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Working memory and creativity: A bibliometric analysis using VOSviewer

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To provide researchers with a systematic reference on initial contact with working memory and creativity, we elucidated an essential bibliometric analysis of publications based on the Web of Science database. Results were as follows: (a) Related research started in 2003 and entered a period of rapid development since 2013, with more than 20 articles published annually; (b) Roger E. Beaty and Benedek Mathias had the most publications, while Ryuta Kawashima, Hikaru Takeuchi, and Yasuyuki Taki had the most extensive cooperation with others; (c) only 9 out of 527 organizations had formed locally finite cooperative networks; and (d) eight major research popular topics were identified: creativity, cognition, memory, working memory, performance, fMRI, cognitive control, and brain. Enhancing the study of the neural mechanisms of working memory and creativity through fMRI or functional connectivity is of great significance so that we can understand how brain regions interact not only with brain regions that are directly connected structurally but also with those that are not structurally connected.

Keywords
working memory, creativity, bibliometric analysis, VOSviewer

Article Highlights

- This is the first bibliometric analysis to explore the literature on working memory and creativity using VOSviewer based on the Web of Science database.
- We elucidated the cooperative network of authors, organizations, and countries.
- Creativity, cognition, memory, working memory, performance, fMRI, cognitive control, and brain were found to be popular research topics.

Creativity is generally defined as the ability to produce novel and useful responses (Runco & Jaeger, 2012). Creative thinking, which is the core of creativity, can be divided into divergent and convergent types (Guilford, 1957). *Divergent thinking* (DT) refers to the ability to seek diversity in answers, whereas *convergent thinking* (CT) refers to the ability to seek uniqueness. Simultaneously, creativity allows us to respond effectively to challenges in life. To explore an effective way of improving creativity, researchers have discussed the association between executive functions and creative thinking, especially for working memory (Nusbaum & Silvia, 2011).

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Working memory (WM) refers to a memory system with limited temporary storage and information processing capacity (Baddeley, 1992). Previous researchers have explored the correlations between WM and DT and CT (Cropley, 2006), and the link between WM and creative thinking pertaining to most tasks involving these (Zhao et al., 2021). Functional magnetic resonance imaging (fMRI) researchers have consistently found that the prefrontal cortex might be the overlapping neural mechanism for creative thinking and WM (Chrysikou, 2019; Vartanian et al., 2013). Furthermore, diffusion tensor imaging studies have found WM has a parietal lobe white matter microstructure similar to that of creative thinking (Takeuchi et al., 2010).

However, the volume of research on WM and creativity may be overwhelming for researchers who are initially entering this field. In addition, research on visualization of this topic is lacking. *Bibliometrics* uses quantitative methods combined with various techniques from scientific mapping, information visualization, and text mining to study the evolution of this field of study (Broadus, 1987). It can assess studies' quality, analyze the key areas of research, and predict the direction of future studies by analyzing publication data, such as author and keywords (Li & Yan, 2018). The literature on WM and creativity provides rich data resources for bibliometric research. Therefore, to provide a reference for those initially entering this field of research, in this study we explored the literature on WM and creativity using bibliometric analysis

Method

We used data in the relevant literature from the Web of Science (WOS) core collection (https://www.webofscience.com, accessed on April 1, 2022). Prerequisites for the search were as follows: (TS = "working memory" and "creative") or (TS = "working memory" and "creative thinking") or (TS = "working memory" and "convergent thinking") or (TS = "working memory" and "divergent thinking"), where TS is the topic, time spans are unlimited, the language is unlimited, and the literature type is journal articles. We retrieved 305 literature records and exported their full texts and cited references as a plain text file to form the data for the VOSviewer. Data included author(s), title, journal, abstract, keywords, cited references, citation count, year of publication, language, organization, country, and document type.

VOSviewer (version 1.6.18) is a text-mining software tool for constructing and visualizing bibliometric networks. It was created by van Eck and Waltman (2010). SCImago graphica (version 1.0.17) is a new tool for exploration and visual communication of data that allows us to create artistic and complex visualizations without programming. Two standard weight attributes are applied: *link strength attribute* and *total link strength attribute*. Nodes of VOSviewer represent information such as authors, organizations, countries, and keywords in the network map. The larger the node, the higher the frequency of research, and the curved lines between nodes represent cooperative and co-occurrence relationships.

Results

VOSviewer Analyses

Number of Article Publications

The number of articles published annually is one of the criteria to judge the progress of field-related research. In Figure 1, the blue line represents the number of articles published associating WM and creativity per year: More than 20 articles have been published per year since 2013, and the number of published articles peaked at 36 in both 2018 and 2020. Moreover, the red dotted line represents the trend chart of the number of published articles; results show that the number of topic-related article publications should continue to grow.

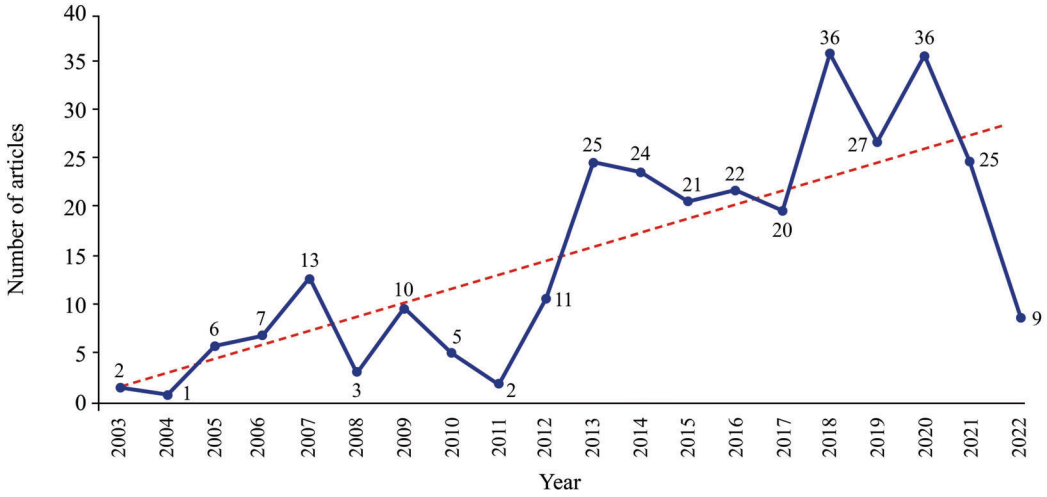
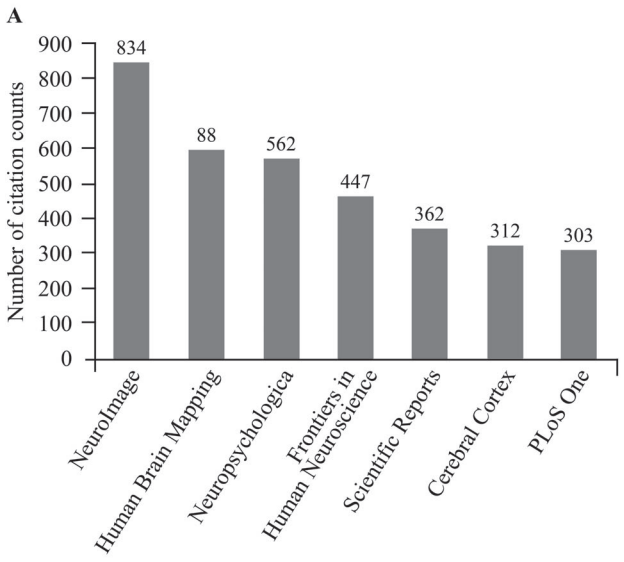


Figure 1. *Trend Graph of Research on Working Memory and Creativity*

Highly Cited Journals

Core journals can provide readers with accurate and highly targeted literature. There are 151 journals that have published research in the field. The largest set of connected items consists of seven journals connected by citations: *NeuroImage*, *Frontiers in Human Neuroscience*, *Neuropsychologia*, *PLoS One*, *Human Brain Mapping*, *Cerebral Cortex*, and *Scientific Reports*. This shows that almost all journals cover the field of neuroscience. The mean citation count of the top seven journals with the most-cited articles in the field is 486 (range = 303–834). The highest-ranking journal is *NeuroImage*, with 20 publications and an impact factor (IF) of 6.556 (Q1, i.e., the top 25% by subject category). The most-cited journal is also *NeuroImage*, with 834 citation counts (see Figures 2A and 2B). In total, 76 papers published in the top seven active journals accounted for only 2.49% (76/305) of all the data (see Figure 2B).



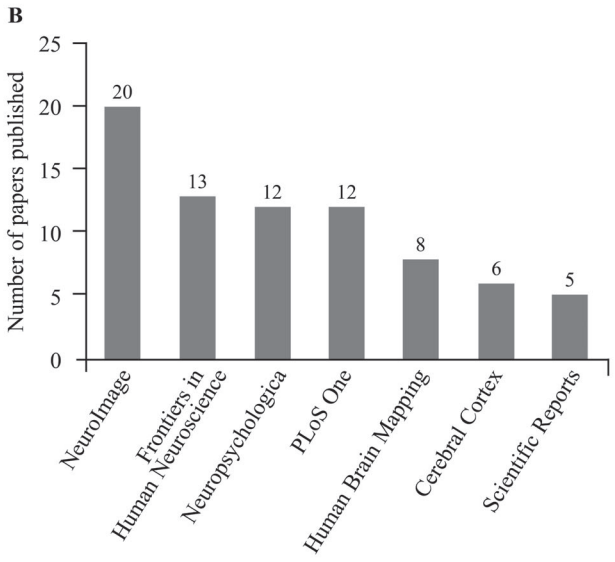


Figure 2A. *Top Seven Journals With the Most-Cited Articles*
Figure 2B. *Top Seven Journals That Have Published the Most Articles*

Coauthorship

The cooperation of authors is conducive to the rapid development of related fields (Du et al., 2012). The nodes in Figure 3 represent authors. There were three major clusters devoted to studying WM and creativity shown in the network visualization map of VOSviewer. Of the 1,294 authors, 24 met the threshold of having published at least five articles. Cluster 1 has 13 authors, which is the largest cooperative author team, and is centered on the three authors: Ryuta Kawashima, Hikaru Takeuchi, and Yasuyuki Taki. Cluster 2 includes six authors centered on Jiang Qiu. Finally, Cluster 3 consists of five authors centered on Roger E. Beaty.

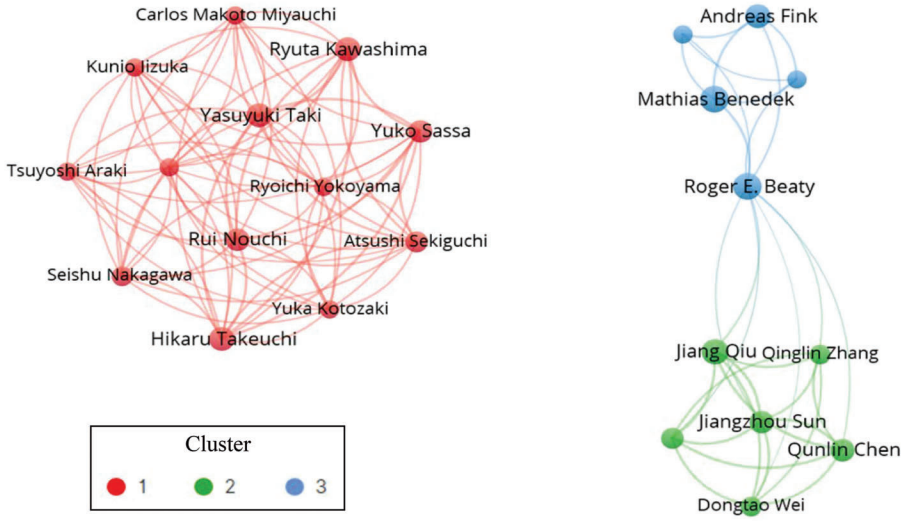


Figure 3. *Cooperative Authors Network Visualization Map*

Link strength is the number of links of one author/organization with another, as measured by co-occurrence. The minimum number of published articles in this field, which is the standard for judging a core author, was calculated by the formula of $m = 0.749 \times \sqrt{n_{max}} = 2.484$ (where m = minimum number of publications by the core author, and n_{max} refers to the number of published articles of the top author; Price, 1963). Therefore, authors with at least three articles were considered core authors, and all 24 authors met this criterion. Among them, Roger E. Beaty (11 articles), Mathias Benedek (11 articles), and Jiang Qiu (10 articles) were the top three authors according to the number of published articles, and Ryuta Kawashima, Hikaru Takeuchi, and Yasuyuki Taki had the most extensive cooperation with others as their total link strength was 77.

Cooperative Organizations

Cooperative organizations give an important platform for researchers to communicate with each other. In Figure 4, nodes represent organizations and show that only nine of the 527 organizations form the largest network of connected organizations through the network visualization map of VOSviewer. Cluster 1 has four organizations, namely, the University of North Carolina System, Chinese Academy of Sciences, Beijing Normal University, and Southwest University. Cluster 2 includes three organizations, which are University of Graz, University of Pennsylvania, and Harvard University. Cluster 3 consists of Stanford University and National Taiwan University. The University of Graz in Austria has fourteen articles highly cited 1,044 times which is far more than those of the second organization, the University of Pennsylvania in America (five articles highly cited 580 times). The University of Graz, meanwhile, has the closest academic exchanges with Harvard University at a link strength of three.

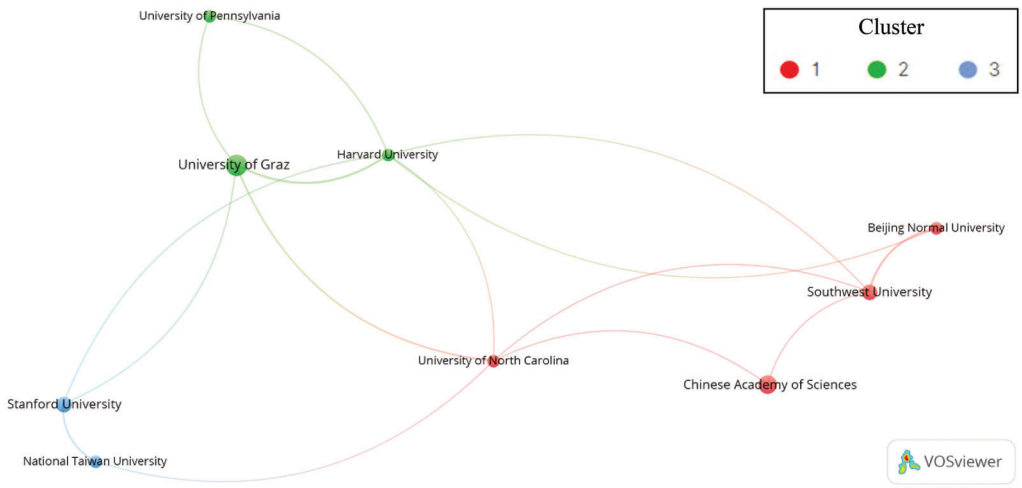


Figure 4. *Cooperative Organizations Network Visualization Map*

Cooperative Countries

Results using SCImago graphica are shown in Figure 5. There were 48 countries conducting related studies, 15 of which met the minimum number of five published articles. The top three countries in terms of the number of articles published were the United States, China, and United Kingdom. The United States topped the list with 104 articles cited 3,718 times and a link strength of 53, which was well ahead of those of the United Kingdom, Austria, and China combined. The closest connection of the United States was China, with a link strength of 14.

Figure 5. *Cooperative Countries Network Map*

Popular Topics

Keywords refer to the words that are used to express the topic of concern or occur many times in the article, and are used to analyze popular topics. Nodes, shown in Figure 6, represent keywords. Through analyzing the co-occurrence of keywords using the network visualization map of VOSviewer, we identified eight clusters (see Figure 6). Of the 1,834

keywords, 91 met the threshold of five occurrences. According to the clustering results in Figure 6, we extracted eight potentially popular topics in the current research field. As shown in Table 1 and Figure 7, Cluster 1 indicated that more attention was paid to creativity from the perspective of creative thinking. Cluster 2 indicated that this theme of WM and creativity focused on the advanced cognitive development of people at different ages. Cluster 3 showed a focus on the development of WM and creativity in different special groups. Clusters 4 to 8 all focused on the neural mechanisms of the brain related to the topic.

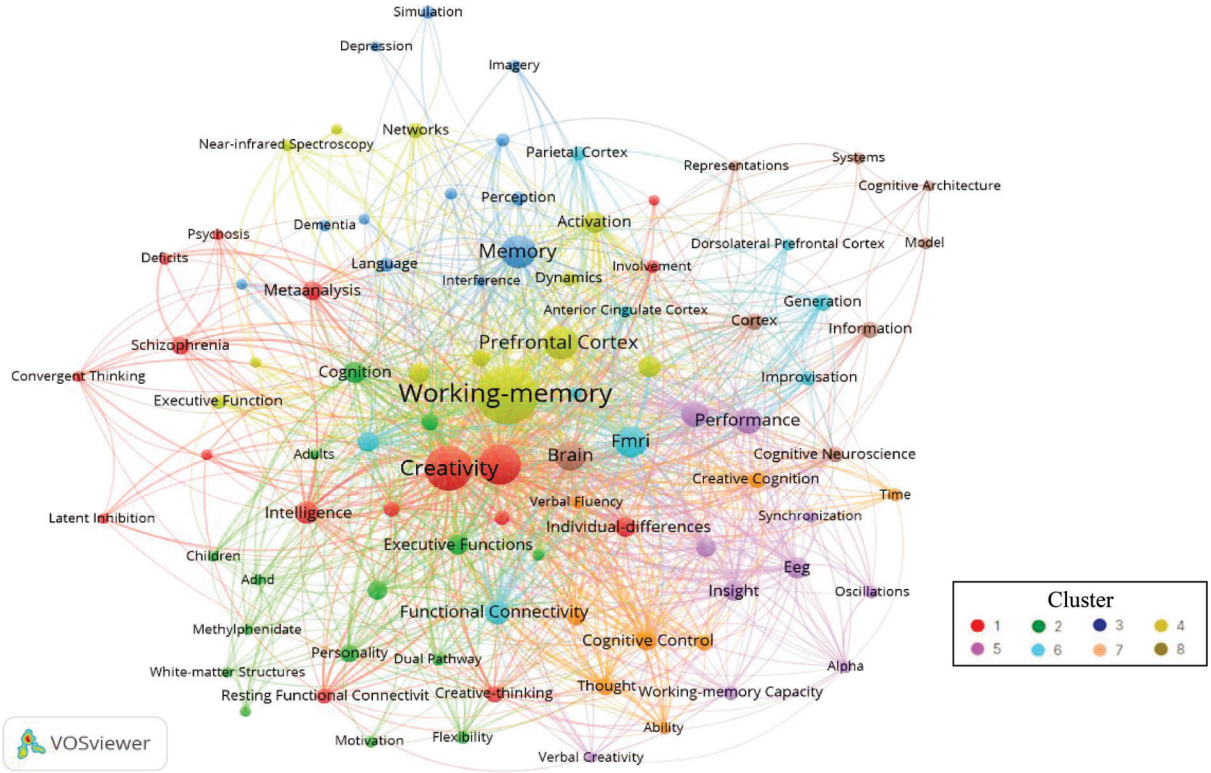


Figure 6. *Keyword Co-Occurrence Network Visualization Map*

Table 1. *Keyword Co-Occurrence Clustering Induction*

Clusters	Popular topics	Main keywords included
1	Creativity	Creativity, creative thinking, divergent thinking, convergent thinking, intelligence, and individual differences
2	Cognition	Adults, children, cognition, executive functions, connectivity, and personality
3	Memory	Memory, Alzheimer, dementia, depression, hippocampus, and language
4	WM	WM, prefrontal cortex, inhibition, activation, behavior, and task
5	Performance	Performance, attention, EEG, insight, neuroscience, and alpha
6	fMRI	fMRI, default network, functional connectivity, and parietal cortex
7	Cognitive control	Cognitive control, thought, default mode network, creative cognition, and neural basis
8	Brain	Brain, cortex, cognitive neuroscience, and information

Note. WM = working memory; fMRI = functional magnetic resonance imaging; EEG = electroencephalogram.

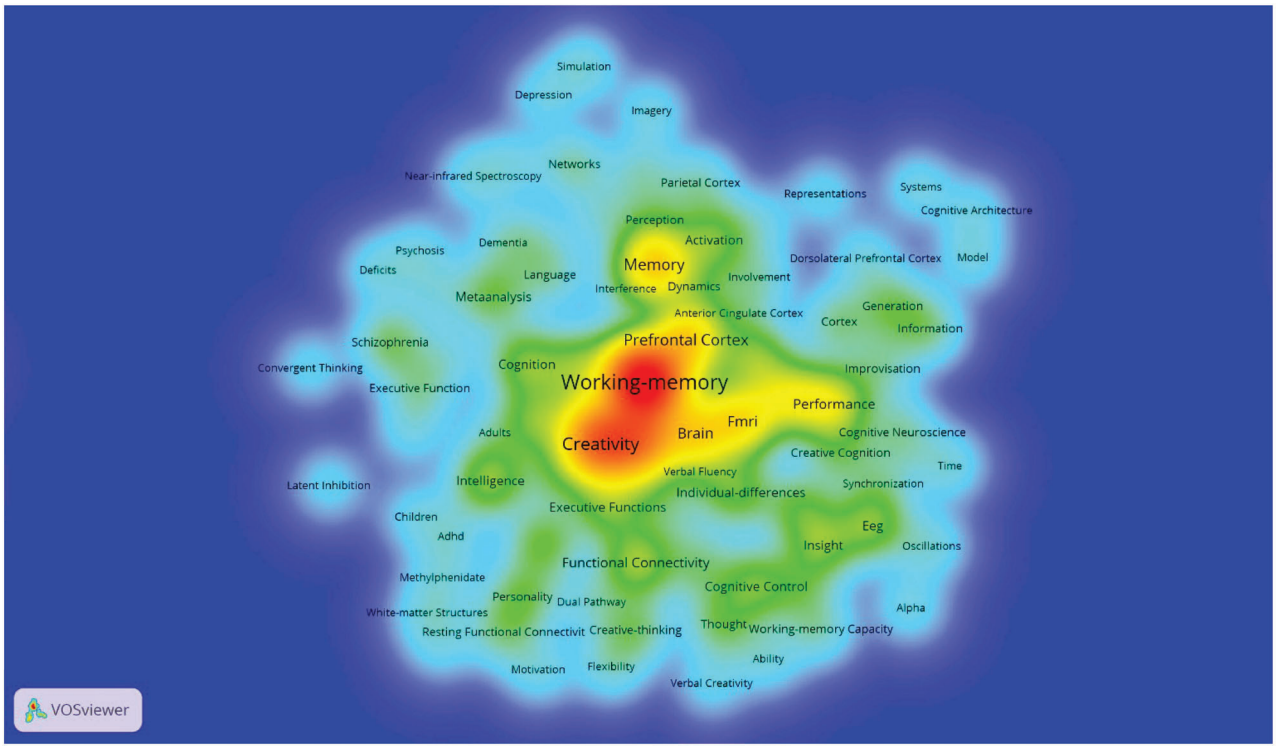


Figure 7. *Keyword Co-Occurrence Item Density Visualization Map*

Frontier Trend Topics

Frontier trend refers to a concept that is likely to become the latest and most promising research topic in scientific research. Nodes still represented keywords in this analysis (see Figure 8). The overlay visualization map of VOSviewer can be used to analyze frontier trend topics. The color of nodes ranged from blue (lowest score) to green to yellow (highest score). The closer the node color was to yellow, the more keywords showed the current research frontier trends. According to Figure 8, functional connectivity (21, 6.89%) was one of the largest of the yellow nodes and represented the association between cognition and brain through the resting-state fMRI (Takeuchi et al., 2012). It has become one of the most important research frontier trends in the field of behavioral and brain science and illustrates that more and more researchers are studying the neural mechanisms of cognition. To corroborate the conclusion of the overall data, we compared the research trends of the last 3 years with the overall research trends (see Figure 9). The results show that functional connectivity was indeed identified as the latest research trend in the WM and creativity fields (see Table 2).

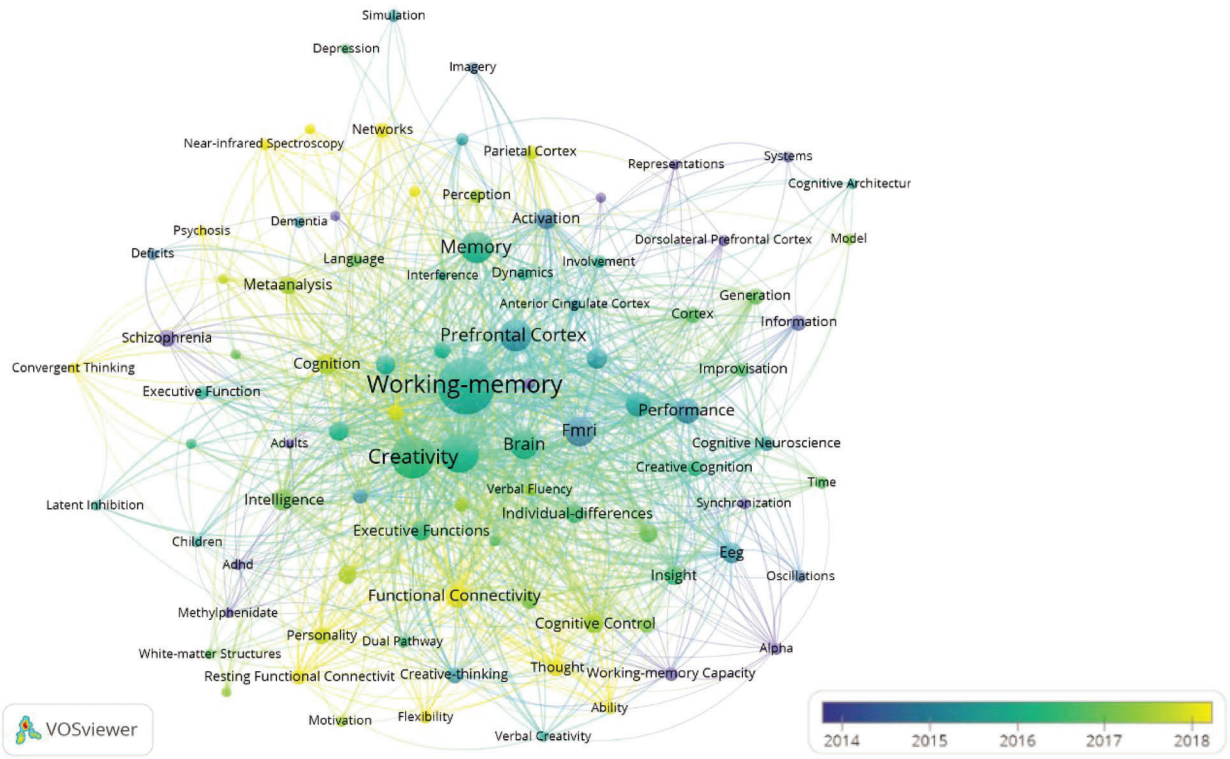


Figure 8. *Keyword Co-Occurrence Overlay Visualization Map Based on Overall Data Analysis*

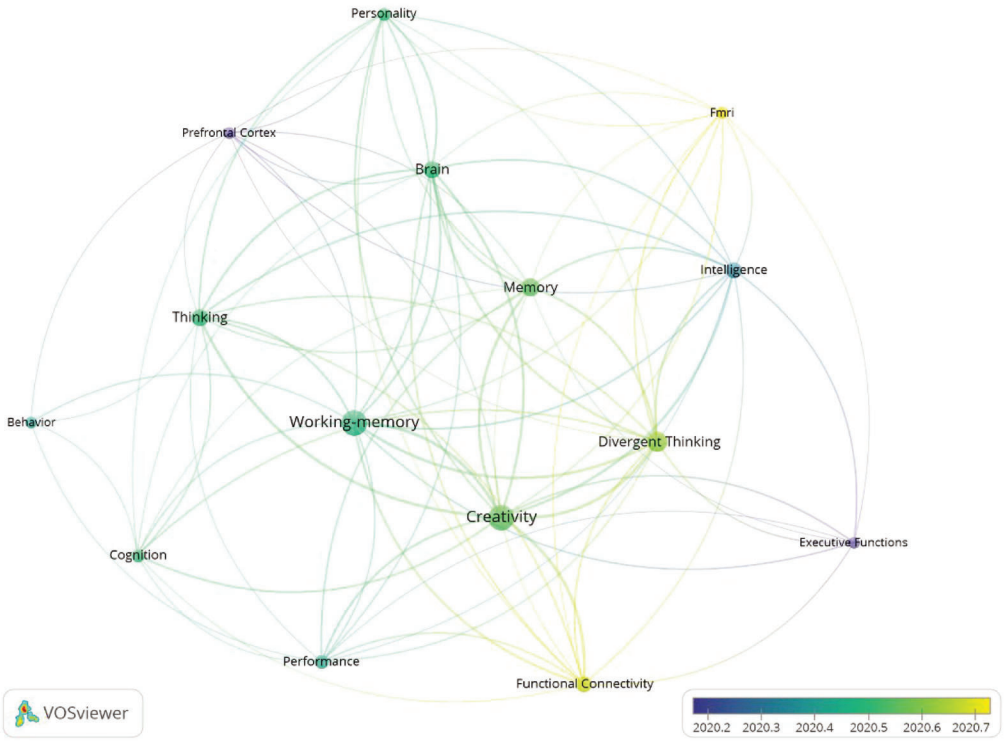


Figure 9. *Overlay Visualization of Keyword Co-Occurrence Based on Local Data Analysis In the Last 3 Years*

Table 2. *Top Two Keywords in Research Trends*

Ranker	Keywords	Count	Cluster	Total link strength
1	Functional connectivity	9	1	34
2	fMRI	5	2	15

Note. fMRI = functional magnetic resonance imaging.

Discussion

We analyzed 305 articles on WM and creativity indexed in the WOS core database and found that the number of published articles shows a rapid linear growth trend. The United States is one of the most significant research countries in this topic, with the largest number of publications and citations, and the closest cooperation with other countries. The University of Pennsylvania, the University of North Carolina System, Harvard University, and Stanford University communicate more frequently with other organizations. Roger E. Beaty has one of the largest numbers of published articles. This shows that research in this field is dominated by Western countries, such as the United States, United Kingdom, and Austria. In addition, the cooperation and communication among organizations in the research on this topic is not frequent. The University of Graz in Austria ranks No. 1 and has 14 articles highly cited 1,044 times; however, they cooperate less strongly with other organizations (total link strength is 7). Thus, we should strengthen the sharing resources and complementary advantages in future research. For example, we could establish an in-depth cooperation mechanism between organizations to facilitate resource sharing and complementary advantages.

Research on popular topics indicates that the neurocognitive mechanisms of WM and creativity are the subject of intense research in behavioral and brain sciences. Compared with behavioral studies in the field, neural mechanisms have received the most attention. fMRI, a noninvasive technique that can use blood as a proxy for measuring neuronal activity within the brain, has played a role in functional brain mapping since the 1990s (Smith, 2012). Around 2014, the researchers applied fMRI to this field to locate its brain regions. For example, the prefrontal cortex being a common neural mechanism for WM and creativity has been confirmed (Chrysikou, 2019; Vartanian et al., 2013). For the frontier trends of this topic, resting state functional connectivity enables us to know how brain regions within and between networks interact, which is a way to compensate for fMRI (Takeuchi et al., 2012).

To our knowledge, this is the first study to use a VOSviewer based on the relevant literature to explore the literature on WM and creativity. The results not only provide a comprehensive reference from journals, authors, organizations, countries, hot topics, and frontier trends but also facilitate researchers who have initial contact with this field to carry out their study more rapidly. Moreover, the conclusion of the research frontier trend suggests that the neural mechanism of WM and creativity is a future trend, so multimodal brain imaging methods (e.g., structural aspects, regional gray matter volume/density, cortical folding, and thickness) will become the research direction in this field.

Although the research results are highly reliable, this study has limitations. In particular, we used only the WOS core database as the bibliometric data source and did not select other databases, such as the American Psychological Association and the China National Knowledge Infrastructure. Additional literature from different databases could be used in future research.

Acknowledgments

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The data that support the findings of this study are available from Peng Lu on request.

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