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Published Version:
Pinelli, E., Zinno, R., Barone, G., Bragonzoni, L. (2024). Barriers and facilitators to exoskeleton use in persons with spinal cord injury: a systematic review. DISABILITY AND REHABILITATION. ASSISTIVE TECHNOLOGY, 19(6), 2355-2363 [10.1080/17483107.2023.2287153].

Availability:
This version is available at: https://hdl.handle.net/11585/950825 since: 2024-11-12

Published:
DOI: http://doi.org/10.1080/17483107.2023.2287153

Barriers and facilitators to exoskeleton use in persons with spinal cord injury: A Systematic Review

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Abstract

Background and Purpose: Exoskeleton can assist individuals with spinal cord injuries (SCI) with simple movements and transform their lives by enhancing strength and mobility. Nonetheless, the current utilization outside of rehabilitation contexts is limited. To promote the widespread adoption of exoskeletons, it is crucial to consider the acceptance of these devices for both rehabilitation and functional purposes. This systematic review aims to identify the barriers or facilitators of the use of exoskeletons for lower limbs, thereby providing strategies to improve interventions and increase the adoption of these devices.

Methods: A comprehensive search was conducted in EMBASE, Web of Science, Scopus, Cochrane, and PubMed. Studies reporting barriers and facilitators of exoskeleton use were included. The studies' quality was assessed using the Mixed Methods Appraisal Tool and undertook a thematic content analysis for papers examining the barriers and facilitators.

Results: Fifteen articles met the inclusion criteria. These revealed various factors that impact the utilization of exoskeletons. Factors like age, engagement in an active lifestyle, and motivation were identified as facilitators, while fear of falling and unfulfilled expectations were recognized as barriers. Physical aspects such as fatigue, neuropathic discomfort, and specific health conditions were found to be barriers.

Discussion and Conclusion: This systematic review provides a comprehensive overview of the barriers and facilitators to the use of exoskeleton technology. There are therefore still challenges to be faced, efforts must be made to improve its design, functionality, and accessibility. By addressing these barriers, exoskeletons can significantly improve the quality of life of people with SCI.

Keywords: systematic review; spinal cord injury; exoskeleton; SCI; qualitative research

Introduction

Exoskeleton technology is a rapidly developing field that has the potential to revolutionize the way we live by augmenting human strength and mobility. These devices consist of a wearable frame attached to the body and powered by motors or hydraulics, which can be programmed to assist with specific movements, such as walking, standing, or lifting. In addition, exoskeletons can be customized to fit the needs of the individual user.

Given these characteristics, exoskeletons find application within the healthcare environment as well. Indeed, exoskeleton assistive technology is utilized for rehabilitation for individuals with spinal cord injuries (SCI) [1]. SCI is a condition that can result in paralysis and loss of mobility. Individuals with SCI often face a total or partial loss of walking function, creating pitfalls in carrying out activities of daily living [2,3]. Physical deconditioning can drastically lower the quality of life (QoL) in individuals living with SCI, by impairing their mobility and cardiorespiratory and muscular function, leaving them fully dependent on others for both social and mobility needs [4]. This underscores the importance of keeping active to improve health, fitness, and overall QoL [5].

Long-term sessions of robotic exoskeleton-assisted walking provide a variety of exercises that may be sufficient to improve cardiovascular fitness [6], increase bone mineral density and lean body mass, lower spasticity, optimize bowel function, and improve gait function in people with SCI, decreasing the risk of secondary health issues [7,8]. Additionally, the quality of life and physical discomfort of person with SCI can benefit from robotic exoskeleton walking [9]. Powered exoskeleton training, according to Portaro et al. [10], can enhance neuromuscular and musculoskeletal function and may also promote neuroplasticity.

Therefore, training programs are now becoming part of supervised exercise programs offered in a clinical context to users with a SCI. The use of wearable exoskeletons for people with SCI is considered safe and feasible [11,12], but intensive training is required before users can safely use an exoskeleton [13–15]. Moreover, the use of wearable exoskeletons outside of rehabilitation contexts holds great potential, enabling individuals with SCI to actively participate in social and community activities, engage in employment opportunities, and pursue recreational pursuits.

In recent years, several qualitative studies [16–23] have begun to investigate the factors that influence the use of the exoskeleton from the point of view of persons with SCI, healthcare professionals and caregivers. However, the results are not comprehensive.

The aim of this systematic review is to identify barriers and facilitators to the use of exoskeleton technology for individuals with SCI to provide strategies for improving interventions and increasing the adoption of these devices. Our goal is to accurately describe barriers and facilitators in the use of the exoskeleton, to tailor these strategies to the specific needs and circumstances of the individual user, as well as consider the broader context in which the exoskeleton can be used. The guiding question of this review was: what are the barriers and facilitators that influence people with SCI to use the exoskeleton?

Methods

Search Strategy and Data Sources

The protocol for this systematic review was registered with the International Prospective Register of Systematic Reviews (registration number CRD42021279336). As this is a systematic review, no raw data have been collected from the persons with SCI, and there was no need for persons with SCI and public involvement.

We searched the following databases: EMBASE, Web of Science, Scopus, Cochrane, and PubMed. Primary search was performed on 15 November 2021 and was updated on 10 April 2023. This systematic review was conducted according to the PRISMA guideline statement.[24] The search strategy was developed based on the search string, specifically "exoskeleton AND (barrier OR facilitator) AND spinal cord injury." The strings were modified by incorporating synonymous terms and tailored to fulfill the specific search requirements of each database. The complete strings for each database can be found in supplementary material 1. Additionally, a grey literature search was conducted by manual searches of key conference proceedings, journals, professional organizations' websites, and guideline clearing houses. Furthermore, the snowball technique was employed to explore the references cited in the primary papers, identifying potential studies that met the eligibility criteria and could be included in this review.

Eligibility Criteria

To be eligible for this review, studies must meet the following inclusion criteria: studies, which contain barriers, motivators, and facilitators to use the exoskeleton to lower limbs from the perspectives of persons with SCI, staff members, and caregivers. Studies were included only if written in English. In addition, the analysis included qualitative studies, mixed methods studies, observational studies, cross-sectional, prospective, retrospective, randomized controlled trials, clinical trials, case reports, and case series that reported opinions or drop-out motivations of persons with SCI using the exoskeleton. Finally, articles describing factors that influence exoskeleton use or factors that influence participation in an exoskeleton rehabilitation program were included. Only articles reporting data of persons with SCI over 18 years of age with spinal cord injuries were included.

Data extraction And Quality Assessment

The search results were imported into the X9.3.3 ENDNOTE software. Duplicated and unrelated studies were removed.

Two reviewers independently screened the titles, abstracts and then full texts of articles identified by the search against the selection criteria. Eligibility for each study was tested against predefined eligibility criteria and quality assessment guidelines. In all cases, the decision to include or exclude a study was approved by two authors. In case of disagreement, a third author made the final decision.

The researchers independently extracted data while adhering to the prescribed standards for literature collection. To conduct a descriptive analysis of the studies, we searched and extracted the following data from the articles: the first author's name, the year of publication, the nation, the study's design, the population, and any barriers or facilitators that were found.

Thematic content analysis was applied to the text of the included articles themselves to draw out key themes from the findings of the selected studies [25]. Finally, to extract important themes from the results of the chosen research, thematic content analysis was performed. Three authors (L.B., E.P., R.Z.) read the results numerous times to become comfortable with the content. Then, using Excel spreadsheets, the primary findings about the facilitators and barriers to goal setting were highlighted. The codes were analyzed, categorized, and polished to create themes and sub-themes. The papers were then read a second time, and new information supporting or refuting the themes and categories was added. All the authors iteratively summarized and clustered the data until they came to an agreement.

The methodological quality of the selected studies was independently assessed by two of the authors (EP and RZ) using the Mixed Methods Appraisal Tool [26]. Consensus was achieved through discussion with a 3rd author (LB) who acted as arbitrator if necessary.

The Mixed Methods Appraisal Tool (MMAT) is designed to structure the appraisal of complex systematic reviews involving studies that use a range of methodologies. It enables the methodological quality of mixed methods, qualitative and quantitative studies to be described and evaluated using different evaluation criteria for each one. For each of the five different study designs the MMAT comprises, it has five questions to determine whether the risk of bias on a certain aspect was low. If the risk of bias was low the article received a ‘yes’, if not it received a ‘no’, and when it was not clearly described it received a ‘can’t tell’. The criteria assessed reflect the factors which impact on the risk of bias, completeness, and transparency.

Data on barriers and facilitators were classified using the socio-ecological model [27]. The model foresees a division into three categories for both barriers and facilitators as potential factors. The model includes factors at the intrapersonal level (e.g., socio-demographic, physical/anthropometric and psychological), interpersonal level (e.g., support from others) and community level (e.g., structural and organizational) and explicitly recognizes that these categories interact across levels. The device-dependent factor was also included.

Results

Identification of articles

A total of 1510 articles were found; 991 unique articles were identified after duplicates were removed. After the title and abstract screening, 935 articles were excluded because they did not meet the inclusion criteria. Then, 56 articles were full-text read, and 41 articles were excluded after reading. Ultimately, 15 articles were included in the data analysis [16–23,28–34]. In Figure 1, the PRISMA flow chart shows the inclusion process [35].

Figure1 PRISMA flowchart of the selection process

[INSERT FIGURE 1 HERE]

Characteristics of the articles

480 persons with SCI were included in the present review. Among all persons with SCI, 71 had a complete SCI, 57 an incomplete SCI and 352 were not specified. In total, 2 articles included also persons with SCI having other disease, such as stroke, polio, and muscular dystrophy. Eleven studies reported an age range of their persons with SCI ranging from 18 to 71 years. The overall gender distribution was 57.73% male and 42.27% female. Time since injury ranged from 7.9 to 9 years. Additionally, 197 healthcare professionals were included in this review. Finally, the studies were performed in different continents, five from Canada [16,17,29,31,34], five from Europe [19,28,30,32,33], four from USA [18,20–22] and one from South Africa [23].

Four study designs were included. Nine articles used a qualitative design [16–18,20,22,23,31,33,34], while three of the included articles used a non-randomized quantitative design [19,30,32], two articles a quantitative descriptive [28,29], and one article used a mixed methods design [21]. The articles taken into consideration are included in a time range that goes from 2014 to 2023.

Quality assessment

The results of quality assessment for each paper are reported in table 1. Briefly, the selected documents were of good quality, answered "Yes" to most of the quality criteria and were included in the synthesis phase. Of the 15 articles included, 80% obtained a "yes" on all five MMAT questions, while four positive answers were provided in 6.67% of the articles, three in 13.3% of the articles.

Table 1. Quality assessment

[INSERT TABLE 1 HERE]

Outcomes

All data extracted from each included study are summarized on supplementary material 2. After data extraction, subcategory and domain were created based on the factors found (Table 2).

Intrapersonal level

At the sociodemographic sublevel age, age at injury onset, active lifestyle, and BMI were most often reported as facilitators of exoskeleton skill performance.

Nine of the included articles discussed facilitators influencing motivation to use an exoskeleton. Motivation to use was considered a factor from five articles, of which the reported facilitators were: "improving independence", "social interaction at eye level", and especially “being able to walk”. Overall participants were happy to try the device and reported physical improvements, increased stamina, and the ability to walk again.

However, some barriers were reported by persons with SCI, such as, " it’s pretty boring just going back and forth [the hallway]". In addition, participants' expectations were considered barriers when the benefits were less than expected. Four studies indicated barriers in the domain of fear of performing activities. However, other studies reported that persons with SCI were not concerned about developing skin lesions, losing balance, or experiencing a drop in blood pressure associated with walking with a robotic exoskeleton. Additionally, three studies examining participants' perceptions of the device reveal that users believe the device to be safe and secure.

At physical level, people with SCI demonstrated a variety of exoskeleton usage facilitators, such as the ability to stand, walk, climb stairs, perform physical activity, and more in general, to improve their state of health. On the other hand, the onset of fatigue, neuropathic discomfort, and sores during the use of the exoskeleton have been identified as barriers. In addition, various pathologies (i.e., osteoporosis) and the female anatomy of the pelvis have been listed as barriers to the use of the exoskeleton.

In terms of life habits, for people with spinal cord damage, the possibility to have more autonomy has been recognized as a facilitator. However, there are obstacles to using the exoskeleton in daily life, including the inability to play sports, operate a vehicle, or climbing stairs and ramps.

Interpersonal level

The interpersonal level's components were least thoroughly examined. The assistance of licensed therapists, receiving support from relatives, and observing others using the exoskeleton are among the most frequently mentioned facilitators. Among the barriers, the need for support from physical therapists with specialist certification is a mentioned factor.

Community level

Four items were included into the community-level factors. The barriers reported were that the exoskeleton can only be used within the clinic and/or in a research setting, due to high costs and because the assistance of a highly skilled physiotherapist is required. Moreover, the lack of time in managing rehabilitation within hospitals and the rigidity in schedules are identified as obstacles to the use of the exoskeleton in this context.

Device

Many factors have been identified in the device subcategory. The device's considerable ease to wear and use of sound feedback have all been reported as facilitators. On the other hand, numerous elements have been noted as impediments in the research that have been evaluated. According to five writers, the most prevalent impediments to use the exoskeleton were device's low wearability, comfort, and considerable weight.

Table 2. Barriers and facilitators: category, subcategory and domain

[INSERT TABLE 2 HERE]

Discussion

This systematic review aimed to identify barriers and facilitators to exoskeleton technology in individuals with spinal cord injuries. For this purpose, we collected and analyzed 15 studies that used exoskeletons with persons with SCI. This review contributes to the literature by conceptualizing a framework of facilitators and barriers for using exoskeletons.

Intrapersonal level

Intrapersonal level categories refer to the users' behaviors and motivations while using and interacting with the system, which are key factors for persons with SCI acceptance of the use of this technology. These factors include persons' with SCI beliefs and perceptions of advantages and disadvantages of the use of exoskeletons.

In the psychological subcategory, the possibility of being able to walk was expressed as motivation. This topic is discussed in several qualitative studies [36,37], where the social significance of the physical change brought about by exoskeleton training and the struggle to achieve normality in life's activities has been discussed.

Exoskeleton training is likely to be appreciated since it allows persons with SCI to walk and enjoy the sensation of inhabiting an upright body. Some people have not felt this way in a long time. The upright stance allows for a self-presentation that can change the nature of the lived environment, just as cultural uses of walking are metaphors for strength, power, and autonomy [38]. The possibility of walking also leads to benefits in psychological well-being and in the quality of sleep.

There are conflicting findings in exoskeleton activity fear; among the barriers we find the fear of the first attempt, the fear of falling, and the fear of not knowing what might happen; however, from the studies of Gagnon [29] and Benson [30], the exoskeleton was found to be safe, and no fear was felt when using it. In a research of Matthews et al.,[39] consumers similarly named safety as their top worry while using any kind of assistive technology. Exoskeletons now on the market pose few safety issues, according to research [40,41], but only when used in clinical settings under supervision with a qualified therapist guarding the user against falls. Therefore, exoskeletons may need to be modified for use in less controlled environments if they are to be employed for functional duties outside of a clinical setting.

Most of the barriers and enablers have been found at the physical sublevel. The use of the exoskeleton certainly leads to numerous advantages on a physical level, but nevertheless, it must be used with caution. Individuals with SCI who have not recently trained to stand or walk should be weight trained before considering the use of an exoskeleton robot. Loss of muscle load, reduction of mechanical stimulation, and duration of paralysis increase the fracture rate in the SCI population and range from 1% to 21% of subjects and may increase over time [42–44].

Another limiting factor in using the exoskeleton is sores. Since the high risk of individuals with SCI to develop pressure ulcers, the soft tissue compression in the strapping area and heel area should be checked after each use of the device, as they are the main contact areas [40]. Despite the application of foam and padding modified to fit everyone, the frequency of mild skin aberrations is still high. For women, the anatomy of the pelvis can influence the optimal positioning and alignment of the exoskeleton, resulting in increased discomfort and a higher risk of pressure sores[22]. It is necessary for the exoskeleton design to consider the specific anatomical variations in females, ensuring adequate support and minimizing any discomfort or pressure points that may arise. Further research and development efforts should focus on addressing these gender-specific considerations to ensure that exoskeleton technology is inclusive and suitable for individuals with diverse anatomical backgrounds.

Finally, some very important factors appear among the barriers, such as the inability to drive a car, play sports, or climb stairs [18,31,33]. Being able to wear the exoskeleton while performing these gestures is important for persons with SCI, to ensure that users are equally mobile and independent even when wearing an exoskeleton, as they are now with their wheelchair.

Conversely, in four studies [17,18,30,33] it was found that participants with no training experience, compared with those who had experience with exoskeleton training, showed higher exoskeleton use expectancy. This implies that the training of the exoskeleton and its capabilities does not match the expectations of person with SCI. Such disillusionment can contribute to the abandonment of exoskeleton training and such technology. It is required to conduct an educational intervention on the use of exoskeletal to inform participants of the true potential of this technology to avoid this from happening.

Interpersonal level

At the intrapersonal level, assistance of licensed therapists emerged as a significant aspect with both facilitators and barriers effects. The presence of certified personnel was perceived positively by participants, primarily due to the sense of safety and trust they provided during the use of exoskeletons [29]. This finding suggests that the involvement of skilled professionals is important in enhancing the overall experience and acceptance of exoskeleton.

On the other hand, the requirement for ongoing assistance also posed a potential barrier. Participants expressed concerns regarding the dependence on external support, which could hinder independent use of exoskeletons. This highlights the importance of exploring strategies to promote self-reliance and autonomy among users while ensuring their safety.

Furthermore, extending support to family members was identified as a valuable facilitator. By involving relatives in the exoskeleton experience, users can benefit from enhanced emotional support and shared understanding. In addition to the previously mentioned facilitators, another significant facilitator identified in the study was "seeing other people using exoskeletons”. This underscores the significance of social influence and peer support in the successful adoption and integration of exoskeleton. By leveraging the power of shared experiences and positive role models, individuals using exoskeletons can be further empowered and motivated to use this device.

Community level

The barriers reported were that the exoskeleton can only be used within the clinic and/or in a research setting, which limits its practicality for daily use. Additionally, the cost of the exoskeleton is currently high, making it inaccessible to many individuals who could benefit from its use. Further research and development may help to address these barriers and make the exoskeleton a more viable option for individuals with mobility impairments.

Another barrier identified in the study was the rigidity of scheduling within the hospital setting. Participants reported difficulties accessing and using the exoskeleton due to limited availability. Limited time slots and the availability of trained personnel within the hospital setting have posed challenges in incorporating the use of the exoskeleton into clinical rehabilitation. The need to coordinate appointments and align schedules with therapists or trained staff has added complexity and limited the practicality of exoskeleton use.

Therefore, it is important to address programming challenges to facilitate the integration of exoskeleton technology into clinical rehabilitation. Expanding trained personnel may improve exoskeleton usability for users with SCI.

Device

Overall, while the ease to wear and audible feedback of exoskeletal devices have been identified as facilitators, low fit, discomfort, and weight have been noted as common impediments to their use.

Additionally, some users have reported difficulty controlling the exoskeleton and adjusting to its movements. This can lead to frustration and a lack of confidence in the device's ability to assist with mobility. Therefore, more research and development are needed to address these challenges and improve the usability and accessibility of exoskeletal devices. Consequently, by improving the usability and accessibility of exoskeletal devices, it may be possible to help people with physical disabilities achieve greater independence and quality of life.

Conclusion

While there are still barriers to overcome, the potential benefits of exoskeletons for people with SCI cannot be ignored. Overall, it is important to continue to explore the potential of exoskeletons and work to improve their design and functionality, so that these devices can be used even in non-rehabilitation and clinical context.

Furthermore, it is crucial to consider the cost-effectiveness of exoskeletons and ensure that they are accessible to people from all socioeconomic backgrounds. Overall, this systematic review highlights the importance of continued research and development in exoskeleton technology for people with spinal cord injury. There are therefore still challenges to be faced, efforts must be made to improve its design, functionality, and accessibility. By addressing these barriers, exoskeletons have the potential to significantly improve the quality of life of people with SCI.

Conflict of interest: The authors do not have conflict of interest or funding to declare.

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