

Research Hotspots of the Rehabilitation Medicine Use of sEMG in Recent 12 Years: A Bibliometric Analysis

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Objective: Surface electromyography (sEMG) has been widely applied to rehabilitation medicine. However, the bibliometric analysis of the rehabilitation medicine use of sEMG is vastly unknown. Therefore, this research aimed to investigate the current trends of the rehabilitation medicine use of sEMG in the recent 12 years by using CiteSpace (5.8).

Methods: Literature relating to rehabilitation medicine use of sEMG from 2010 to 2021 was retrieved from the Web of Science. CiteSpace analyzed country, institution, cited journals, authors, cited references and keywords. An analysis of counts and centrality was used to reveal publication outputs, countries, institutions, core journals, active authors, foundation references, hot topics and frontiers.

Results: A total of 1949 publications were retrieved from 2010 to 2021. The total number of publications continually increased over the past 12 years, and the most active countries, institutions, journals and authors in rehabilitation medicine use of sEMG were identified. The most productive country and institution in this field were America (484) and the University of Sao Paulo (36). Andersen LL (28) was the most prolific author, and Dario Farina ranked first among the cited authors. Besides, there were three main frontiers in keywords for sEMG research, including “activation”, “exercise”, and “strength”.

Conclusion: The findings from this bibliometric study provide the current status and trends in clinical research of rehabilitation medicine use of sEMG over the past ten years, which may help researchers identify hot topics and explore new directions for future research in this field.

Keywords: surface electromyography, rehabilitation medicine, bibliometric analysis, CiteSpace

Introduction

Surface electromyography (sEMG) referred to the collective electric signal from muscles controlled by the nervous system and produced during muscle contraction and is guided and recorded from the surface of the human power through the electrode.^{1,2} Placing the surface electrode on the skin and conducting, amplifying, displaying and recording these electrical signals can reflect the synchronization of motor unit activities, muscle fibre recruitment, muscle fatigue, muscle activation sequence and activation time to a certain extent.³ The standard analysis methods of sEMG could be divided into the time-domain analysis (linear analysis) and frequency domain analysis (nonlinear analysis). The common analysis indexes in domain analysis were average electromyography (AEMG), root mean square (RMS), integrated electromyography (iEMG) and synergistic contractility; the frequency domain indicators included median frequency and average power frequency.⁴ Mulroy applied sEMG to analyze the electromyography activities of the supraspinatus muscle and posterior deltoid muscle in patients with post-stroke hemiplegic shoulder pain and compared the degree of shoulder subluxation and pain local muscle activation and upper limb function before and after treatment.⁵ The results showed that task-oriented EMG biofeedback treatment could improve the degree of shoulder subluxation, pain, muscle activation and upper limb role in patients with post-stroke hemiplegic shoulder pain. Tabard used surface electromyography

biofeedback (sEMG-B) to diagnose and treat the elderly after stroke and determined the effectiveness of sEMG-B in the muscles responsible for hand extension and foot dorsum extension in elderly subjects after stroke.⁶ sEMG signals are considered most useful as electrophysiological signals in medical and engineering fields.^{5,7} As a safe and noninvasive tool for neuromuscular function evaluation, sEMG is widely used in rehabilitation medicine.^{8–10}

Bibliometrics is a cross-science that uses mathematical and statistical methods to analyze all knowledge carriers quantitatively.¹¹ It is a statistical analysis and quantitative tool for research publications. Evaluative bibliometrics is a field of quantitative science that has emerged as a powerful tool to evaluate research performance, which can identify influential articles that have shaped the medical practice and fostered new research ideas.^{12–14} In recent years, there has been growing recognition of the significance of the rehabilitation medicine use of sEMG. At present, the number of papers published in related fields is increasing, but no scholars have carried out a comprehensive literature visual analysis based on a knowledge map in this field. Therefore, it is essential to understand the current status of the rehabilitation medicine use of sEMG as a whole. This study aims to evaluate the research trends of the rehabilitation medicine use of sEMG and conduct a macroscopic overview of a significant amount of academic literature in the past 12 years through bibliometric analysis.

CiteSpace visual analysis software is a kind of scientific literature visual analysis software based on Java language, created by Dr Chaomei Chen (School of Information Science and Technology, Drexel University, Philadelphia, PA, USA).^{15,16} In this study, CiteSpace was used to make a bibliometric analysis to explore the current status and research trends on the global rehabilitation medicine use of sEMG within the past 12 years (from 2010 to 2021). All eligible literature was extracted from the Web of Science database to provide some reference for the research in this field and the development of related disciplines.

Methods

Data Source and Search Strategy

Two independent searchers selected the retrieval data used for measurement and statistical analysis from the Web of Science Core Collection (WoSCC). It provides citation search, allows access to multiple databases referring to interdisciplinary research, and allows in-depth exploration of professional subareas. The data retrieval time range was from January 1, 2010, to December 31, 2021; the data type of WoSCC was “article” and “review”, the language was “English”, and data such as conference abstracts, proofreading notices, news, conference papers and withdrawal notices were excluded. Full-text records and cited references were selected in plain text format and downloaded for further analysis. The specific search strategies are shown in Table 1.

Table 1 The Topic Search Query

Set	Search Query
#1	TS=(rehabilitation)
#2	TS=(rehabilitation treatment)
#3	TS=(physiotherapeutics)
#4	TS=(therapy)
#5	TS=(electromyogram)
#6	TS=(electromyography)
#7	TS=(EMG)
#8	(#1 OR #2 OR #3 OR #4) AND (#5 OR #6 OR #7)

Abbreviation: sEMG, surface electromyography.

Analysis Tool and Data Analysis

This study utilized CiteSpace V.5.8.R3 to analyze existing studies related to the rehabilitation medicine use of sEMG and aims to evaluate the research trends in this field.¹⁷ CiteSpace was invented by Dr Chaomei Chen (School of Information Science and Technology, Drexel University, Philadelphia, PA, USA) and his team in 2004 and used to determine the information related according to countries, institutions, active authors, foundation references and so on in the data. The parameters of CiteSpace were set as below: selected the period was from January 2010 to December 2021, years per slice (1); the subject word source and critical path were the system default values; the threshold item was selected as “top n” and liked it to 50. Visualization knowledge figures were mainly composed of nodes and links. The node type was determined according to the kind of analysis performed. The node types, countries, institutions, authors and keywords were analyzed to form visualization knowledge figures. The observable indicators in the Visualization knowledge figures were: the number of nodes, node size and colours of nodes, etc. The node’s size, which commonly suggests the frequency of appearance or citation, and links between nodes represent relationships of collaboration. The purple circles represent centrality. High centrality is usually regarded as a turning point or critical point in the field.^{18,19}

Results and Discussion

Annual Publications Trends

Through the method of searching topic words, it was found that a total of 1949 articles in related fields were included on the Web of Science. The number of rehabilitation medicine use of sEMG research papers was generally increasing year by year, but the growth rate was slow. The number of articles published each year is shown in Figure 1. The period from 2010 to 2014 was a gradual development period, and the publication outputs were 133 references in 2010, rising to 187 contacts in 2014. However, from 2014 to 2015, publications decreased from 187 references to 146 references. From 2015 to 2019, the number of articles published increased significantly, and the highest number of articles published in 2019 was 193 references, reaching the peak in the recent 12 years. However, the number of articles published felled to 153 in 2018. Furthermore, the number of publications decreased slightly, from 193 references in 2019 to 186 references in 2021, but it remained at a high level. These results indicate that sEMG, detection and treatment tool for rehabilitation medicine, is receiving increased attention, and more surface electromyography research is being performed.^{20–25}

Analysis of Country and Institution

The country distribution map was generated through CiteSpace, and 79 nodes and 243 links form the combined network (Figure 2). The 1949 references were published by researchers in 79 countries. The top five countries in the publication quantity were the USA, the People’s Republic of China, Canada, Brazil and Italy (Table 2). A total of 484 articles have been published in the United States, which may be related to the origin of EMG in the West. China was ranked in

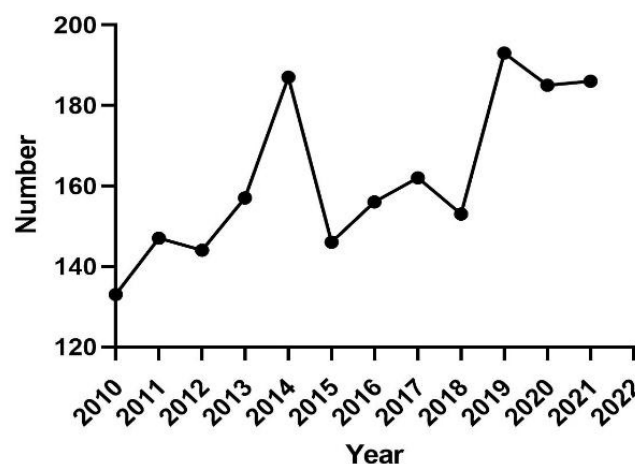


Figure 1 The annual number of publications on the rehabilitation medicine use of sEMG between 2010 to 2021 on the Web of Science.

Abbreviation: sEMG, surface electromyography.



Figure 2 Map of countries researching the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.

Abbreviation: sEMG, surface electromyography.

the second position in the number of published literature (200), indicating that the rehabilitation medical application of sEMG has been widely used in China. The top five countries in terms of centrality (purple round) were the USA (0.41), Germany (0.23), Australia (0.19), Italy (0.12) and England (0.10), which indicated that these five countries had established good research cooperation relations with other countries (Table 2). Interestingly, the USA was not only the most prolific country but also the highest centrality country, suggesting that the USA is the most important country for researching rehabilitation medicine of application of sEMG. Analysis shows that China has issued many publications in the past 12 years, but the centrality was not dominant (0.05).^{26–28}

The institution distribution map was generated through CiteSpace, and 381 nodes and 284 links form the combined network (Figure 3). The 1949 references were distributed among 381 research institutions. The top five institutions in the publication quantity were the University of Sao Paulo, Yonsei University of Korea, University of Montreal, University of Aalborg and Shanghai Jiaotong University (Table 2). The University of Sao Paulo in Brazil has published the most significant number of studies (36), followed by the Yonsei University of Korea (28) and the University of Montreal in Canada (20). Therefore, based on the publications, we found that the institutions from Brazil, Korea, Canada and China paid more concerned with the research of the rehabilitation medicine use of sEMG currently.^{29,30}

Analysis of Author and Cited Authors

The authors of the 1949 publications were analyzed and resulted in 553 nodes and 566 links (Figure 4), expressing that the 1949 articles were published by 553 authors. Eight authors have published more than 15 articles. The author map was

Table 2 Top 10 Prolific Countries and Institutions Were Researching the Rehabilitation Medicine Use of sEMG Between 2010 to 2021 on the Web of Science

Ranking	Country	Publications	Centrality	Ranking	Institution	Publications
1	USA	484	0.41	1	University of Sao Paulo	36
2	China	200	0.05	2	Yonsei University of Korea	28
3	Canada	160	0.07	3	University of Montreal	20
4	Brazil	145	0.06	4	University of Aalborg	20
5	Italy	139	0.12	5	Shanghai Jiaotong University	18
6	South Korea	115	0.00	6	Northwestern University	17
7	Japan	90	0.01	7	Hong Kong Polytechnic University	15
8	Australia	84	0.19	8	China University of science and technology	15
9	Germany	81	0.23	9	Natural resources and Environment Center	14
10	England	67	0.10	10	University of Waterloo	14

Abbreviation: sEMG, surface electromyography.

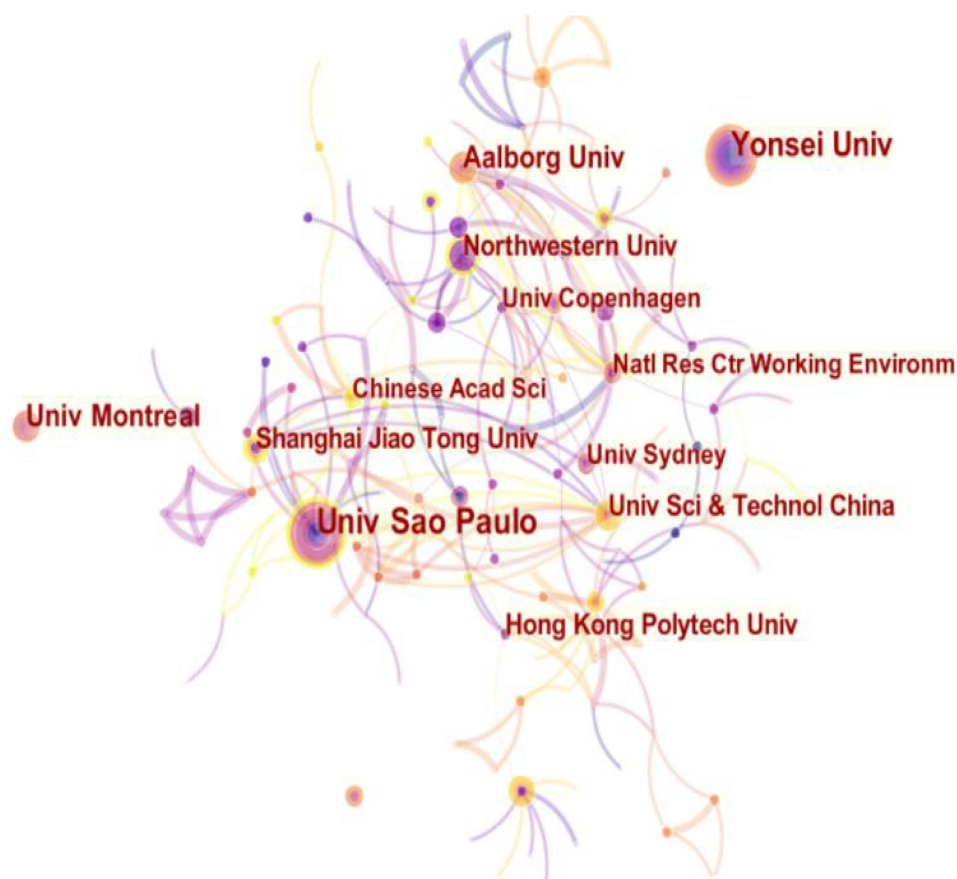


Figure 3 Map of institutions researching the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.

Abbreviation: sEMG, surface electromyography.

designed to show the most productive authors and reveal the close cooperation between authors, which could provide messages about influential research teams and latent cooperators and help researchers build partnerships. The top 5 authors were Andersen LL, Zhang X, Zhou P, Chen X and Hu XL (Table 3).^{29,31–39} They are active and professional authors in this field. The most prolific author was Andersen LL, from the Mayo Clinic in the United States, with 28 articles. Andersen LL chose high-intensity resistance training for the prevention and rehabilitation of musculoskeletal injuries and diseases and measured the degree of muscle activation with electromyography. His results show that a relatively high level of muscle activation was obtained in resistance training using dumbbells and flexible catheters, and sEMG can be a valuable tool to detect muscle activation. There were some collaborations between Andersen LL, Zhang X, Zhou P, and Hermens HJ. However, the centrality for such partnerships was low, and Professor Farina D had the highest document centrality (0.17). This indicates a lack of close cooperation among authors in this field. In the future, authors can strengthen collaboration and create more high-quality research.

The map of cited authors was composed of 642 nodes and 3661 links (Figure 5). The top five cited authors were Hermens HJ, De Luca CJ, Farina D, Hodges PW and Winter DA. Hermens HJ had the highest citation counts (405), followed by De Luca CJ (207), Farina D (186), Hodges PW (176) and Winter DA (152) (Table 3). Hermens HJ ranked first in the cited author frequency, and he is a professor at the University of Virginia. There is some cooperation among the author teams, which is more evident among the high-yield authors, but there is a lack of highly focused authors. Chinese scholars account for 50% of the highly influential authors.

Analysis of Cited References

The map of cited references with 641 nodes and 1214 links were obtained (Figure 6). The top 10 frequency of cited references were shown in Table 4. By analyzing the literature with high co-citation frequency, we can obtain the



Figure 4 Map of author related to the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.

Abbreviation: sEMG, surface electromyography.

knowledge base of this field. The top 5 articles were published in Physical Therapy, Journal of Orthopaedic & Sports Physical Therapy, Lasers in Medical Science, BMC Musculoskeletal Disorders and Journal of Orthopaedic & Sports Physical Therapy, respectively, implying that the importance of these articles in this field, which has also had a far-reaching impact in this field. The cited situation was one of the important indicators to reflect the research hotspots. Through reading and analyzing the documents with high cited frequency and centrality, we could understand some research results with high attention, so as to reveal the areas of concern in the research. It was found that resistance training, biomechanics, low-intensity laser EMG therapy, shoulder joint, injury risk, trunk muscle and lower limb muscle strength had received extensive attention from researchers by reading and analyzing the top 10 highly cited literatures.⁴⁰ Among the top 10 highly cited literatures, there were 4 literatures on Low-level laser therapy (LLLT). Some scholars

Table 3 Top 10 Prolific Authors and Cited Authors Related to the Rehabilitation Medicine Use of sEMG Between 2010 to 2021 on the Web of Science

Ranking	Author	Country	Publications	Ranking	Cited Author	Cited Frequency
1	Andersen LL	USA	28	1	Hermens HJ	405
2	Zhang X	Denmark	27	2	De Luca CJ	207
3	Zhou P	China	24	3	Farina D	186
4	Chen X	China	22	4	Hodges PW	176
5	Hu XL	China	18	5	WINTER DA	152
6	Politti F	Brazil	17	6	Merletti R	152
7	Cynn HS	South Korea	16	7	Escamila RF	138
8	Tong KY	China	15	8	Ekstrom RA	135
9	Chen Y	China	14	9	Anonymous	129
10	Song R	China	14	10	BOHANNON RW	128

Abbreviation: sEMG, surface electromyography.

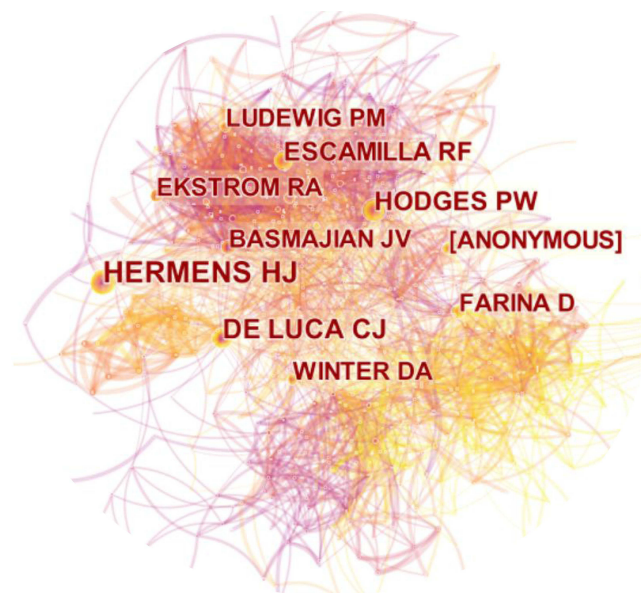


Figure 5 Map of cited author related to the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.
Abbreviation: sEMG, surface electromyography.

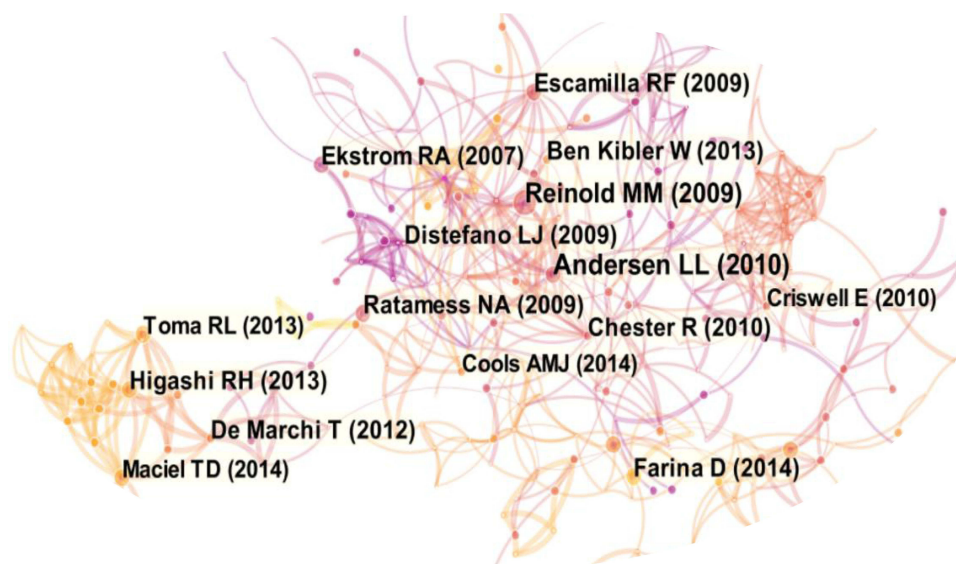


Figure 6 Map of cited references related to the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.
Abbreviation: sEMG, surface electromyography.

believed that using LLLT before high-intensity running can improve exercise performance and reduce exercise-induced oxidative stress and muscle injury, which indicated that the regulation of LLLT on oxygenation reduction system might be related to the delay of skeletal muscle fatigue observed after using LLLT.⁴¹

Analysis of Keyword

Keyword Cooccurrence

With the passage of time, the knowledge map of keyword co-occurrence could reflect the research hotspots, and burst keywords play a key role in summarizing the frontier topics of research. The map of keywords co-collocation was produced and consisted of 455 nodes and 668 links (Figure 7). An analysis in the light of co-occurrence frequency and centrality (Table 5 and Figure 7) disclosed that the hot keywords were activation, abdominal muscle, exercise, disability,

Table 4 Top 10 Frequency of Cited References Related to the Rehabilitation Medicine Use of sEMG Between 2010 to 2021 on the Web of Science

Ranking	Representative Author (Publication Year)	Cited Reference	Frequency
1	Andersen LL (2010) ³¹	Muscle activation and perceived loading during rehabilitation exercises: comparison of dumbbells and elastic resistance.	10
2	Reinold MM (2009) ³²	Current concepts in the scientific and clinical rationale behind exercises for glenohumeral and scapulothoracic musculature.	9
3	De Marchi T (2012) ³⁹	Low-level laser therapy (LLLT) in human progressive-intensity running: effects on exercise performance, skeletal muscle status, and oxidative stress.	8
4	Chester R (2010) ³³	The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies.	8
5	Distefano LJ (2009) ³⁴	Gluteal muscle activation during common therapeutic exercises.	8
6	Escamilla RF (2009) ³⁵	Shoulder muscle activity and function in common shoulder rehabilitation exercises.	8
7	Kraemer WJ (2009) ³⁶	American College of Sports Medicine position stand. Progression models in resistance training for healthy adults.	8
8	Farina D (2014) ²⁹	The extraction of neural information from the surface EMG for the control of upper-limb prostheses: emerging avenues and challenges.	8
9	Higashi RH (2013) ³⁷	Effects of low-level laser therapy on biceps brachialis muscle fatigue in young women.	8
10	Ekstrom RA (2007) ³⁸	Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises.	8

Abbreviation: sEMG, surface electromyography.

controlled trial, low back pain and feedback. Andersen found that a higher level of muscle activation was obtained by comparing the muscle activation and perceived load of dumbbell and elastic catheter in upper limb resistance training. Chester, DiStefano, Escamilla and Ekstrom explored the role of sEMG in assessing the risk of injury by stimulating different parts of sEMG.

Burst Keywords

Burst words represent frequently cited keywords in a certain period of time, indicating hot spots and trends. Figure 8 shows the top 8 keywords with the most powerful citation burst from 2010 to 2021. The mutation cycle of six burst words is concentrated in 2010–2015. The most recent burst keywords were lumbar spine, risk factor and design. The emg analysis was the most intense mutation (6.32); the second was the lumbar spine (5.68); in the third place was the risk factor (5.16). The research on the burst word “design” continued until now, and it was likely to maintain the research heat all the time.

Keyword Cluster

The clusters were named by extracting keywords from the titles of references as tags. The LLR (log-likelihood ratio) algorithm was used for the purpose of the extraction method. Figure 9 demonstrates the clustering visualization of the keyword co-reference network, which is divided into ten co-reference clusters. The top five keyword clusters were 0# pattern recognition, 1# low back pain, 2# transcranial magnetic stimulation, 3# kinematic, 4# shoulder and 5# trunk muscles. The keyword cluster of #0, #1, #2, #3 were closely intertwined, which could be summarized as the scope of application of sEMG; the cluster of #4, #5, #6, #7 were staggered, which could be translated as the applicable parts of sEMG. The keyword co-occurrence and cluster analysis could obtain biomechanical angles, different muscle parts, different populations and randomized controlled trials, which were the research hotspots in this field.

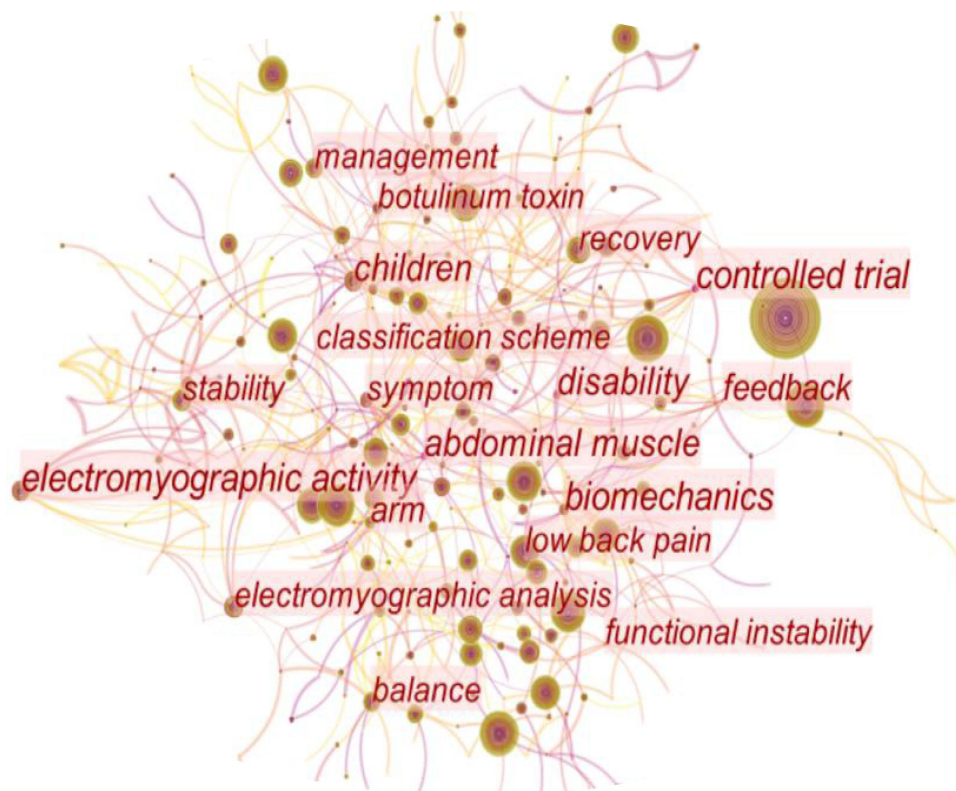


Figure 7 Map of keywords occurrence related to the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science.

Abbreviation: sEMG, surface electromyography.

There were some limitations in our study. Firstly, we only searched the literature in the core database of the web of science, which might ignore the high-quality literature of other databases in this field. There were some limitations in literature retrieval, which was not conducive to the summary of research hotspots. In addition, although the research subject words were limited in the search, we could not ensure that every document was wholly related to the subject. However, we believe that our research can still be used to describe the overall situation and trends in the rehabilitation medicine use of the sEMG field.

Conclusion

As a safe and noninvasive detection technology for quantifying the bioelectrical activity of the neuromuscular system, sEMG was helpful to deeply understanding the behaviour of the neuromuscular system and can better evaluate the

Table 5 Top 10 Frequency and Centrality of Keywords Related to the Rehabilitation Medicine Use of sEMG Between 2010 to 2021 on the Web of Science

Ranking	Keyword	Frequency	Ranking	Keyword	Centrality
1	Rehabilitation	302	1	Abdominal muscle	0.26
2	Activation	173	2	Disability	0.23
3	Exercise	170	3	Controlled trial	0.22
4	Strength	149	4	Electromyographic activity	0.18
5	Therapy	143	5	Symptom	0.16
6	Emg	134	6	Feedback	0.14
7	Reliability	131	7	Classification scheme	0.14
8	Muscle	118	8	Children	0.13
9	Performance	107	9	Motor control	0.12
10	Low back pain	103	10	Biomechanics	0.12

Abbreviation: sEMG, surface electromyography.



Figure 8 Top 8 keywords with the strongest citation bursts from 2010 to 2021 on the Web of Science. The red bars demonstrated that the keyword was cited frequently, the green bars showed that the keyword was cited infrequently.

Abbreviation: sEMG, surface electromyography.

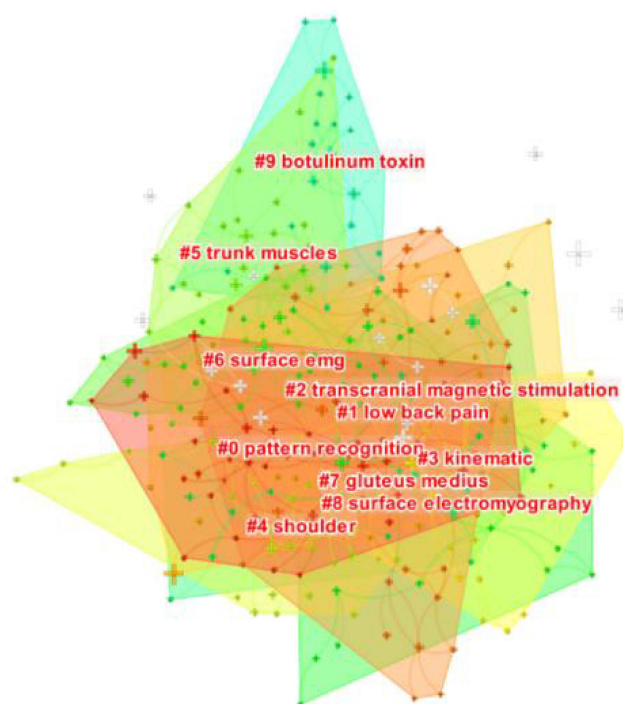


Figure 9 Map of keyword cluster related to the rehabilitation medicine use of sEMG from 2010 to 2021 on the Web of Science. The square area between nodes represents the co-occurrence relationship.

Abbreviation: sEMG, surface electromyography.

muscle function, muscle activation and coordination of patients. At the same time, it could also purposefully guide the rehabilitation treatment of patients and evaluate the rehabilitation effect. It could be found that the current research paid more attention to the influence of sEMG on its movement mechanism, focusing on its internal theoretical mechanism. At the same time, the study also paid special attention to children and people with disabilities.⁴² Many developed countries and famous institutions had close cooperative relations, which was conducive to the development of the rehabilitation medicine use of sEMG.^{42,43}

In this study, many countries had published papers on related topics, among which Chinese scholars had issued a large number of documents, but the centrality was low. The main research hotspots of Chinese scholars primarily focused on stroke, pelvic floor function, walking ability and shoulder joint. The characteristic research hotspots were acupuncture and the rehabilitation of traditional Chinese medicine (TCM). Chinese scholars paid more attention to the research of clinical treatment and paid less attention to the research of injury mechanisms. Therefore, we need to continue to follow the international research direction, increase the research on the tool and continue to increase the research on TCM rehabilitation in the future so as to promote the formation of unique research results. The hot topics and research frontiers discussed in this study revealed the development trend of the rehabilitation medicine use of sEMG, which might help researchers redefine new directions and priorities.

In conclusion, this study provides the rehabilitation medicine use of sEMG with in-depth understanding and valuable information for rehabilitation researchers so as to help researchers explore new directions and new topics for future research in this field.

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Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. Liya XU is the co-first author.

Disclosure

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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