84	0.07
2	Gillberg C	78	0.05
3	Buitelaar J	70	0.03
4	Larsson H	64	0.03
5	Franke B	40	0.06
6	Anckarsater H	36	0.06

(Continued)

**Table 4** (Continued).

Rank	Author	Count	Centrality
7	Lundstrom S	33	0.03
8	Anagnostou E	31	0.03
9	Faraone S	31	0.06
10	Charman T	24	0.01

**Table 5** Top 10 Co-Cited References Concerning the Research of ASD Co-Occurring ADHD

Rank	Author	Journals	DOI	Year	Citations
1	Demontis D	Nature Genetics	10.1038/s41588-018-0269-7	2019	120
2	Grove J	Nature Genetics	10.1038/s41588-019-0344-8	2019	108
3	Baio J	MMWR Surveill Summ	10.15585/mmwr.ss6706a1	2018	82
4	Anttila V	Science	10.1126/science.aap8757	2018	70
5	Craig F	Neuropsychiatric Disease and Treatment	10.2147/NDT.S104620	2016	68
6	Rommelse NNJ	European Child & Adolescent Psychiatry	10.1007/s00787-010-0092-x	2010	61
7	Thapar A	Lancet Psychiatry	10.1016/S2215-0366(16)30376-5	2017	61
8	Smoller JW	Lancet	10.1016/S0140-6736(12)62129-1	2013	59
9	Lee SH	Nature Genetics	10.1038/ng.2711	2013	57
10	Lai MC	Lancet	10.1016/S0140-6736(13)61539-1	2014	57

higher the frequency of that keyword, and the line links two keywords together, with the whole graph reflecting the degree of association between keywords. The top 10 keywords in terms of frequency are autism spectrum disorder, children, attention-deficit/hyperactivity disorder, deficit hyperactivity disorder, ADHD, autism, prevalence, adolescent, spectrum disorder and psychiatric disorder. This suggests that disease type and diagnosis, population, and prevention measures are the hotspots of research on ASD co-morbidity with ADHD (Table 6).

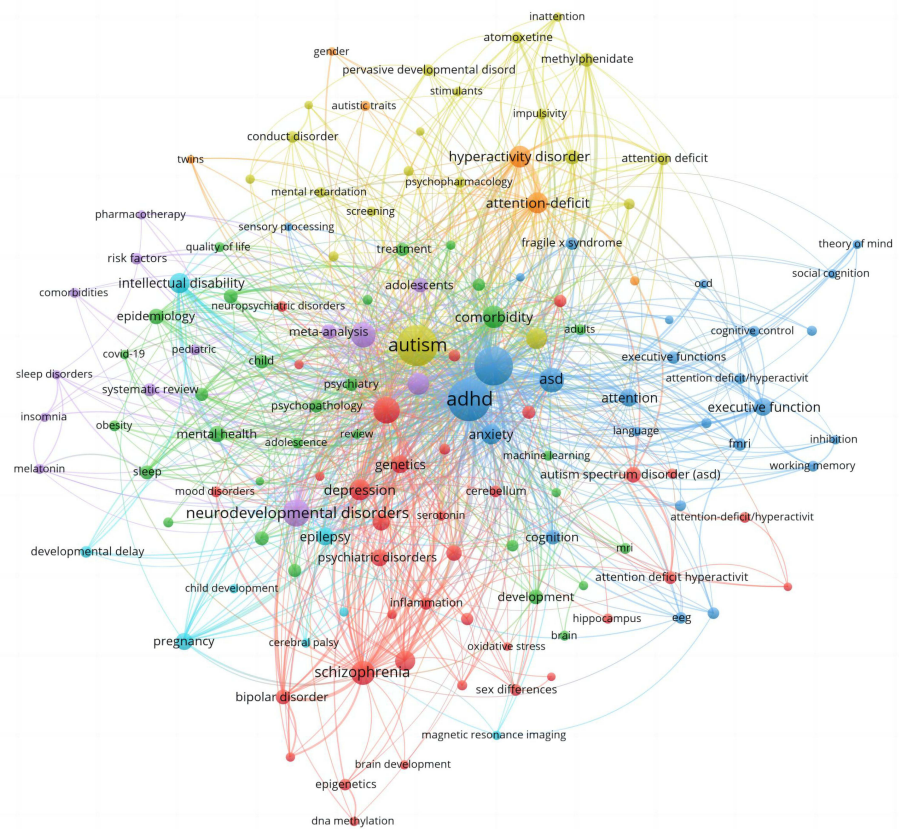
### Keyword Clustering Analysis

Based on the keyword co-occurrence network, the LLR algorithm was used to cluster the keywords in the literature, showing the cluster labels with cluster IDs #0 to #17, and the visualisation results are shown in Figure 9. The cluster modularity value ( $Q$ ) = 0.7716 > 0.3 and the mean profile value ( $S$ ) = 0.9136 > 0.5, indicating that the clustering results were all significant and trustworthy. It was found that most of the clusters in the cluster mapping were more concentrated, suggesting that the clusters were closely linked and the research themes were close. A summary of the keywords with greater weight in the clustering is shown in Table 7. Centrality was as high as 0.52 for Autism and 0.48 for ADHD, which are comparable. Combined with the keyword clustering it is evident that perceptions about the disease have been the focus of research, with the etiology and clinical assessment of ASD and ADHD and the differential diagnosis of their co-morbidities being the focus of attention.

### Keyword Timeline Analysis

The timeline view, with the year of occurrence of the keywords in the clusters on the X-axis and the clusters of each keyword on the Y-axis, further demonstrates the occurrence, end, and temporal trends of each cluster, and can reflect the importance of a particular cluster and the time span of its distribution. A timeline view analysis was conducted based on





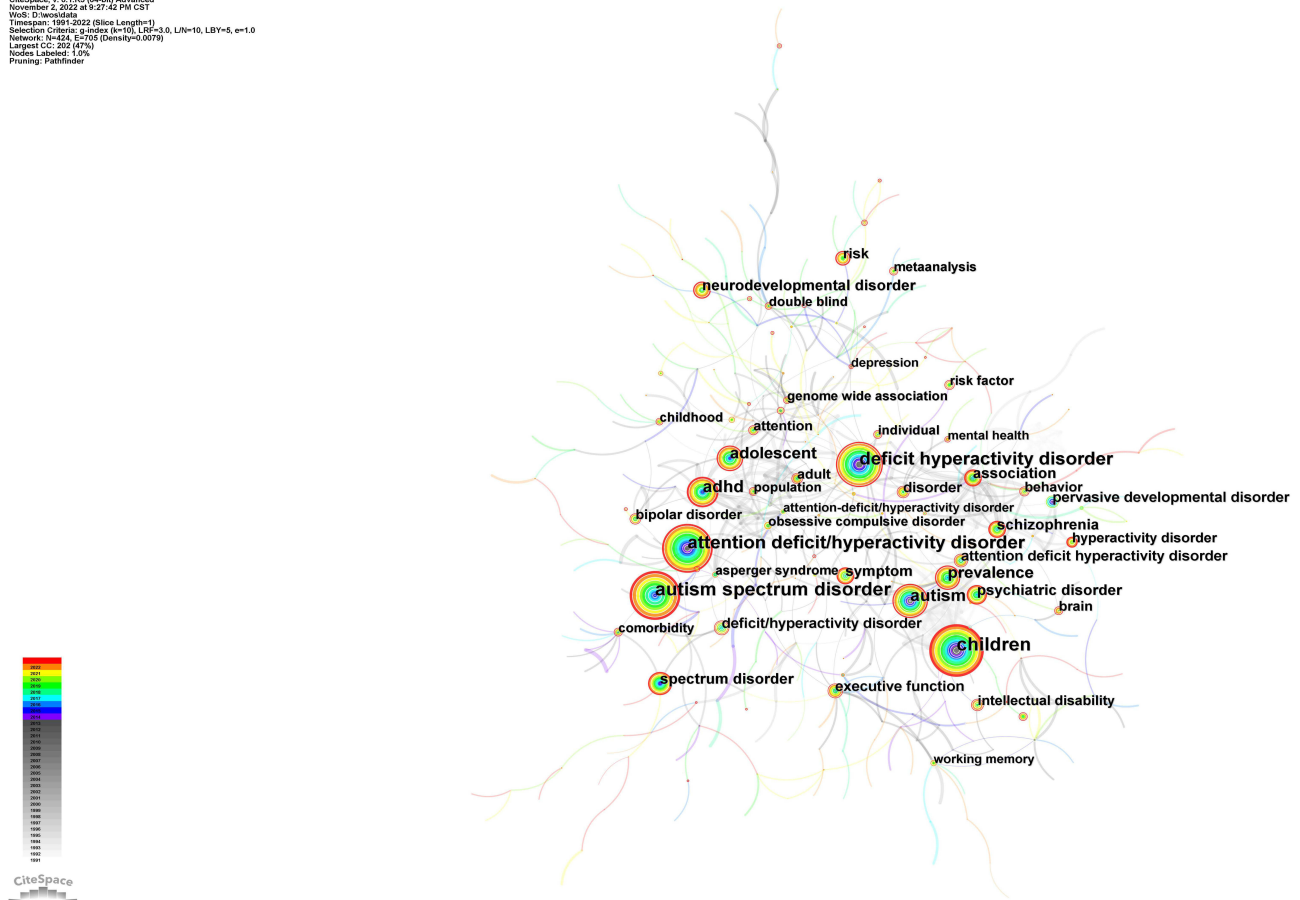
**Figure 7** The network visualization map of keywords was performed with VOSviewer.

keyword co-occurrence (see Figure 10). Cluster themes #0 attention-deficit hyperactivity disorder, #1 other psychiatric diseases, and #2 fragile-x syndrome all emerged early, persisted to the present and, were hot. After 2010, “body mass index pregnancy”, ‘susceptibility Since 2010, keywords such as “body mass index pregnancy” and “susceptibility phenotype” have emerged, suggesting that the exploration and study of the etiology of ADHD in patients with ASD comorbidities are becoming a focus of attention.

### Keyword Pop-Up

The keyword emergence analysis focuses on algorithmically deriving research hotspots that reflect the emergence or continued interest in the period time, reflecting changes and trends in hotspots in the research field. The keyword emergence analysis was obtained by adjusting the  $\gamma$  value based on keyword co-occurrence respectively, with the blue line indicating the time interval and the red line indicating the period time in which the keyword emergence was found (see Figure 11). “autism” and “Tourette syndrome” were the earliest (1991) words to emerge, and “Tourette syndrome” maintained a high intensity of emergence from 1991–2015, with an emergence intensity of 7.07, suggesting that ASD and ADHD share many similarities with Tourette’s syndrome and that they belong to the same mental disorder category and are closely related in terms of prevalence and treatment measures. Among all 25 emergent words, the keyword with the strongest emergent intensity was pervasive developmental disorder (41.29), and the highest intensity emergent word had an emergent intensity of over 40, indicating that the emergence of this keyword was significant, and all 25 keywords had an emergent intensity of over 6.5. gender difference” (8.05), “classification” (7.20), “asd” (8.82) and “gut microbiota” (6.88) were the most popular keywords in the field in the last five years. This indicates that the current exploration of co-occurring ADHD in ASD is increasingly focused on the underlying mechanisms of the disease, especially the

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 Largest CC: 202 (47%)  
 Nodes Labeled: 1.0%  
 Pruning: Pathfinder



**Figure 8** The network of keywords on ASD co-occurring ADHD.

important role of genetic factors in the etiology of co-occurring ADHD in ASD. The search for new and effective interventions is also an increasingly popular area of research in this field.

## Discussion

In this paper, we have used CiteSpace and VOSviewer software to systematically analyse the literature on ASD co-morbidities in the field of ADHD intuitively and effectively. Through the visualisation of the knowledge graph, we show

**Table 6** The Co-Occurrence Keywords of ASD Co-Occurring ADHD Research

Rank	Count	Keywords	Rank	Centrality	Keywords
1	1362	Autism spectrum disorder	1	0.52	Autism
2	1112	Children	2	0.48	Adhd
3	1027	Attention deficit/hyperactivity disorder	3	0.29	Adolescent
4	906	Deficit hyperactivity disorder	4	0.24	Attention deficit hyperactivity disorder
5	593	ADHD	5	0.21	Association
6	563	Autism	6	0.21	Executive function
7	478	prevalence	7	0.18	Asperger syndrome

(Continued)

Table 6 (Continued).

Rank	Count	Keywords	Rank	Centrality	Keywords
8	431	Adolescent	8	0.18	Depression
9	312	Spectrum disorder	9	0.17	Disorder
10	296	Psychiatric disorder	10	0.17	Double blind

the country/institution collaboration, authors, cited journals, and research hotspots in this field, revealing the research trends and cutting-edge trends in this field, which is a positive guide to promote the development of this field.

The trend in postings shows that research on ASD co-morbidities with ADHD began to take a large leap after 2012, and has since maintained a fluctuating upward trend with an overall increase. This rapid growth trend may be due to several factors. Firstly, the increasing social awareness of both ASD and ADHD has led to a growing number of scholars taking these two disorders seriously.<sup>17</sup> Secondly, the Diagnostic and Statistical Manual of Mental Disorders 5th edition (DSM-5) has now been updated to include diagnostic criteria for ASD and ADHD, allowing for a diagnosis of co-morbidity between the two disorders.<sup>18</sup> ASD and ADHD can be co-morbidly diagnosed. The new system is aimed toward a greater sensitivity for these individuals, providing earlier detection, diagnosis, and treatment planning. Overall, the goal

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 Network: N=524, E=705 (Density=0.0073)  
 Largest CC: 233 (54%)  
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 Pruning: Pathfinder  
 Modularity Q=0.7716  
 Weighted Mean Silhouette S=0.9136  
 Harmonic Mean(Q, S)=0.8366

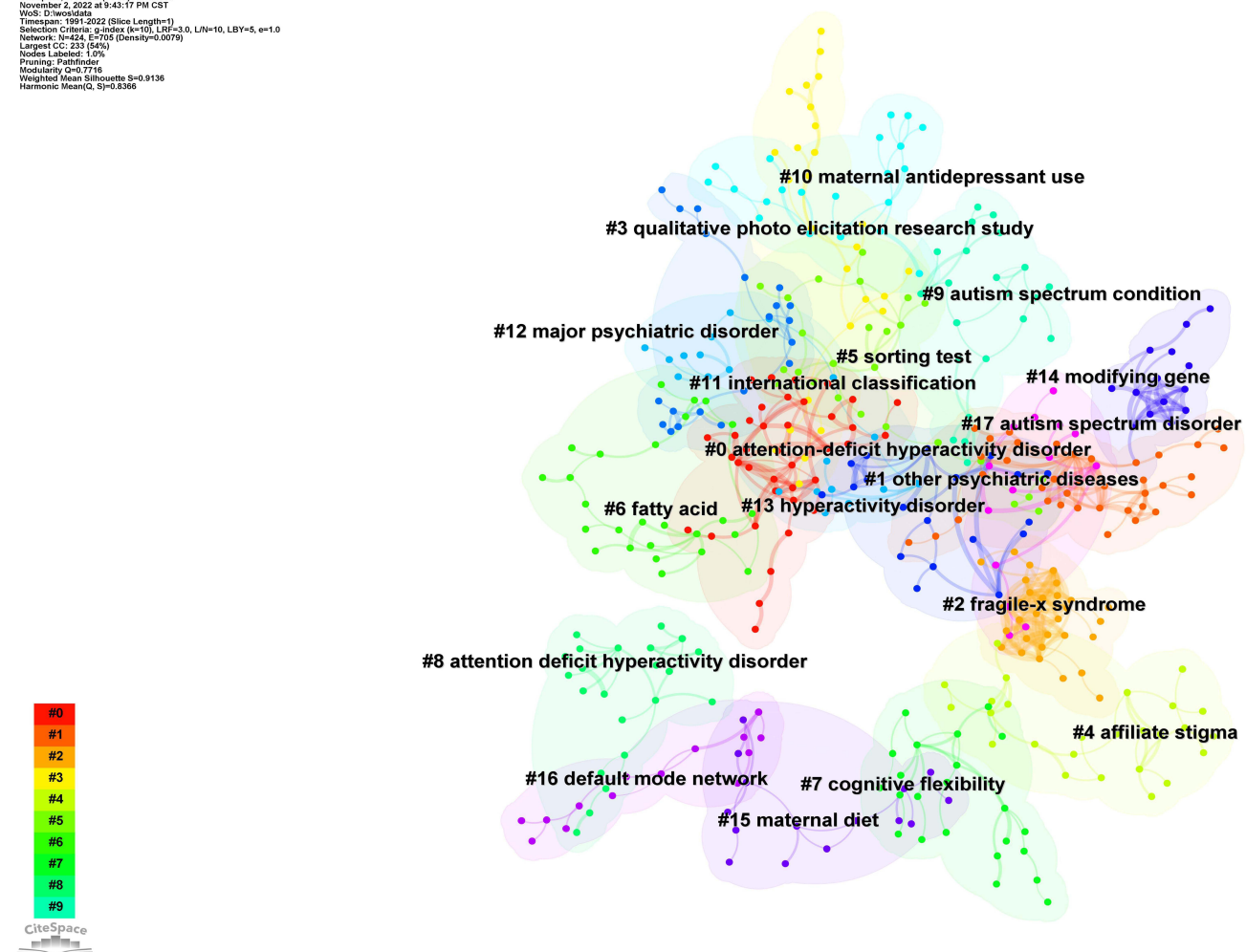


Figure 9 Visualization of the keywords cluster analysis.

**Table 7** Analysis of the Top 10 Clusters of Keywords in the ASD Co-Occurring ADHD Research Field

Cluster ID	Size	Silhouette	Label	Included Keywords (Top 5)	Mean (Year)
0	38	0.935	Attention-deficit hyperactivity disorder	Attention-deficit hyperactivity disorder; high-functioning autism spectrum disorder; attention-deficit hyperactivity disorder symptom; non-respiratory sleep disturbance; neurodevelopmental disorder	2004
1	37	0.785	Other psychiatric diseases	Other psychiatric diseases; metabotropic glutamate receptor; genetic variant; erp difference; estrogen receptor alpha	2006
2	30	0.949	Fragile-X syndrome	Fragile-x syndrome; young female; 23 duplication syndrome; recent advance; tic disorder	1998
3	27	0.959	Qualitative photo elicitation research study	Qualitative photo elicitation research study; or dcd; term birth weight; systematic scoping review; behavior dendrite morphology	2014
4	26	0.902	Affiliate stigma	Affiliate stigma; cognitive control; functional connectivity; neural substrate; behavioral outcome	2011
5	26	0.816	Sorting test	Sorting test; wisconsin card; behavioral problem; gut-brain axis; temporal parameter	2011
6	26	0.889	Fatty acid	Fatty acid; omega-3 fatty acid; polyunsaturated fatty acid; psychiatric diseases; oxidative stress	2010
7	23	0.972	Cognitive flexibility	Cognitive flexibility; intra-individual variability; everyday working memory difficulties; inhibitory control; neuropsychological measure	2014
8	22	0.917	Attention deficit hyperactivity disorder	Attention deficit hyperactivity disorder; autistic trait; attention-deficit hyperactivity disorder; attention problem; disorder-specific functional abnormalities	2014
9	22	0.906	Autism spectrum condition	Autism spectrum condition; covid-19 pandemic; life change; adverse event; influencing resilience	2013

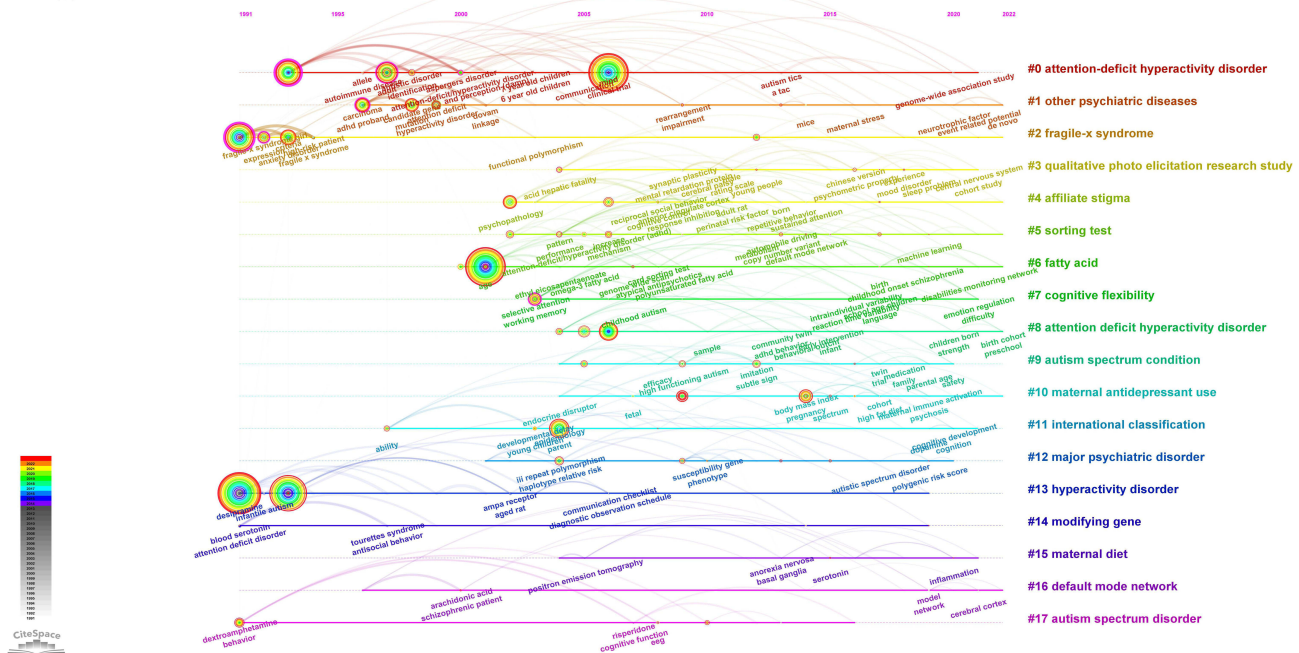
behind the revisions of ASD and ADHD, is to create a category that represents the developmental trajectories of these disorders, which will create diagnostic systems that accurately accommodate the plasticity of neurodevelopment over the lifespan. As a result, more attention is being paid to the area of ASD co-morbidity with ADHD.

According to the analysis of country/geographical distribution, the research related to ASD co-morbidities shows a global participation pattern, with the top 10 countries in terms of the number of publications mainly located in Europe, North America, and Asia, especially the European-American countries have the highest participation and closer cooperation, such as France (centrality: 0.24), Russia (centrality: 0.21) and Canada (centrality: 0.19). This indicates that Euro-American countries are at the forefront of the world in the field of ASD co-morbidity ADHD. Apart from the Euro-American countries, China has the highest number of publications (320) but a low centrality (0.01), suggesting that although the number of publications in China has increased, there is still a lack of high-quality articles, probably due to China's late start in this field, with the earliest available publication being in 2006.<sup>19</sup> The earliest available paper was published in 2006, 15 years after the US, which has the highest number of publications. It is worth noting that, apart from China, the top ten countries with the highest number of publications are all developed countries, suggesting that research in this area in developing countries is significantly behind that in developed countries, which may be closely linked to poor government finances, low public health awareness and inadequate health care systems.<sup>20</sup>

The study of high-frequency publications and cited journals can help us understand the current state of ASD co-occurring ADHD research, thus enriching the theoretical basis of the field and improving the quality of relevant research articles. It can be seen that the impact factor of the publications and cited journals in the field of ASD co-occurring



CiteSpace v. 5.10.R3 (64-bit) Advanced  
 November 2, 2022 at 9:45:17 PM CST  
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 Timestamp: 16912022 (Size: Length=1)  
 Selection Criteria: Pfinder (wPLF=0.1, LRF=1.0, U=0.5, M=10, LBY=5, e=1.0)  
 Network: N=124, E=705 (Density=0.0779)  
 Largest CC: 233 (54%)  
 Nodes Labeled: 120  
 Pruning: Pathfinder  
 Modularity Q=0.716  
 Weighted Mean Silhouette S=0.9136  
 Harmonic Mean(Q, S)=0.8356



**Figure 10** The cluster timeline view network of keywords related to ASD co-occurring ADHD.

ADHD research is generally high, indicating that the quality of the articles published in this field is high and the papers published are of high academic value. The Journal of autism and developmental disorders is both the most published and most frequently cited journal, and is undoubtedly a core journal in this field, with recent articles reporting that the attention deficit symptoms of co-occurring ADHD in ASD may differ from the underlying neurological mechanisms of ADHD, and hoping that brain imaging and genetics studies, as well as ADHD-related symptomatology, will have an impact on the developmental changes in ASD symptoms. It is hoped that clinical interventions to manage developmental changes in ASD symptoms will further elucidate the behavioral symptoms of co-occurring ADHD in ASD and the mechanisms underlying them.<sup>21</sup>

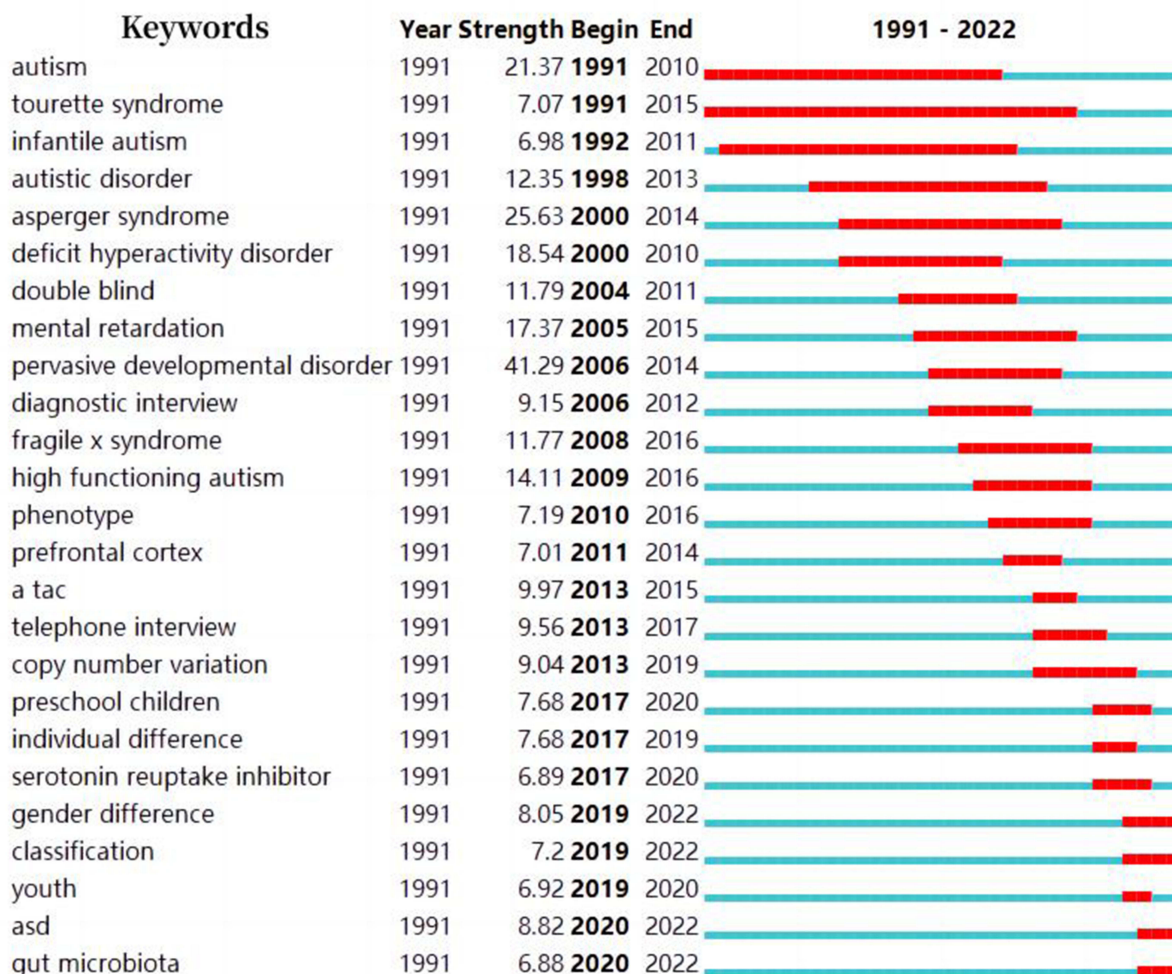
The author’s collaboration network mapping allows us to understand the representative scholars in the field of ASD co-morbid ADHD research. The most published scholar is Lichtenstein P, whose main research interests are in the development of child health and behavioral problems.<sup>22–24</sup> His most recent publication attempts to explain the inheritance and occurrence of mental disorders in children from a genetic and epidemiological perspective.<sup>25,26</sup> The macroscopic view of the graph shows that the nodes are scattered, suggesting that only a few authors collaborate closely, eg Lichtenstein P and Anckarsater H are more connected to each other, suggesting closer collaboration. Other scientific collaborations between various scholars need to be strengthened to promote deeper development of the field.

Reading the high-frequency co-cited literature helps to provide a quick overview of important content in the field. The most frequently co-cited study is that of Demontis et al, which identifies variants surpassing genome-wide significance in 12 independent loci, finding important new information about the underlying biology of ADHD.<sup>27</sup> Grove et al, found both quantitative and qualitative polygenic heterogeneity across ASD subtypes and this study was the second most frequently cited.<sup>28</sup> Baio et al, reveal the latest prevalence of ASD, which is the third most frequently cited study.<sup>29</sup>

Keywords can directly reflect research hotspots. We summarized high-frequency keywords, conducted a cluster analysis of these keywords, constructed a keyword clustering timeline graph, and finally conducted an emergent analysis of keywords. We found that research on ASD co-morbidities with ADHD has focused on the etiology and clinical diagnosis of the two disorders. This is because exploring the etiology of ASD and ADHD can help to find the interrelationship between the two disorders and predict the risk of their occurrence, which can facilitate correct diagnosis



## Top 25 Keywords with the Strongest Citation Bursts



**Figure 11** The top 25 keywords with the strongest citation bursts.

and early intervention in children with the disorders, thus improving the outcome of the disorders. Research into the causes of co-occurring ADHD in ASD is still in the developmental stage. ASD and ADHD share similar neuropsychological mechanisms, and children with both disorders exhibit impaired executive function and response inhibition.<sup>30</sup> ASD and ADHD share similar neuropsychological mechanisms. In terms of genetics, both ASD and ADHD are strongly associated with genetic factors.<sup>31</sup> Both ASD and ADHD are genetically linked. The majority of current research suggests that the genetic basis for the co-morbidity of ASD and ADHD is the overlap of their causative genes. Researchers have conducted several studies on the genetic causes of ASD co-morbidity with ADHD, including family lineage analyses and twin studies, single gene studies, and multiple gene studies. Among them, in single causative gene studies, ADHD candidate genes such as DRD3 (dopamine D3 receptor gene) and MAOA (monoamine oxidase gene) may be associated with ASD symptoms.<sup>32</sup> Some ASD candidate genes (eg 5-hydroxytryptamine-related genes) may also be associated with ADHD symptoms.<sup>33</sup> However, these genetic studies still need more biological samples to obtain further and more comprehensive data. In terms of neuroimaging, structural MRI and functional MRI have revealed that while there are differences in brain structure and activity between children with ASD and those with ADHD, there are also similarities. For example, the corpus callosum, the white matter volume of the brain, was reduced in both ASD and ADHD patients.<sup>34</sup> In terms of grey matter volume, the severity of symptoms in both children with ASD and children with ADHD has positively correlated with grey matter volume in the left inferior frontal gyrus.<sup>35</sup> The severity of symptoms in both

children with ASD and ADHD was positively correlated with the volume of the left inferior frontal gyrus. Functional MRI revealed low levels of activity in the frontal and parietal lobes in both ASD and ADHD patients.<sup>36</sup>

The correct diagnosis of co-occurring ADHD in ASD allows for a more specific determination of the child's functional impairment.<sup>37</sup> Children with co-occurring ASD have more severe impairments in cognitive functioning, social functioning, adaptive skills, and academic achievement.<sup>38</sup> A correct and early clinical diagnosis is a prerequisite for the development of a comprehensive and effective treatment plan. The clinical diagnosis of ASD and ADHD currently relies on history, neuropsychological assessment and behavioral observations by the physician, and given the instability of this descriptive diagnosis, more and more research is focusing on identifying specific biomarkers of different psychiatric disorders, such as various neuroimaging, behavioral and cognitive measures.<sup>39</sup> With the promulgation of the DSM-5, it is believed that future research on the diagnosis of co-occurring ADHD in ASD will progress more comprehensively.

Interventions for co-occurring ADHD in ASD seem to be gradually becoming a new research hotspot. In addition to traditional methods such as special education and psychotherapy, dietary supplements seem to be gaining popularity. For example, Omega-3 unsaturated fatty acids play an important role in the development of the central nervous system<sup>40</sup> in children with ASD<sup>41</sup> and children with ADHD.<sup>42</sup> The use of Omega-3 unsaturated fatty acids in children with ASD and ADHD has shown promising results. In recent years, intervention studies targeting gut microbes have also emerged as a new therapeutic tool, with Shaaban et al's open study of 30 children with ASD aged 5–9 years confirming that probiotic interventions not only resulted in beneficial changes in the gut flora of children with ASD but also in significant improvements in gastrointestinal and clinical symptoms.<sup>43</sup> Partty et al found that continuous administration of *Lactobacillus rhamnosus* from birth to 6 months of age may reduce the risk of ADHD.<sup>44</sup> The possible mechanism is that *Lactobacillus rhamnosus* may stabilise intestinal permeability by affecting the production of cellular tight junctions, mucins, and antigen-specific immunoglobulin A, reducing the risk of a range of neurobehavioural manifestations resulting from immune system activation following damage to the intestinal barrier.<sup>45</sup> The risk of neurobehavioural manifestations due to immune system activation following intestinal barrier damage is reduced. However, it is important to note that interventions still require data from large clinical samples combined with rigorous methodological trials to provide more convincing evidence-based guidance.

## Limitations

This study is subject to several limitations. Firstly, this study only included relevant literature from the WOS core collection for inclusion analysis, which may have introduced some bias to the analysis results. Secondly, although CiteSpace and VOSviewer are professional bibliometric tools that provide objective analysis, there may be some subjective bias as different researchers may have different views and interpretations of the same content. Finally, the quality of the literature varies and the global results on the overall structure of the research field may be more limited.

## Conclusions

There is no doubt that our understanding of ASD co-morbidities in ADHD has advanced considerably through high-quality research over the past almost 30 years. With the help of visual analyses, we have identified general trends and research hotspots in the field. Based on these findings, we believe that research into the pathogenesis of ASD co-occurring ADHD and related clinical diagnostics is the main hotspot in this field and that interventions for ASD co-occurring ADHD will be the focus of future research.

## Data Sharing Statement

The raw data supporting the conclusions of this article will be made available by Annan Liu, without undue reservation.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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