Journal of Associated Medical Sciences 2024; 57(2): 173-182

JAMS
Journal of Associated Medical Sciences

Scopus Indexed & Thai-Journal Citation Index Centre (TCI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index




# Updated research trend and clustering algorithm on virtual reality and pulmonary rehabilitation: Scopus-based bibliometric and visual analysis

**Jirakrit Leelarungrayub[1,2*] Pongkorn Chantaraj[1] Supattanawaree Thipcharoen[1] Jutamat Jintana[1]**

*[1]Department of Data Science and Digital Innovation, Faculty of Innovation Technology and Creativity, The Far Eastern University, Chiang Mai Province, Thailand.*
*[2]Department of Physical Therapy, Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai Province, Thailand.*

**ARTICLE INFO**

*Article history:*
*Received 30 December 2023*
*Accepted as revised 24 April 2024*
*Available online 28 April 2024*

*Keywords:*
*Bibliometric, clustering, pulmonary rehabilitation, virtual reality*

**ABSTRACT**

**Background:** Virtual reality (VR) is a new innovative technology that can enhance intervention and should promote the effectiveness of rehabilitation, but there is a lack of scientific evidence on the clustering and topic research trend, especially on VR and pulmonary rehabilitation (PR). More evidence about network clusters and trends will encourage the research in the future.

**Objective:** This study aimed to explore, identify, cluster, and forecast analysis for the research trend of VR and PR from the research articles on the SCOPUS database.

**Materials and methods:** In this study, the search terms "virtual reality" AND "pulmonary rehabilitation" were extracted from specific English research articles published on the SCOPUS database between 2013-2023. RStudio software was used to perform bibliometric and visual analysis. During the analysis in the bibliometric tool, the normalization process with Salton's Cosine and network clustering via trend topic with the Walktrap algorithm was analyzed before specific visualization with the network clustering mapping, Treemap, and trend topic line by Kamada-Kawai layout algorithm.

**Results:** From the 1,396 articles on "VR" published between 2010 and 2023, there were 13 research articles on "VR AND PR" published between 2013 and 2023. The bibliometric result from 13 articles showed total of 36 subdisciplines correlated networks among virtual reality (20, 7%), male (16, 6%), female (15, 5%), aged (12, 4%), chronic obstructive lung disease (12, 4%), exercise (11, 4%), human (10, 4%), humans (10, 4%), middle-aged (10, 4%), quality of life (10, 4%), article (9, 3%), pulmonary rehabilitation (9, 3%), controlled study (8, 3%), adult (6, 2%), chronic obstructive (6, 2%), clinical article (6, 2%), forced expiratory volume (6, 2%), pulmonary disease (6, 2%), randomized controlled trial (6, 2%), and forced vital capacity (5, 2%), etc., respectively. Three network clusters were reported after the normalization process and clustering evaluation by factorial analysis. The first cluster was composed of virtual reality, male, female, aged, chronic obstructive lung disease, exercise, human, humans, middle-aged, quality of life, article, pulmonary rehabilitation, controlled study, adult, chronic obstructive, clinical article, forced expiratory volume, randomized controlled trial, forced vital capacity, six-minute walk test, depression, technology, telerehabilitation, breathing exercise, Covid-19, dyspnea, functional status, hospital patient, and physical activity, respectively. The second cluster consisted of procedure and exercise therapy, and the last cluster consisted of exercise tolerance, lung, treatment outcome, health program, and convalescence. Finally, trend research topics were presented in virtual reality, male, female, aged, chronic obstructive lung disease, human, exercise, quality of life, and middle-aged, respectively, in 2023.

**Conclusion:** Therefore, the contribution from data analysis in this article can identify the clustering and trend topics of VR, chronic obstructive lung disease, aging participants, exercise, and quality of life in future research.

∗ **Corresponding contributor.**
**Author's Address:** *Department of Data Science and Digital Innovation, Faculty of Innovation Technology and Creativity, The Far Eastern University, Chiang Mai Province, Thailand.*
**E-mail address:** jirakrit@feu.edu
**doi:** 10.12982/JAMS.2024.040
**E-ISSN:** 2539-6056

## Introduction

New innovative technology, Virtual Reality (VR), is one of many devices that can answer future challenges.[1] Various types of VR such as non-immersive, immersive, and 3D-displays, is a novel technology defined as "the use of interactive simulations created with computer hardware and software to present users with synchronized virtual environments that feel similar to real-world situations.[2] In a VR system, the complexities of the real world can be simulated in a controlled program.[3] The rehabilitation field can be facilitated using different devices or equipment.[4] Some evidence reported that the manual rehabilitation process following many injuries and disabilities is long, arduous, and tedious; therefore, patients mostly lack the motivation to follow the program, which can lead to ineffective rehabilitation outcomes and less quality of improvement.[5,6] The advantages of VR for rehabilitation have been applied and performed because of real-time feedback, individual setup, ease of adjustment, and simple measurement possibility,[7,8] especially in physical therapy that has been documented in the fact sheet in the International Association for the Study of Pain (IASP) 2022 as the same as other digital modalities with medical applications (mHealth apps), and telemedicine.[9]

Presently, VR shows initial promising results in clinical studies. VR integrates mechanisms of distraction, behavioral modification, relaxation, and education in many conditions such as neuropathic pain and low back pain.[10] Several VR systems have been developed for rehabilitation. Moreover, clinical engagement through VR can reduce pain perception and improve physical movement.[11] Different studies have investigated the effectiveness of VR in rehabilitation or the design and development of VR systems to facilitate rehabilitation exercises. For example, using Kinect for motor disabilities and exercises for shoulder abduction, path following, play along, and balloon pop, Roy and coworkers found that both patients and clinicians considered it an engaging and motivational intervention in rehabilitation.[12] In addition, Su and coworkers designed a VR to help patients do lower back exercises and the result showed a high degree of acceptance in motivating the patients to perform the exercises.[13] Moreover, Kim and co-workers evaluated the effects of an unsupervised VR-based exercise program on hip muscle strength and balance control in older adults. The results reported that the VR group had shown a great improvement in hip strength of extensors, flexors, and adductors (changes = 55.5%, 29.9%, and 48.6%, respectively). In contrast, the control group did not show significant improvements (changes = 1.5%, 4.6%, and 2.1%, respectively).[14] As well, the study of Bryanton *et al*. reported that greater mean ankle active ranges of motion to hold time after practicing with VR-based ET when compared to conventional therapies.[15] Moreover, many reviews have further investigated specific patients or goals to use VR with exercise to achieve rehabilitation, e.g., in multiple sclerosis,[16] chronic stroke,[17] balance and gait,[18] and Down syndrome, and cerebral palsy.[19]

Therefore, the previous evidence shows that VR programs are considered more effective tools for rehabilitation than traditional approaches in the new digital technology.[20] Because VR is an enjoyable activity with valuable feedback and improves motor learning and adherence to exercise with non-immersive,[21] semi-immersive, and fully immersive systems.[22] Unfortunately, there were rare previously published articles that showed the applications of VR in pulmonary rehabilitation and suggested a trend study in the future. Therefore, this study aimed to explore and identify the network cluster and forecast the research topic trend of VR and PR from the prior data based on the SCOPUS that can be useful to encourage future research.

## Methodology

This study employs a research design combining quantitative and qualitative methods to analyze and visualize data. It is a component of a large-scale research project that was approved by the Human Ethics Committee at the Faculty of Associated Medical Science, Chiang Mai, Thailand (STUDY CODE: AMSEC-67Ex-004). Bibliometric analysis under RStudio Software (version 4.3.2) is one of many software related to various databases, i.e., Web of Science, PubMed, Cochrane, or SCOPUS.[23] However, this study aimed to explore the network clustering and trend topics in the research between 2010 and 2023. The search terms or inclusion criteria were focused on specific keywords, such as "Virtual Reality (VR)" and "Pulmonary Rehabilitation" in the research articles based on the particular SCOPUS database with literature type of research article and English language. As a property of Scopus, it is relatively more comprehensive than PubMed or Web of Science (WoS). For example, Garrido-Cardenas et al. argue that Scopus covers 84% of the WoS titles, whereas only 54% of the publications in Scopus are indexed in WoS.[24] Scopus is also more precise than Google Scholar because of its superior control over the referred publications and the controlled indexing.[25] As a result, the Scopus database was the only reasonable option for conducting the study because of its accessibility and extensive coverage of peer-reviewed academic literature.[26] Exclusion criteria were types of literature categorized as letters, reports, conferences, proceedings, or review data (Cochrane). Generally, Cobo *et al*. proposed the method of bibliometric analysis for application to the analysis of scientific domains.[27] There are eight steps: data collection, selection of analyzed units, data processing, normalization process, creation of science mapping, analysis methods, visualization techniques, and interpretation.

This research ran on the methodology of bibliometric analysis from Steps 1 to 5 [28] as in Figure 1, which was modified from Aria and Cuccrullo.[29] The data from research articles on "virtual reality" and "pulmonary rehabilitation" was collected on the SCOPUS database in steps I and II. All data was transformed into a " BibTex " file type before processing in the Bibliometric method within RStudio Software in Step III. Then, the data processing on bibliometric analysis, the primary most relevant sources or journals, number of documents, keyword occurrences,

most relevant words, or most frequency words was computerized evaluated. During processing in bibliometric analysis, the normalization process with Salton's Cosine [27] (Step IV) and network clustering and trend topic analysis were identified by the Walktrap distance algorithm.[30] The creation of science mapping visualization in the bibliometric tool as network clustering mapping, Treemap, or trend topic was presented by the Kamada-Kawai layout algorithm which is used to present a specific visualized layout with weight edged based on the distance among all data.[28,32] In this study, Salton Cosine normalization was selected because previous evidence reported that Salton's cos is similar to the Person's cosine that was used to investigate the potential co-cited in the library environment.[33] The Walktrap distance algorithm was used to analyze the network clustering and trend research topic in a small database,[34] and following as in the previous suggestion.[35,36] Therefore, all algorithms in this study were used to analyze either a big or small database.

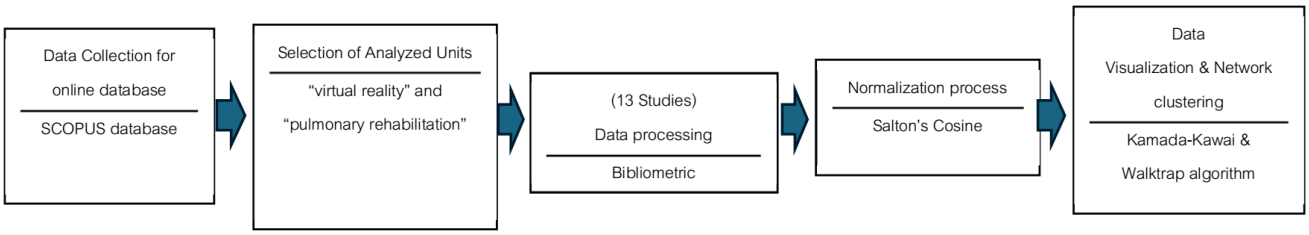



***Figure 1.*** *Five steps of data collection, analysis, data processing, normalization, and clustering processes.*[28]

## Results

### *Distribution by Time and Journal publication*

A total of 1,396 original publication articles on "Virtual reality" or VR were found between 2010 and 2023. Still, there were only 13 research articles published in 11 journals with 63 authors under the specific words of "Virtual Reality AND Pulmonary Rehabilitation" published between 2013 and 2023. All articles with the author's name, journal, research title, and published page were presented in Table 1. The most relevant sources or journals and the number of documents were the International Journal of COPD (N=2), International Journal of Environmental Research and Public Health (N=2), BMJ Open (N=1), Canadian Respiratory Journal (n=1), Contrast Media and Molecular Imaging (n=1), Frontiers in Public Health (N=1), Journal of Medical Internet Research (N=1), Journal of Clinical Medicine (N=1), Journal of Healthcare Engineering (N=1), Journal of Human Kinetics (N=1), and Journal of Medical Internet Research (N=1).

**Table 1.** Cited Article Results in SCOPUS database between 2013-2023.

| Authors | Title |
|---|---|
| Li Y, *et al*.[37] | Virtual reality as an adjunct to pulmonary rehabilitation of patients with chronic obstructive pulmonary disease: a protocol for systematic review and meta-analysis. |
| Rutkowski S, *et al*. [38] | Inpatient post-COVID-19 rehabilitation program featuring virtual reality-preliminary results of randomized controlled trial. |
| Rutkowski S, *et al*.[39] | Effectiveness of an inpatient virtual reality-based pulmonary rehabilitation program among COVID-19 patients on symptoms of anxiety, depression, and quality of Life: preliminary results from a randomized controlled trial. |
| Cerdan-De-las-heras J, *et al*. [40] | Tele-rehabilitation program in idiopathic pulmonary fibrosis-A single-center randomized trial |
| Rutkowski S, *et al*. [41] | Evaluation of the efficacy of immersive virtual reality therapy as a method-supporting pulmonary rehabilitation: A randomized controlled trial. |
| Liu H, *et al*.[42] | Study on adjuvant medication for patients with mild cognitive impairment based on VR technology and health education. |
| Xie X, *et al*.[43] | Virtual reality technology combined with comprehensive pulmonary rehabilitation on patients with stable chronic obstructive pulmonary disease. |
| Jung T, *et al*.[44] | A virtual reality-supported intervention for pulmonary rehabilitation of patients with chronic obstructive pulmonary disease: Mixed methods study. |
| Rutkowshi S, *et al*. [45] | Virtual reality rehabilitation in patients with chronic obstructive pulmonary disease: A randomized controlled trial. |
| Alves da Cruz MM, *et al*.[46] | Acute hemodynamic effects of virtual reality-based therapy in patients of cardiovascular rehabilitation; a cluster randomized crossover trial. |
| Knox L, *et al*.[47] | Safety, feasibility, and effectiveness of virtual pulmonary rehabilitation in the real world. |
| Rutkowski S, *et al*.[48] | Effect of virtual reality-based rehabilitation on physical fitness in patients with chronic obstructive pulmonary disease. |
| Wardini R, *et al*.[49] | Using a virtual game system to innovate pulmonary rehabilitation: Safety, adherence, and enjoyment in severe chronic obstructive pulmonary disease. |

***Co-occurring keywords and Network Clustering analysis***

The result of the bibliometric analysis of 13 articles with specific keywords of "VR and PR" from the research articles in SCOPUS showed a total of 36 subdisciplines. The most frequency words, word clustering, and Treemap used subdisciplines in 13 articles including virtual reality (N=20, 7%), male (N=16, 6%), female (N=15, 5%), aged (N=12, 4%), chronic obstructive lung disease (N=12, 4%), exercise (N=11, 4%), human (N=10, 4%), humans (N=10, 4%), middle-aged (N=10, 4%), quality of life (N=10, 4%), article (N=9, 3%), pulmonary rehabilitation (N=9, 3%), controlled study (N=8, 3%), adult (N=6, 2%), chronic obstructive (N=6, 2%), clinical article (N=6, 2%), forced expiratory volume (N=6, 2%), pulmonary disease (N=6, 2%), randomized controlled trial (N=6, 2%), and forced vital capacity (N=5, 2%), etc., respectively. After the normalization with Salton's Cosine, the science mapping from 36 subdisciplines was presented from the bibliometric analysis with the Kamada-Kawai algorithm, shown in Figures 2-4.

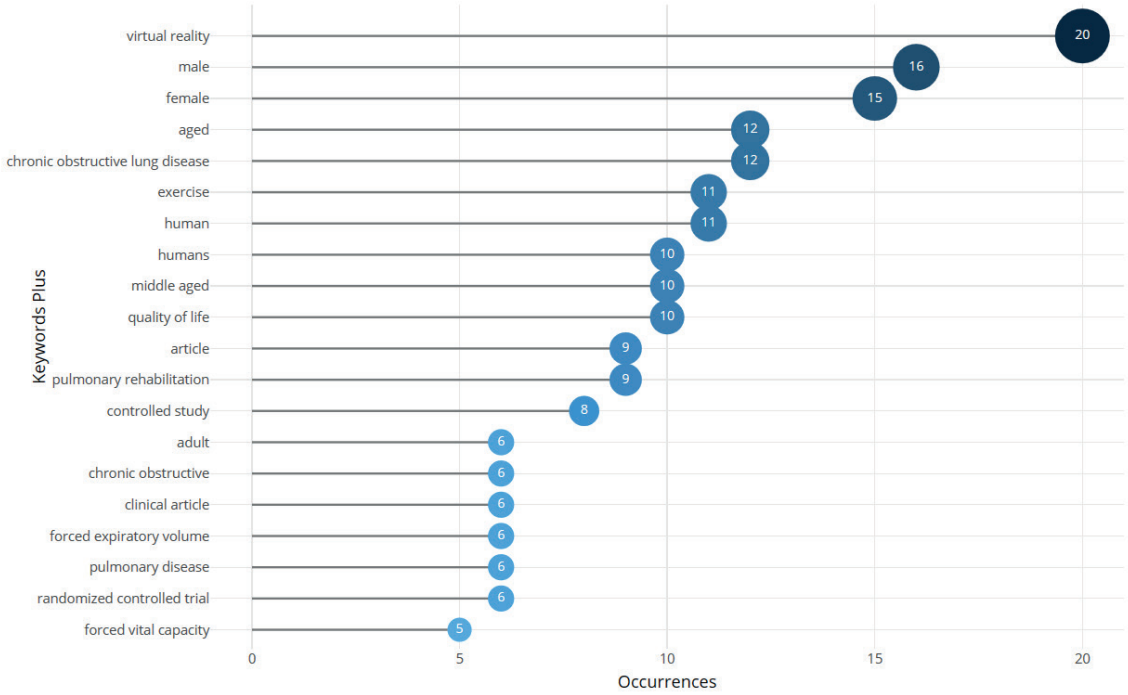



***Figure 2.*** *Most frequency words in 13 published articles between 2013 and 2023.*

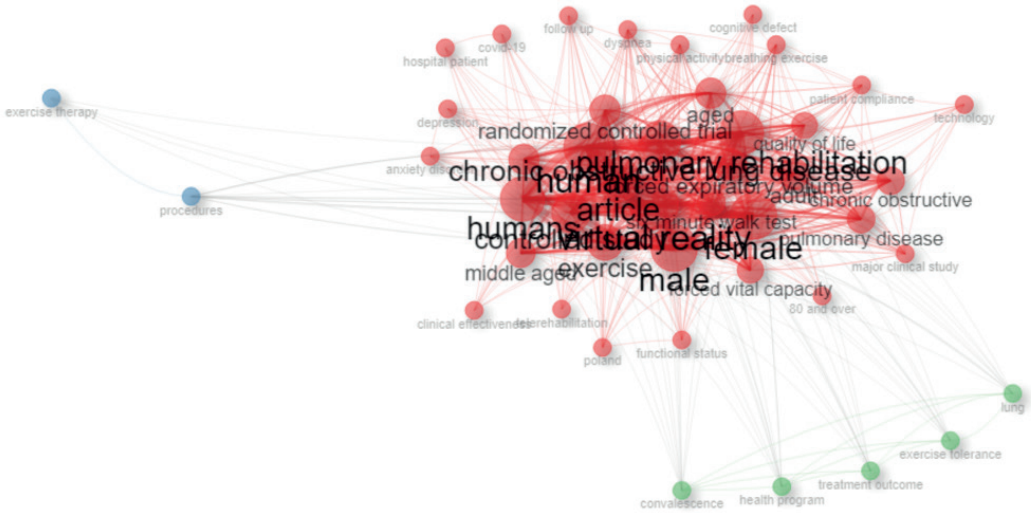



***Figure 3.*** *Network clustering visualization with Walktrap distance algorithm of 36 subdisciplines from 13 cited articles.*




***Figure 4.*** *Treemap analysis of a total of 36 subdisciplines from "virtual reality" and "pulmonary rehabilitation" after citation between 2013 and 2023 in the SCOPUS database.*

The results represented three clusters and map network clustering as presented in Table 2 and Figure 5. The first cluster was composed of 29 subdisciplines: Virtual reality, male, female, aged, chronic obstructive lung disease, exercise, human, humans, middle-aged, quality of life, article, pulmonary rehabilitation, controlled study, adult, chronic obstructive, clinical article, forced expiratory volume, randomized controlled trial, forced vital capacity, six-minute walk test, depression, technology, telerehabilitation, breathing exercise, Covid-19, dyspnea, functional status, hospital patient, physical activity, respectively. The second cluster of 2 subdisciplines consisted of procedure and exercise therapy, and the last cluster of 5 subdisciplines consisted of exercise tolerance, lung, treatment outcome, health program, and convalescence.

**Table 2.** Network Clustering and 36 subdisciplines from "virtual reality" and "pulmonary rehabilitation"

| Network Clustering | Subdisciplines |
|---|---|
| 1 | Virtual reality, male, female, aged, chronic obstructive lung disease, exercise, human, humans, middle-aged, quality of life, article, pulmonary rehabilitation, controlled study, adult, chronic obstructive, clinical article, forced expiratory volume, randomized controlled trial, forced vital capacity, six-minute walk test, depression, technology, telerehabilitation, breathing exercise, Covid-19, dyspnea, functional status, hospital patient, physical activity |
| 2 | Procedures, exercise therapy |
| 3 | Exercise tolerance, lung, treatment outcome, health program, convalescence |

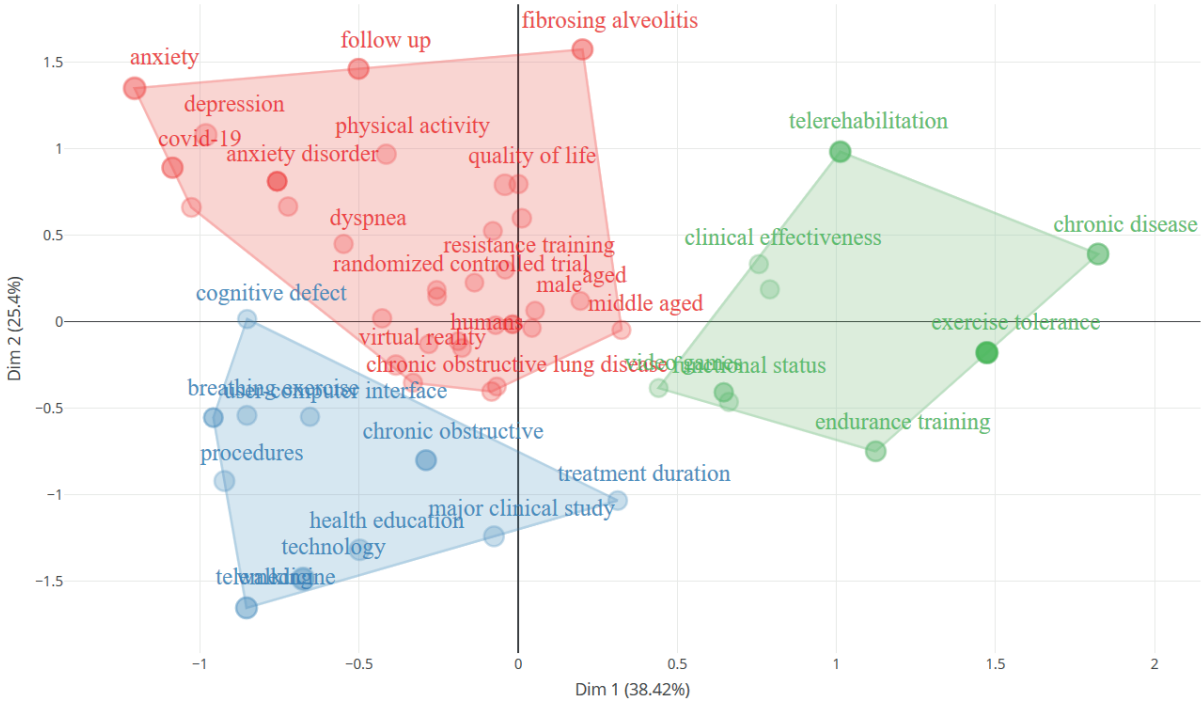



***Figure 5.*** *Three-map network clustering analysis from all 36 subdisciplines or words in 13 published articles between 2013 and 2023.*

***Trend research Topic related to the keywords of Virtual reality and Pulmonary rehabilitation.***

From the words' frequency over time since 2013, the results showed an increased trend of the top ten words. Trend research topics were virtual reality (1 to 20), male (2 to 16), female (2 to 15), aged (3 to 12), chronic obstructive lung disease (1 to 12), human (2 to 11), exercise (2 to 11), humans (2-10), quality of life (0 to 10) and middle-aged (1 to 10), respectively in 2023 when compared to 2013 (Figure 6).

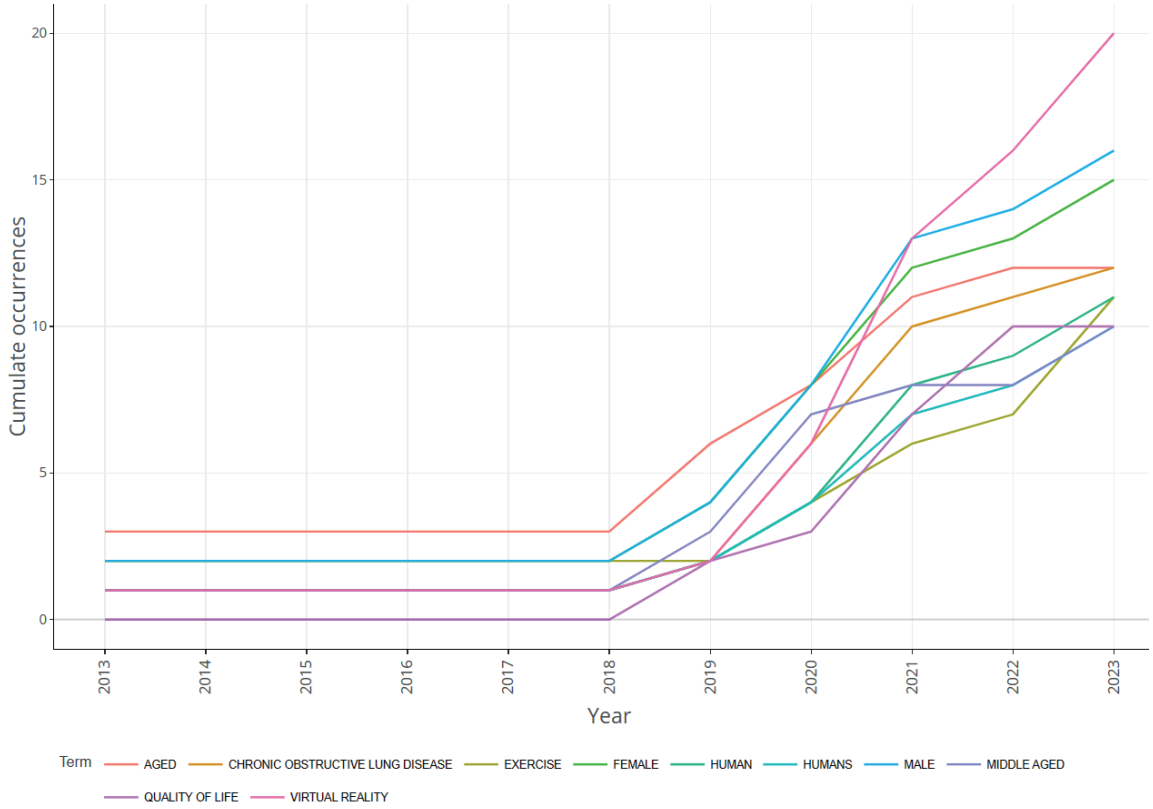



***Figure 6.*** *Trend topics from the words' frequency over time from 2013 to 2023 analysis.*

## Discussion

The bibliometric analysis used mainly in this study is one of many software product line engineering at lower costs, in a shorter time, and with higher quality.[50] Bibliometric analysis has been popular in business research in recent years which can be attributed to the advancement, availability, and accessibility of software such as Gephi, VOSviewer, and scientific databases such as SCOPUS in this study.[35] In addition, this method can be applied for discovering knowledge and identifying novel ideas for investigation or research and the position of the intended contributions to all fields.[51] The advantages of this method are that it can be used and tested repeatability in a broad scope from either small or big datasets from the globally published articles in SCOPUS or PubMed with both quantitative as most frequency words or Treemap percentages and qualitative as network clustering, trend topic, and network clustering visualization analysis when compared to other qualitative analysis in Meta-analysis, and Systematic literature review.

This study applied the bibliometric tool to explore and identify the network clustering analysis because it was popularly used in business research; for example, to analyze risk management from the SCOPUS database.[52] That report could identify the six clusters of all risk parameters in the same way as the three network clustering identifications that can be evaluated in this study. Thus, bibliometric analysis in this study is reflected as a great tool to get reliable, clear, and unbiased quantitative estimate results as a prior report.[53]

### *Network clustering and most frequency words.*

The results of 13 research articles showed the top ten frequency words of virtual reality, male, female, aged, chronic obstructive lung disease, exercise, human, humans, middle-aged, quality of life, article, pulmonary rehabilitation, controlled study, and adults, etc. No previous studies have been reported on data citations, which is likely this result. However, a previous report documented seven electronic libraries and 32 review studies from 2010 to 2023 from Digital Library, Google Scholar, IEEE Explore, MEDICINE, PubMed, Sage, and ScienceDirect.[54] Therefore, the meaning of this study can be suggested that VR and PR have been studied concerning VR's impact on the quality of life from exercise and pulmonary rehabilitation in humans with chronic lung disease under a controlled study design. Moreover, the validity of the results of the three clusters in this study with the Cosine normalization algorithm can be supported by previous evidence, [33]data visualization from the occurrence matrix,[55] network mapping visualization with Kamada-Kawai layout algorithm,[56,] and related to the Walktrap algorithm.[35] The network clustering visualization from this study can be represented as same as in the network in various research areas[57] with other algorithms such as Edge, Fast Greedy, Eigenvector, Infomap, Label Propagation, Louvain,[58] and Walktrap algorithm in this study.[59] Moreover, the small data from 13 research articles and three networks in this results, the Walktrap algorithm can be selected automatically in the RStudio and bibliometric analysis. In addition, some previous research reports on data mining or data analysis on the different algorithms, various modularity, processing time, and cluster members, suggested that frequency analysis and co-occurring networks should be identified and applied.[59,60] This study showed partial results on network clustering from database citations. However, this study aims mainly to present the clustering of words related to the research topic in the future. From the network clustering analysis from the most frequent words in this study, "Virtual Reality" and "Pulmonary Rehabilitation" were dominant outcomes in research articles automatically presented in the SCOPUS database between 2013 and 2023. This confirms the future view on VR, which is a promising technology for implementing personalized, motivating, and controlled rehabilitation scenarios as previous evidence.[61]

### *Trend research topics of virtual reality and pulmonary rehabilitation*

Identifying the research trend in the future of this study is consistent with a previous review document.[62] The reviewed report of Patsaki and co-workers claimed that VR application has been recommended for COPD patients and variables examined with aerobic capacity for exercise, lung function, anxiety, depression, six-minute walk test, and FEV1. In this study, the Bibliometric tool successfully analyzed the summarizing articles, which is the same as the previous suggestion.[63] Although the 13 research articles were cited between 2013 and 2023, the frequency of the words over time could also be analyzed. Trend topics were virtual reality (1 to 20), male (2 to 16), female (2 to 15), aged (3 to 12), chronic obstructive lung disease (1 to 12), human (2 to 11), exercise (2 to 11), quality of life (0 to 10) and middle-aged (1 to 10), respectively in 2023 when compared to 2013. Unfortunately, the sub-classified analysis found nine articles published between 2019 and 2023 and one research article in 2023 that studied "VR and pulmonary rehabilitation and chronic obstructive lung disease." In addition, breathing exercise, breathing exercise gaming, pulmonary rehabilitation, respiratory biofeedback, and virtual reality were the keywords that have been continued respectively citation that help to improve the quality of life in patients with chronic lung disease.[38] Therefore, future research on VR-innovative technology in pulmonary rehabilitation in case of chronic pulmonary disease should be encouraged.

### *Limitation of study*

This data was mainly cited from the SCOPUS database, English literature, and specific research articles on the keywords "Virtual reality and Pulmonary rehabilitation". Moreover, some new research articles in the in-press situation may not appear in the SCOPUS database. Therefore, continuous study should be followed or performed for the strong evidence. In addition, the keywords such as specific programs such as "chest mobilization exercise" or/and "purse-lip breathing exercises" or/and "incentive spirometer" or/and "education", etc.,

were not recorded. Thus, the limitation of the network clustering and trend topic analysis cannot be evaluated for future research studies.

***Conclusion and Clinical Application***

The bibliometric analysis of specific research articles in the SCOPUS database in the 10-year update on the keywords "VR and Pulmonary rehabilitation" can be helpful and suggest more future studies and encouraged in the cardiopulmonary research area, relating to the other keywords such as chronic obstructive lung disease, exercise, breathing exercise, pulmonary rehabilitation, quality of life, forced expiratory volume, forced vital capacity, six-minute walk test, dyspnea, functional status, and physical activity". Moreover, this study encourages future research in clinical cardiopulmonary rehabilitation through the discovery of knowledge from the data-mining analysis tool.

## Acknowledgments

This study is a part of all segments of the Master's thesis conducted at the Department of Data Science and Digital Innovation, Faculty of Innovation Technology and Creativity, The Far Eastern University, Chiang Mai, Thailand. I am standing as a corresponding author thanks to all the chief and co-advisors for their excellent suggestions, recommendations, and full support. In addition, we would like to express our gratitude to the Faculty of Associated Medical Sciences at Chiang Mai University in Thailand for their kind funding support of this research study.

## Conflict of Interest

The authors declare no conflict of interest.

## References

[1] Dockx K, Bekkers EM, Van den Bergh V, Ginis P, Rochester L, Hausdorff JM, et al. Virtual reality for rehabilitation in Parkinson's disease. Cochrane Database Syst Rev. 2016; 12(12): CD010760. doi: 10.1002/14651858. CD010760.pub2.

[2] Weiss PL, Kizony R, Feintuch U, Katz N. Virtual reality in neurorehabilitation. In: Gage F, Cohen L, Selzer M, Duncan P, Clarke S, editors. Textbook of neural repair and rehabilitation: Volume 2: Medical Neuro-rehabilitation. 2nd Ed. Cambridge: Cambridge University Press; 2006: 182-97.

[3] Keshner EA. Virtual reality and physical rehabilitation; a new toy or a new research and rehabilitation tool? J Neuroeng Rehabil. 2004: 1(1): 8. doi: 10.1186/1743-0003-1-8.

[4] Lee LG, Krovi VN. Musculoskeletal simulation-based optimization of rehabilitation program. International Workshop on Virtual Rehabilitation, New York, NY, USA, 2006, pp. 36-41, doi: 10.1109/IWVR.2006.1707524.

[5] Kizony R, Katz N, Weiss PL. Adapting an immersive virtual reality system for rehabilitation. Comput Animat Virtual Worlds. 2003; 14(5): 261-8. doi: 10.1002/vis.323.

[6] Weiss PL, Rand D, Katz N, Kizony R. Video captures virtual reality as a flexible and effective rehabilitation tool. J Neuroeng Rehabil. 2004; 1(1): 12. doi: 10.1186/1743-0003-1-12.

[7] Burdea GC. Virtual rehabilitation benefits and challenges. Methods Inf Med. 2003; 42: 519-23. doi: 10.1267/METH03050519.

[8] Yang X. Virtual reality in rehabilitation. Rehabilitation Engineering. [Internet]. Tan Yen Kheng (Ed), ISBN: 978-953-307-023-0, InTech, Available from: http://www.intechopen.com/books/rehabilitation-engineering/virtual-reality-in-rehabilitation.

[9] Schäfer AGM, Zalpour C, von Piekartz H, Hall TM, Paelke V. The efficacy of electronic health supported home exercise interventions for patients with osteoarthritis of the knee: systematic review. J Med Internet Res. 2018; 20(4): e152. doi: 10.2196/jmir.9465.

[10] Trost Z, Anam M, Seward J, Shum C, Rumble D, Sturgeon J, *et al*. Immersive interactive virtual walking reduces neuropathic pain in spinal cord injury: findings from a preliminary investigation of feasibility and clinical efficacy. Pain. 2022; 163(2): 350-61. doi: 10.1097/j.pain.0000000000002348.

[11] Powell V, Powell W. Therapy-led design of home-based virtual rehabilitation. 2015 IEEE 1st Workshop on Everyday Virtual Reality (WEVR), Arles, France; 2015: 11-4. doi: 10.1109/WEVR.2015.7151688.

[12] Roy AK, Soni Y, Dubey S. Enhancing the effectiveness of motor rehabilitation using Kinect motion sensing technology. 2013 IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS), Trivandrum, India; 2013: 298-304. doi: 10.1109/GHTC-SAS.2013.6629934.

[13] Su WC, Yeh SC, Lee SH, Huang HC. A virtual reality lower-back pain rehabilitation approach: System design and user acceptance analysis. In Stephanidis C, Antona M, Stephanidis C, editors, Universal Access in Human-Computer Interaction: Access to Learning, Health and Well-Being. Proceedings of the 9th International Conference, UAHCI 2015 Held as Part of HCI International 2015. Springer Verlag; 2015: 374-82. doi: 10.1007/978-3-319-20684-4_37.

[14] Kim J, Son J, Ko N, Yoon B. Unsupervised virtual reality-based exercise program improves hip muscle strength and balance control in older adults: a pilot study. Arch Phys Med Rehabil. 2013; 94(5): 937-43. doi: 10.1016/j.apmr.2012.12.010. Epub 2012 Dec 21.

[15] Bryanton C, Bosse J, Brien M, Mclean J, McCormick A, Sveistrup H. Feasibility, motivation, and selective motor control: virtual reality compared to conventional home exercise in children with cerebral palsy. Cyberpsychol Behav. 2006; 9(2): 123-8. doi: 10.1089/cpb.2006.9.123.

[16] Casuso-Holgado MJ, Martín-Valero R, Carazo AF, Medrano-Sanchez EM, Cortes Vega M.D, Montero-Bancalero FJ. Effectiveness of virtual reality on training for balance and gait rehabilitation in people with multiple sclerosis: a systematic review and

meta-analysis. Clin Rehabil. 2018; 32: 1220-34. doi: 10.1177/0269215518768084. Epub 2018 Apr 13.

[17] Iruthayarajah J, McIntyre A, Cotoi A, Macaluso S, Teasell R. The use of virtual reality for balance among individuals with chronic stroke: a systematic review and meta-analysis. Top Stroke Rehabil. 2017; 24(1): 68-79. doi: 10.1080/10749357.2016.1192361. Epub 2016 Jun 16.

[18] Porras DC, Siemonsma P, Inzellberg R, Zeilig G, Plotnik M. Advantages of virtual reality in the rehabilitation of balance and gait: Systematic review. Neurology. 2018; 90(22): 1017-25. doi: 10.1212/WNL.00000000000056 03.Epub 2018 May 2.

[19] Lopes JBP, de Almeida-Carvalho Duarte N, Lazzari RD, Oliveira CS. Virtual reality in the rehabilitation process for individuals with cerebral palsy and Down syndrome: A systematic review. J Bodyw Mov Ther. 2018; 24(4): 479-83. doi: 10.1016/j.jbmt.2018.06.006. Epub 2018 Jun 28.

[20] Howard MC. A meta-analysis and systematic literature review of virtual reality rehabilitation programs. Comput Human Behav Rep. 2017; 70: 317-27. doi: 10.1016/j.chb.2017.01.013.

[21] Peek K, Sanson-Fisher R, Mackenzie L, Carey M. Interventions to aid patient adherence to physiotherapist prescribed self-management strategies: a systematic review. Physiotherapy. 2016; 102(2): 127-35. doi: 10.1016/j.physio.2015.10.003. Epub 2015 Oct 22.

[22] Mujber TS, Szecsi T, Hashmi MSJ. Virtual reality applications in manufacturing process simulation. J Mater Process Technol. 2004; 156: 1834-8. doi:10.1016/j.jmatprotec.2004.04.401.

[23] Zhang G, Qin Y, Liu S, Chen X, Zhang W. Bibliometric analysis of research trends and topic area in traditional Chinese medicine therapy for lymphoma. Pharm Biol. 2024; 62(1): 13-21. doi: 10.1080/13880209.2023.2288697. Epub 2023 Dec 13.

[24] Garrido-Cardenas JA, de Lamo-Sevilla C, Cabezas-Fernandez MT, Manzano-Agugliaro F, Martinerx-Lirola M. Global tuberculosis research and its future prospects. Tuberculosis. 2020; 121: 101917. doi: 10.1016/j.tube.2020.101917. Epub 2020 Feb 23.

[25] Dinic BM, Jevremov, T. Trends in research related to the dark triad: A bibliometric analysis. Curr Psychol. 2021; 40(7): 3206-15. doi: 10.1007/s12144-019-00250-9.

[26] Mongeon, P, Paul-Hus, A. The Journal coverage of web of science and Scopus: A comparative analysis. Scientometrics. 2016: 106(1): 213-28. doi:10.1007/s11192-021-03948-5.

[27] Cobo MJ, Lopez-Herrera AG, Herrera-Viedma E, Herrera F. Science mapping software tools; review, analysis, and cooperative study among tools, J Amer Soc Inform Sci Technol. 2011; 62(7): 1382-402. doi: 10.1002/asi.21525.

[28] Wichaisri S, Sapadan, A. Trends and future future directions in sustainable development. Sustain Develop. 2018; 26(1): 1-17. doi:10.1002/sd.1687.

[29] Aria M, Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J Inform. 2017; 11(4): 959-75. doi:10.1016/j.joi.2017.08.007.

[30] Salton G, McHill MJ. Introduction to Modern Information Retrieval, McGraw-Hill, Auckland. 1983.

[31] Cons P, Latapy M. Computing communities in large networks using random walks. J Graph Algorithms Appl. 2006; 10(2): 191-218. doi:10.7155/jgaa.00124.

[32] Kamada T, Kawai S. An algorithm for drawing general undirected graphs. Inform Process Letters. 1989; 49 (1112): 7-15.doi:10.1016/0020-0190(89)90102-6.

[33] Leydesdorff L. On the normalization and visualization of author co-citation data: Salton's Cosine versus the Jaccard Index. J Amer Inform Sci Technol. 2008; 59(1): 77-85. doi:10.1002/asi.20732.

[34] Pons P, Latapy M. Computing communities in large networks using random walks. In: Yolum P, Güngör T, Gürgen F, Özturan C. (eds) Computer and Information Sciences - ISCIS 2005. Springer, Berlin, Heidelberg. 2005; 284-93. doi:10.1007/11569596_31.

[35] Kang GJ, Ewing-Nelson SR, Mackey L, Schlitt JT, Marathe A, Abbas KM, *et al*. Semantic network analysis of vaccine sentiment in online social media. Vaccine. 2017; 35(29): 3621-38. doi:10.1016/j.vaccine.2017.05.052.

[36] Lee Y, Lee Y, Seong J, Stanescu A, Hwang CS. A comparison of network clustering algorithms in keyword network analysis: a case study with geography conference presentations. Int J Geospat Environ Res. 2020; 7(3): 1-14. https://dc.uwm.edu/ijger/vol7/iss3/1.

[37] Li Y, Jiang H, Lyu X. Virtual reality as an adjunct to pulmonary rehabilitation of patients with chronic obstructive pulmonary disease: a protocol for systematic review and meta-analysis. BMJ Open. 2023; 13(12): e074688. doi: 10.1136/bmjopen-2023-074688.

[38] Rutkowski S, Bogacz K, Rutkowska A, Szczegielniak J, Casaburi R. Inpatient post-COVID-19 rehabilitation program featuring virtual reality-Preliminary results of randomized controlled trial. Front Public Health. 2023; 11: 1121554. doi: 10.3389/fpubh.2023.1121554. eCollection 2023.

[39] Rutkowski S, Bogacz K, Czech O, Rutkowsha A, Szczegielniak J. Effectiveness of an Inpatient Virtual Reality-Based Pulmonary Rehabilitation Program among COVID-19 Patients on Symptoms of Anxiety, Depression, and Quality of Life: Preliminary Results from a Randomized Controlled Trial. Int J Environ Res Public Health. 2022; 19(24): 16980. doi:10.3390/ijerph192416980.

[40] Cerdan-De-las-heras J, Balbino F, Lokke A, Catalan-Matamoros D, Hilberg O, Bendstrup E. Tele-rehabilitation program in idiopathic pulmonary fibrosis-A single-center randomized trial. Int J Environ Res Public Health. 2021; 18(19): 10016. doi:10.3390/ijerph181910016.

[41] Rutkowski S, Szczegielniak J, Szczepanska-gieracha J. Evaluation of the efficacy of immersive virtual reality therapy as a method-supporting pulmonary rehabilitation: A randomized controlled trial. J Clin Med. 2021; 10(2): 1-12, 352. doi: 10.3390/jcm10020352.

[42] Liu H, Yang X, Wang X, Zhang X, Zhang X, Li Q. Study on adjuvant medication for patients with mild cognitive impairment based on VR technology and health education. Contrast Media Mol Imag. 2021: 1187704. doi:10.1155/2021/1187704.

[43] Xie X, Fan J, Chen H, Zhu L, Wan T, Zhou J, *et al*. Virtual reality technology combined with comprehensive pulmonary rehabilitation on patients with stable chronic obstructive pulmonary disease. J Healthc Eng. 2021: 9987200. doi: 10.1155/2021/9987200.

[44] Jung T, Moorhouse N, Shi X, Amin MF. A virtual reality-supported intervention for pulmonary rehabilitation of patients with chronic obstructive pulmonary disease: Mixed methods study. J Med Internet Res. 2020; 22(7): e14178. doi:10.2196/14178.

[45] Rutkowshi S, Rutknowska A, Kiper P, Jastrzebski D, Racheniuk H, Turolla A, et al. Virtual reality rehabilitation in patients with chronic obstructive pulmonary disease: A randomized controlled trial. Int J Chron Obstruct Pulmon Dis. 2020; 15: 117-24. doi: 10.2147/COPD.S223592.

[46] Alves da Cruz, MM, Ricci-Vitor AL, Bonnini Borges GL, Fernanda da Silva P, Ribeiro F, Marques Vanderlei LC. Acute hemodynamic effects of virtual reality-based therapy in patients of cardiovascular rehabilitation; a cluster randomized crossover trial. Arch Phys Med Rehabil. 2020; 10(14): 642-49. doi: 10.1016/j.apmr.2019.12.006.

[47] Knox L, Dunning M, Davies CA, Bennet RM, Sion TW, Phipps K, et al. Safety, feasibility, and effectiveness of virtual pulmonary rehabilitation in the real world. Int J Chron Obstruct Pulmon Dis. 2019; 12: 775-80. doi: 10.2147/COPD.S193827.

[48] Rutkowski S, Rutkowska A, Jastrzebski D, Racheniuk H, Pawetczyk W, Szczegielniak J. Effect of virtual reality-based rehabilitation on physical fitness in patients with chronic obstructive pulmonary disease. J Hum Kinet. 2019; 69(1): 149-57. doi: 10.2478/hukin-2019-0022.

[49] Wardini R, Dajczman E, Yang N, Baltzan M, Prefontaine D, Stathatos M, et al. Using a virtual game system to innovate pulmonary rehabilitation: Safety, adherence, and enjoyment in severe chronic obstructive pulmonary disease. Can Respir J. 2013; 20(5): 357-61. doi:10.1155/ 2013/563861.

[50] Heradio R, Perez-Morago H, Perez-Morago D, Cabrerizo FJ, Herrera-Viedma E. A bibliometric analysis of 20 years of research on software product lines. Inform Sof Technol. 2016; 72: 1-15. doi: 10.1016/j.infsof.2015.11.004.

[51] Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM. How to conduct a bibliometric analysis: An overview and guidelines. J Bus Res. 2021; 133(2021): 285-96. doi:10.1016/j.jbusres.2021.04.070.

[52] Sapountzoglou N. A bibliometric analysis of risk management methods in the space sector. J Space Saf Eng. 2023; 10(1): 13-21. doi:10.13140/RG.2.2.36270.84808/1.

[53] Kokol L, Vosner HB, Zavrsnik J. Application of bibliometrics in medicine; a historical analysis. Health Inform Libr J. 2021; 38(2): 125-38. doi: 10.1111/hir.12295.

[54] Pittara M, Matsangidou M, Pattichis CS. Virtual reality for pulmonary rehabilitation: Comprehensive Review. JMIE Rehabil Assist Technol. 2023; 10: e477114. doi:10.2196/47114.

[55] Luukkonen T, Tijssen R, Persson O, Sivertsen G. The measurement of international scientific collaboration. Scientometrics. 1993; 28(1): 15-36. doi:10.1007/BF02016282.

[56] Kobourov SG. Force-directed drawing algorithms. In. Tamassia R (editor). Handbook of graph drawing and visualization, New York: CRC Press; 2013: 383-408.

[57] Waltman L, van Eck NJ. A smart local moving algorithm for large-scale modularity-based community detection. Eur Phys J B. 2013; 86(11): 471. doi:10.1140/epjb/e2013-40829-0.

[58] Wang S, Koopman R. They are clustering articles based on semantic similarity. Scientometrics. 2017; 111(2): 1017-31. doi:10.1007/s11192-017-2298-x.

[59] De Rezende LB, Blackwell P, Pessanha Goncalves M.D. Research focuses, trends, and major findings on project complexity; A bibliometric network analysis of 50 years of project complexity research. Proj Manag J. 2018; 49(1): 42-9. doi:10.1177/875697281804900104.

[60] Zhuang Y, Liu X, Nguyen T, He Q, Hong S. Global remote sensing research trends during 1991-2010; a bibliometric analysis. Scientometrics. 2013; 96(1): 203-19. doi:10.1007/s11192-012-0918-z.

[61] Colombo V, Aliverti A, Sacco M. Virtual reality for COPD rehabilitation: a technological perspective. Pulmonology. 2022; 28(2): 119-33. doi:10.1016/j.pulmoe.2020.11.010.

[62] Patsaki I, Avgeri V, Rigoulia T, Zekis T, Koumantakis GA, Grammatopoulou E. Benefits from incorporating virtual reality in pulmonary rehabilitation of COPD patients: A systematic review and meta-analysis. Adv Respir Med. 2023; 91(4): 324-36. doi:10.3390/arm91040026.

[63] Nederhof AJ. Bibliometric monitoring of research performance in the social sciences and the humanity: A review. Scientometrics.2006; 66(1): 81-100. doi:10.1007/s11192-006-0007-2.