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Bibliometric Analysis of Wearable Technology Studies in The Healthcare Industry

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ABSTRACT

In recent years, it has been observed that expectations from health services and investments in this field are primarily directed towards studies for the early detection of diseases, more effective monitoring of health conditions, and studies to increase the general quality of life and healthy lifestyle. This study aims to present a bibliometric analysis by examining wearable technology studies in medicine. For wearable technology studies in the medical field, analyzes were performed with 616 articles listed in the Scopus database. The VOSviewer software created an international cooperation network, co-citation author network, and common word network. According to the analysis results, it is seen that the publications are distributed between 1997-2022. The country that contributed the most to these 616 studies in the United States (USA), with 216 publications, followed by China and the United Kingdom. In addition, the USA ranks first among the cooperating countries with the highest connection strength and number of connections. The top contributing author is Najafi, B. Wang J. is the most cited author in the co-citation network author analysis. According to the results of the common word analysis, 5 clusters were formed, and after the most repeated words "wearable technologies" and "wearable technology" were removed, "physical activity" and "machine learning" respectively words. This study is an essential resource to present the current issues of wearable technology studies in the field of health and to examine research trends.

Keywords : *Healthcare, Medicine, Wearable Technology, Bibliometric Analysis*

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Sağlık Sektöründe Giyilebilir Teknoloji Çalışmalarının Bibliyometrik Analizi

ÖZ

Son yıllarda sağlık hizmetlerinden beklentiler ve bu alanda yatırımlar daha çok hastalıkların önceden tespitine yönelik çalışmalara, sağlık durumlarının daha etkin izlenmesi, genel yaşam kalitesinin ve sağlıklı yaşam tarzını arttırılmasına yönelik çalışmalara doğru yöneldiği gözlenmektedir. Bu çalışmanın amacı, giyilebilir teknoloji çalışmalarını tıp alanı özelinde inceleyerek, bibliyometrik bir analiz ortaya koymaktır. Tıp alanındaki giyilebilir teknoloji çalışmaları için, Scopus veri tabanında listelenen 616 makale ile analizler gerçekleştirilmiştir. VOSviewer yazılımı ile, ülkeler arası iş birliği ağı, ortak atıf yazar ağı ve ortak kelime ağı oluşturulmuştur. Analiz sonuçlarına göre, yayınların 1997-2022 yılları arasında dağılım gösterdiği görülmektedir. Bu 616 çalışmaya en çok katkıda bulunan ülke 216 yayın ile Amerika Birleşik Devletleri (ABD), ardından sırası ile Çin ve Birleşik Krallık gelmektedir. Ayrıca, ABD en yüksek bağlantı gücü ve bağlantı sayısı ile iş birliği yapan ülkeler arasında birinci sırada yer almaktadır. En çok katkıda bulunan yazar, Najafi, B.'dir. Ortak atıf ağı yazar analizinde en çok atıfta bulunulan yazar ise Wang J. olarak karşımıza çıkmaktadır. Ortak kelime analizi sonuçlarına göre 5 küme oluşmuştur ve en çok tekrar edilen kelime "giyilebilir teknolojiler (wearable technologies)" ve "giyilebilir teknoloji (wearable technology)" kelimeleri çıkarıldıktan sonra sırasıyla "fiziksel aktivite (physical activity)" ve "makine öğrenmesi (machine learning)" kelimeleridir. Bu çalışma tıp alanında giyilebilir teknoloji uygulamalarının güncel konularını sunmak ve araştırma eğilimlerini incelemek için önemli bir kaynak niteliğindedir.

Anahtar Kelimeler : *Sağlık, Tıp, Giyilebilir Teknoloji, Bibliyometrik Analiz*

INTRODUCTION

Wearable technology applications can be encountered in many areas today. With the rapid progress in information technologies, developers have improved the applicability of wearable technological applications in various sectors, including healthcare (Due, 2014; Kim & Shin, 2015; Lee et al., 2016). The majority of users prefer wearable technological applications with a mobile application or can be compatible with their smartphones. However, there may be different reasons for the preference of wearable technology applications. According to the World Health Organization research, it is stated that the global elderly population aged 60 and over is expected to reach 2 billion by 2050 (WHO, 2015). It is also noted that the aging population has increased risks for chronic diseases, disability, falls, and many other adverse health outcomes (Ambrose et al., 2013). In this sense, depending on the rapidly aging population in the European continent, individuals are trying to keep their health under control and stay healthy with new technological applications (Büyükgöze, 2019, p. 1240).

The word "wearable" is often used together with other words such as technology (wearable technology) devices (wearable devices), and sometimes the word "wearable" is used (colloquially) as a plural (Tehrani & Andrew, 2014). Wearable technologies are defined as "accessories and clothing containing computer and electronic technologies that can be easily worn on the human body" (Wright & Keith, 2014). Wearable technological applications include many devices that can be worn or connected directly to a person (Amft & Lukowicz, 2009).

Wearable technologies can continuously monitor physiological and biochemical parameters and human physical activity and behavior throughout ordinary life. The most generally measured data contain critical signs such as blood tension, body temperature, heart rate, blood oxygen saturation, and physical activity through a cardiogram, ballistocardiogram, and other instruments. In addition, wearable photographic or video instruments can supply further clinical information. Wearable devices can be attached to shoes, earrings, glasses, clothing, watches, and gloves. Wearable devices can also evolve as devices worn on the skin. The sensors can be placed in chairs, car seats, and mattresses (Wu & Luo, 2019). Wearable technologies develop innovative solutions for health problems, contribute significantly to consumer health, and enable users to easily monitor their health status (Zhang et al., 2017).

When the literature on wearable technology applications in health services is examined, it is seen that some wearable technology applications such as physical activity monitoring and weight control are used for disease prevention and protection, disease management, and patient management (Wu & Luo, 2019).

To give an example of the studies carried out in the literature within the framework of these essential titles; studies on disease prevention and health maintenance include wearable devices and related algorithms (Awais et al., 2016), pre-fall and post-impact detection results evaluations to order and analyze rate data to prevent falls (Hsieh et al., 2017). Regarding physical activity and interaction monitoring, the significance of using smartphones and wearable devices to monitor language patterns (Choo et al., 2017), whether reminders can change student posture (Frank et al., 2017); Regarding mental rate monitoring; wearable devices to detect children's stress patterns (Choi et al., 2017), Regarding weight control and tracking; device comparison to measure exercise intensities (Dooley et al., 2017). smart contact lenses measured glucose levels in tears (Zheng et al., 2015). Related to disease management and patient management; use of wearable technology for earlier detection of health imbalances (Ghafar Zadeh, 2015), wearable activity trackers as behavioral interventions to raise reduce sedentary behavior and physical activity (Nguyen et al., 2017), a sensor-based application for patients with regular respiratory complications (Tey et al., 2017). A wearable patch-style heart activity monitoring system to record the electrocardiography signal (Yang et al., 2008), Wearable instruments to detect hypertension by physiological signals (Ghosh et al., 2015). It is seen that studies such as wearable technology screening of psychiatric disorders such as depression (Valenza et al., 2015) are carried out. As can be understood from the research mentioned above, wearable technology stands as a field that is quite wide and includes new studies.

Moreover, many studies have been carried out in many countries on wearable technologies, and they continue to be done. One of them is the research results using the word wearable technology. According to these results, research on wearable technology is still scarce (Dehghani, 2020). Another study observed that the studies on wearable technologies and health developed continuously during the determined dates (2000-2017), and the studies focused on monitoring systems (Burbano-Fernandez & Ramirez-Gonzalez, 2018). Another study tried to identify the different trends and themes that dominate the wearable technology literature and found that it developed between the specified dates (Ferreira et al., 2021). The results of this study show that changes and developments continue in the field of wearable technologies with each passing day, and there is still a need to monitor these changes and monitor the process.

The aim of this study is to present a bibliometric analysis by examining the studies on wearable technology in the field of medicine. In this way, a framework will be drawn by examining the level of studies on wearable technology in the medical field, the growth trajectory, the authors working in this field, and the most used keywords. It is expected to guide researchers who want to work in this field.

The scope of the research consists of 616 articles published on wearable technology in the field of medicine in the Scopus database.

In line with this scope, answers to the following research questions were sought.

1. What is the distribution of wearable technology studies in medicine by years?
2. What is the distribution of the journals in which wearable technology studies in medicine are published?
3. What is the level of contribution and cooperation of countries in wearable technology studies in the field of medicine?
4. What is the distribution of authors contributing to wearable technology studies in medicine?
5. Who are the authors cited by wearable technology studies in the medical field and what is the co-citation author network like?
6. What is the keyword network for wearable technology studies in the medical field?

1. METHOD

The bibliometric method is used to obtain a quantitative analysis of written publications. Researchers use bibliometric analysis for various reasons, such as revealing trends in article and journal performances, collaboration models, and research components, and exploring the intellectual makeup of a particular field in the existing literature (Donthu et al., 2021). Bibliometric analysis is developed with scientific maps representing the relationship between different actors (authors, institutions, countries, etc.). Thus, a science map is a spatial representation of disciplines, fields, specialties, and how individual articles or authors relate to one another (Small, 1999). Various software creates these maps, such as Bibexcel, Biblioshiny, CiteSpace, and VOSviewer. VOSviewer creates a map based on the co-occurrence matrix. Creating the map is a three-step process. A similarity matrix is calculated based on the co-occurrence matrix in the first step. The similarity matrix is derived from a co-occurrence matrix by correcting the matrix for differences in the total number of occurrences or co-occurrence of elements. The second step is to generate a map by applying the VOS mapping technique to the similarity matrix. And finally, in the third step, the map is inverted, rotated, and mirrored. These three transformations are necessary to ensure that VOSviewer produces consistent results (Van Eck & Waltman, 2010). To be able to perform bibliometric analysis, the first step is to decide on the best data source that fits the scientific scope of the research area (Moral-Muñoz et al., 2020).

The first search was done on February 9, 2022, to identify publications in the Scopus database with the keywords "wearable technologies" or "wearable technology." The 19517 results listed are restricted to the subject area "medicine" and the document type to "article." The string used in the last search is as follows; KEY ("wearable technology" OR " wearable technologies") AND (LIMIT-TO (SUBJAREA, "MEDI")) AND (LIMIT-TO (DOCTYPE, "ar")). In line with these constraints, 616 studies were listed. The data were downloaded in CSV format and made ready for analysis.

In this study, citation analysis, countries collaboration, co-citations, cited authors network, and co-occurrence keyword was analyzed using VOSviewer software. The graphs of the change in the number of publications by year, country, and journal were created with Microsoft Excel.

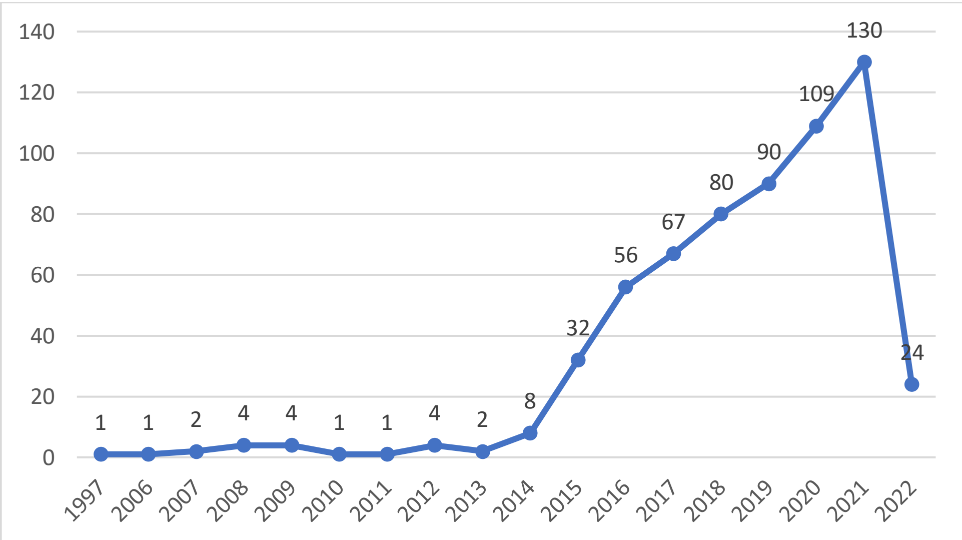
VOSviewer is a software that provides visualization of bibliometric networks (Van Eck & Waltman, 2014). Bibliometric network nodes and edges are essential for interpreting software-generated outputs (Mohamed et al., 2020, p.36). According to Van Eck and Waltman (2014, p.289), many issues should be considered when talking about nodes and edges: i) the size of the circles (nodes) indicates the frequency of entities such as the number of publications, the number of citations; ii) the distance between the nodes shows the relatedness of the nodes (closed nodes are more related); iii) the edges show the relationships and strength of the relationship between two nodes, and iv) the color of the nodes shows the classifications of the nodes. Colors represent a group of closely related commodities.

2. FINDINGS

With 616 wearable technology studies in medicine listed in the Scopus database, the distribution of publications by years, the number of citations, international contributions and collaborations, prominent journals, and keyword analysis were carried out.

The first research question focuses on determining the distribution of publications by year. For this reason, as a result of the analysis, it was seen that the publications were distributed between 1997-2022. Graph 1 was created regarding the distribution of publications by year.

A general search for the keywords "wearable technologies" or "wearable technology" in the Scopus database reveals that the first study in medicine was published in 1997. However, in other fields, the first study was done in 1991. Until 2013, the studies remained low, but after 2013, there was a severe increase.



Graph 1: Distribution of Publications by Years

The second research question focuses on determining the journal distribution to which the publications belong. Therefore, the analysis shows that there are 199 journals these 616 publications were published. According to the analysis results, Table 1, which includes the top 10 journals with the highest number of publications, was created.

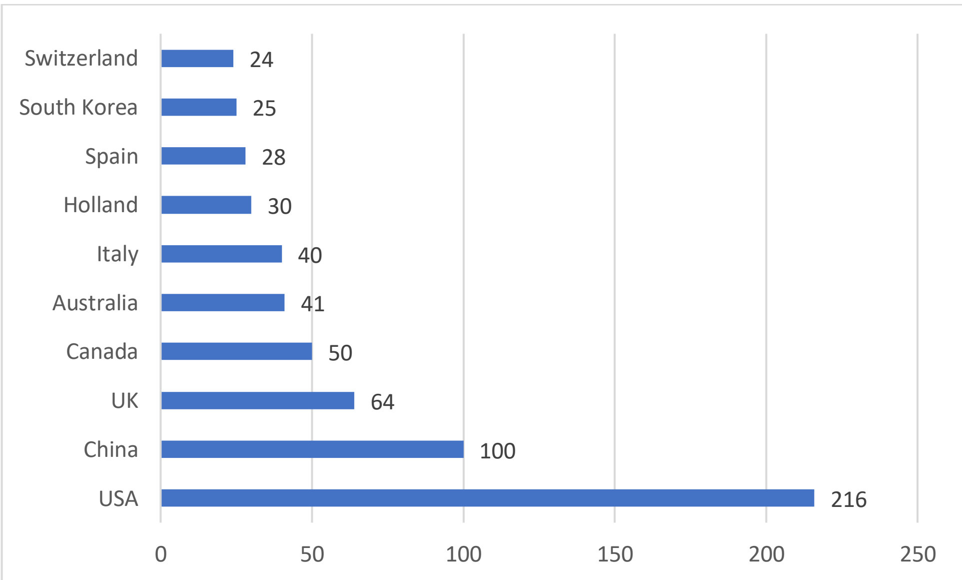
When Table 1 is examined, IEEE Transactions on Rehabilitation Engineering and Neural Systems, which ranks first with 54 publications, is published in computer science, engineering, medicine, and neuroscience. According to the Scimago Journal & Country Rank (SJR) data, the h-index is 144. Ranking second in terms of the number of publications, Advanced Science magazine publishes in chemical engineering, materials science, medicine, physics, and astronomy. According to SJR data, the h-index is 100. The Physiological

Measurement journal, which ranks third, publishes in biochemistry, genetics, molecular biology, biomedical engineering, and medicine. According to SJR data, the h-index is 101.

Table 1: Journal Ranking by Total Number of Publications

No	Publication Name	Number of Publications
1	IEEE Transactions on Rehabilitation Engineering and Neural Systems	54
2	Advanced Science	32
3	Physiological Measurement	31
4	Journal of Biomechanics	24
5	Journal of Healthcare Engineering	22
6	Biomedical Signal Processing and Control	19
7	Computers in Biology and Medicine	17
8	BioMedical Engineering Online	16
9	Healthcare Technology Letters	15
10	JMIR mHealth and uHealth	13
10	Computer Methods and Programs in Biomedicine	13

The third research question focuses on measuring the contribution level of countries in wearable technologies studies in medicine. According to the analysis results made for this purpose, Graph 2 was created for the countries with the highest number of publications. The most significant contributor is the USA, with 216 publications then, followed by China and the UK.



Graph 2: Countries by Number of Publications

As a result of the analysis with VOSviewer, it was seen that 37 of the 74 contributing countries emerged in the collaboration network. According to the cross-country cooperation network in Figure 1, the USA ranks first among the cooperating countries with the highest connection strength (119) and the number of connections (26). United Kingdom (19) and China (15) follow the USA.

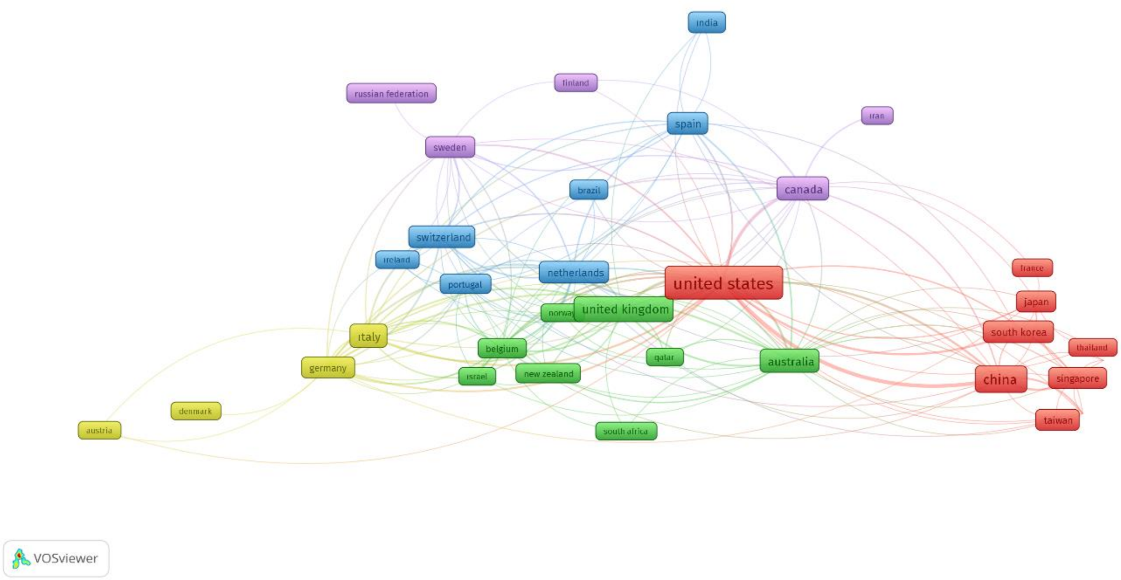


Figure 1: Country Collaboration Network

The fourth research question identifies the authors who contributed to wearable technology studies in medicine. A total of 2,911 authors contributed to these 616 publications listed in the Scopus database for wearable technology studies in medicine. Table 2, which includes 9 authors with more than 3 publications, was created.

Table 2: Contributing Authors

Author	Number of Publications
Najafi, B.	10
Bazaev, N.A.	7
Rochester, L.	5
Robertson, S.	4
Papi, E.	4
Mohler, J.	4
McGregor, A.H.	4
Del Din, S.	4
Galna, B.	4

When Table 2 is examined, the most productive authors are Najafi with 10 publications, B. Bazaev with 7 publications, N.A. and Rochester, L. with 5 publications. When the authors in the table are examined, it is determined that most of them work in medicine and engineering.

The fifth research question identifies the authors cited by wearable technology studies in medicine and the network of authors. The 616 studies included in the research referred to 24541 studies in total. The number of cited authors is 46672. The minimum number of citations to an author was chosen as 20 among 46672 authors to create the co-author network. Since all

182 listed authors were linked, 182 authors were included in the common network analysis in Figure 2.

When Figure 2 is examined, the size of each node and node reflects the author's co-citation volume. The most cited and most connected author is Wang J. The author with the second-highest number of publications is Najafi, B.

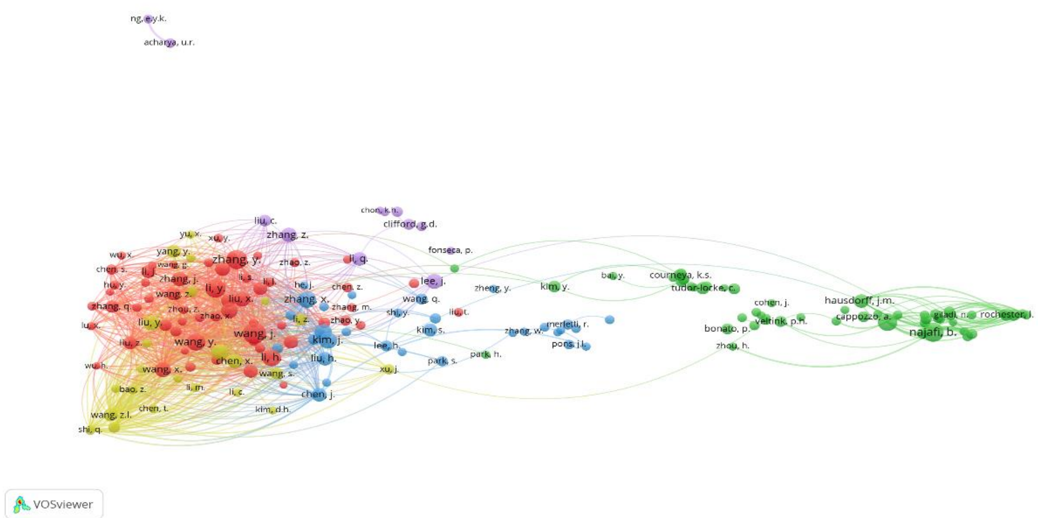


Figure 2: Co-Cited Author Analysis Network

The sixth research question focuses on finding the keyword network for wearable technology studies in medicine. Identifying commonly studied concepts provides a different perspective on the conceptual structure of the knowledge base within the relevant data boundary (Mohamed et al., 2020, p.42). Keyword co-occurrence indicates a keyword occurring together in two documents. The presence of two keywords in the same article indicates a relationship between the topics they refer to (Cambrosio et al., 1993). The co-occurrence keywords search was set to "author-defined keywords". There are 1935 author-defined keywords in 616 studies Out of the 53 keywords that cross the threshold of at least 5 co-occurring, 52 words connecting are observed in the common word network. The map of co-occurrence keywords is shown in Figure 3. On the other hand, it is seen that the keywords create 5 clusters, and the fastener of these clusters is the "wearable technology" cluster. Clustering is a technique of placing objects in a group based on similarity or difference (Ravikumar et al., 2015). An item with a higher weight is considered more important than an item with a lower weight. VOSviewer assumes the weight properties have a ratio scale. In other words, if the weight of one item is twice the weight of another item, the previous item is considered twice as important as the second item. The weight given to the color of a particular cluster is determined by the number of items belonging to that cluster in the neighborhood of the point (Van Eck & Waltman, 2013).

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When the words that make up the green cluster were examined, it was observed that the words "deep learning", "machine learning", "heart rate" were found together. When the words that make up the red cluster are examined, it is seen that the words "digital health", "mobile health", "smartphone" are found together. It is seen that the words "elderly", "fatigue", "Parkinson's disease", which make up the blue cluster, take place together. Purple and yellow words are sets with fewer elements. The word "google glass" in the yellow cluster stands apart from other words. This distance means that the connection strength is low. Among the words that make up, the purple cluster is the words "EMG", “electromyography" "stroke", and "ECG".

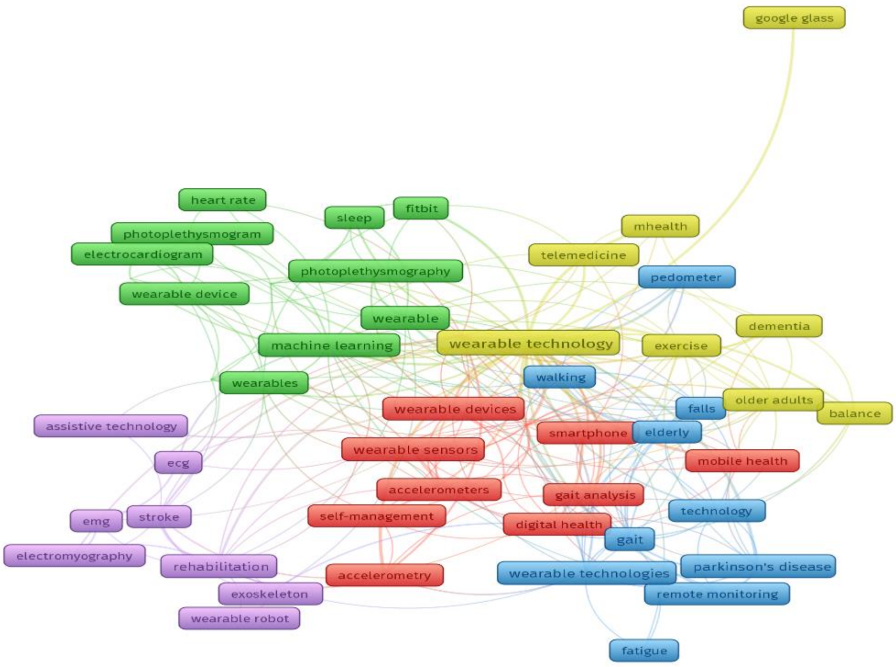

Fıgure 3: Co-occurence Keywords Network

Vosviewer helps us to find out the frequency and co-occurrences of keywords from a document in a corpus. Each cluster is represented keywords having highest frequency in the cluster. Position of a cluster (sub-domain) in the graph depicts the relation of its keyword with other clusters (Ravikumar et al., 2014).

When the most repetitive words are examined, it is seen that the keyword "wearable technology" is used more than the word "wearable technologies" in studies. Table 3, which includes all the words repeated at least 5 times, was created.

Table 3: Keyword Frequency and Link Strength

Keyword	Frequency	Connection Strength	Keyword	Frequency	Connection Strength
Physical Activity	33	50	Elderly	7	19
Machine Learning	21	28	Mhealth	7	11
Wearable	20	16	Photoplethysmography	7	10
Wearable Devices	20	19	Telemedicine	7	10
Accelerometer	18	30	Actigraphy	6	12
Wearable Sensors	18	16	Assistive Technology	6	5
Gait	16	33	Biomechanics	6	10
Parkinson's Disease	14	20	Dementia	6	11
Rehabilitation	14	23	Electromyography	6	7
Stroke	13	18	Exoskeleton	6	6
Wearables	13	13	Google Glass	6	5
Wearable Device	12	10	Heart Rate	6	4
Exercise	11	25	Pedometer	6	12
Mobile Health	11	16	Sleep	6	10
Older Adults	11	22	Smartphone	6	10
Accelerometry	10	19	Balance	5	12
Digital Health	10	15	Emg	5	7
Wearable Electronics	9	0	Fatigue	5	3
Ecg	8	7	Gyroscope	5	9
Electrocardiogram	8	10	Photoplethysmogram	5	9
Falls	8	21	Remote Monitoring	5	11
Fitbit	8	11	Self-Management	5	8
Gait Analysis	8	12	Technology	5	15
Heart Rate Variability	8	10	Walking	5	14
Accelerometers	7	11	Wearable Robot	5	2
Deep Learning	7	6			

4. CONCLUSION AND DISCUSSION

In this research, publications on "wearable technology" in the literature were revealed using content analysis and bibliometric analysis methods. In Scopus, the distribution of publications on "wearable technology" by years, journals, authors, and countries were examined using content analysis. Then, co-citation author, co-author, and common word analyzes of the publications in the literature on "wearable technology" were carried out with the bibliometric analysis method.

According to the results obtained from the research, it is seen that the studies in the field of wearable technology did not show a regular increase between 1997 and 2013, but there has been a severe increase since 2013. As of February 9, 2022, when the data was analyzed, it is seen that the number of publications for 2022 is 24.

These results highlight the increase in the importance of wearable technology. When the clusters formed in the common word analysis were examined, it was seen that the studies focused on the product-oriented development of wearable technology, the technology behind it, and health services focusing on the health status of patients. The findings demonstrate the underlying structure of this cross-cutting area of study, highlighting the emergence of wearables in healthcare. The study also highlights the current status of wearable technologies in healthcare and is expected to drive future research. As with similar studies, it shows that the greatest potential for wearable technologies is concentrated in health and other areas (Chan et al., 2012; Sultan, 2015; Burbano-Fernandez & Ramirez-Gonzalez, 2018).

When the authors who contributed the most to 616 studies published in the Scopus database on "wearable technology" and the cited authors are examined, it is seen that their fields of study are general medicine and engineering. These results are similar to the bibliometric analysis conducted by Dehghani (2020) between 2010 and 2016 with 7279 studies including wearable technology and words with combinations in the Scopus database. According to Dehghani (2020, p.13), scientists mainly focused on health care during the period studied, such as rehabilitation and disabled patients.

When the common word analysis of wearable technology studies in Scopus is examined, it is seen that there are 5 clusters. The shorter the distance between two terms, the closer the relationship between them, and therefore the higher the number of co-occurrences in keyword groups for each cluster. To elaborate further, the red cluster is heavily represented by academics whose research focuses on the connection of products with technology (such as digital health, mobile health). The green cluster is dominated by underlying technology-related terms such as "deep learning" and "machine learning." The words in this cluster focus on health issues such as "heart rate" and "heart rate variability." The words "fatigue," "elderly," and "parkinson's disease" are in the blue cluster. It is seen that the other words used in this cluster are related to "walking," "remote monitoring," "pedometer." It is seen that there is a relationship between the subjects that researchers focus on, especially for diseases that may occur in older ages. Similarly, Burbano-Fernandez and Ramirez-Gonzalez (2018) found that the "older" theme was essential. The fact that the word "google glass" in the yellow cluster is separate from other words indicates low connection strength. At the same time, the low number of repetitions concludes that the researchers do not show much inclination to this issue. Among the words that make up the purple cluster is the words "EMG," "stroke," and "ECG". This cluster also seems to focus more on devices.

5. RECOMMENDATIONS AND LIMITATIONS

This research is limited to the articles obtained due to the search made with the keywords "wearable technology" or "wearable technologies" in the Scopus database. For this reason, the results of the research are limited to the relevant data only. Another limitation is that only articles were included in this study.

It is predicted that wearable technology will undoubtedly be more effective in the field of health in the coming years. As a result of increasing scientific research, health services will become wholly virtual, increasing with artificial intelligence-based systems (Akalın & Veranyurt, 2020). In this sense, the need for wearable technology applications in health is increasing day by day. However, the adoption of these devices has been relatively slow compared to mainstream technologies such as smartphones (Kalantari, 2017). In addition to all these, better designs are needed for mass appeal in wearable technology applications, and they need to be integrated more seamlessly into daily life. Although wearable technology applications are increasing day by day, many applications are still in the prototype stage. In future studies, it is thought that cases such as security, user acceptance, ethics, and significant data matters in wearable technology should be investigated to improve the functionality and usability of these gadgets for advantageous use.

Wearables have had a significant influence on one of the areas where traditional healthcare systems are transforming into active models that will take care of a patient's medical state through continuous monitoring and early diagnosis of the problem (Thakkar, et al, 2022). Larger studies are required to estimate the true potential of wearable technology (Gordt et al., 2018).

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