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REVIEW ARTICLE

Virtual reality and dementia: A bibliometric analysis

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Abstract
Background and objective: Some studies have shown that the Virtual Reality (VR) has emerged as a promising tool for the diagnosis, treatment and cognitive improvement in people with dementia. The objective was to make a bibliometric analysis to reflect on VR and dementia research from 1998 until 2018, identifying its intellectual structure and emerging trends.
Methods: Data encompassing 356 documents and 19,238 citations collated between 1998 and 2018 from Web-of-Science and Scopus databases was analyzed through CiteSpace.
Results: There is an increasing growth of VR research as an instrument of diagnosis and intervention in dementia. Both databases show differences in terms of scope, the volume of data, and coverage policies. The *Journal of Alzheimer's Disease* is the top source. Giuseppe Riva is the most productive author. The USA and the UK are leading contributors. There is a dynamic shift in the focus of research over time and some new topics are now catching the attention of researchers. The results showed the relevance of VR in improving the health of patients with dementia and they found that the use of VR in people with dementia had a precious applicability, fundamentally, as a tool in diagnosis, treatment, cognitive improvement, or rehabilitation.
Conclusion: The co-citation and co-authorship network analysis, the identification of critical papers, and the development of new emerging tendencies highlights the priorities in this field, pointing to new opportunities to guide researchers.

Introduction

Dementia is a syndrome whose symptoms are characterized by difficulties in memory, language, problem solving and other cognitive abilities that affect a person's ability to perform daily activities.[1] Alzheimer's Disease (AD) is the most

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common form of dementia in the elderly[1–3]and is a progressive neurodegenerative disorder that is characterized by deterioration of cognitive and functional abilities and a number of neuropsychiatric and behavioral symptoms.[4,5] People with dementia may experience difficulties interacting with their physical and social environments.[6] Symptoms of cognitive, behavioral and psychological impairment can be treated with a variety of nonpharmacological interventions.

Virtual reality (VR) is as a combination of technologies,[7] being used as a tool to improve memory capacities, to explore the nature of interactions with different environments[6] and virtual environments.[8] VR combines traditional treatments which require repetitive training to improve the cognitive and motor skills with computer simulation VR-based methods, offering an effective, safe and interactive approach to the treatment of individuals with disabilities. VR can create perceivable information for human senses, such as visual and audio stimuli and that maintain known aspects of the real world, such as space and time.

The VR as aids to person living with dementia is to maintain their independent living, providing calming experiences, memory aids and cognitive stimulation.[9,10] According to Diaz-Perez and colleagues,[11] VR is a very promising area for psychological intervention in general, and more particularly for the treatment of dementia and can improve the wellbeing of people with dementia[10,12,13] and is also helping researchers to discover ways to diagnose the condition much earlier.[14]

Bibliometric analysis adopts quantitative performance indicators, to get over the disadvantage of subjectivity in peer review and expert judgments.[15] It allows us to explore the breadth and depth of research areas, to improve access to information and to learn more about the knowledge structure of a given scientific domain.[16] It is critical for conducting periodic reviews of existing research fields, identifying contributions to knowledge, and constructing substantiated arguments about the development of a field.[17] Moreover, the increasing number and complexity of research papers has created a need for bibliometric visualization tools that can produce maps, graphs, and diagrams to illuminate patterns, trends, and processes.[18] CiteSpace, the most popular bibliometric visualization tool[19] used in our research, allows us to analyze different bibliometric networks producing a new, more systematic and complete analysis of VR and dementia research. We apply the CiteSpace co-citation network (authors, documents and journals), co-occurring keywords network (author keywords and keywords plus) and co-authorship network (authors, co-authors' country).

This paper applied bibliometric visualization analysis in the domain of VR and dementia. The objective was to make a bibliometric analysis to reflect on VR and dementia research from 1998 until 2018, identifying its intellectual structure and emerging trends. Only a small number of academic studies have used bibliometric visualization to explore the network structure of dementia knowledge,[20–23] and we did not know any studies that had including co-citations and co-authorship analysis thus providing a simpler but more accurate interpretation from a holistic perspective.

More precisely, our analytical mapping can answered research questions about VR and dementia of the following types:

- What is the overlap, uniqueness and coverage between WoS and Scopus?
- How the research work has grown over time in WoS and Scopus in publications and citations?
- What are the top publication journals of research in WoS and Scopus?
- What co-citation and co-authorship patterns are observed in WoS and Scopus?
- What are the most productive authors and institutions in WoS and Scopus?
- In which countries most of the work has been done in WoS and Scopus?
- What is the amount of co-authors'national and international collaboration in WoS and Scopus?
- Who are the most cited papers in WoS and Scopus?
- Who are the trends in VR and dementia?

Material and methods

The WoS and Scopus databases generated global scientific outputs and were then analyzed by CiteSpace (http://cluster.cis.drexel.edu/∼cchen/citespace/). The analysis reviews published work from 1998 to 2018 in keeping with the timeframe of other studies where a similar time horizon has been adopted.[24] We divided the study period into intervals to better analyze changes in the development network. Four time-periods were identified: first slice 1998–2002; second slice 2003–2007; third slice 2008–2012; and fourth slice 2013–2018.

The dimensions chosen as the basis for selecting the documents in virtual reality (VR) and dementia from WoS and Scopus were keywords, years of publication and areas of research. Concerning keywords, given the focus of the study, the following keywords and Boolean operators *''virtual reality'' AND ''dementia''* were used together. To obtain more scientific and accurate data, only those articles containing the searched keywords in the title, abstract or keywords were extracted.[25] The analysis embraces twenty-one years, from 1998, corresponding to the first year when those keywords appear in WoS and Scopus, until 22 December 2018, when the empirical study was carried out. The platforms WoS and Scopus are considered the most widespread databases in different scientific fields which are frequently used for searching the literature.[26]

Using the criteria time horizon and keywords, the WoS database included 158 documents, 113 articles, 136 sources of publication, 118 journals, and 1300 citations; while the Scopus database includes 198 documents, 90 articles, 139 sources of publication, 71 journals, and 17,938 citations. Papers and journals are considered to be responsible for the advancements within and among disciplines.[27] The articles analyzed represent 71.5% of the documents in WoS, and 45.5% of those in Scopus, while journals represent 86.8% of all sources in WoS and 51.1% in Scopus.

There were a total of 18 articles and 25 journals that are shared between WoS and Scopus and 11 that are anonymous.

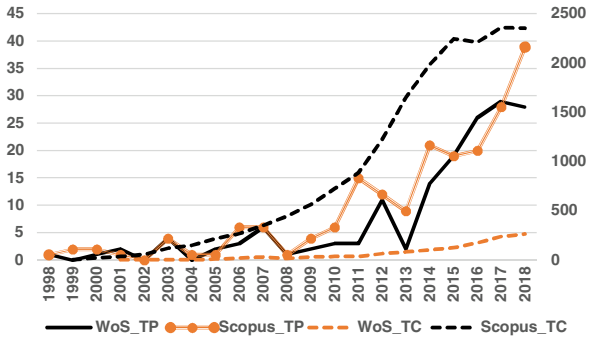

Figure 1 Publications and Citations in WoS and Scopus (1998–2018).
Source: The authors. TP, publications; TC, citations.

The two datasets provided a net sample of 185 different articles in 164 different journals.

Results

The growth of the research over time in WoS and Scopus

Comparing the rate of growth of publications and citations on VR and dementia for each of the years since 1998 to 2018, the relative growth rate of publications is 28.1% per year in WoS and 28.7% per year in Scopus. The number of research publications was doubling in 4.444 years in WoS and 4.179 years in Scopus. Therefore, there was a similar and relatively high growth in the amount of research work being undertaken on VR and dementia in both datasets. Nevertheless, the documents in Scopus have a greater probability of expanding the scientific field of research, being read, on average 10 times more because the number of citations per publication is 90.6 in Scopus and only 8.3 in WoS. In fact, the number of citations gained by a research publication was one of the effective and easy ways to use measures of the importance of that publication.[28]

We can observe in Fig. 1 that both curves of publications and citations have an increasing trend in both datasets, explaining the progress of scientific literature in this field of research. In the last five years (2014–2018), 68% of documents on VR and dementia, were published in WoS (116) and Scopus (127).

The overlap, uniqueness and coverage between WoS and Scopus

This paper analyses the overlap between the two platforms concerning, on one hand, all the sources of publication and all the type of documents, and on the other hand focusing only in journals and articles.

Advancements within and among disciplines are chiefly recognized through journals that publish research and evidence within their field.[27] In WoS there are 113 articles and 118 journals, while in Scopus those numbers are 90 and 71 respectively. There are 18 shared articles and 25 shared journals between WoS and Scopus. Between WoS and Scopus there is 15.2% ($= 25 \div (118 + 71 - 25) \times 1100$) of similarity for journals, and 9.73% ($= 18 \div (113 + 90 - 18) \times 100$) of similarity for articles, adapting the index of traditional overlap defined by Gluck (1990:45): $(WoS \cap Scopus) \div (WoS \cup Scopus)$.

The study of the singularity of WoS and Scopus is performed using two indices: (1) the percentage of unique documents in each database; and (2) the Meyer's index. In the case of the percentage of unique information, WoS includes 78.2% of unique journals (= 100−21.2% of repeated journals), and 84.1% of unique articles (=100−15.9% of repeated articles); while Scopus includes 82% of unique journals and 80% of unique articles.

To analyze the degree to which a database covers the subject of VR and dementia, we adopt the Meyer index,[29] for journals ($=\sum$journals $\times$ weight$)\div\sum$ journals) and for articles ($=\sum$articles $\times$ weight$)\div\sum$articles. The weight is 1 for unique articles or journals included in a single base, and 0.5 for duplicates. The Meyer index in the case of WoS is $0.89 = \frac{(93+25\times0.5)}{118}$ for journals and 0.92 for articles, and in the Scopus database is 0.82 for journals and 0.9 for articles. These indexes have high values, meaning that each dataset is singular, that is, it contains a high number of unique journals and articles.[30] There was a strong correlation between WoS and Scopus in VR and dementia. We found that for each new document in Scopus there is almost one (more precisely 0.99) new document in WoS. A similar analysis in terms of citations revealed the same strong correlation ($R = 0.92$) between the two datasets indicating that for each new citation in WoS there was on average 10.3 times more new citations in Scopus. Therefore, we saw that Scopus publications had a higher perceived quality and impact than those in WoS in the diffusion of knowledge by the scientific community.

Data analysis

CiteSpace includes structural and temporal metrics. Structural metrics include *betweenness centrality, modularity*, and *silhouette*: *betweenness centrality* indicates the important position of a node in bridging different stages of the development of a scientific field[20]; *modularity* is the extent to which a network can be divided into independent clusters with clear boundaries; *silhouette* gives the quality of a clustering configuration. The silhouette value range between −1 and 1, and its highest value represent a perfect fit, while a modularity between 0.4 and 0.8 represents a good fit and superior to 0.8 represents an excellent fit.[20] Both modularity and silhouette scores should be balanced simultaneously to ensure a sound interpretation of the cluster properties of the network in CiteSpace.[19] Temporal metrics include *citation burst* and *sigma*: *citation burst* is a specific duration in which the frequency of an entity increases abruptly with reference to its peers. It represents a statistically significant change in the number of citations about a specific phenomenon over a short time-span within the overall time interval,[31] irrespective of the frequency of the host entity; *sigma* is a combination of *betweenness centrality* and citation burst. It highlights those articles that herald new ideas.[31]

Monitoring research trends has always been a major concern of policy-makers of science and technology, since it helps research resource allocation and technological

forecasting. In such a situation, an attractive direction is to investigate the evolution footprints of an emerging research domain and detect the hot topics (research fronts) in some important technological domains.[32] Research fronts represent the most dynamic areas that attract the most scientific interest. Various types of techniques have been advocated for the purpose of delineating research areas including document co-citation,[33] author co-citation and co-word analysis.[34] In the current study, the following analyses were made: co-citation analysis of cited references, cited journals and cited authors; co-authorship analysis of countries and authors; and co-occurrence analysis of keywords. Co-citation is one of the most frequently used bibliometric techniques[33] for dealing with a diverse and growing academic literature. Co-authorship analysis identifies the underlying patterns of collaboration between researchers working in the field.[34] Authors and countries are connected to each other when they share authorship of an article included in the sample of source articles. Co-occurrence analysis is based on the theory that research fields can be analyzed according to patterns of keyword usage in publications, and it has been largely and successfully used for the dynamic evolution of science. It is a content analysis technique that is effective in mapping the strength of association between keywords in textual data.[34] CiteSpace includes co-occurring author keywords and keywords plus to evaluate the trend of VR and dementia research. Keywords plus are generated independently of the title and author keywords, describing an article's contents with greater depth and variety. In recent years, the distribution changed of keywords in different periods was applied to evaluate research trends,[35] justifying its application in our study.

Table 1 includes CiteSpace metrics enabling a dynamic analysis of the network of VR and dementia research.

The network of journals (Table 1) had good modularity over time which indicated that the journals tend to have more connections inside the group within which they are located, exhibiting a good degree of collaboration. After 2007 the density decreases while the number of clusters increases (from 4 to 11), suggesting the connection among the top journals is becoming more decentralized with the passage of time as more new journals become involved in VR and dementia research.

The top publication journals of research in WoS and Scopus

The *Journal of Alzheimer Disease* was at the top of the publications with 15 articles in VR and dementia, being 7.63% included in WoS, and 8.45% in Scopus. It is also the journal which accepts more collaboration in terms articles shared by eight and more co-authors. *Cyberpsychology and Behaviour* was the second journal with more articles (12), the majority coming from Scopus (11.27%), followed by *Frontiers in Aging and Neuroscience* with 11 articles, the majority coming from WoS (6.78%). The concentration of articles in both datasets is superior in WoS than in Scopus, as observed through the Lorenz curve: 5.9% of journals included 31.9% of the articles in WoS while in Scopus 9.9% of journals concentrated 33.3% of the papers. The quality of the Alzheimer's and Dementia journal as well as the higher proportion of papers indexed in Scopus top journals (60.19%), corroborate the fact that the citation scores of Scopus were higher than the ones of WoS.

Co-authorship patterns in WoS and Scopus

The co-authorship network displayed in Table 1 had the objective of demonstrating the collaboration relationship between authors in the research area.[34] The co-authorship network for VR and dementia after 2002 had a reasonable modularity and was a centralized network with high density until 2012 with a number of central authors around whom the other nodes are arranged. Between 2013 and 2018 there was a considerable decrease in density, however, and therefore, centralization declined during the same period leading to a looser network where the connections become more unclear as more researchers become involved. Considering WoS, most documents had four co-authors (14.56%), and the index of co-authorship is 5.63 authors per document. In Scopus most documents were authored by three researchers (18.18%) and the index of co-authorship is 4.90 per document.

Given that research teams now dominate the impact of scientific work across various disciplines,[36] we examined the influence of scientific collaboration between the number of co-authors from the same country (national collaboration), and from different countries (international collaboration). Most documents in VR and dementia included co-authors from the same country, corresponding to 76.6% in WoS and increasing to 80.1% in Scopus. Then, the co-authorship international collaboration was higher in WoS (23.4%) than in Scopus (19.9%) and corresponded to an index of co-authorship of 6.78 documents in WoS and 6.19 in Scopus.

The most productive authors and institutions in WoS and Scopus

We analyzed author productivity in both WoS and Scopus by considering the articles which were the basis for any research study. There were 720 authors in WoS and 160 in Scopus. The average productivity was 1.23 articles per author in WoS, but 2.14 articles per author in Scopus.

The most productive author in VR and dementia was the Italian Giuseppe Riva with 13 articles indexed in WoS and 11 articles indexed in Scopus. The affiliation of Giuseppe Riva was the Universitá Cattolica del Sacro Cuore ranked as third in WoS and second in Scopus. The institutions ranked first were the Aristotle University of Thessaloniki for WoS, and IMCC Istituto Auxologico Italiano for Scopus. The results of the present research showed similar rankings in the h-index among WoS and Scopus (see Table 2).

Co-authorship country collaboration

Regarding the development of VR and dementia research collaboration in different countries it was found that the structure of the network was more concentrated in some countries. The USA and UK have acted as the foundation for collaboration with other countries in later years. Indeed, the decreasing values of density after 2007 and the increased number of nodes and links, highlights that the

Table 1 CiteSpace metrics by node type.

Network	Node type by year	Modularity	Nodes	Links	Density	# Clusters	Mean Silhouette
Journal co-citation	**Journals**						
Network	1998–2002	0.6366	57	80	0.0501	9	0.7778
	2003–2007	0.6873	20	38	0.2000	4	1
	2008–2012	0.684	34	50	0.0891	9	0.7778
Network of	2013–2018	0.7699	60	58	0.0328	11	0.8182
Co-authors'Institutions	**Institutions**						
	1998–2002	0.3629	11	19	0.3455	2	1
	2003–2007	0.5	9	1	0.0278	4	0.25
	2008–2012	0.5625	11	8	0.0145	5	0.6
	2013–2018	0.6979	19	12	0.0712	8	0.5
Network of	**Countries**						
Co-authors'country	1998–2002	0.2552	11	26	0.4727	3	1
	2003–2007	0.4438	11	13	0.2364	4	0.5
	2008–2012	0.7031	15	8	0.0762	8	0.5
	2013–2018	0.691	31	24	0.0516	10	0.6
Document	**References**						
Co-citation network	1998–2002	0.1489	13	39	0.5000	4	0.4957
	2003–2007	0.72	9	9	0.1389	4	0.6
	2008–2012	0.5942	14	14	0.2088	4	0.9966
	2013–2018	0.997	23	23	0.1225	4	0.997
Author	**Cited Author**						
Co-citation network	1998–2002	0.2296	15	45	0.4286	4	1
	2003–2007	0.2882	13	35	0.4487	2	1
	2008–2012	0.5064	24	33	0.1196	6	0.8333
	2013–2018	0.7032	62	95	0.0502	10	0.5135
Co-authorship	**Author**						
Network	1998–2002	0.144	9	27	0.75	2	1
	2003–2007	0.75	4	2	0.3333	2	1
	2008–2012	0.4828	13	28	0.359	3	1
	2013–2018	0.8662	83	201	0.0059	18	0.8889
Co-occurring	**Keyword**						
Author keywords	1998–2002	0.6016	4	1	0.1667	1	3.8284
and keywords Plus	2003–2007	0.5197	32	92	0.1855	5	1
	2008–2012	0.5103	53	159	0.1254	7	0.8571
	2013–2018	0.4909	52	156	0.1176	6	0.6377

Source: The authors.

foundation researchers were active collaborators with researchers across many countries.

In the USA, Rizzo et al.[37] found the importance given to the development of VR systems that target cognitive processes and functional skills for populations with central nervous system dysfunction and for the assessment of unimpaired performance. The analysis of strengths, weaknesses, opportunities and threats for the field of rehabilitation and VR therapy was considered.[38] In the UK, the capacity of a novel AD screening tests based on VR environments and game principles allowed to distinguee healthy people from AD patients in terms of memory loss, understanding and expressing language; to recognize abnormalities; and to differentiate between virtual worlds and reality.[39] In Australia, the used of a VR game involving older adults in physical and cognitive exercise was able to reduce the risk of developing dementia.[40] The used of a VR cognitive training and a computerized cognitive training showed significant reductions on depressive symptoms and anxiety and an increases on memory strategy. In the UK and Malaysia the detection of early AD using virtual simulation designed to assess visuospatial memory was shown to be an alternative method to the existing neuropsychological tests.[41] In France, neuropsychological tests have shown benefits from VR and a multi-component approach to assess episodic memory as well as to encourage active encoding of information in patients suffering from mild or severe age-related memory impairment.[42] Interventions based on VR techniques, errorless learning and vanishing-cue indicated that AD patients could relearn some cooking activities and this performance remained stable over time.[43] Similar results were obtained in Japan and France, where a dual-modal VR platform succeed in training everyday cooking activities in patients with AD.[44] In Canada, VR training has proven to be viable, safe and

Table 2 Author level impact indicators.

Dataset	WoS	Scopus	WoS	Scopus	Country	Affiliation
Average productivity	1.23	2138	h-Index			
Most productive authors	Total publications					
Riva, Giuseppe	13	11	47	47	Italy	Universitá Cattolica del Sacro Cuore
Tsolaki, Magda	7	7	47	56	Greece	Aristotle University of Thessaloniki
Yamaguchi, Takehiko	7	5	15	6	Japan	Tokyo University of Science
Nef, Tobias	6	4	18	24	Switzerland	University of Bern
Serino, Silvia	5	4	17	18	Italy	IRCCS Istituto Auxologico Italiano
Tarnanas, Ioannis	5	6	6	8	Switzerland	University of Bern
Blackman, Tim	4	4	21	16	UK	University of Teesside
Morganti, Francesca	4	4	12	13	Italy	Università degli Studi di Bergamo
Ohwada, Hayato	4	4	2	8	Japan	Tokyo University of Science
Martono, Niken Prasasti	4	4	1	1	Japan	Tokyo University of Science
Tzovaras, Dimitros	3	4	21	26	Greece	Center For Research and Technology-Hellas
Polistico, Kevin	3	4	2	4	USA	Bright Cloud International Corp
Burdea, Grigoryc	2	4	10	35	USA	Bright Cloud International Corp
Buckwalter, J. Galen	2	4	21	31	USA	University of Southern California
Pallavicini, Frederica	2	4	13	14	Italy	University of Milano - Bicocca

Source: The authors.

enjoyable for people with dementia, with positive effects on balance and mobility.[45] In Italy, VR has emerged as a potentially effective way of providing general and specialized care services and thus be integrated into conventional psychotherapy.[46] A review that outlines the state of clinical research relevant to the development of virtual environments for use in psychotherapy was presented.[47] A free NeuroVR software platform should be used by no-expert therapists because it provides the possibility to enhance the patient's feeling of familiarity and intimacy with the virtual scene which contributed to increase the realism of the simulated scene.[48] The use of VR applications in the rehabilitation of cognitive processes and memory-related functional skills has been supported by different studies that show procedural memory often remain relatively intact in persons with neurologically-based memory impairment. VR training intervention try to lessen cognitive decline and improve memory functions by enhancing focused attention.[49] In Greece, VR computer-based intervention were used for cognitive stimulating in patients with a wide range of cognitive disorders ranging mild cognitive impairment to AD.[50] VR cognitive training application can detect mild cognitive impairment in persons using the application at home without the help of an examiner.[51] In Spain, a brief review and evaluation of recent and current VR technology for AD applications was presented.[52] In Taiwan, the rehabilitation of memory-related cognitive processes and functional abilities was supported using a VR application.[53] In summary, some research results by countries are showed the relevance of VR in improving the health of patients with dementia. In fact, the researchers found that the use of VR in people with dementia had a precious applicability, fundamentally, as a tool in diagnosis, treatment, cognitive improvement or rehabilitation.

Co-authors'national and international collaboration in WoS and Scopus

Regarding the distribution of co-authorship collaboration (Total, National, International) by country in VR and dementia (see Table 3), the top countries that produced VR and dementia were similar in both platforms: 1st rank UK, 2nd rank United States, 3rd rank France, and 4th rank Switzerland. The USA was at the top of international co-authorship collaborations with 23 publications, while the UK was at the top of national co-authorship collaborations, with 64 publications. The UK emerged as the leading contributor with 80 publications in VR and dementia, followed by USA (73), France (62), and Switzerland (53). All 11 countries that were paired in both databases increase their ranking when they pass from WoS to Scopus, meaning that indexation in Scopus predominates national co-authorship collaboration per document, while international co-authorship collaborations predominated in WoS.

Research themes

The density was highest in all time periods where a group of keywords was dominating. The analysis of keywords and their co-occurrences allowed us to map the intellectual structure of a discipline and the changes in that structure over time.[54] The existence of *betweenness centrality* identified the keywords that are strongly interconnected with other keywords. This provided information on the possible convergence fields of research in VR and dementia. The examination of keywords indicated that 537 author keywords and keywords plus was used from 1998 to 2018. Only 32 (= 5.96%) of keywords were used more than three times,

Table 3 Co-authorship country collaboration.

Country	National collaboration			International collaboration			Total
	WoS (rank)	Scopus (rank)	TP	WoS (rank)	Scopus (rank)	TP	Publications
USA	20 (3°)	30 (1°)	50	12 (1°)	11 (1°)	23	73
France	44 (1°)	7 (7°)	51	7 (2°)	4 (5°)	11	62
UK	34 (2°)	30 (1°)	64	7 (2°)	9 (2°)	16	80
Switzerland	19 (4°)	20 (3°)	39	7 (2°)	7 (3°)	14	53
Germany	12 (7°)	16 (5°)	28	6 (3°)	9 (2°)	15	43
Australia	6 (11°)	3 (9°)	9	5 (4°)	1 (8°)	6	15
Greece	20 (3°)	13 (6°)	33	4 (5°)	6 (4°)	10	43
P.R. China	16 (5°)	1 (11°)	17	4 (5°)	1 (8°)	5	22
Japan	10 (8°)	13 (6°)	23	4 (5°)	3 (6°)	7	30
Brazil	14 (6°)	0 (12°)	14	3 (6°)	0 (9°)	3	17
Spain	8 (9°)	4 (8°)	12	3 (6°)	3 (6°)	6	18
Netherlands	8 (9°)	1 (11°)	9	3 (6°)	1 (8°)	4	13
Canada	3 (13°)	19 (4°)	22	3 (6°)	7 (3°)	10	32
Italy	7 (10°)	28 (2°)	35	2 (7°)	6 (4°)	8	43
Hungary	5 (12°)	0 (12°)	5	2 (7°)	0 (9°)	2	7
Portugal	2 (14°)	0 (12°)	2	2 (7°)	0 (9°)	2	4
Sweden	0 (15°)	2 (10°)	2	0 (8°)	2 (7°)	2	4
Israel	0 (15°)	4 (8°)	4	0 (8°)	2 (7°)	2	6

Source: The authors.
National collaboration = co-authors from the same country; International collaboration = co-authors from different countries; TP = Total publications from WoS and Scopus.

suggesting that mainstream research on VR and dementia focused on a small area. Through the analysis of the top 31 most frequently used keywords, we can draw the research trends. Most of the research was related to the following topics: AD, memory, cognitive rehabilitation, aging, brain injury, virtual environment, psychomotor performance, cognition disorder, randomized controlled trials, transcranial magnetic stimulation, stroke, quality of life, Parkinson disease, exercise, health, therapy and early diagnosis. Changes in research are found throughout the entire period. Between 1998 and 2002 AD and brain injury were the main topics. We observed that AD maintained the highest rank in the first and the last period, while brain injury although increasing in frequency over the period, showed a decrease in its importance, passing from 10 (2nd rank in first period) to 12 (10th rank in the last period). Between 2003 and 2007 the following new topics emerge: memory being relevant in all time periods, with a rank between 1 and 4 in all periods; cognitive rehabilitation (2nd rank) recovering its relevance only in the last period (3rd rank); and the following new topics are characterized by a decrease in frequency and importance through time: virtual environment, episodic memory, stroke, health, therapy, fmri, depression, executive function and system. Motor image only appears in this period. Between 2008 and 2012 the following new topics emerge: aging, performance, cognition disorder, randomized controlled trial, quality of life, Parkinson disease, diagnosis, hippocampus, intervention. Ecological validity and disorientation only appear in investigations during this period of time. Finally, between 2013 and 2018 the main topics of research, ranked in the first ten positions were keywords applied in previous periods: Alzheimer's disease, rehabilitation, memory, aging, performance, cognition disorder, exercise, randomized controlled trial, episodic memory, and brain injury. The new topics that only appear in the last period are: meta-analysis and attention.

The most cited authors in WoS and Scopus

The article with the highest strength of citation bursts (7.8597) and sigma scores (1.74) of all the co-citation network was Weniger et al.[55] being a relevant mark in VR and dementia research, with a citation burst between 2012 until 2017. There was a gap of just 1 year between its publication and subsequent citation burst. This article focused on the advantage of VR environments for the assessment of spatial navigation, and memory deficits and memory formation for person with mild cognitive impairment. Plancher et al.[42] and Zakzanis et al.[56] were the following articles with the highest citation burst before 2017. Zakzanis et al.,[56] focused on the potential applications of VR in neuropsychology as a validation tool to the study of spatial navigation. All the following articles had citations burst near 2018. Zygouris et al.[57] focused on the VR applications in assessing cognitive functions for the diagnosis of amnestic mild cognitive impairment. Tarnanas et al.,[58] focused on using VR measures of functional ability to diagnosis functional impairment using a randomized control trial. Plancher et al.[59] focused on virtual environments which could provide helpful standard tools for assessing age effects on the main aspects of episodic memory. Serino et al.[60] focus on VR for assessing the amnestic impairment of AD patients and for patients suffering from amnestic mild cognitive impairment disease, using a randomized control trial. Coyle et al.[61] focused on VR for a long-term improvement of cognition for those patients that are at high risk of cognitive decline. Man et al.[62] focused on

Table 4 Top articles with citation burst and sigma counts.

References	Publication year	Sigma	Citation burst				Years to burst
			Strength	Begin	End	Duration (1998–2018)	
1. Weniger G., Ruhleder M., Lange C., Wolf S., Irle E.	2011	1.74	7.8597	**2012**	2017		1
2. Plancher G., Tirard A., Gyselinck V., Nicolas S., Piolino P.	2012	1.28	5.9857	**2015**	2017		3
3. Zakzanis K.K., Quintin G., Graham S.J., Mraz R.	2009	1.00	3.5311	**2016**	2017		7
4. Tarnanas I., Mouzakidis C., Schlee W.	2013	1.00	2.9900	**2015**	2018		2
5. Serino S., Morganti F., Di Stefano F., Riva G.	2015	1.00	2.6883	**2015**	2018		0
6. Coyle H., Traynor V., Solowij N.	2015	1.00	2.5176	**2017**	2018		2
7. Plancher G., Gyselinck V., Nicolas S., Piolino P.	2010	1.00	2.3871	**2015**	2018		5
8. Zygouris S., Giakoumis D., Votis K., Doumpoulakis S., Ntovas K., Segkouli S., Karagiannidis C., Tzovaras D., Tsolaki M.	2015	1.00	2.0958	**2017**	2018		2
9. Man D.W.K., Chung J.C.C., Lee G.Y.Y.	2012	1.00	1.0872	**2015**	2018		3

Source: The authors.

using VR to be used as an early intervention for older adults who are at risk of progressing to dementia. All these top articles included research using keywords with high citation burst like: *memory, AD, randomized control trials, memory, virtual environments* (Table 4).

The most cited papers in WoS and Scopus

The most cited papers give a historical perspective on scientific progress and reveal recognition of scientific advancement.[31] The most cited papers were Anderson-Hanley et al.[63] and Rizzo et al.[64] (see Table 5). They represented the pillars of VR and dementia research. Anderson-Hanley et al.[63] had shown that older people cyber cyclists had achieved better cognitive function than traditional practitioners, suggesting that simultaneous cognitive and physical exercise has greater potential to prevent cognitive decline. Rizzo et al.[64] developed a VR system for the assessment and rehabilitation of attention deficits in patient populations with central nervous system dysfunction. The most cited articles included some of the citation burst terms noted before, namely: *cognitive decline, attention deficits, episodic memory, cognitive rehabilitation* and *Alzheimer's disease*.

Discussion

The objective was to make a bibliometric analysis to reflect on VR and dementia research from 1998 until 2018, identifying its intellectual structure and emerging trends. We answer the research questions:

What is the overlap, uniqueness and coverage between WoS and Scopus? – The exploration of the literature on VR and dementia from WoS and Scopus databases has outlined the evolutionary trajectory of the collective knowledge over the past twenty one years and highlighted the areas of active pursuit. Based on the network visualization and document co-citation and co-author analysis through CiteSpace, this research evaluated emerging trends and patterns of publications, citations, authors, journals, institutions, countries and keywords.

By visualizing the relational analysis of top authors and articles, the study provided insides into patterns of international research focus. The clustering technique used in this work identifies key articles that share similar topics. Papers that served as an important bridge between two clusters were also detected in the network, namely Riva et al.[65] and Weniger et al.[55]

A longitudinal view of cluster analysis and citation bursts of key articles adds a new dimension to the analysis and provides insights into the flow of major trends and collaborations. These temporal data allow researchers to identify research frontiers by highlighting emergent hot topics, authors, and articles.[20]

How the research work has grown over time in WoS and Scopus in publications and citations? – This research focused on a bibliometric analysis using issues-controlled databases and peer-reviewed journals in WoS and Scopus, characterized by their accuracy for comprehensive systematic reviews in medical sciences.[16,66] WoS and Scopus are the

Table 5 Top articles with more citations and centrality counts.

Citations	Centrality	First author	Year	Source	Co-authors
187	0.13	Anderson-Hanley C. et al.	2012	*American Journal of Preventive Medicine*	11
137	0.10	Rizzo A.A. et al.	2000	*Cyberpsychology and Behavior*	10
97	0.14	Plancher G. et al.	2012	*Neuropsychologia*	5
85	0.27	Weniger G. et al.	2011	*Neuropsychologia*	5
70	0.10	Blackman T. et al.	2003	*Disability and Society*	7
66	0.10	Hill N.T.M. et al.	2017	*American Journal of Psychiatry*	6
66	0.21	Plancher G. et al.	2010	*Neuropsychology*	4
54	0.10	Klinger E. et al.	2006	*Cyberpsychology and Behavior*	4
53	0.28	Riva G. et al.	2006	*Behavior Research Methods*	3
52	0.05	Coyle H. et al.	2015	*American Journal of Geriatric Psychiatry*	3
50	0.13	Tarnanas I. et al.	2013	*Journal of Medical Internet Research*	6
47	0.09	Burgess N. et al.	2006	*Reviews in the Neurosciences*	5
45	0.05	Harris M.A. et al.	2012	*Hippocampus*	2
43	0.08	Flynn D. et al.	2003	*Cyberpsychology and Behavior*	6
40	0.24	Bellassen V. et al.	2012	*Journal of Neuroscience*	5
35	0.10	Cherniack E.P.	2011	*Disability and Rehabilitation: Assistive Technology*	1
35	0.09	Man D.W.K. et al.	2012	*International Journal of Geriatric Psychiatry*	3
35	0.21	Zakzanis K.K. et al.	2009	*Medical Science Monitor*	4
32	0.06	Turner W.A. et al.	2014	*Clinical Psychology Review*	2
31	0.22	Morganti F. et al.	2013	*Cognitive Neuroscience*	3

Source: The authors.

databases used most often in bibliometric studies because they include scientific literature of greater international impact,[67] while other national databases play a more peripheral role in communicating the scientific literature.

Comparing the rate of growth of publications and citations on VR and dementia for each of the years since 1998 to 2018, the relative growth rate of publications is 28.1% per year in WoS and 28.7% per year in Scopus. The number of research publications was doubling in 4.444 years in WoS and 4.179 years in Scopus.

There is a steady increase in the number of publications of scientific research since 1998 until 2018. The publications had a high degree of collaboration among the authors, which is an indicator of the scientific strength and vitality of VR and dementia. Collaborations between co-authors can improve results both in quantity and quality, elements that are indispensable for the development of any field of research.

The progressive increase in the number of the scientific papers overall 21-year period studied is likely to combine the effects of a number of factors: (a) the aging of the population, (b) the risk of dementia grows exponentially with age; (c) an increase in the global prevalence of dementia; (d) an increase in the awareness of dementia as a serious public health problem; and (e) other factors that may influence the augmentation of scientific activity regardless of the scientific discipline.

What co-citation and co-authorship patterns are observed in WoS and Scopus? – Co-citation analysis and co-authorship are useful methods to provide insights into a field based on a large sample of documents. Multiple metrics helped to understand and explore relationships between documents and citations. Betweenness centrality and sigma can reflect the potential pivotal point and new ideas on the VR and dementia field while density, modularity and burst strength provide a more objective metric analysis of network.

The research brings the understanding regarding the way knowledge is structured in the field of VR as an instrument of diagnosis and intervention in dementia. This paper is in line with the review published studies on dementia and VR as the published by D'Cunha and colleagues10 found that the use of VR technology for people living with dementia was a novel and emerging method may which provide cognitive stimulation and improve well-being.

What are the most productive authors and institutions in WoS and Scopus? What is the amount of co-authors'national and international collaboration in WoS and Scopus? In which countries most of the work has been done in WoS and Scopus? – In terms of authors, the leader in VR and dementia publications is Riva G. from University Catholica del Sacro Cuore in Italy, followed by Tsolaki M., from Aristotle University of Thessalonic located in Greence, and by Yamaguchi T. from Tokyo University of Science located in Japan. USA and UK are the countries with the highest number of co-authorship international collaborations, while France and UK are leaders in co-authorship national collaboration.

What are the top publication journals of research in WoS and Scopus? – The network of journals showed a core-peripheral structure where the *Journal of Alzheimer Disease* is ranked first, followed by the journal *Cyberpsychology and Bevaviour*. Mainly after 2007 with a great decrease in journals' network density, new journals appeared publisihing VR and dementia research.

Who are the most cited authors in WoS and Scopus? – Anderson-Hanley et al.[63] and Rizzo et al.[64] had the highest number of citations. We think that what has changed the research on VR and dementia was undoubtedly the studies presented by that Weniger et al.[55] and Plancher et al.[42] that heralded new ideas. Tarnanas et al.,[58] Serino et al.,[60] Coyle

et al.,[61] Plancher et al.,[59] Zygouris et al.[56] and Man et al.[62] were the article that have a significant increase in the number of citation near 2018, being a reference to the current research in VR and dementia. The investigation of the more cited, central and citations burst articles has allowed for the mapping of the intellectual structure of this field. The results showed the relevance of VR in improving the health of patients with dementia and they found that the use of VR in people with dementia had a precious applicability, fundamentally, as a tool in diagnosis, treatment, cognitive improvement, or rehabilitation.

The study had natural limitations. We have focused on journals, excluding works published elsewhere, like in books and in conference papers. This work was restricted to the English language journals. Also, despite the relevance of WoS and Scopus databases, other important studies could be included into other databases.

Conclusion

The bibliometric study carried out during the period 1998–2018 has allowed gathering a number of conclusions in line with the objective of this article. The top clusters covered a range of interests, reflecting the interdisciplinary nature of VR and dementia. The evolution of keywords over the 21 years allowed us to see which were the most common and which new keywords are coming in various time periods. This dynamic allows us to use them as mapping the frontiers of research in VR and dementia. Therefore, despite its slow introduction of new topics, this field of study is becoming more multidisciplinary, being progressively analyzed from the new angles provided by the different scientific approaches that complement and enrich its content. Our findings can provide useful insights to better understand the research themes, their changes and trends over time and opportunities for future research. Especially, this research may make contribution to enlarge research method in that our study go beyond popular bibliometric analysis, by using co-citation and co-occurrence network analysis.

Ethical considerations

Review article. This work does not involve the use of humans.

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Conflict of interest

The authors have no conflict of interest to declare.

References

1. Alzheimer's Association. 2019 Alzheimer's disease facts and figures. Alzheimers Dement. 2019;15:321–87.
2. Berr C, Wancata J, Ritchie K. Prevalence of dementia in elderly in Europe. Eur Neuropsychopharmacol. 2005;15:463–71, http://dx.doi.org/10.1016/j.euroneuro.2005.04.003.
3. Cummings JL. Alzheimer's Disease. N Engl J Med. 2004;351:56–67, http://dx.doi.org/10.1056/NEJMra040223.
4. Lanctôt KL, Amatniek J, Ancoli-Israel S, Arnold SE, Ballard C, Cohen-Mansfield J, et al. Neuropsychiatric signs and symptoms of Alzheimer's disease: new treatment paradigms. Alzheimer's Dement: Transl Res Clin Interv. 2017;3:440–9, http://dx.doi.org/10.1016/j.trci.2017.07.001.
5. Lyketsos CG, Carrillo MC, Ryan JM, Khachaturian AS, Trzepacz P, Amatniek J, et al. Alzheimer's Dement. 2011;7:532–9, http://dx.doi.org/10.1016/j.jalz.2011.05.2410.
6. Garcia L, Kartolo A, Methot-Curtis E. A discussion of the use of virtual reality in dementia. Virtual reality in psychological, medical and pedagogical applications, Christiane Eichenberg. IntechOpen; 2012, http://dx.doi.org/10.5772/46412. Available from: https://www.intechopen.com/books/virtual-reality-in-psychological-medical-and-pedagogical-applications/a-discussion-of-the-use-of-virtual-reality-in-dementia
7. Barnes S. Understanding virtual reality in marketing: nature, implications and potential; 2016. Available from SSRN: https://ssrn.com/abstract=2909100
8. Christou C. Virtual reality in education. In: Tzanavari A, Tsapatsoulis N, editors. Affective, interactive and cognitive methods for e-learning design: creating an optimal education experience, Edition: 1, Chapter: 12. IGI Global; 2010. p. 228–43, http://dx.doi.org/10.4018/978-1-60566-940-3.ch012.
9. Hayhurst J. How augmented reality and virtual reality is being used to support people living with dementia – design challenges and future directions. In: Augmented reality and virtual reality. Project: use of AR, game engine and IoT to help dementia patients; 2018, http://dx.doi.org/10.1007/978-3-319-64027-3_20.
10. D'Cunha NM, Nguyen D, Naumovski N, McKune A, Kellett J, Georgousopoulou EN, et al. A Mini-Review of vitual reality-based interventions to promove well-being for people living with dementia and mild cognitive impairment. Gerontology. 2019;65:430–40, http://dx.doi.org/10.1159/000500040.
11. Diaz-Perez E, Florez-Lozano J. Realidad virtual y demencia. Rev Neurol. 2018;66:344–52.
12. Imbeault H, Bier N, Pigot H, Gagnon L, Marcotte N, Fulop T, et al. Electronic organiser and Alzheimer's disease: fact or fiction? Neuropsychol Rehabil. 2014;24:71–100, http://dx.doi.org/10.1080/09602011.2013.858641.
13. Hoey J, Poupart P, von Bertoldi A, Craig T, Boutilier C, Mihailidis A. Automated handwashing assistance for persons with dementia using video and a partially observable markov decision process. Comput Vis Image Understand. 2010;114:503–19, http://dx.doi.org/10.1016/j.cviu.2009.06.008.
14. Swaney R. Virtual reality delivers real-world benefits to dementia patients. Aging in place; 2018. https://insights.samsung.com/2018/03/13/virtual-reality-delivers-real-world-benefits-to-dementia-patients/
15. Van Raan AFJ. Sleeping beauties in science. Scientometrics. 2004;59:467–72.
16. Asghar I, Cang S, Yu H. Assistive technology for people with dementia: an overview and bibliometric study. Health Libr Group Health Inf Libr J. 2017;34:5–19, http://dx.doi.org/10.1111/hir.12173.
17. Denyer D, Tranfield D. Using qualitative research synthesis to build an actionable knowledge base. Manag Decis. 2006;44:213–27, http://dx.doi.org/10.1108/00251740610650201.
18. Speel PH, Shadbolt N, De Vries W, Van Dam PH, O'hara K. Knowledge Mapping for industrial purpose. 1999.

19. Chen C, Ibekwe-SanJuan F, Hou J. The structure and dynamics of co-citation clusters: a multiple-perspective co-citation analysis. J Am Soc Inf Sci Technol. 2010;61:1386–409, http://dx.doi.org/10.1002/asi.21309.
20. Chen C, Dubin R, Kim MC. Emerging trends and new developments in regenerative medicine: a scientometric update (2000–2014). Expert Opin Biol Therapy. 2014;14:1295–317, http://dx.doi.org/10.1517/14712598.2014.920813.
21. Sorensen AA. Alzheimer's disease research: scientific productivity and impact of the top 100 investigators in the field. J Alzheimer's Dis. 2009;16:451–65, http://dx.doi.org/10.3233/JAD-2009-1046.
22. Pestana MH, Sobral MR. Alzheimer's disease research: a network science approach. Int J Multivar Data Anal. 2018;1:201–17, http://dx.doi.org/10.1504/IJMDA.2018.091838.
23. Pestana MH, Sobral M. Cognitive reserve and dementia: a scientometric review. Dement Neuropsychol. 2019;13:1–10, http://dx.doi.org/10.1590/1980-57642018dn13-010001.
24. Ye Q, Li T, Law R. A coauthorship network analysis of tourism and hospitality research collaboration. J Hosp Tour Res. 2013;37:51–76.
25. Fu HZ, Wang MH, Ho YS. The most frequently cited adsorption research articles in the Science Citation Index (Expanded). J Colloid Interface Sci. 2012;379:148–56, http://dx.doi.org/10.1016/j.jcis.2012.04.051.
26. Guz AN, Rushchitsky JJ. Scopus: a system for the evaluation of scientific journals. Int Appl Mech. 2009;45:351–62, http://dx.doi.org/10.1007/s10778-009-0189-4.
27. Lewis BR, Templeton GF, Luo X. A scientrometric investigation into the validity of IS journal quality measures. J Assoc Inf Syst. 2007;8:619–33.
28. Bajwa R, Yaldram K, Hussain S, Ahmed T. Nanotechnology research among some leading OIC member states. J Nanopart Res. 2012;14:1–10.
29. Pulgarin A, Escalona MA. Medida del solapamiento en três bases de dados com información sobre Ingeniería. An Doc. 2007;10:335–44.
30. Costas R, Moreno L, Bordons M. Solapamiento y singularidad de MEDLINE, WoS e IME para el análisis de la actividad científica en una región en Ciencias de la Salud. Rev Esp Doc Cient. 2008;31:327–43.
31. Chen C. Citespace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. J Am Soc Inf Sci Technol. 2006;57:359–97.
32. Tseng Y-H, Lin Y-I, Lee Y-Y, et al. A comparison of methods for detecting hot topics. Scientometrics. 2009;81:73–90.
33. Evren S, Kozak N. Bibliometric analysis of tourism and hospitality related articles published in Turkey. Anatolia. 2014;25:61–80.
34. Jiang Y, Ritchie BW, Benckendorff P. Bibliometric visualisation: an application in tourism crisis and disaster management research. Curr Issues Tour. 2017:1–33, http://dx.doi.org/10.1080/13683500.2017.1408574.
35. Wang LH, Wang QH, Zhang X, et al. A bibliometric analysis of anaerobic digestion for methane research during the period 1994-2011. J Mater Cycles Waste Manag. 2013;15:1–8, http://dx.doi.org/10.1007/s10163-012-0094-5.
36. Wuchty S, Jones BF, Uzzi B. The increasing dominance of teams in production of knowledge. Science. 2007;316:1036–9, http://dx.doi.org/10.1126/science.1136099 PMID:17431139.
37. Rizzo AA, Buckwalter JG, McGee JS, Bowerly T, der Zaag C, Neumann U, et al. Presence: Teleoper Virtual Environ. 2001;10:359–74, http://dx.doi.org/10.1162/1054746011470226.
38. Rizzo A, Kim GJ. ASWOT analysis of the field of virtual reality rehabilitation and therapy. Presence (Camb). 2005;14:119–46, http://dx.doi.org/10.1162/1054746053967094.
39. Montenegro JMF, Argyriou V. Cognitive evaluation for the diagnosis of Alzheimer's disease based on Turing test and virtual environments. Physiol Behav. 2017;173:42–51, http://dx.doi.org/10.1016/j.physbeh.2017.01.034.
40. Ijaz K, Wang Y, Milne D, Calvo RA. VR-rides: interactive VR games for health. In: Marsh T, Ma M, Oliveira M, Baalsrud Hauge J, Göbel S, editors. JCSG 2016. Lecture notes in computer science, vol. 9894. Cham: Springer; 2016., http://dx.doi.org/10.1007/978-3-319-45841-0_33.
41. Lesk VE, Wan Shamsuddin SN, Walters ER, Ugail H. Using a virtual environment to assess cognition in the elderly. Virtual Real. 2014;18:271–9, http://dx.doi.org/10.1007/s10055-014-0252-2.
42. Plancher G, Tirard A, Gyselinck V, et al. Using virtual reality to characterize episodic memory profiles in amnestic mild cognitive impairment and Alzheimer's disease: Influence of active and passive encoding. Neuropsychologia. 2012;50:592–602, http://dx.doi.org/10.1016/j.neuropsychologia.2011.12.013.
43. Foloppe DA, Richard P, Yamaguchi T, Etcharry-Bouyx F, Allain P. The potential of virtual reality-based training to enhance the functional autonomy of Alzheimer's disease patients in cooking activities: a single case study. Neuropsychol Rehabil. 2018;28:709–33, http://dx.doi.org/10.1080/09602011.2015.1094394.
44. Yamaguchi T, Foloppe DA, Richard P, Richard E, Allain P. A dual-modal virtual reality kitchen for (re)learning of everyday cooking activities in Alzheimer's disease. Presence: Teleoper Virtual Environ. 2012;21:43–57, http://dx.doi.org/10.1162/PRES_a_00080.
45. McEwen D, Taillon-Hobson A, Bilodeau M, Sveistrup H, Finestone H. Two-week virtual reality training for dementia: single case feasibility study. J Rehabil Res Dev. 2014;51:1069–76, http://dx.doi.org/10.1682/JRRD.2013.10.0231.
46. Riva G, editor. Virtual reality in neuro-psychophysiology: cognitive, clinical and methodological issue in assessment and rehabilitation. Amsterdam: IOS Press; 1997. Available from: http://www.cybertherapy.info/pages/book1.htm
47. Riva G. Virtual reality in psychotherapy: review. CyberPsychol Behav. 2005;8:220–30, http://dx.doi.org/10.1089/cpb.2005.8.220.
48. Riva G, Carelli L, Gaggioli A, Gorini A, Vigna C, Corsi R, et al. Neuro VR 1.5 – a free virtual reality platform for the assessment and treatment in clinical psychology and neuroscience. Stud Health Technol Inform. 2009;142:268–70, http://dx.doi.org/10.3233/978-1-58603-964-6-268.
49. Optale G, Capodieci S, Pinelli P, Zara D, Gamberini L, Riva G. Music-enhanced immersive virtual reality in the rehabilitation of memory-related cognitive processes and functional abilities: a case report. Presence: Teleoper Virtual Environ. 2001;10:450–62, http://dx.doi.org/10.1162/1054746011470217.
50. Tarnanas I, Tsolakis A, Tsolaki M. Assessing virtual reality environments as cognitive stimulation method for patients with MCI. In: Brahnam S, Jain LC, editors. Technologies of inclusive well-being: serious games, alternative realities, and pay therapy. Anthony Lewis Brooks, vol. 536. Springer; 2014. p. 39–74, http://dx.doi.org/10.1007/978-3-642-45432-5.
51. Zygouris S, Ntovas K, Giakoumis D, Votis K, Doumpoulakis S, Segkouli S, et al. A preliminary study on the feasibility of using a virtual reality cognitive training application for remote detection of mild cognitive impairment. J Alzheimer's Dis. 2016;56:1–9, http://dx.doi.org/10.3233/JAD-160518.

52. García-Betances RI, Waldmeyer MTA, Fico G, Cabrera-Umpiérrez MF. A succinct overview of virtual reality technology use in Alzheimer's disease. Front Aging Neurosci. 2015;7:80, http://dx.doi.org/10.3389/fnagi.2015.00080.
53. Jiang C-F, Chen D-K, Sung W-H. Development of a neurocognitive remediation system by virtual reality. In: Annual international conference of the IEEE engineering in medicine and biology society. IEEE engineering in medicine and biology society. Conference. 2005. p. 2559–62, http://dx.doi.org/10.1109/IEMBS.2005.1616991.
54. Ding Y, Chowdhury GG, Foo S. Bibliometric cartography of information retrieval research by using co-word analysis. Inf Process Manag. 2001;37:817–42.
55. Weniger G, Ruhleder M, Lange C, et al. Egocentric and allocentric memory as assessed by virtual reality in individuals with amnestic mild cognitive impairment. Neuropsychologia. 2011;49:518–27.
56. Zakzanis K, Quintin G, Graham S, Mraz R. Age and dementia related differences in spatial navigation within an immersive virtual environment. Med Sci Monit. 2009;15: CR140–50.
57. Zygouris S, Giakoumis D, Votis K, et al. Can a virtual reality cognitive training application fulfill a dual role? Using the virtual supermarket cognitive training application as a screening tool for mild cognitive impairment. J Alzheimer's Dis. 2015;44:1333–47, http://dx.doi.org/10.3233/JAD-141260.
58. Tarnanas I, Schlee W, Tsolaki M, et al. Ecological validity of virtual reality daily living activities screening for early dementia: longitudinal study. JMIR Serious Games. 2013;1:e1, http://dx.doi.org/10.2196/games.2778.
59. Plancher G, Gyselinck V, Nicolas S, Piolino P. Age effect on components of episodic memory and feature binding: a virtual reality study. Neuropsychology. 2010;24:379–90, http://dx.doi.org/10.1037/a0018680.
60. Serino S, Morganti F, Cipresso P, Magni EER, Riva G. The potentiality of virtual reality for the evaluation of spatial abilities: the mental spatial reference frame test. Recent Adv Using Virtual Real Technol Rehabil. 2015:103–9.
61. Coyle H, Traynor V, Solowij N. Computerized and virtual reality cognitive training for individuals at high risk of cognitive decline: systematic review of the literature. Am J Geriatr Psychiatry. 2015;23:335–59, http://dx.doi.org/10.1016/j.jagp.2014.04.009.
62. Man DW, Chung JC, Lee GY. Evaluation of a virtual reality-based memory training programme for Hong Kong Chinese older adults with questionable dementia: a pilot study. Int J Geriatr Psychiatry. 2012;27:513–20, http://dx.doi.org/10.1002/gps.2746.
63. Anderson-Hanley C, Arciero PJ, Brickman AM, et al. Exergaming and older adult cognition. Am J Prev Med. 2012;42:109–19, http://dx.doi.org/10.1016/j.amepre.2011.10.016.
64. Rizzo AA, Buckwalter JG, Bowerly T, et al. The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits. CyberPsychol Behav. 2000;3, http://dx.doi.org/10.1089/10949310050078940.
65. Riva G, Castelnuovo G, Mantovani F. Transformation of flow in rehabilitation: the role of advanced communication technologies. Behav Res Methods. 2006;38:237–44, http://dx.doi.org/10.3758/BF03192775.
66. Rew D. SCOPUS: another step towards seamless integration of the world's medical literature. Eur J Surg Oncol (EJSO). 2010;36:2–3, http://dx.doi.org/10.1016/j.ejso.2009.08.001.
67. Bartol T, Budimir G, Dekleva-Smrekar D, Pusnik M, Juznic P. Assessment of research fields in Scopus and Web of Science in the view of national research evaluation in Slovenia. Scientometrics. 2014;98:1491–504, http://dx.doi.org/10.1007/s11192-013-1148-8.