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ABOUT COVER

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AIMS AND SCOPE

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Knowledge domain and emerging trends in visual hallucination research: A scientometric analysis

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Abstract

BACKGROUND

Visual hallucination (VH) refers to a spontaneous visual perception without corresponding external stimuli and often occurs in ophthalmological and neuropsychiatric disorders. It is associated with poor quality of life, and increased patient hospitalization and nursing home admission. To date, a scientometric analysis of research on VH is lacking.

AIM

To objectively summarize the features of VH research and gain insights into the emerging trends in research on VH.

METHODS

CiteSpace V was used in this article. Publication outputs, document types, geographic distributions, co-authorship status, research hotspots, and co-citation status were analyzed. A total of 2176 original articles and 465 reviews were included in the database downloaded from the Web of Science Core Collection. We selected the top 50 most cited or occurring articles or items to create a visualized network with a 1-year interval. In the document co-citation analysis stage, we performed clustering analysis on co-cited references, and log likelihood tests were used to name the clusters.

RESULTS

The results showed that most publications can be classified into neurology, sports, and ophthalmology studies. In addition, North America, Europe, Asia and Australia published the most documents. Some well-known authors have always had a leading role in this field; meanwhile, new authors keep emerging. A relatively stable cooperation has been formed among many authors. Furthermore,

neuropsychiatric symptom and functional connectivity are the top hotspots. Research on VH in dementia with Lewy bodies and Parkinson's disease (PD) have received much attention. Studies on VH in PD are likely to be the new emerging trends in the future, especially the mechanisms of VH.

CONCLUSION
Research on VH has formed a complete system. More large-scale clinical and in-depth basic research are required to better understand the mechanisms underlying VH, which will contribute to our understanding of the patho-physiology and therapeutic options for VH.

Key Words: Visual hallucination; Psychiatry; Parkinson's disease; Dementia with Lewy bodies; CiteSpace; Scientometric

Core Tip: Visual hallucination (VH) is very common and research on VH keeps emerging. In this review, CiteSpace V was used to objectively summarize the features of VH research and gain insights into the emerging trends for research on VH. Publication outputs, document types, geographic distributions, co-authorship status, research hotspots, and co-citation status were analyzed.

INTRODUCTION

Visual hallucination (VH) is a spontaneous visual perception in the absence of corresponding external stimuli; it has been aptly described by Collerton *et al*[1] as seeing things that are not there. It is a common symptom often associated with eye diseases (*e.g.*, Charles Bonnet syndrome [CBS])[2,3] and neuropsychiatric conditions (*e.g.*, Parkinson's disease [PD][4-6], dementia with Lewy bodies [DLB][7-9], epilepsy[10], schizophrenia[11,12], occipital stroke[13]). In some cases, it can be a side effect of medications, such as anticholinergics, dopamine agonists, and a wide range of medications modulating diverse neurochemical pathways[14]. VH is related to the poisoning and withdrawal of alcohol, cannabis, and cocaine and other physical conditions such as physical illness and stress[15-17]. A small percentage of healthy individuals have reported experienced VH in their life[18,19]. Although VH occurs in a significant proportion of cases, it mostly occurs sporadically in healthy people. The frequent occurrence of VH tends to be a signal of pathology[20].

The prevalence of VH varies widely in different diseases. Almost 40% of people with eye or visual pathway disease, typically macular degeneration, develop VH known as CBS[3]. VH is also a core feature for DLB diagnosis and has a 54%-70% prevalence in DLB[21,22]. Furthermore, 22%-78% of patients with PD suffer from VH [23]. Hallucinations have been described as a hallmark of schizophrenia, showing a prevalence of 36.5%[24]. The lifetime prevalence of VH in healthy subjects is 3.4%[25]. Progressive and recurrent VH is often associated with a likelihood of poor life quality, increased patient hospitalization, and nursing home admission[26,27]. In addition, it is a risk factor for dementia and is associated with the high mortality rate of patients with dementia[28,29].

Extensive research on VH has been widely conducted worldwide, and a large number of papers have been published. However, to the best of our knowledge, VH has not been systematically reviewed by scientometric analysis. The knowledge domain and emerging trends of existing research have not been fully understood. Therefore, objectively summarizing the features of VH and gaining insights into the new emerging trends for research on VH are crucial. This work conducted a systematic

and scientific analysis of the research on VH by using CiteSpace, a powerful tool for data analysis and visualization[30]. The findings elaborate on annual publications, document type, co-country, co-authorship, burst keywords, and document co-citation.

MATERIALS AND METHODS

Data collection

Our data were retrieved from the Web of Science Core Collection (WOSCC), which is the specified article data source for CiteSpace as it contains citation information. An initial topic search for 'visual hallucination' resulted in 3178 records published between 1985 and 2020. We filtered out conference abstracts and proceedings and corrigendum documents, which were less representative[31]. We believe that original research papers can better represent the state of the research field compared with other types of documents. Review papers can attach additional importance to the repres-entative papers selected by domain experts[32]. A total of 2641 publications which consist of 2176 articles and 465 reviews, were selected as a database to be used in subsequent analysis (537 were excluded). Then we downloaded raw data, which included full records and cited references, from WOSCC in the form of plain text files.

Statistical methods

CiteSpace V based on Java was utilized for information visualization analysis, which provides insights into VH research and makes it easy to effectively follow the progress of information[30,32,33]. In this study, we selected the top 50 most cited or occurring articles or items to create a visualized network with a 1-year interval. In the document co-citation analysis stage, we performed clustering analysis on co-cited references, in which similar references were combined to determine related research fields. Moreover, log likelihood tests (LLRs) typically provide the unique and best results that consider all of the contents of a cluster; thus, we extracted noun phrases from the keywords of articles that cited a cluster on the basis of LLR to characterize the nature of the cluster[34]. Office Excel 2019 was also applied to our study.

RESULTS

Characters of publication outputs

To determine the general trend of VH research, we summarized the publications of original articles and reviews over the years. The earliest record we found in WOSCC was published in 1999. The results in Figure 1 show that the publication outputs are mainly in a fluctuating growth trend, with an increase from 61 in 1999 to 182 in 2020.

Analysis of document type

Dual-map overlays in CiteSpace can help reveal the trends of the scientific portfolio under a background of a global map of scientific literature. The background has two base maps, the left part shows a base map of citing journals and the right part shows the cited journals, each containing a network of over 10000 journals. Similar journals form a cluster, which is labeled on the basis of the terms in the journal titles of the cluster. The reference relationships between the left and right parts are connected by colored curves that indicate how a current research obtains inspiration from previous works[33]. The vertical and horizontal axes of the ellipse in the left part respectively indicate the number of articles and authors published in journals. The number of citations determines the size of the ellipse in the right part[34]. Figure 2 shows a dual-map overlay visualization of the citing and cited papers with regard to the topic search on VH. Four threads of citations stand out. They originate from four clusters in the citing base map: the orange threads from the cluster of molecular, biology and immunology, the pink threads from the cluster of neurology sports and ophthal-mology, the blue threads from the cluster of psychology, education and health, and the green threads from the cluster of medicine, medical and clinical. These threads generally point to two clusters in the cited base map. One is the cluster of molecular, biology and genetics; the other is the cluster of psychology, education and social. New developments are highlighted in red from the publication point of view. The new progression of VH is in the field of mathematics, systems and mathematical, which is worth further research.
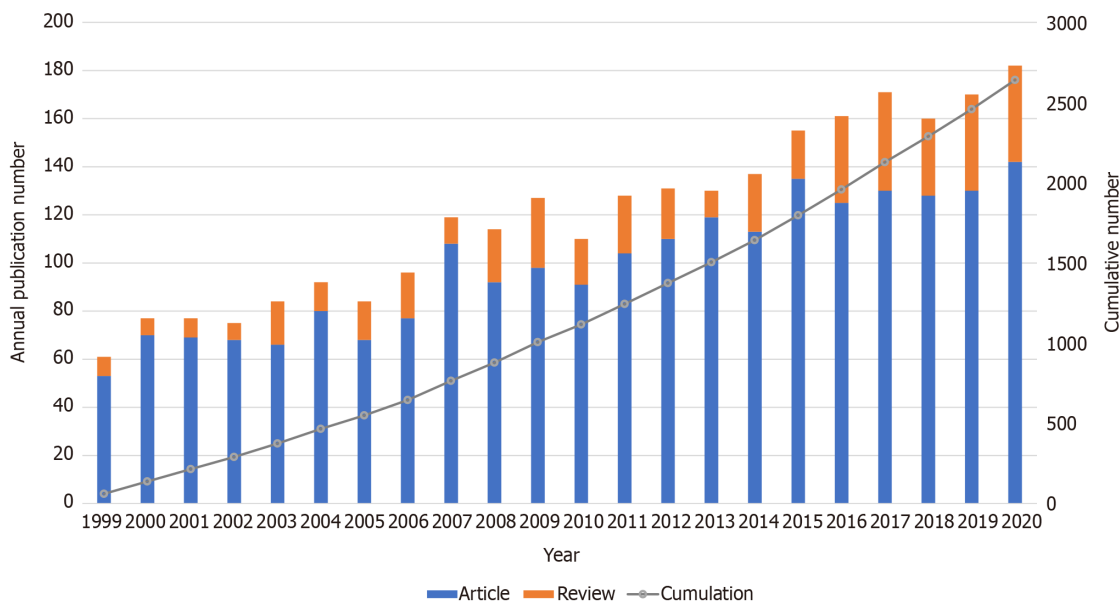
Figure 1 Publication output performance during 1999-2020.
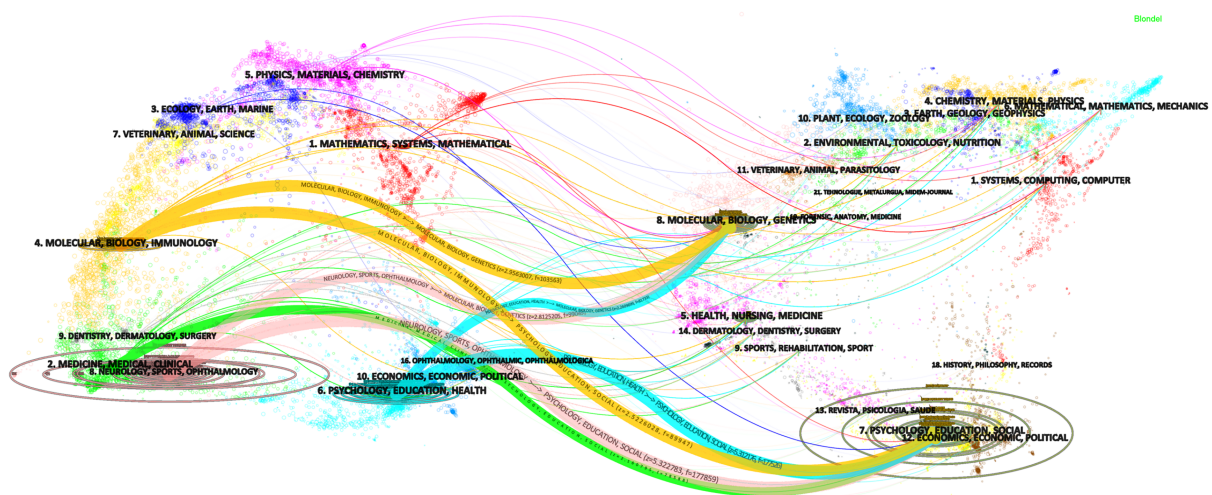
Figure 2 Dual-map overlay for final document storage. The nature of each region is labeled by the journal of the corresponding region. The colored curve represents the reference path from the citing base map on the left to the cited base map on the right. The number of articles and authors published in journals determines the size of the ellipse in the graph.

Geographic distribution of the publications

The total number of publications by country was analyzed to understand their geographic distribution. We checked the names of all countries and merged some regions into corresponding countries. The analysis is presented in Figure 3. The larger the published quantity, the deeper the color. The United States, England, and Japan were the top three countries.

Distribution of authors and co-authorship

Co-authorship was analyzed to detect active authors and their cooperation in the field. For accuracy and objectivity, we reviewed all of the authors' names to reduce misidentification. The result is displayed in Figure 4. The font size of each author's name corresponds to the number of articles by each author, which represents the contribution of the author to this field. The color of the tree ring stands for the year in which the author published his or her articles. The thickness of the tree ring represents the number of his or her articles in a particular year. Collaborative intensity between authors is indicated by the thickness of a connecting line. Chronological order information is included in the color of the lines that appear together between nodes:
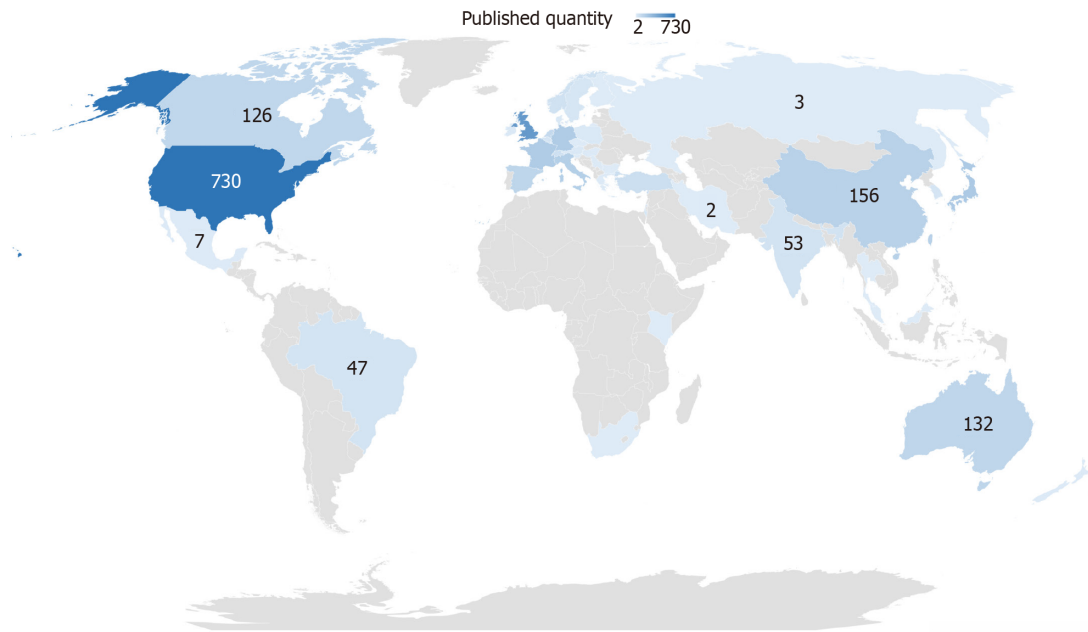
Figure 3 Geographic distribution of the countries. The figures represent the corresponding country's total published quantity on visual hallucination between 1999 and 2020. The larger the published quantity, the deeper the color.
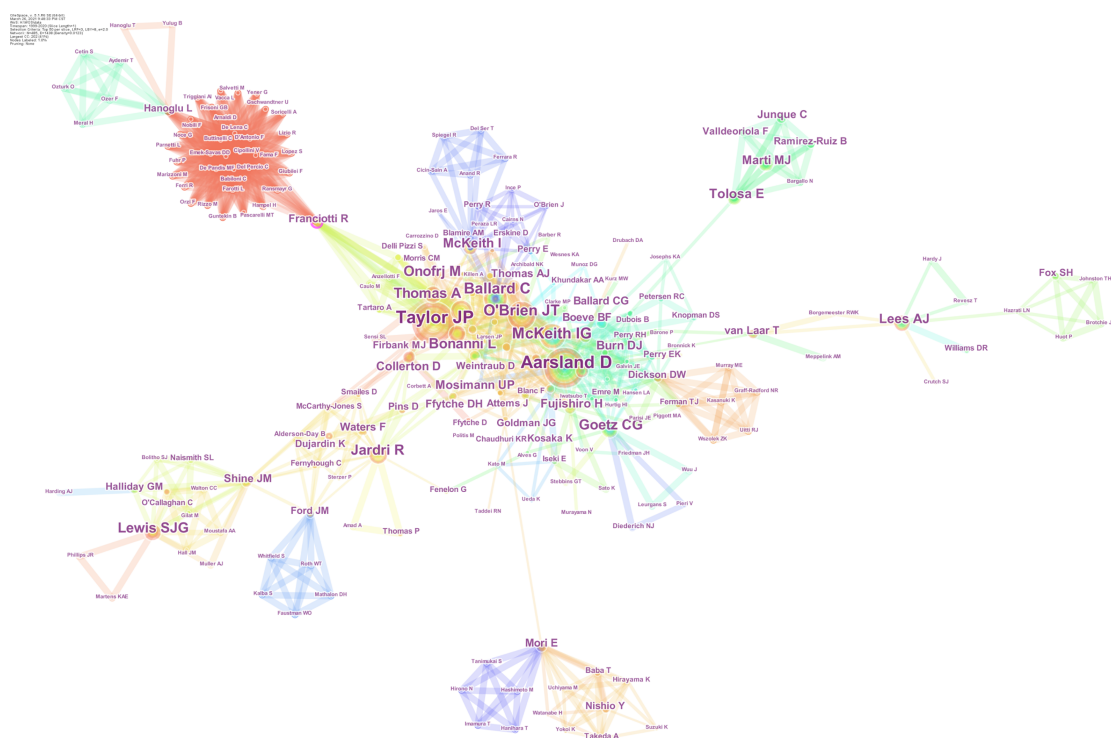
Figure 4 Map of active authors in the visual hallucination field. The font size of each author's name represents the article counts of each author. Different colors inside the circle represent different time intervals. The collaborative intensity between authors can be seen from the thickness of the connecting line.

blue represents the oldest, green the middle, and red the newest. In summary, top-productivity authors have greatly contributed to this field, and a relatively stable cooperation has formed among many authors. More than 485 authors have made contributions to the research on VH. Among these authors, Taylor JP (40 articles) ranked first, followed by Aarsland D (38 articles), O'Brien JT (25 articles) and McKeith IG (24 articles).

Keywords burst detection
The topics involved in VH can be described by the keywords extracted from each

article in the dataset[31]; however, new insights into this field should be determined. The burst patterns of keywords reveal research hotspots in the field of VH because a burst of a keyword is a sharp increase of the keyword that is likely to have a great influence[32]. Among the 340 selected keywords, 104 have the strongest strength of burst during 1999-2020. Figure 5 lists the top 104 keywords with strongest burst. The blue line represents the timeline from 1999 to 2020, and the red line stands for the years when a keyword has burst. Among the top 104 keywords, particular attention was paid to those keywords that remain to have a burst until 2020, such as 'neuropsychiatric symptom' and 'functional connectivity'. Other burst keywords included 'auditory verbal hallucination, diagnostic criteria, functional magnetic resonance imaging (fMRI), meta-analysis, management, impulse control disorder, sleep behavior disorder, and default mode network'.

Analysis of co-cited references

The most outstanding function in CiteSpace is co-citation analysis, which was used to analyze all references of the 2641 documents downloaded from WOSCC, and the top 50 most-cited references each year was select. As a result, 776 nodes of references were generated and automatically linked in the visual interface. Only if two references were cited by the same document could they be connected. If two references were often cited by documents together, they tended to have a close relationship, so they were classified to the same cluster. In our analysis, the smallest clusters were filed out, and 69 clusters were left. The information on all references formed the intellectual base of this field, and 776 highly cited references were classic documents[32]. By mining the most classic references in each cluster, we can understand the general development process and research frontiers of the VH research field. An overview of a co-cited reference network is shown in Figure 6. The overall structure can be divided into three major parts: the upper left part of the nodes and links, which represent the co-citation of the first 7 years from 1999 to 2005, is essentially in blue. The central part of the network is mainly in green and yellow, which indicates that the relationship was probably constructed between 2006 and 2012. The bottom right part is predominantly in red, and connections are formed credibly in the most recent 8 years.

The quantity of the clusters can be measured *via* two indexes: Modularity Q value and Silhouettre value. Modularity Q value is a network modularization index with a value range of 0-1. $Q > 0.3$ indicates that the structure of a certain cluster is significant. Silhouettre value indicates the homogeneity or consistency of the cluster. The closer the S value is to 1, the better the homogeneity of the cluster is. When $S > 0.5$, the clustering result can be considered reasonable; when $S > 0.7$, the clustering result is efficient. The number of references constituting the cluster must be greater than 10 [35]. Table 1 lists the major clusters of co-cited references selected from 69 clusters. In general, the 10 clusters in the table represent 10 research directions in the field.

The earliest formed cluster is Cluster #1 senile dementia, whose average publication year is 1997. It has more than 100 references as its members. A common theme of this cluster is identifying DLB from Alzheimer's disease, which are both belong to senile dementia[36-38]. The 82 members of Cluster #2 are evenly published in 2001, mainly involve PD with hallucination and focus on phenomenology[39]. Cluster #5 Charles bonnet syndrome, #3 incident dementia, and #6 schizophrenia introduce CBS, DLB and schizophrenia, respectively. These diseases all have VH as a hallmark. The research foundation in the three fields was mostly established in 2001, 2005, and 2014. Their high silhouette values indicate a high homogeneity of the clusters. Importantly, Cluster #2 and #3 are very close to each other in Figure 6; this may be partly because both PD and DLB are Lewy bodies (LB) diseases[40], and persistent VH is related to the spread of LBs[29].

The largest cluster is Cluster #0 labeled body disease, which includes 154 complete references. These references' average publication year is 2011. Cluster #4 Parkinson's disease dementia (PDD), which has 70 group members with an average publication year of 2014. These two clusters constitute the main body of VH research in the last decade and are closely connected in Figure 6 because they include research that introduces PD with VH. Cluster #0 focuses on the evidence of changes in brain structure and function in PD with VH[41,42], while Cluster #4 is mainly about the comparison and management of VH in PDD and DLB[43,44].

Other clusters, such as Cluster #7 impulse control disorder and Cluster #9 REM sleep behavior disorder (RBD) are formed more recently. Impulse control disorder and RBD are both included in the non-motor symptoms of PD. The co-cited references in these two clusters demonstrate the relationship between these two symptoms and VH respectively. Cluster #10 5-HT2A involves the investigation of serotonin 2A receptor in PD with psychosis (PDP)[45,46]. It includes publications averagely in 2010.

Table 1 Major clusters of co-cited references

Cluster	Size	Silhouette	Mean (year)	Label (LLR)
0	154	0.727	2011	Body disease
1	110	0.883	1997	Senile dementia
2	82	0.715	2001	Hallucinosis
3	71	0.77	2005	Incident dementia
4	70	0.903	2014	Parkinson's disease dementia
5	57	0.957	2001	Charles bonnet syndrome
6	52	0.968	2014	Schizophrenia
7	47	0.822	2008	Impulse control disorder
9	11	0.975	2006	Rem sleep behavior disorder
10	11	0.99	2010	5 HT2a receptor

Ten major clusters were selected from the total 69 clusters. Each cluster represents a research subfield. The size is the number of cited articles in one cluster. The Silhouettre value indicates the homogeneity or consistency of the cluster. Mean year stands for the mean publication year of the cited articles. The label of cluster is based on log-likelihood ratio.

To detect emerging trends in the field, we further investigated the top high-quality co-cited references. In this part, we used the first author's name plus the publication year as a notion to refer to the articles extracted from 776 co-cited articles. Top three references are shown in Table 2 as ranked by citation counts, centrality, burst and sigma respectively.

DISCUSSION

Research on VH has formed a complete system. A total of 2641 articles were published between 1999 and 2020. Apparently, more original articles than reviews were published every year. In terms of the cumulative number of publications, the cumulation in 2020 (2641) is approximately twice that in 2011 (1244). Following the analysis of the chart, we can predict that this study period will further attract attention and continually grow in the next few years.

On a global scale, many countries conduct numerous studies on VH. This field has attracted wide attention worldwide. However, research imbalance between countries exists. To date, studies on VH have been predominantly conducted in North America (*e.g.*, United States and Canada), Europe (*e.g.*, United Kingdom, France, Germany), Asia (*e.g.*, Japan and China), and Australia. The United States published the largest number of studies between 1999 and 2020. England was the second country that stands out in studies involving VH.

Dr. Taylor JP and Dr. Aarsland D are pioneers in the field. Dr. Taylor JP pushes back the frontiers of DLB[47] and plays an important role in the studies on the visual cortical excitability in the VH of DLB[7,48-50]. Dr. Aarsland D opens doors to reveal the psychiatric symptoms of PD[51-54]; his outstanding contribution to this field is clarifying that the presence of hallucination in PD is an important contributor to institutionalization and caregiver distress[55,56]. In addition, a group of new experts has emerged in this field in 2020, and their cooperation is very close. The team is mainly engaged in the research of electroencephalogram and evoked potentials of VHs, which is a new research breakthrough[57,58].

The most active topics of this field are 'neuropsychiatric symptom' and 'functional connectivity'. For example, the burst period of keywords 'neuropsychiatric symptom' is from 2014 to 2020, and the burst intensity is 11.91. Cross-diseases (mainly psychiatric and neurological diseases) VH research started in 2014[59]. This article sparked a heated discussion on the relationship between VH in psychiatric and neurological diseases. Many scholars tend to believe that VH in different neuropsychiatry disorders have the same mechanism. Some experts have proposed that impairments in attentional network activity can explain all hallucinations in various diseases[60]. Yao *et al*[61] proposed that apart from schizophrenia, aberrant default mode network (DMN) was also found to contribute to the VH in PD. Meanwhile, the dorsal attention

Table 2 Top three references ranked by four values respectively

Values		Ref.	Journal, volume, start page	Cluster #
Counts	124	Mckeith *et al*[69], 2005	*Neurology*, 65, 1863	3
	93	Harding *et al*[70], 2002	*Brain*, 125, 391	3
	91	Mckeith *et al*[36], 1996	*Neurology*, 47, 1113	1
Centrality	0.09	Aarsland *et al*[71], 2002	*J Neurol Neurosur Ps*, 72, 708	1
	0.08	Goetz *et al*[72], 2011	*Movement Disord*, 26, 2196	0
	0.07	Cummings *et al*[46], 2014	*Lancet*, 383, 533	0
Bursts	44.12	Mckeith *et al*[74], 2017	*Neurology*, 89, 88	4
	43.96	Mckeith *et al*[36], 1996	*Neurology*, 47, 1113	1
	43.86	Mckeith *et al*[69], 2005	*Neurology*, 65, 1863	3
Sigma	4.49	Teunisse *et al*[79], 1996,	*Lancet*, 347, 794	5
	4.36	Cummings *et al*[46], 2014	*Lancet*, 383, 533	0
	4.04	Mckeith *et al*[69], 2005	*Neurology*, 65, 1863	3

network (DAN) and the ventral attention network (VAN) also play important roles in the occurrence of VH[62]. DMN involves the function of sensory information perception and processing, while VAN engages attention to salient stimuli and DAN generates selective attention. The underactivation of VAN and overactivation of DAN and DMN lead to the recall of previously stored perception information, resulting in VH[63]. In the cohort of patients with VH, thinner retinal nerve fiber layer thickness was found by using spectral domain optical coherence tomography[64], and grey matter atrophy in visual perception region was shown in structural magnetic resonance imaging. These all provide evidence to support the attention deficit network model.

The keyword 'functional connectivity' burst from 2017 to 2020 with a burst intensity of 11.6008. Although current research has produced deep insights into the symptoms and nature of VH, the pathophysiology and etiology of VH remain unclear. Therefore, understanding neural mechanisms has considerable scientific and clinical significance. Evidence from the autopsy can only reveal changes in VH and not explain the cause of VH[65]. Functional neuroimaging studies are beneficial at capturing spontaneous VH in the neuroimaging scanner and the examination is noninvasive[66]. fMRI can investigate changes in specific parts of the brain rather than gross brain abnormalities [67]. It can reveal alterations in brain connectivity even before structural deficits occur. Resting state and task state are two main types of functional neuroimaging in the studies on VH[66]. The most recent research into the neural underpinnings of VH in schizophrenia concluded that the lateral occipital cortex (LOC) of patients showed increased connection with the frontoparietal task-control network and thalamus in the resting state; however, during task switching, LOC has an increase in interaction with the DMN[68].

Emerging trends of VH were identified based on structural and temporal properties derived from the relevant publications.

Landmark articles

Given the groundbreaking contributions, the most cited articles in the research field are often considered the landmarks[31]. Mckeith IG (2005) and Harding AJ (2002) are at the top of the list. Both of them are in Cluster #3. Mckeith IG (1996) is the third most cited article and belongs to Cluster #1. Notably, Mckeith IG is a pioneer in the field of DLB and has published a series of DLB clinical guidelines in Neurology. Mckeith IG (1996) proposed the first consensus guideline for the clinicopathological diagnosis of DLB[36]. In 2005, Mckeith *et al*[69] published the third revised clinical diagnostic and treatment criteria for DLB, which included management in the criteria for the first time. These two guidelines authoritatively summarized the clinicopathological diagnosis of DLB and showed the direction of DLB treatment at that time. The article by Harding *et al*[70] entitled *Visual hallucinations in Lewy body disease relate to Lewy bodies in the temporal lobe* advanced the finding that temporal lobe LB is strikingly associated with VH given the distribution of LB in the brain. This result is a
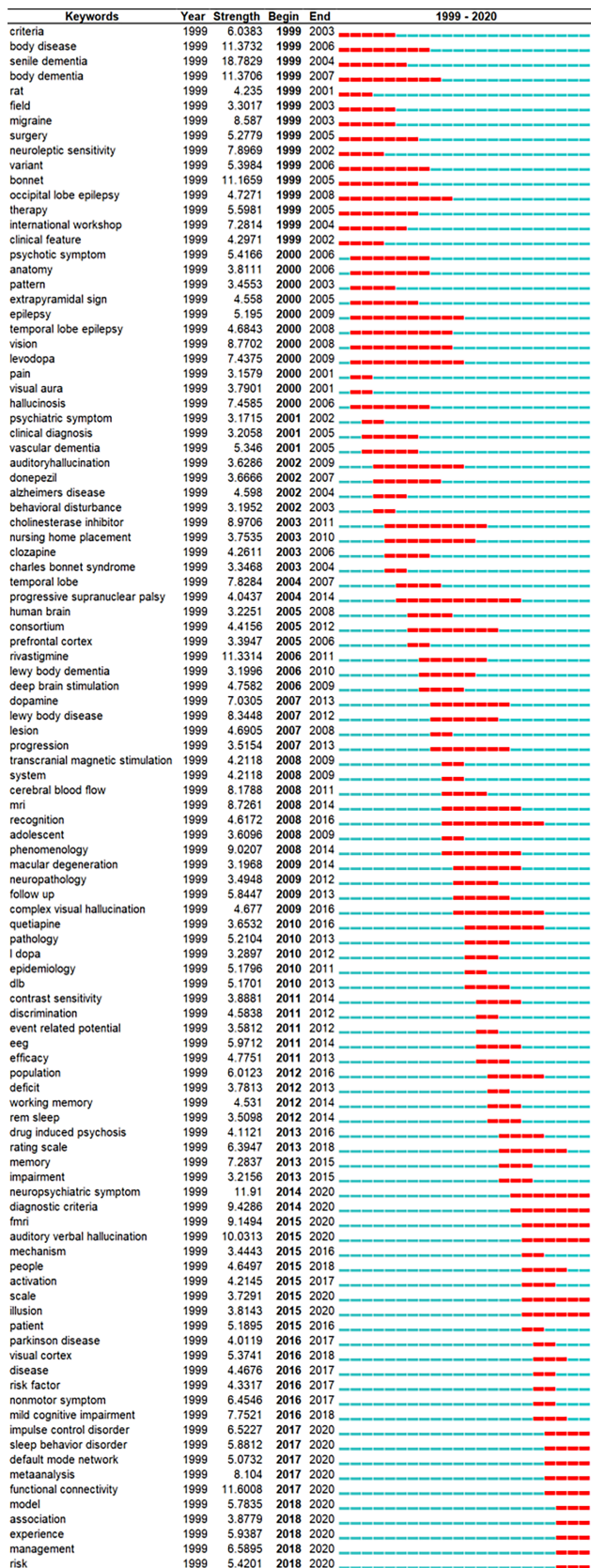
Keywords	Year	Strength	Begin	End	1999 - 2020
criteria	1999	6.0383	1999	2003	
body disease	1999	11.3732	1999	2006	
senile dementia	1999	18.7829	1999	2004	
body dementia	1999	11.3706	1999	2007	
rat	1999	4.235	1999	2001	
field	1999	3.3017	1999	2003	
migraine	1999	8.587	1999	2003	
surgery	1999	5.2779	1999	2005	
neuroleptic sensitivity	1999	7.8969	1999	2002	
variant	1999	5.3984	1999	2006	
bonnet	1999	11.1659	1999	2005	
occipital lobe epilepsy	1999	4.7271	1999	2008	
therapy	1999	5.5981	1999	2005	
international workshop	1999	7.2814	1999	2004	
clinical feature	1999	4.2971	1999	2002	
psychotic symptom	1999	5.4166	2000	2006	
anatomy	1999	3.8111	2000	2006	
pattern	1999	3.4553	2000	2003	
extrapyramidal sign	1999	4.558	2000	2005	
epilepsy	1999	5.195	2000	2009	
temporal lobe epilepsy	1999	4.6843	2000	2008	
vision	1999	8.7702	2000	2008	
levodopa	1999	7.4375	2000	2009	
pain	1999	3.1579	2000	2001	
visual aura	1999	3.7901	2000	2001	
hallucinosis	1999	7.4585	2000	2006	
psychiatric symptom	1999	3.1715	2001	2002	
clinical diagnosis	1999	3.2058	2001	2005	
vascular dementia	1999	5.346	2001	2005	
auditoryhallucination	1999	3.6286	2002	2009	
donepezil	1999	3.6666	2002	2007	
alzheimers disease	1999	4.598	2002	2004	
behavioral disturbance	1999	3.1952	2002	2003	
cholinesterase inhibitor	1999	8.9706	2003	2011	
nursing home placement	1999	3.7535	2003	2010	
clozapine	1999	4.2611	2003	2006	
charles bonnet syndrome	1999	3.3468	2003	2004	
temporal lobe	1999	7.8284	2004	2007	
progressive supranuclear palsy	1999	4.0437	2004	2014	
human brain	1999	3.2251	2005	2008	
consortium	1999	4.4156	2005	2012	
prefrontal cortex	1999	3.3947	2005	2006	
rivastigmine	1999	11.3314	2006	2011	
lewy body dementia	1999	3.1996	2006	2010	
deep brain stimulation	1999	4.7582	2006	2009	
dopamine	1999	7.0305	2007	2013	
lewy body disease	1999	8.3448	2007	2012	
lesion	1999	4.6905	2007	2008	
progression	1999	3.5154	2007	2013	
transcranial magnetic stimulation	1999	4.2118	2008	2009	
system	1999	4.2118	2008	2009	
cerebral blood flow	1999	8.1788	2008	2011	
mri	1999	8.7261	2008	2014	
recognition	1999	4.6172	2008	2016	
adolescent	1999	3.6096	2008	2009	
phenomenology	1999	9.0207	2008	2014	
macular degeneration	1999	3.1968	2009	2014	
neuropathology	1999	3.4948	2009	2012	
follow up	1999	5.8447	2009	2013	
complex visual hallucination	1999	4.677	2009	2016	
quetiapine	1999	3.6532	2010	2016	
pathology	1999	5.2104	2010	2013	
l dopa	1999	3.2897	2010	2012	
epidemiology	1999	5.1796	2010	2011	
dlb	1999	5.1701	2010	2013	
contrast sensitivity	1999	3.8881	2011	2014	
discrimination	1999	4.5838	2011	2012	
event related potential	1999	3.5812	2011	2012	
eeg	1999	5.9712	2011	2014	
efficacy	1999	4.7751	2011	2013	
population	1999	6.0123	2012	2016	
deficit	1999	3.7813	2012	2013	
working memory	1999	4.531	2012	2014	
rem sleep	1999	3.5098	2012	2014	
drug induced psychosis	1999	4.1121	2013	2016	
rating scale	1999	6.3947	2013	2018	
memory	1999	7.2837	2013	2015	
impairment	1999	3.2156	2013	2015	
neuropsychiatric symptom	1999	11.91	2014	2020	
diagnostic criteria	1999	9.4286	2014	2020	
fmri	1999	9.1494	2015	2020	
auditory verbal hallucination	1999	10.0313	2015	2020	
mechanism	1999	3.4443	2015	2016	
people	1999	4.6497	2015	2018	
activation	1999	4.2145	2015	2017	
scale	1999	3.7291	2015	2020	
illusion	1999	3.8143	2015	2020	
patient	1999	5.1895	2015	2016	
parkinson disease	1999	4.0119	2016	2017	
visual cortex	1999	5.3741	2016	2018	
disease	1999	4.4676	2016	2017	
risk factor	1999	4.3317	2016	2017	
nonmotor symptom	1999	6.4546	2016	2017	
mild cognitive impairment	1999	7.7521	2016	2018	
impulse control disorder	1999	6.5227	2017	2020	
sleep behavior disorder	1999	5.8812	2017	2020	
default mode network	1999	5.0732	2017	2020	
metaanalysis	1999	8.104	2017	2020	
functional connectivity	1999	11.6008	2017	2020	
model	1999	5.7835	2018	2020	
association	1999	3.8779	2018	2020	
experience	1999	5.9387	2018	2020	
management	1999	6.5895	2018	2020	
risk	1999	5.4201	2018	2020	

Figure 5 The top 104 burst keywords. The blue line represents the timeline from 1999 to 2020, while the red line stands for the years when a keyword has burst.

remarkable finding that links the clinical and pathological features of DLB together [70].
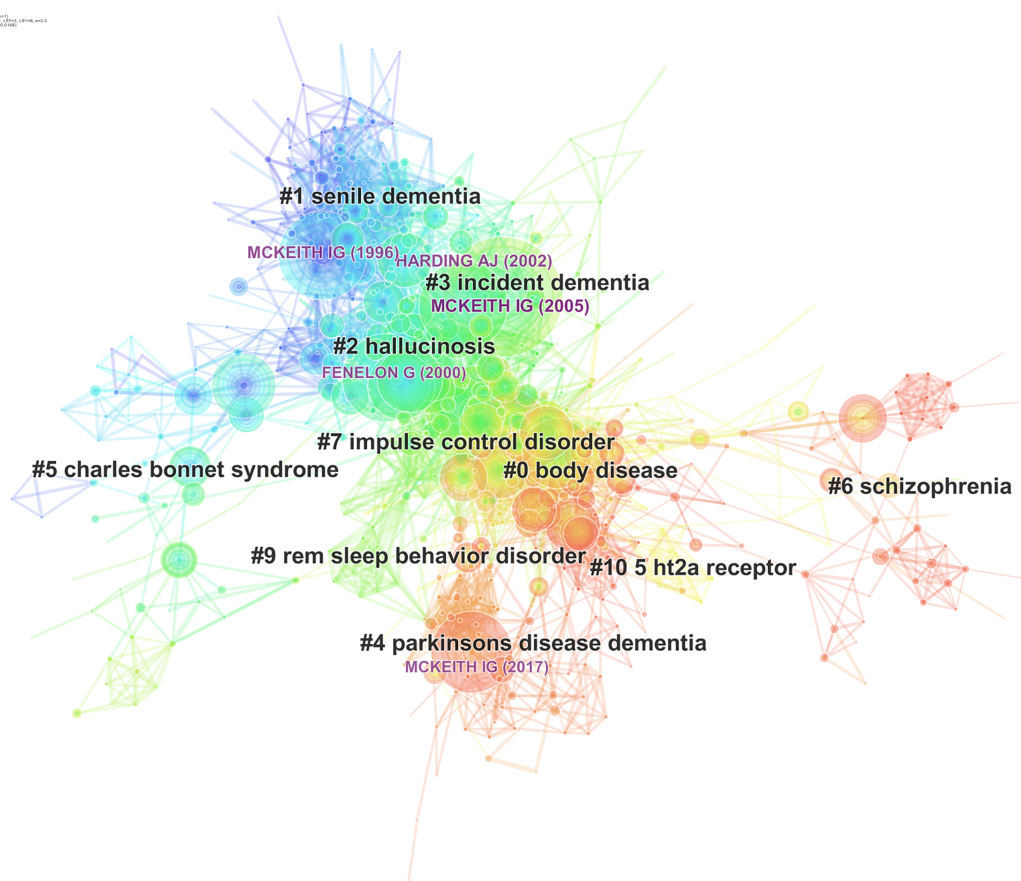
Figure 6 A network of 776 co-cited references representing citation patterns of top 50 articles per year between 1999 and 2020. The overall structure can be divided into three major parts: the upper left part of the network is essentially in blue, which represent the co-citation between 1999 and 2005. The central part of the network is mainly in green and yellow, which indicates the relationship is probably constructed in the middle 7 yr from 2006 to 2012. The bottom right part is predominantly in red and connections were formed credibly in the most recent 8 yr, that is 2013-2020.

Pivot articles

Pivot articles often refer to gateway articles between two densely connected subfields with a unique position. This type of articles can provide insights into emerging trends. The top ranked article by centrality is Aarsland D (2002) in Cluster #1, which has a centrality of 0.09. This double-blind, randomized, placebo-controlled study included 14 PDD patients to study the safety and effectiveness of the cholinesterase inhibitor donepezil in the treatment of PDD. This study lasted for 20 wk and finally they found that donepezil is safe and effective, also it does not worsen motor symptoms of PD [71]. This outstanding discovery has important therapeutic implications for PDD. The second one is Goetz CG (2011) in Cluster #0, with centrality of 0.08. Goetz *et al*[72] followed up 60 patients with PD but without hallucinations at baseline for more than 10 years. VH was found to dominate in early hallucination profile. This discovery revealed the outstanding position of VH in PDP. The third is Cummings J (2014) in Cluster #0, with centrality of 0.07. Cummings *et al*[46] conducted a randomized controlled double-blind trial on patients with PDP and concluded that this population can achieve benefit from Pimavanserin, a selective serotonin 5-HT2A inverse agonist, which is the only U.S. Food and Drug Administration-approved medication for PDP [23]. This study was a phase 3 trial that marks a critical breakthrough in the treatment of PDP, in which VH is a common symptom[73].

Burst articles

The importance of burst cannot be overemphasized. Through burst testing of all cited articles, we easily found that Mckeith IG (2017), Mckeith IG (1996), and Mckeith IG (2005) are on the top of the diagram. They are the milestones in relation to DLB. We discussed the last two articles in front part. The top one was Mckeith IG (2017) in Cluster #4. Mckeith *et al*[74] renewed the consensus report of DLB in 2017. Compared with the 2005 edition, the 2017 edition clearly distinguished clinical features and biological markers. According to different clinical features and biological markers, the

Ref.	Strength	Begin	End	1999-2020
Waters *et al*[59], 2014	19.3898	2015	2020	
Pagonabarraga *et al*[29], 2016	19.2073	2016	2020	
Onofrj *et al*[80], 2013	12.6453	2014	2020	
Mckeith *et al*[74], 2017	44.1227	2018	2020	
Lenka *et al*[81], 2015	13.3785	2016	2020	
Vann Jones *al*[82], 2014	12.621	2017	2020	
Goldman *et al*[83], 2014	14.5101	2015	2020	
Ffytche *et al*[73], 2017	18.9805	2018	2020	
Cummings *et al*[46], 2014	21.7452	2016	2020	
Archibald *et al*[84], 2011	12.3342	2014	2020	

Figure 7 The top 10 references that retained citation burst until 2020.

diagnosis was divided into probable and possible DLB. Consistency of the diagnostic criteria for DLB will be more conducive to further research on DLB.

It is valuable to examine the citation burst in more recent articles while eliminating the overshadow burst of those landmark articles. The top 10 references that retained citation burst until 2020 are shown in Figure 7, which anticipates emerging trends in the future. In general, a new emerging trend involves PD with VH. Waters F (2014) is a relatively early article comparing VH in different diseases[59]. This article opened up a new dimension in VH research. Although many hypotheses have been proposed to explain the mechanism of VH, and many imaging and electrophysiological studies have partly proved these hypotheses; it is still unclear whether VH in different diseases has the same mechanism, and further research is needed. Pagonabarraga J (2016) is the only article that had citation burst as soon as its publication. PD minor hallucination is not a newly found phenomenon in PD but is underestimated because previous research on PDP focused on the study of well-structured VH. Pagonabarraga *et al*[29] reported that minor hallucination is the most frequent symptom in PDP and may even occur before the onset of parkinsonism. The third paper was Onofrj M (2013). This paper reviews the hypothetical mechanisms of VH in PD and DLB. To date, three predominant mechanistic models have been presented: a disturbance between top-down and bottom-up aspects of visual perception[1,75]; chronic deafferentation causing hyperexcitability to cortical structures involved in vision[3,76]; and the misattribution of internal imagery[59,77,78]. The authors tend to identify with the attention deficit network model as mentioned before.

Structurally and temporally significant articles
Sigma is defined as: (*centrality* + 1)^{burstness}, which can simultaneously measure a cited reference's structural centrality and citation burstness. Teunisse RJ (1996) is at the top of the list, which objectively describes the characteristics of CBS by using a semi-structured interview[79]. The advanced nature of this article lies not only in the formation of the prototype semi-structured interview of VH but also in the occurrence of CBS, which is partly due to sensory deprivation and low arousal. The second was Cummings J (2014) in Cluster #4, Mckeith IG (2005) ranked third in this part and their importance is self-evident.

CONCLUSION
Through systematic analysis of the literature of VH over the past 22 years, we found that with the yearly progress of research on VH, its mystery has been gradually unveiled. Current research mainly focuses on neuropsychiatry. Countless countries,

institutions, and authors have collaborated together and contributed to this field. North America, Europe, Asia and Australia showed outstanding contributions, and Dr. Taylor JP and Dr. Aarsland D are the most active contributors. Several research hotspots in the field of VH were detected in the recent research. The neuropsychiatry symptom and MRI function connectivity have been paid much attention. In the field of VH, neurodegenerative diseases, especially PD and DLB, were found to be widely studied. We believe that research on these two diseases will continue to advance the field of VH.

Although VH is of clinical importance, and its pathophysiology or treatment is mainly focused on single diseases and its mechanisms remain unclear. Additional clinical studies are required to provide higher evidence-based support for the diagnosis and treatment of VH. We investigated the basic literature related to VH and concluded that the small number of such studies is partly caused by difficulty in inducing and testing VH in animal models. Further efforts are required in this direction to obtain profound insights into the mechanisms that underlie VH. This issue will have important pathophysiologic and possible therapeutic implications in the future.

ARTICLE HIGHLIGHTS

Research background
Visual hallucination (VH) refers to a spontaneous visual perception without corresponding external stimuli and often occurs in ophthalmological and neuropsychiatric disorders. It is associated with poor life quality, increased patient hospitalization, and nursing home admission.

Research motivation
To date, there is a lack of scientometric analysis of the research on VH.

Research objectives
To objectively summarize the features of VH research and gain insights into the emerging trends for research on VH.

Research methods
CiteSpace V was used in this article. Publication outputs, document types, geographic distributions, co-authorship status, research hotspots, and co-citation status were analyzed. A total of 2176 original articles and 465 reviews were included in the database downloaded from the Web of Science Core Collection.

Research results
The results showed that most publications can be classified into neurology, sports and ophthalmology studies. In addition, North America, Europe, Asia, and Australia published the most documents. Some well-known authors have always had a leading role in this field; meanwhile, new authors keep emerging. A relatively stable cooperation has been formed among many authors. Furthermore, neuropsychiatric symptom and functional connectivity are the top hotspots. Research on VH in dementia with Lewy bodies and Parkinson's disease (PD) have received much attention.

Research conclusions
Studies on VH in PD are likely to be the new emerging trends in the future, especially the mechanism of VH.

Research perspectives
More large-scale clinical and in-depth basic research studies are required to better understand the mechanisms underlie VH, which will contribute to our understanding of pathophysiology and therapy in VH.

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