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ORIGINAL ARTICLE

A Visualization Analysis of Hotspots and Frontiers in Obesity-Related Executive Functions Research: A Bibliometric Study

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Abstract

Objective. This study aims to provide a visual analysis of the research hotspots and frontiers in the field of obesity-related executive functions using bibliometric methods.

Methodology. Our analysis is based on 5814 English-language documents retrieved from the Web of Science Core Collection database. CiteSpace 6.2.R4 software was utilized to conduct bibliometric analysis. The study examines the trends, key players, and thematic evolution in obesity-related executive function research over the past decade.

Results. The number of publications in this domain has exhibited a steady linear growth trend, with American institutions and scholars leading in research contributions. The current research focus encompasses co-occurrence and cluster analysis of keywords and references, as well as the brain and associated cognitive functions. Our bibliometric analysis reveals a shift in focus towards the brain, cognition, executive functions, the prefrontal cortex and other related topics in obese individuals, in addition to established areas such as metabolic syndromes, insulin resistance, diabetes, gut microbiota, and dietary intake.

Conclusion. This study highlights new entry points for aspiring researchers in the field of obesity and executive functions. Future research directions may include a deeper exploration of the relationship between obesity and specific components of executive functions, such as working memory, inhibitory control, cognitive flexibility, and planning.

Key words: obesity, executive functions, bibliometric study, working memory, inhibition control, cognitive flexibility

INTRODUCTION

The increasing prevalence of obesity in developing countries has led to its emergence as one of the most significant global health problems.[1] Obesity is associated with several chronic conditions, including cardiovascular diseases, several types of cancers and an increased risk of all-cause mortality.[2] Moreover, several studies have provided evidence that obesity may have deleterious effects on the brain, making it a major risk factor for cognitive impairment. Midlife obesity is associated with an increased risk of dementia and accelerated brain atrophy in older patients.[3] Given the widespread prevalence of obesity, identifying the pathogenic mechanisms underlying the deleterious cognitive effects of obesity is a growing public health problem. Traditionally, the effect of obesity on cognition was attributed to cardiovascular risk factors such as diabetes and hypertension. However, many reports have shown that there may be a direct link between obesity and cognitive decline beyond the influence of cardiovascular risk factors, implying that obesity itself may be detrimental to the functioning of the central nervous system (CNS).

Relationship between obesity and executive functions

Overall, existing theories acknowledge that obesity is associated with impaired executive functions. A meta-analysis[4] found that obese participants demonstrated a wide range of impairments in executive functions such as inhibitory control, cognitive flexibility, working memory, decision-making, verbal fluency and task-planning. However, the underlying mechanisms remain unclear. This association can be partially explained by the Body Mass Index (BMI)-related reduction in the thickness of the prefrontal cortex (PFC), which leads to impaired executive functions.[5] Children with obesity and impaired

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executive functions may exhibit a dysregulated behavioural phenotype ranging from internalizing to externalizing behaviours and weight-related symptoms.[6] Muscle strength, speed dexterity and cardiorespiratory fitness also correlated with executive functions in overweight and obese children. Further, cognitive flexibility appears to be more closely related to all fitness components during obesity treatment, whereas planning capacity and inhibition may depend on the analyzed components.[7] Poor executive functions may hinder the efficacy of obesity treatment in children, while improvements in executive functions are associated with increased weight loss efficacy.[8] Relatedly, obese adults with higher executive functions regain a certain amount of weight; however, younger adults with executive function deficits have a greater risk of severe obesity.[9] Furthermore, recent studies have shown that there may be a weak but positive association between executive functions and eating behavior among obese individuals,[10] that obesity and unhealthy lifestyles among adolescents are associated with poor executive functions[11] and that executive dysfunction in obese youths may be related to behavioral eating disorders.[12]

The majority of studies on obesity-related executive functions used questionnaires such as executive function-related psychological tests that typically examined small, local sample sizes, Statistical Package for the Social Sciences (SPSS) software, and meta-analyses. Therefore, developing a macroscopic grasp of the status of current research and hotspots in research on obesity-related executive functions is difficult. Although SPSS analysis and meta-analysis were utilized in many papers, national areas, keywords, author and institutional partnerships, publications and references could not be studied. It is vital to search for national regions, keywords, author and institutional collaborations, journals and references to identify the research hotspots and frontiers of obesity-related executive functions.

Unique role of bibliometrics in discovering the laws of scientific development

Bibliometrics is a type of metrology method based on the analysis of published literature in disciplines such as mathematics and statistics catalyzed in the digital era. It evaluates and predicts the research status and development trends in certain core research areas, explores characteristic laws that are implicit in a particular subject area, predicts future research trends in medicine and engineering, and provides intelligence analysis in fields such as agronomy and management and in software for robust knowledge network analysis, such as CiteSpace.[13] The bibliometric tool VOSviewer,[14] which has the advantages of rich graphic presentation, clear hierarchy and simple interpretation of analysis results, is widely recognized and cited in science metrology and knowledge mapping. Although obesity-related executive functions have been widely studied, there is no systematic understanding of research hotspots and evolutionary trends. Thus, the present study primarily used the Web of Science (WOS) core collection's full-text database to search the literature and relevant publicly published research articles on obesity and executive functions, including inhibitory control, working memory and cognitive flexibility. These articles were used to draw CiteSpace and Bibliometrix webpages to construct a knowledge co-occurrence network and visualization map. This study aimed to refine and summarize the hidden connotations and laws in the literature and reveal the course of development, research progress, current status, hotspots of cutting-edge research and trends in the field to provide a reference for further research on obesity and executive functions.

METHODOLOGY

Data sources

The relevant literature was sourced from the Web of Science (WOS) Core Collection database. Overall, scholars agree that executive functions include inhibitory control, cognitive flexibility, working memory, decision-making, verbal fluency and planning.[15] A search was conducted using the keywords 'Executive function' SAME obesity or 'Working Memory' SAME Obesity or Inhibition SAME obesity or 'Cognitive flexibility' SAME obesity. The included studies should be published in English, resulting in 15104 articles. Setting the time period from January 1, 2013 to December 31, 2022, excluding 4615 articles, there were 10489 remaining. The article type was selected for refinement, with 1385 excluded and 9104 remaining. Upon selecting 'open access' and excluding 3290 articles, the search results showed 5814 relevant literature (Figure 1).

Analytical method

The 5,814 articles retrieved and screened were imported into the software Citespace 6.2.R4 in Refworks format for

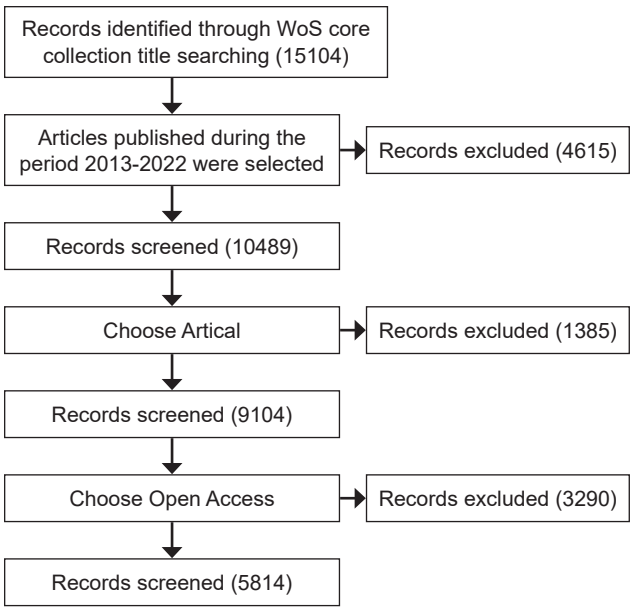

Figure 1. Data source retrieval process.

visualization analysis, where the authors, research institutions, countries and keywords were extracted. The time period was set from January 2013 to December 2022 with a partition length of 1 year, and the time slice selected was "1." The threshold setting selected the top 50 frequent occurrences within each time slice. Descriptive statistics were used to discuss the authors, countries and the number of articles published. The influence of the articles was evaluated through citation analysis and co-occurrence analysis, while the keywords' conceptual relevance and academic interaction were assessed. Furthermore, content analysis based on keyword clustering clarified the main themes, hot topics and development trends.

In the analysis diagram of the issuing organization and author, the higher the density, the closer the cooperation between the author or organization; in the co-occurrence analysis diagram of keywords, the higher the density, the higher the degree of closeness between the keywords.

RESULTS

Overall description

Volume is an extrinsic indicator of the field, and the inter-annual change in the volume of a publication can be used to observe and understand the development dynamics of the field. The search method retrieved a total of 5814 articles published on the topic "obesity and executive functions," during the period 2013–2022. Figure 2 indicates that the annual publication volume in the field of executive functions in obesity over the last decade (i.e., between 2013 and 2019) showed a steady linear increasing trend. The number of journals published in 2020 was significantly higher than in 2019; however, the growth rate slowed in 2021 relative to 2020, and the volume of journals showed a downtrend in 2022. This data illustrates international scholars' increasing emphasis on studying obesity and executive functions.

International concern

An analysis of countries where the literature was published shows that the volume of publications produced on a given subject area reflects the overall level of concern and international influence of a country/region on that issue.

A total of 2,290 articles were published in the United States (US), representing 39.39% of the overall count. This was nearly 1.89 times more than the number of articles published in China, which ranked second (1210 articles), and 4.94 times more than the number of articles published in South Korea, which ranked third (464 articles). Thus, US research contributions in obesity and executive functions are much higher than in other countries. Research by Chinese scholars on obesity and executive functions is gradually gaining importance and is ranked second in terms in the volume of publications (Figure 3).

As seen in Figure 4, the US contributes the most to this research area (larger dots indicate greater contributions), followed by China, South Korea, Germany and Japan. As shown in the relationship network (Figure 5), the US showed the largest cooperative strength with other countries, followed by South Korea, Germany, Japan, England, Spain and Australia (data not given). For instance, the more connected the network, the greater the cooperative strength; similarly, numerous partial connections with other countries indicate greater cooperative strength (Figure 5). The intensity of cooperation between China and other countries was significantly much lower than that of other countries, such as the US and South Korea, illustrating that scientific cooperation between China and other countries in the field of obesity and executive functions should be enhanced.

Analysis of article sources

Academic journals are important vectors for displaying the results of scientific research. A total of 1188 journals and 5814 relevant literature sources on obesity and executive functions from 2013 to 2022 were screened by statistical analysis from the WOS. Owing to the large number of journals, only the journal volume of the ten top-rated journals was considered (Table 1). Among the top ten journals (Table 1), PLoS One had the highest volume with 237 articles, representing 4.08% of the total literature sample, with a journal impact factor of 3.752 (JIF 2021) and journal citation reports (JCR) partition of Q2.

Scientific Reports and International Journal of Molecular Sciences came second and third, with 217 articles (3.73%; JIF 2021 = 4.997, Q2) and 138 articles (2.37%; JIF 2021 =

Table 1. Journal name before article source (Top 10) and number published in the journal and the journal impact factor

Order	Journal name	Number	JCR partition	IF (2021)	IF (5 years)
1	PLOS ONE	237	Q2	3.752	4.096
2	SCIENTIFIC REPORTS	217	Q2	4.997	5.516
3	INTERNATIONAL JOURNAL OF MOLECULAR SCIENCES	138	Q1/Q2	6.208	6.628
4	NUTRIENTS	126	Q1	6.706	7.185
5	DIABETES	112	Q1	9.305	10.493
6	MOLECULES	85	Q2	4.927	5.110
7	JOURNAL OF BIOLOGICAL CHEMISTRY	82	Q2	5.485	5.294
8	MOLECULAR METABOLISM	82	Q1	8.568	8.928
9	NATURE COMMUNICATIONS	73	Q1	17.694	17.764
10	APPETITE	59	Q1/Q2	5.016	5.653

6.208, Q1), respectively. They were followed by Nutrients (JIF 2021 = 6.706, Q1) and Diabetes (JIF 2021 = 9.305, Q1) with 126 and 112 articles, respectively, and the remaining journals had published under 100 articles. Among them, Nature Communications had the highest impact factor (JIF 2021 = 17.694); however, its journal volume was not high at 30.8% (73 articles). In contrast, PLoS One had the lowest impact factor (JIF 2021 = 3.752), but its journal volume was the highest. Thus, the number of journal articles did not correspond to influence, which may relate to the topic-journal fit, highlights of journal articles and the submission cycle. The analysis of the main research areas of the top ten journals in this field showed that studies focused on nutrition, diabetes, molecular metabolism, biochemistry, diet and other disciplines, indicating a multi-disciplinary approach.

Analysis of institutions and authors

Institutions reflect the distribution of research units in the field, as indicated by the analysis of institutions with emphasis on obesity and executive functions (Table 2). The institutional publications that ranked among the top 20 were not only tertiary institutes and institutes of science but also medical research centers and veterans' health management institutions, of which the University of California System, Harvard University and Harvard University of Texas System were ranked as the top three with 217, 163 and 150 publications, respectively. Inserm, or the *Institut natural de la Sante et de la recherche medical* (National Institute for Health and Medical Research), ranked fourth with 145 publications. Chinese institutions ranked among the top 20, including the Chinese Academy of Sciences and Shanghai Jiao Tong University, with 95 and 72 publications, respectively.

Visual relationship maps (Figure 6) were obtained using CiteSpace 6.1. R6 Basic. The authors John Gunstad, Mary Beth Spitznagel, Gladys Strain, James E. Mitchell, Ross D. Crossby, Michael Devlin and Ronald Cohen – all from colleges or institutes in the US – showed close academic communication and cooperation (the blue dots and

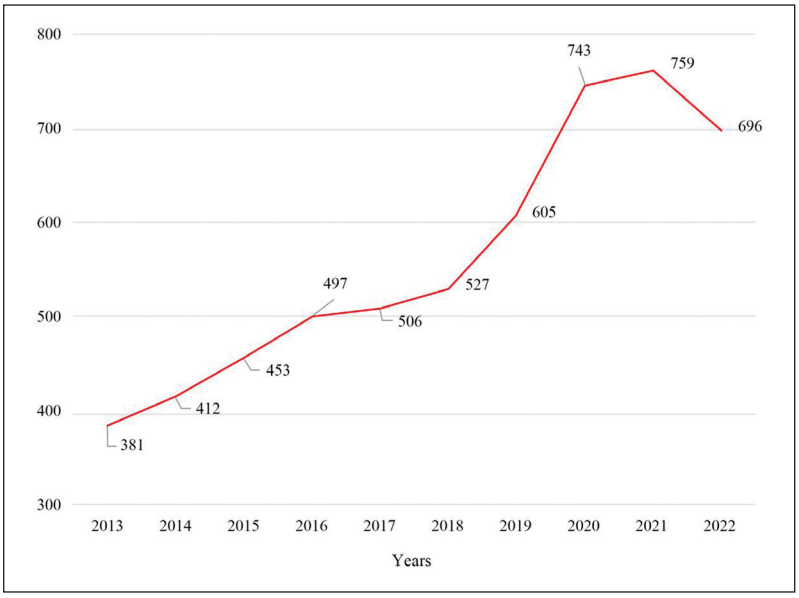

Figure 2. Annual scientific production growth chart.

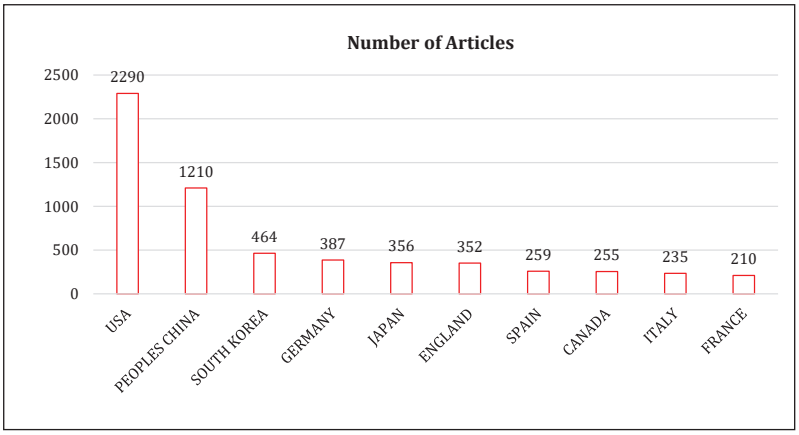

Figure 3. Top ten countries by publication volume.

Table 2. Top 20 institutional publications

Order	Institution name	Numbers
1	UNIVERSITY OF CALIFORNIA SYSTEM	217
2	HARVARD UNIVERSITY	163
3	UNIVERSITY OF TEXAS SYSTEM	150
4	INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE INSERM	145
5	US DEPARTMENT OF VETERANS AFFAIRS	141
6	VETERANS HEALTH ADMINISTRATION VHA	140
7	UDICE FRENCH RESEARCH UNIVERSITIES	128
8	NATIONAL INSTITUTES OF HEALTH NIH USA	120
9	CIBER CENTRO DE INVESTIGACION BIOMEDICA EN RED	117
10	HARVARD MEDICAL SCHOOL	117
11	PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE	112
12	UNIVERSITY SYSTEM OF OHIO	98
13	CHINESE ACADEMY OF SCIENCES	95
14	UNIVERSITY OF LONDON	90
15	UNIVERSITY OF CALIFORNIA SAN DIEGO	85
16	UNIVERSITY OF MICHIGAN	81
17	UNIVERSITY OF MICHIGAN SYSTEM	81
18	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	80
19	SHANGHAI JIAO TONG UNIVERSITY	72
20	YALE UNIVERSITY	72

Figure 4. A visualization of the national knowledge map of publication volume.

Table 3. Top 20 authors and their corresponding number of articles

Order	Author	Number
1	Gunstad, John	20
2	Spitznagel, Mary Beth	14
3	Strain, Gladys	13
4	Mitchell, James E	13
5	Crosby, Ross D	12
6	Devlin, Michael	11
7	Cohen, Ronald	11
8	Wang, Wei	11
9	Jiang, Changtao	11
10	Lee, In-Kyu	10
11	Gonzalez, Frank J	10
12	Dieguez, Carlos	10
13	Blueher, Matthias	9
14	Tinahones, Francisco J	9
15	Alosco, Michael L	9
16	Drucker, Daniel J	8
17	Bae-jump, Victoria L	8
18	Al-mulla, Fahd	8
19	Ahmad, Rasheed	7
20	Demarco, Vincent G	7

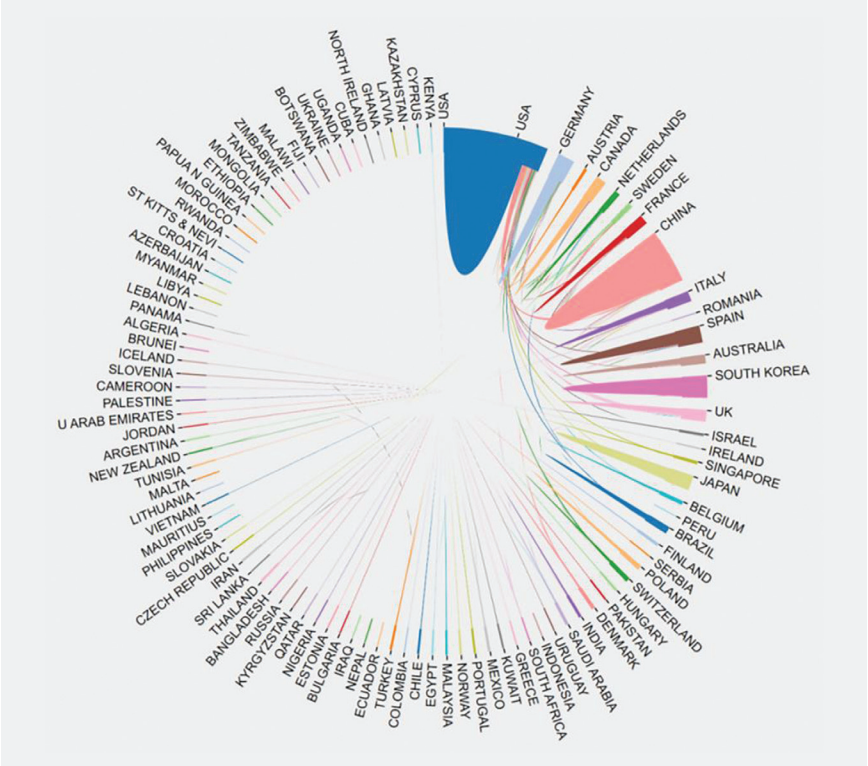

Figure 5. National publication visual map: the relationship network of countries.

connections in Figure 6). Based on an author relationship map, Gunstad et al., formed a core team of authors in the field and contributed significantly. We found no evidence of similar cooperative networks among the other authors.

Analysis of research hotspot

Keyword analysis allows for a better understanding of important issues in the research field. The analyzed keywords included keyword co-occurrence, keyword cluster analysis, keyword timeline plots, and keyword convex atlas.

Co-occurrence of keywords

Running CiteSpace, setting the year slice to one year, and ticking keywords at node types resulted in a keyword co-occurrence map. Among them, Tables 4 and 5 present statistics on the frequency and betweenness centrality

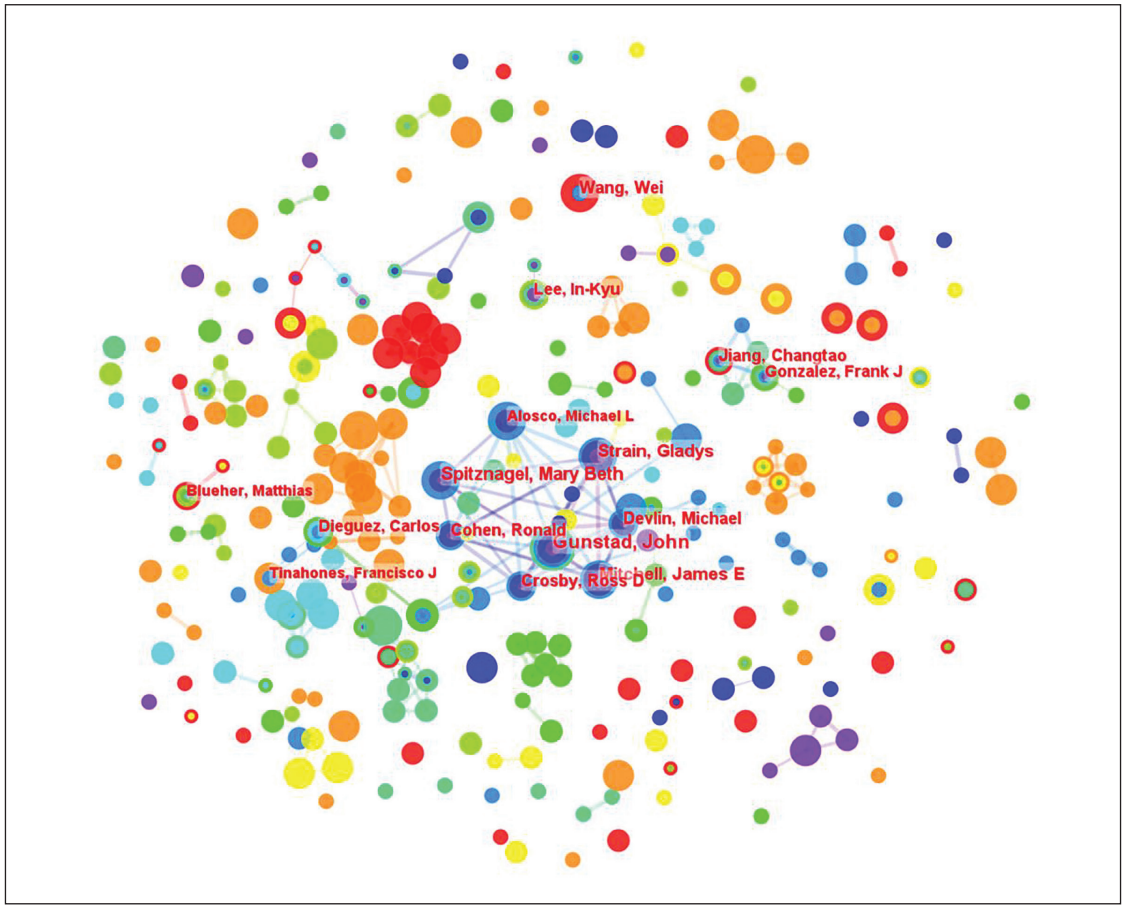

Figure 6. Author co-occurrence map.

Table 4. Keyword frequency

Order	Keyword	Frequency
1	obesity	2160
2	inhibition	1233
3	insulin resistance	1170
4	expression	915
5	activation	635
6	adipose tissue	634
7	inflammation	618
8	mice	434
9	metabolism	430
10	metabolic syndrome	378
11	mechanism	374
12	oxidative stress	372
13	cell	370
14	gene expression	319
15	receptor	302
16	body mass index	289
17	disease	285
18	risk	262
19	resistance	262
20	protein	246
21	glucose	242
22	pathway	238
23	diet-induced obesity	235
24	differentiation	229
25	executive functions	227
26	association	223
27	dysfunction	214
28	skeletal muscle	206
29	ppar gamma	205
30	food intake	204

Table 5. Keyword centrality

Order	Keyword	Centrality
1	glucose metabolism	0.06
2	adiposity	0.05
3	system	0.04
4	polyphenol	0.04
5	secretion	0.03
6	nlrp3 inflammasome	0.03
7	nitric oxide synthase	0.03
8	mouse model	0.03
9	messenger rna	0.03
10	memory	0.03
11	macrophage	0.03
12	kinase	0.03
13	kappa b	0.03
14	impairment	0.03
15	hyperglycemia	0.03
16	health	0.03
17	glucose tolerance	0.03
18	energy expenditure	0.03
19	endothelial dysfunction	0.03
20	down regulation	0.03
21	chronic kidney disease	0.03
22	cancer cell	0.03
23	breast cancer	0.03
24	binding	0.03
25	beta	0.03
26	bariatric surgery	0.03
27	activated receptor gamma	0.03
28	3t3 l1 adipocyte	0.02
29	abdominal obesity	0.02
30	absorption	0.02

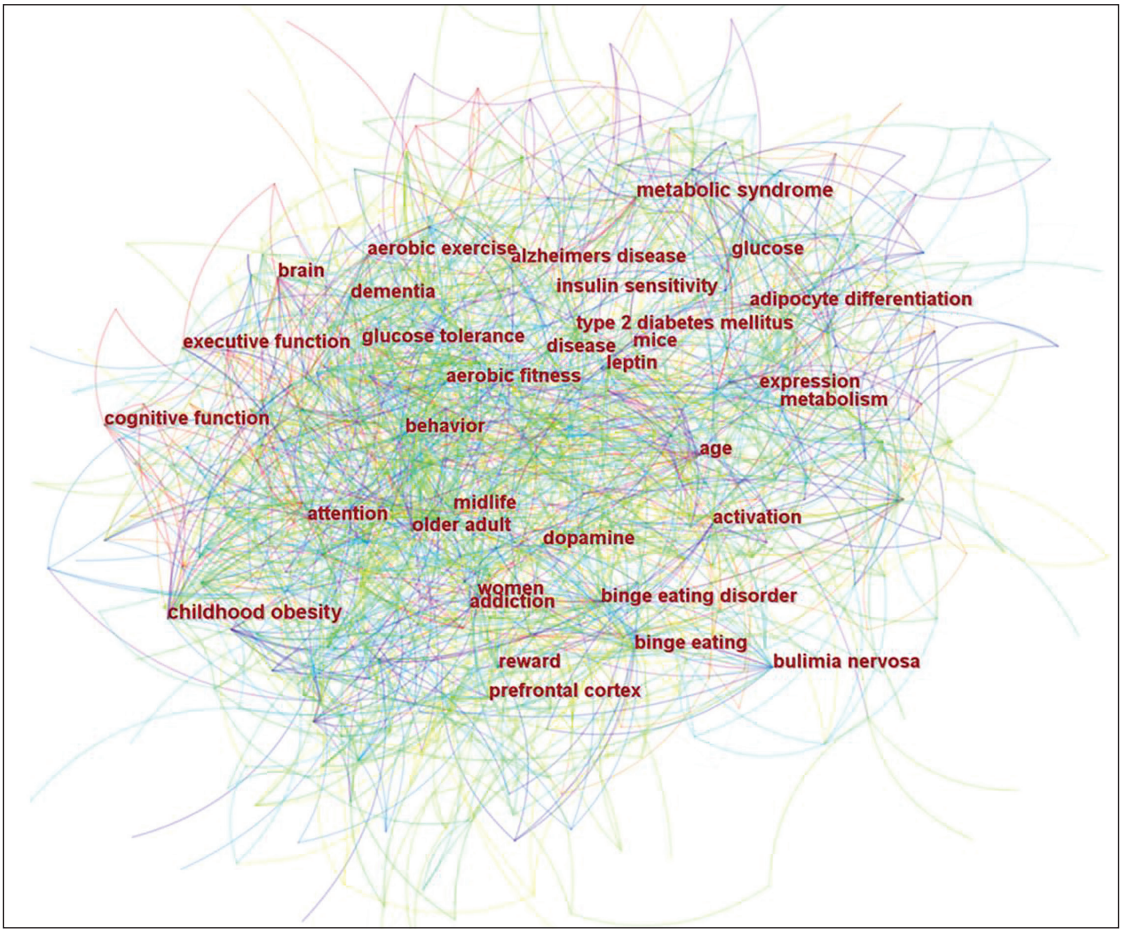

Figure 7. Keyword co-occurrence plot.

of the keywords. The top 30 keywords were selected for each frequency and betweenness centrality based on comprehensive consideration. Diversity in research themes was evident from the frequency of keywords. Specifically, excluding the subject heading obesity, suppression of inhibition was the highest (1233 times), followed by insulin resistance (1170), expression (915), activation (635), adipose tissue (634) and inflammation (618). In terms of the betweenness centrality of the keywords, the highest centrality was for glucose metabolism, with a centrality of up to 0.06, which was collinear with all other keywords, followed by systems (0.04), polyphenols (0.04) and secretion (0.04).

The atlas structure showed that these keywords were important hub nodes, Together with the other keywords in surrounding nodes, they constituted a popular research topic in the field (Figure 7). Researchers mainly focused on insulin resistance, adipose tissue, and inflammation in obese people, which may be inseparable from the glucose metabolism function in obese people. Among the atlas keywords, psychologically relevant keywords, such as brain, cognitive function, prefrontal cortex, attention, behavior, reward and addiction, received much attention. In terms of age, there was a greater focus on obesity in children and women than in men.

Analysis of keyword clusters

Running the CiteSpace software, the time was set from January 2013 to December 2022, the year slice was set to one year, the log-likelihood ratio (LLR) was employed for clustering keywords with high frequencies and clear keyword clustering profiles were obtained using multiple adjustment thresholds (Figure 8). The modular clustering

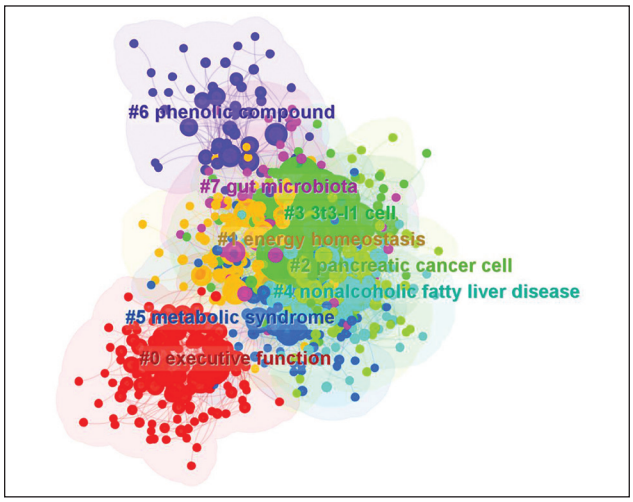

Figure 8. Keyword extraction and visual map construction of WOS data set from 2013–2022.

value (Q-value) was 0.4435 (Q >0.3 implies a significant clustering structure). The silhouette cluster average profile value (s-value) was 0.7349 (s >0.5 indicates that the clustering is generally considered reasonable, and s >0.7 indicates that the clustering is convincing). The results of the keyword cluster analysis for the cluster structure of obesity and executive functions (Figure 8) were significant and compelling. The clustering order was 0–7, and the lower the clustering order, the higher the number of keywords included in the clustering. Each cluster was comprised of multiple closely related words. The core keyword cluster map (Figure 8) can be divided into eight research hotspot directions: (1) those with the smallest clustering order (#0) are executive functions (e.g. inhibition, working memory, cognitive flexibility, cognitive control, etc.); (2) clustering order #1, energy homeostasis; (3) clustering order #2, pancreatic cancer cells; (4) clustering order #3, 3T3-L1 cells (a type of cell associated with fat metabolism);[16] (5) clustering order #4, non-alcoholic fatty liver disease; (6) clustering order #5, metabolic syndrome; (7) clustering order #6, phenolic compounds, which have some inhibitory effects on adipose tissue formation; and (8) clustering order #7, gut microbiota.

Timeline diagram of keywords

Based on the keyword clustering, we drew a keyword timeline diagram (Figure 9) using CiteSpace 6.1. R6 Basic to depict the keyword evolution process under each cluster on the relationship between obesity and executive functions from a temporal perspective, thereby enabling a deeper understanding of the thematic changes in this topic. Eight clusters emerged in 2013 and included BMI, glucose resistance, NF-kappa B, high-fat diet, insulin resistance, diet-induced obesity and oxidative stress, indicating that this area was explored from a weight, nutritional, biological and clinical perspective in 2013. Research results on the clustering of #0 executive functions, #3 adipogenesis, #5 oxidative stress, #4 oxidative stress and #7 gut microbiota increased across the study's timeframe and continued to receive considerable attention. Researchers paid less attention to clustering #1 food intake, #2 NF kappa B, #4 endoplasmic reticulum stress, and #6 pancreatic lipase levels after 2020.

Keyword prominence atlas

Words for the top 25 bursts of intensity (Figure 10) were obtained using CiteSpace 6.1. R6 Basic, all of which were greater than five in burst intensity. Overall, research on the relationship between obesity and executive functions was conducted mainly from 2013 to 2022. Burst words for induced insulin resistance and fatty acid oxidation had the longest duration of four years, and the remaining burst words had a duration of one to three years. Keywords with the strongest burst intensity were "metabolic syndrome" (12.34), followed by "induced insulin resistance" (8.72), "growth factor" (7.12), "fatty acid oxidation" (7), and "gene expression" (6.32), and so on. Interestingly, "non-alcoholic fatty liver disease," "diabetes mellitus," "sex difference," "interleukin-6," and "mellitus-6," which presented higher outbreak intensity in recent years, and are expected to become new areas of research focus in this field.

Analysis of the references

References were analyzed to help determine influential literature and authors in the research field. Keywords, including analysis of frequency, betweenness centrality, co-citation co-occurrence map of the literature, and the clustering map of keywords in the co-cited literature, were plotted against a timeline.

Running CiteSpace and setting the year slice to one year and the literature reference tick at node types resulted in a literature co-occurrence map (Figure 11A). Tables 6 and 7 show statistics for the citation frequency and betweenness centrality of references, and the top 10 articles ranked for frequency and betweenness centrality were selected for each review. Based on citation frequency, the top three ranked articles were those by Yang,[4] Bluher[17] and Ng,[18] with frequencies of 75, 57, and 49, respectively. From

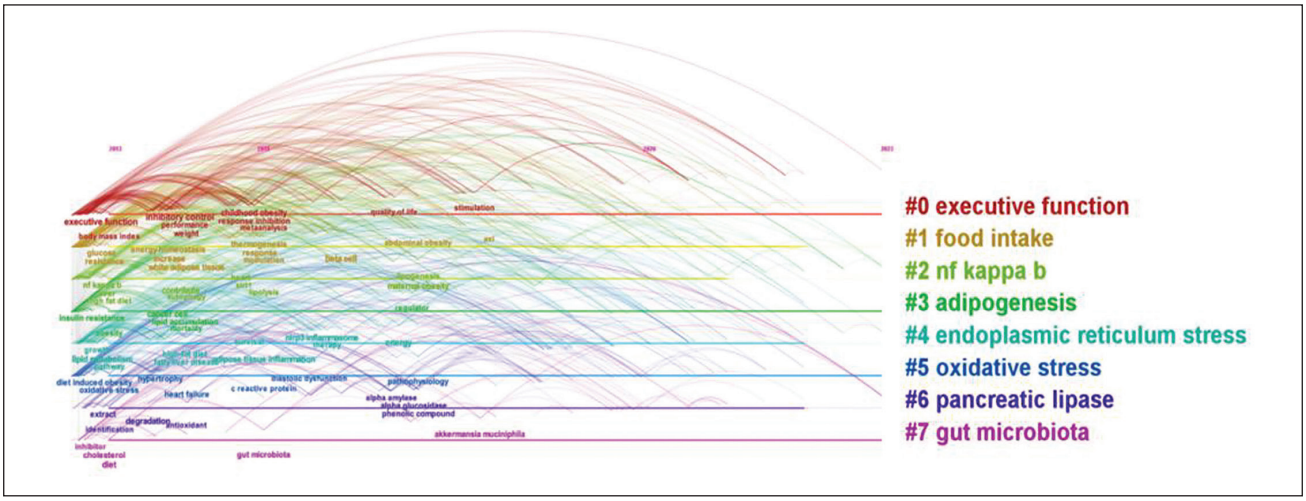

Figure 9. Keyword timeline plot.

Keywords	Year	Strength	Begin	End	2013 - 2022
metabolic syndrome	2013	12.34	2013	2014	
induced insulin resistance	2013	8.72	2013	2017	
growth factor	2013	7.12	2013	2016	
fatty acid oxidation	2013	7	2013	2017	
gene expression	2013	6.32	2013	2014	
receptor substrate 1	2013	6.15	2013	2014	
factor kappa b	2013	5.93	2013	2016	
up regulation	2013	5.88	2013	2015	
mammalian target	2013	6.58	2014	2016	
amp-activated protein kinase	2014	5.43	2014	2015	
mesenchymal stem cell	2015	5.52	2015	2017	
microrna	2015	5.38	2015	2016	
ppar gamma	2013	5.34	2015	2016	
united states	2016	6.42	2016	2019	
akt	2016	6.12	2016	2019	
progression	2016	5.34	2016	2017	
agonist	2017	5.45	2017	2019	
metastasis	2018	6.11	2018	2020	
heart	2015	5.33	2018	2020	
complication	2018	5.28	2018	2019	
nonalcoholic fatty liver disease	2019	7.44	2019	2022	
contribute	2014	5.46	2019	2020	
mellitus	2020	5.91	2020	2022	
sex difference	2020	5.61	2020	2022	
interleukin 6	2020	5.39	2020	2022	

Figure 10. Top 25 keywords with the strongest citation bursts.

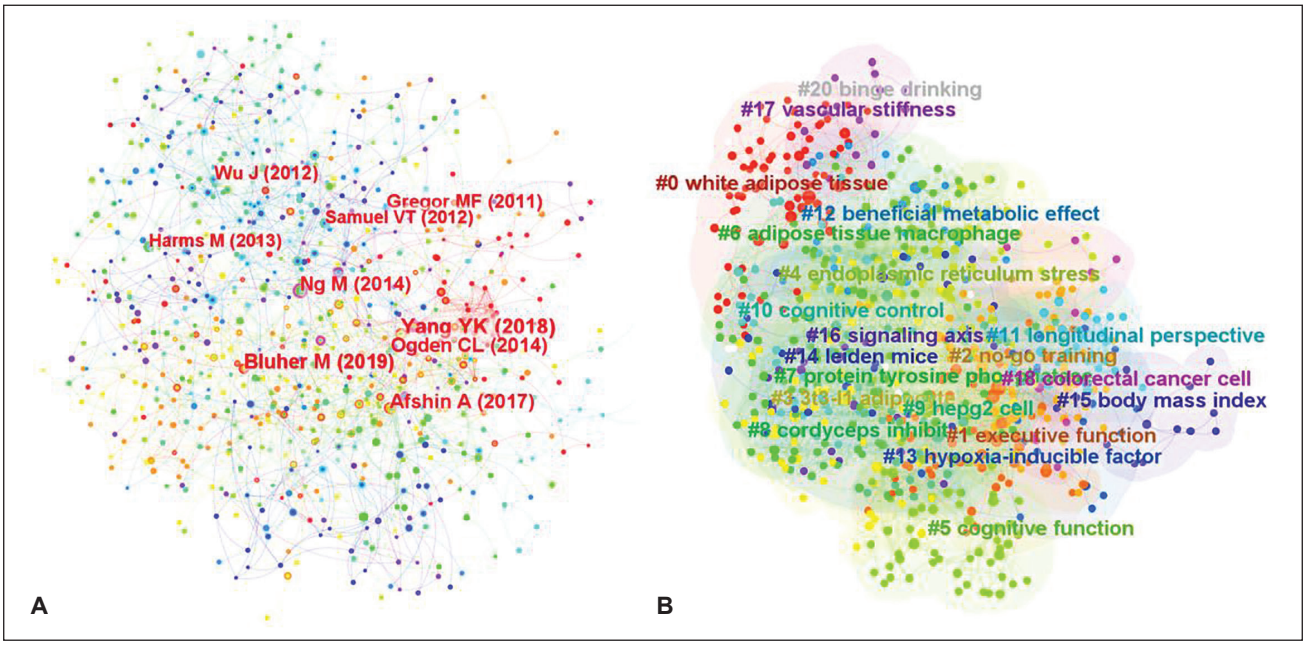

Figure 11. (A) The cited literature co-occurrence map; **(B)** The cited cluster plot.

the perspective of betweenness centrality, the top three ranked articles were by Ng,[18] Chavez[19] and Gettens,[20] with betweenness centralities of 0.16, 0.14, and 0.13, respectively. Among them, the article by Ng[18] was ranked among the top three for both frequency and betweenness centrality, illustrating that this is a research paper with important implications in the field.

Consistent with the literature co-occurrence map structure (Figure 11A), the highlighted authors were among the top ten ranked authors. The cited cluster map (Figure 11B) presents 20 keyword clusters. The modular clustering value (Q-value) was 0.7789 (Q >0.3 implies a significant clustering structure). The silhouette cluster average profile value (s-value) was 0.8384 (s >0.5 implies that the clustering is generally considered reasonable; s >0.7 implies that the clustering is convincing). There were 20 research hotspot directions for 'co-clustering': #0 white adipose tissue, #1 executive functions, #2 go/no-go training, #3 3T3-L1 adipocytes, #4 endoplasmic reticulum stress, and #5 cognitive function.

Based on the clustering of references, a literature timeline diagram (Figure 12) was created to gain more insight into subject changes in the field from a temporal perspective.

Taking 2013 as the community, the direction of keywords cited in the literature before 2013 was: #11 longitudinal

Table 6. Frequency of cited articles

Order	Cited references	Count
1	Yang YK, 2018, NEUROSCI BIOBEHAV R, V84, P225, DOI 10.1016/j.neubiorev.2017.11.020	75
2	Bluher M, 2019, NAT REV ENDOCRINOL, V15, P288, DOI 10.1038/s41574-019-0176-8	57
3	Ng M, 2014, LANCET, V384, P766, DOI 10.1016/S0140-6736(14)60460-8	49
4	Afshin A, 2017, NEW ENGL J MED, V377, P13, DOI 10.1056/NEJMoa1614362	49
5	Ogden CL, 2014, JAMA-J AM MED ASSOC, V311, P806, DOI 10.1001/jama.2014.732	48
6	Gregor MF, 2011, ANNU REV IMMUNOL, V29, P415, DOI 10.1146/annurev-immunol-031210-101322	39
7	Wu J, 2012, CELL, V150, P366, DOI 10.1016/j.cell.2012.05.016	35
8	Samuel VT, 2012, CELL, V148, P852, DOI 10.1016/j.cell.2012.02.017	33
9	Harms M, 2013, NAT MED, V19, P1252, DOI 10.1038/nm.3361	32
10	Rosen ED, 2014, CELL, V156, P20, DOI 10.1016/j.cell.2013.12.012	29

Table 7. Centrality of references

Order	Cited references	Centrality
1	Ng M, 2014, LANCET, V384, P766, DOI 10.1016/S0140-6736(14)60460-8	0.16
2	Chavez JA, 2012, CELL METAB, V15, P585, DOI 10.1016/j.cmet.2012.04.002	0.14
3	Gettens KM, 2017, J BEHAV MED, V40, P687, DOI 10.1007/s10865-017-9831-5	0.13
4	Lackey DE, 2016, NAT REV ENDOCRINOL, V12, P15, DOI 10.1038/nrendo.2015.189	0.11
5	Flegal KM, 2010, JAMA-J AM MED ASSOC, V303, P235, DOI 10.1001/jama.2009.2014	0.10
6	Alosco ML, 2014, AM J SURG, V207, P870, DOI 10.1016/j.amjsurg.2013.05.018	0.10
7	Czech MP, 2017, NAT MED, V23, P804, DOI 10.1038/nm.4350	0.10
8	Samuel VT, 2012, CELL, V148, P852, DOI 10.1016/j.cell.2012.02.017	0.09
9	Emery RL, 2017, PSYCHOL BULL, V143, P868, DOI 10.1037/bul0000105	0.09
10	Bluher M, 2019, NAT REV ENDOCRINOL, V15, P288, DOI 10.1038/s41574-019-0176-8	0.08

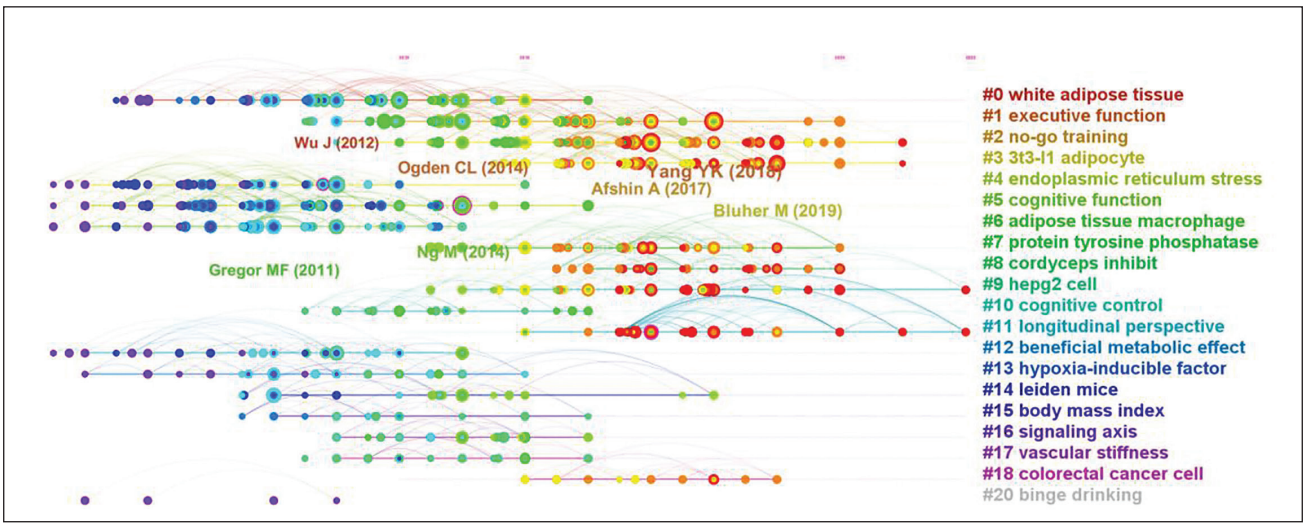

Figure 12. Reference timeline map.

perspective, #12 beneficial metabolic effects, #13 hypoxia-inducible factor, #14 Leiden mice, #15 BMI, #16 signaling axis, #17 vascular stiffness, #18 colorectal cancer cell, and #20 binge drinking. The direction of keywords cited in the literature during the period 2013–2016 was: #10 cognitive control, #9 HepG2 cell, #8 Cordyceps inhibit, #7 protein tyrosine phosphatase, and #6 adipose tissue macrophage. During 2016–2022, the literature had the following keyword directions: #5 cognitive function, #4 endoplasmic reticulum stress, #3 3T3-L1adipose, #2 go/no-go training, #1 executive function, and #0 white adipose tissue. Among these, researchers' focus on #0 white adipose tissue and #1 executive functions is ongoing.

DISCUSSION

This study conducted an internationally focused analysis and examined the relationship between obesity and executive functions using bibliometric methods, study characteristics, keywords and references, and found that the performance of executive functions in the obese population is still a topic of intense research. This may be because scholars have paid increasing attention to brain structure and CNS changes in obese people. Executive functions, which are higher cognitive abilities closely related to brain structure and the nervous system, are a series of operational processes through which individuals supervise and control their consciousness and behavior; they play an important role in cognitive processes. Researchers generally agree that executive functions include inhibitory control, cognitive flexibility, working memory, decision-making, verbal fluency and planning.[15] Chronic stress induces preclinical changes in the metabolic, cardiovascular and immune systems. This phenomenon, known as allostatic load (AL), can impair executive functions (EF), which may be even more affected in individuals with excess weight due to their characteristic inflammatory state and cardiometabolic changes.[21] Obese adolescents had impaired EF, as evidenced by low inhibition and cognitive flexibility levels compared to healthy-weight adolescents.[22] We tested interactions between emotion regulation and executive functioning in relation to eating pathology in AwO/O while considering stimuli-specific deficits (e.g., food-specific deficits) in behavioral task performance. The result shows[23] that among adults with AwO/O, emotion regulation difficulties are closely related to eating pathology, regardless of performance on working memory and inhibitory control tasks.

However, a more influential model argues that executive functions encompass three key dimensions: (1) inhibitory control, which refers to the ability to suppress impulses or automatic (preponderant) responses; (2) cognitive flexibility, which is the ability to shift attention, adjust solutions, or find resources in appropriate circumstances when difficulties are encountered; and (3) working memory, which refers to the ability to monitor the relevance of incoming stimuli and memorize updated information.[24]

Relationship between obesity and suppressive control

Wang et al.,[25] found that P3 could serve as an important neural marker for the future development of novel therapeutic strategies to improve the suppressive control of obesity. One such strategy is using mobile apps employing sweet food-specific inhibitory control training (SF-ICT), which may effectively change the eating behavior of children who overeat sweet foods.[26] Identifying individuals with low inhibitory control (IC) may facilitate early detection of adolescents at risk for obesity.[27] Moreover, food-specific inhibitory control training is particularly effective in individuals with low IC and a high BMI.[28] However, in a randomized controlled study of event-related potentials, Carbine et al.,[29] found that multiple food-specific or universal IC training over four weeks did not affect overall weight loss, calorie intake, or N2 ERP amplitude. In addition, pubertal obesity is associated with a decline in the ability to mediate cognitive conflict during inhibitory control[30] and indivi dual differences in conflict monitoring may explain binge eating behavior among obese adolescents in situations where more inhibitory control efforts are required.[30] Neuroimaging studies in obesity have shown that reduced prefrontal cortical activity affects inhibitory control and BMI,[31] and the findings of Brockmeyer et al.,[32] highlight the relevance of the interplay between inhibitory control and food reward assessment in maintaining obesity.

Relationship between obesity and working memory

In the general population, the adult BMI polygenic genetic risk scores are associated with working memory in children;[33] however, all genetic risks are not modulated by childhood BMI per se and may relate directly to working memory deficits.[33] Sánchez-SanSegundo et al.,[34] found that obese individuals had lower working memory performance than overweight individuals, providing evidence for the influence of obesity on cognitive functioning. Inflammation may mediate the relationship between obesity and impaired working memory.[35] Obesity hinders working memory via gut microbial metabolism of aromatic amino acids, according to research.[36] Obesity is associated with impaired working memory in women but not males, according to a study based on a nationally representative dataset of US adults.[37] In a similar vein, stereotype threat has been linked to decreased working memory in obese women.[38] Furthermore, Wu et al.,[39] found that obese children had domain-specific working memory deficiencies and remembered more items than children of normal weight during food-and-drink-related working memory tasks. Obese individuals exhibit decreased working memory and stimulus-reward learning.[40] Youth with Children with loss of control (LOC) eating and overweight/obesity demonstrated difficulties mentally retaining and manipulating numerical information in daily life, replicating prior laboratory-based research. Overeating may be related to improved working memory (WM), regardless of LOC status, but temporality and causality should be further explored.[41]

Association of obesity with cognitive flexibility

Cognition underpins the flexibility of human eating and disruption to higher cognitive processes, such as inhibitory control and memory, resulting in increased food intake, which could result in weight gain in the long term. Data from longitudinal and interventional studies and non-human animal models suggest a reciprocal relationship exists between obesity and cognitive function. However, whether disruption to higher cognitive processes is a primary cause of obesity in humans remains unclear.[42] In a sample of overweight and obese adults, greater dietary intake of choline, lutein, and zeaxanthin was associated with rapid performance in cognitive flexibility tasks.[43] Further, reduced cognitive flexibility may lead to behavioral rigidity that induces a disordered eating state and, subsequently, obesity.[44] The cognitive reserve that accumulates over one's lifetime and cognitive flexibility can reduce the detrimental effects of obesity on cognitive functioning during old age.[45]

Executive functions training for obese individuals

The clinical relevance of executive functions in diagnosis, treatment, and prognosis cannot be overlooked; therefore, La Marra et al.,[46] proposed that executive functions should be included in managing obese patients. The effects of executive functions related to training activities have also been examined in individuals with obesity. Obesity treatments that combine cognitive training, particularly those that train compensatory strategies, may improve weight loss.[47] Executive function training approaches improve weight control and comorbidity in obese children.[48] Further, by administering cognitive remediation therapy to obese individuals, weight loss effectiveness may improve because any improvement in executive functions may disrupt unhealthy lifestyle habits.[49,50] Riggs et al.,[50] suggested that obesity interventions must include programs that promote executive functions tailored for potential groups of adolescents with different levels of obesity risk.

Limitations

Regarding data collection, the resulting database source was limited to the WOS, and studies on Chinese and English databases, excluding the WOS, were not performed. Additionally, in data processing, considering the possibility of duplication between theses and academic journals, which may affect the integration and analysis of information such as final authors, institutions, and keywords, this study selected only articles for the data source. Reviews, theses, and other content were not included. A more comprehensive integrative analysis of Chinese and English databases could be considered in subsequent studies.

CONCLUSIONS

This study used bibliometric approaches to facilitate in-depth and quantitative analysis of the relationship structure between obesity-related executive functions and scientific findings over the past decade. The findings show that US institutions and academia are leading in terms of the current volume and impact of literature contributions to the field. The analysis of research hotspots showed that in addition to focusing on metabolic syndromes, insulin resistance, diabetes, gut flora and dietary intake, researchers have also focused in recent years on related topics such as the brain, cognition, executive functions and the prefrontal cortex of obese people. These topics can provide a reference point for aspiring scientific researchers. Future researchers must consider providing insights into the relationship between obesity and specific components of executive functions, such as working memory, inhibitory control, cognitive flexibility and planning.

Statement of Authorship
All authors certified fulfillment of ICMJE authorship criteria.

CRediT Author Statement
SQ: Conceptualization, Supervision; **LS:** Conceptualization, Investigation, Writing – original draft preparation; **JH:** Methodology, Writing – original draft preparation, Writing – review and editing; **YX:** Resources, Data Curation, Visualization; **XH:** Software, Visualization; **RS:** Formal analysis, Investigation; **XW:** Resources; **YST:** Project administration

Data Availability Statement
Datasets generated and analyzed are included in the published article.

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The authors declared no conflict of interest.

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