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What are user perspectives of exoskeleton technology? a literature review.

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Title: What Are User Perspectives of Exoskeleton Technology? – A Literature Review

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Abstract

Objectives: Exoskeletons are electromechanical devices that are worn by a human operator and designed to increase the physical performance of the wearer. Exoskeleton technology has developed significantly over the past decade as a result of improvements in robotics technology and mechatronics technology. However the existing generation of exoskeletons have significant limitations with respect to their affordability, size, weight, speed and efficiency. These limitations may reduce the functional usefulness of the devices for individuals with neurological impairment, a population who are most likely to benefit from the technology.

The aim of this study is to identify existing literature that reports user perspectives of exoskeleton technology in order to inform the design and technical development of future wearable assistive materials.

Methods: An in depth literature search was conducted across several healthcare related online databases.

Results: 912 articles were identified, 893 were eliminated based on a review of their abstracts. Seven further articles were identified from references cited in the 19 articles fully reviewed. No published studies that consider the user's perspective of exoskeleton technology were identified. However nine articles document the importance of user involvement in the design of assistive technology. Assistive technology being any item, piece of equipment, software or product system that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities (1).

Conclusions: Evidence identified across a wider spectrum of literature relating to assistive technology and disability suggests the value of involving end users in the design of assistive technology to ensure their often-complex needs are met. Therefore, further research is needed to identify the aspirations and concerns of potential users of exoskeleton technology in order to inform the design and technical development of this innovative technology.

Key words

Robotics, bionics, equipment design, spinal cord injuries

Introduction

Exoskeletons are electromechanical devices that are worn by a human operator and designed to increase the physical performance of the wearer (2). Exoskeleton technology has developed significantly over the past decade as a result of improvements in robotics technology and mechatronics technology (3). Exoskeletons produced by Ekso Bionics Holdings (EKSO™) in the USA, Rex Bionics PLC (REX®) in New Zealand (4), ReWalk Robotics (ReWalk™) in Israel (5) and Parker Hannifin Corp (Indego®) have already reached the commercial market internationally (6). In addition a system developed by Cyberdene (the hybrid assisted limb - HAL®) in Japan received a global safety certification in 2013 and has subsequently received an EC Certificate of Conformity in Germany, although is yet to be distributed widely within Europe (7).

All of the currently available commercial systems have different design specifications in terms of overall configuration, weight, battery life, cost, adjustability and functionality (see table 1), but the overall aim of each system is to enable individuals who have been paralysed by neurological dysfunction to stand up and walk.

There have been recent reports in the media, which sensationally refer to the current exoskeleton systems as "*extraordinary robotic suits that enable those with paralysis to stand and walk" (8, 9)*. Indeed for some individuals with neurological impairment, these exoskeletons will provide their first opportunity to be mobile without their wheelchair. However there are also opposing accounts on social media, written by wheelchair users who do not consider current exoskeletons to be a satisfactory alternative to the independence afforded to them by their wheelchairs. For example, Nicholson (10)states "*My wheelchair is a very capable tool and to be honest, the last thing I want is to be strapped to a District 9-esque robot and become a puppet in some corporations half-baked execution of an obsession with making the non-walkers walk again".*

Despite their impressive functional capabilities, the existing generation of exoskeletons have significant limitations with respect to their affordability, size, weight, speed and efficiency (3, 11, 12). The exoskeletons available within the United Kingdom to date weigh between 23 Kg to 38.5 Kg (4, 13) Whilst the user physically carries none of the weight of the device whilst standing and walking (because the device fully supports the user's body weight in addition to its own weight), they are heavy and cumbersome pieces of equipment to maneuver when trying to put on and take off, transport and store.

Furthermore, walking speed is markedly reduced when wearing an exoskeleton as compared to normal walking speed in an able-bodied adult. Velocity of gait is defined as the average horizontal speed of the body measured over one or more strides (14, 15). Bohannon (16) published normative values for comfortable and maximal gait speeds based on normative data from 230 healthy individuals. Comfortable gait speed for young adults in their 20s is cited as 1.39 m/sec (males) and 1.40 m/sec (females), whilst for those in their 70s as 1.33 m/sec (males) and 1.27 m/sec (females). In contrast, walking speeds for those with spinal cord injury who have been trained to walk using the ReWalk™ exoskeleton are reported to range from 0.03 to 0.5 m/sec (6, 17). Consequently whilst the exoskeleton may restore an individual's ability to walk it does not yet do so at a speed that is commensurate with ambulation being a functional component of mobility for those with neurological impairment. Indeed there is evidence to suggest that walking within an exoskeleton is slower than mobilising in either a manual or powered wheelchair. Karmarkar (18) report an average speed of manual wheelchair propulsion of 0.64 m/s and an average speed of powered wheelchair mobility of 0.7m/s in adults aged 50 years or older whilst using their wheelchairs in a community setting.

These limitations reduce the access to and hence the functional usefulness of these devices for individuals with neurological impairment. Future devices are likely to harness emerging innovative technology such as 3D printing to develop bespoke, lightweight devices based on individual body size and shape (11, 12). The development of a device, which is functionally useful, safe and imperceptible to all but the user, is therefore likely to be the ultimate goal in the design of exoskeleton technology.
A recent Wintergreen research report states that the rehabilitation robot market will grow from $43.3 million to $1.8 billion by 2020 (15). The lucrative potential of this technology however should not overshadow the need for the technology to be accessible and useful to the end user.

Evidence that considers the development of more established and accessible assistive technology such as functional electrical stimulation (FES), advocates user involvement in the design process in order to ensure appropriate usability of the end product within everyday life (19, 20). McMillen and Söderberg

(21) suggest that assistive technology may only be accepted by a person with disability if they see the device as useful for their own purposes. Whilst others (22-24) advocate that people with disability act as consultants in the development process of assistive technology, to provide valuable insight, ensuring that devices developed provide end users with worthwhile gains in independence and quality of life.

The authors are part of a team at University College London (UCL) who, with a grant from the Engineering and Physical Science Research Council (EPSCR), seek to develop a wearable assistive material for use in exoskeleton technology. Thus the current study aims to identify and review existing literature that reports user perspectives of exoskeleton technology in order to inform the design and technical development of future devices.

Methods

A literature search was conducted across several healthcare related online databases including Pubmed; Scopus; The Cochrane Library; Medline and Cinahl. The search terms exoskeleton, robot or technology were combined with the terms user perspectives, user experiences or qualitative using Boolean operators (see table 2). These terms were then further combined with the terms rehabilitation and spinal cord injury, or neurological, or stroke. Terms were truncated to capture all possible derivatives of a key word. The searches were limited to published articles, written in English. No year restriction was entered. Articles found were then reviewed, duplicates deleted and references cited reviewed to determine if any other articles were relevant.

Results

A total of 912 articles (see table 2) were identified using the search terms, of which 893 were eliminated based on a review of their abstracts. The remaining 19 articles were reviewed in full. A further seven articles were identified from references cited in those articles. Of the articles selected for review, no studies were identified that specifically consider users' perspectives of exoskeleton technology. However nine articles document the importance of user involvement in the design of assistive technology (Figure 1).

Discussion

Within the literature there are examples of different prototype exoskeletons that have been developed for use during rehabilitation of individuals with neurological impairment. A number of studies use therapeutic outcome measures to determine the efficacy of exoskeleton technology as compared to standard rehabilitation (17, 25, 26). Other studies describe the development of specific design features of exoskeletons to augment or replace functional movement in individuals with neurological impairment (17, 27-29). However, to date there have been no published studies that consider the user's perspective of exoskeleton technology. This is somewhat unsurprising given that it is relatively novel technology. Indeed in the United Kingdom exoskeletons are currently only available for individuals to trial within a handful of specialist private clinics and one of the eleven national spinal cord injury centres. Consequently only a small number of users have had the opportunity to use the technology, with very few individuals having their own exoskeleton device.

However, evidence identified across a wide spectrum of literature relating to more established assistive technology and its use by those with neurological disability suggests the value of involving end users in technology design to ensure their often-complex needs are met (11, 22, 30-33). In fact the importance of user involvement in design of novel technologies has been stressed in many technologies including crisis response (34) and technologies for children (35, 36) and the elderly (37, 38).

Within the novel area of exoskeleton development there are no published examples of the integration of users within the design process. Nevertheless there is evidence from related studies that suggests such integration is beneficial and therefore might be advocated.

Kilgore, Scherer (22) considered consumers priorities for the development of neuroprostheses to support standing and ambulation in individuals following spinal cord injury. Key themes and priorities identified by their participants with respect to this specific technology were independence, ease of movement, ease of control and being able to "do what you did before the injury". Exoskeletons are different to neuroprostheses in that they provide structural support and automated movement driven by motors and actuators rather than initiating muscular contraction in paralysed muscle with electrical stimulation. Nevertheless, the functional outcomes for both different types of technology are similar in that they relate to restoration of standing and walking following SCI. Consequently it could be hypothesised that similar priorities might be identified by potential users of exoskeleton technology as those identified by Kilgore, Scherer (22). However such assumptions can only be hypothetical at this time given the lack of publications in user perspectives of exoskeleton technology to date.

Lane, Usiak (30) state that capturing the wants and needs of the end user is a common practice in consumer product marketing and in the medical device design process but is a practice not widely applied to assistive technology. Assistive technology abandonment by end users is a well-documented phenomenon (39-42) and underlies the emerging awareness that individuals with disability should be involved in the development of assistive technology relevant to their needs (11).

Shah and Robinson (32) identify that the main benefits of user involvement with respect to medical device technology development and evaluation are increased access to user needs, experiences and ideas; improvements in medical device design and user interfaces; and an increase in the functionality, usability and quality of the devices. The authors also identified barriers to user participation, which relate to the time and cost associated with involving them in the design process. However they conclude that despite limited resources user involvement is essential in the development and evaluation of medical device technology.

Pape, Kim (43) suggest that the successful integration of assistive technology into daily living requires potential device users to explore the meanings they assign to specific devices; their expectations of assistive technology; the anticipated social costs and the degree to which their disability defines their identity. All of these considerations could be usefully explored with respect to exoskeleton technology in those with neurological impairment. Some individuals might view exoskeleton technology as a means to restore their ability to walk, with the expectation that they will be able to resume normal functional ambulation in daily activities. As such the anticipated impact on social participation and quality of life is likely to redefine their perception of self. However for others the technology may not meet their aspirations with respect to functional ambulation, for example due to speed, whilst the appearance of the device in situ might lead them to feel more conspicuous with respect to their disability. Brown-Triolo, Roach (23) in their study looking at consumer perspectives on mobility relating to neuroprosthesis design, report that individuals with SCI seem ready to disregard anything that will add to stigma, regardless of how effective it is. Therefore, only by seeking an understanding of potential stigma associated with the use of exoskeleton technology will designers be able to develop products that mitigate these concerns.

Kiesler and Hinds (44) suggest that technical advances with respect to assistive technology have up until now dominated the published literature and argue that the fundamentals of robotic design need also to consider psychological and social factors. Certainly this review found a disproportionate volume of literature that reports design specifications of exoskeleton systems as compared to the absence of literature that considers user perspectives of the technology.

Bates, Spencer (45) report the possibility of intense emotional responses to the introduction of wheelchairs and other assistive devices into a person's life following the onset of acquired disability. It is likely that similar and extreme emotional responses might be expected when an individual is introduced to exoskeleton technology. The responses may vary from the extremes of euphoria associated with re-enablement, to despair associated with a renewed realisation of loss. Meanings attributed by the user to assistive technology play a decisive role in whether the technology will be successfully integrated into an individual's life (43). Therefore, unless research seeks to understand the views and perceptions of potential end users of exoskeleton technology, speculation and uncertainty must remain as to whether the technology will be accepted by the population it seeks to enable and empower.

McMillen and Söderberg (21) suggest that a device may only be accepted by the person who sees the aid as useful for their own purposes. Shah, Robinson (33) suggest that end users quickly discard devices that do not fulfil their personal expectations, even though manufacturers and healthcare professionals may consider those end users' requirements met. It is therefore important to acknowledge a potential for discrepancy between end users of technology and those responsible for its development and prescription, further justifying the relevance and importance of user involvement within design processes.

Demain, Burridge (19) used focus groups to ascertain the views of people with stroke, their carers and therapists regarding various assistive technology devices for the upper limb. The therapists in their purposive sample identified concerns about devices which needed complex adjustment or complex programming between patients. Concerns were also raised about devices which would be time consuming to clean and difficult to store. For people with stroke and their carers, it was important that devices were easy to get on and off and intuitive with respect to positioning and use. Whilst this study does not consider exoskeleton technology, the authors define assistive technologies as “electrical or mechanical devices designed to help people recover movement”. This definition could readily be applied to exoskeleton technology. It is therefore not unlikely that similar concerns might be raised with respect to exoskeleton technology by both clinicians responsible for provision and set up of the devices and those with neurological impairment who seek to use the devices for functional gain.

It has been suggested that the development of most medical devices arise from either the desire to fulfil an unmet need in healthcare diagnosis or treatment, or because a scientific/technological advance offers an improved solution to a known problem (46). The latter certainly applies to exoskeleton technology. However, Kilgore, Scherer (22) suggest that from the consumer’s perspective, the focus of research to restore function ought to be based on the needs and desires of the consumer, not just in the scientifically intriguing aspects of a particular technology.

Pioneers of new medical technology are typically scientists or engineers with little experience as device users (46). As a consequence, there is a risk that end-products will not meet the needs of the population for which they have been developed. The development of exoskeleton technology has caught the attention of popular media, who describe the technology as revolutionary. Nevertheless, the current literature review has identified a paucity of evidence to suggest that the scientific community responsible for development of exoskeleton technology have identified or sought to understand the needs or desires of individuals who may ultimately benefit from using it to augment their functional independence.

Conclusion

Whilst there have been some breakthroughs in exoskeleton technology in recent years, further research is needed to identify the aspirations and concerns of potential users of exoskeleton technology in order to inform the design and technical development of this innovative technology.

Given the potential that exoskeleton technology has to improve the functional capability and quality of life of individuals with neurological impairment it is imperative that their views are sought in relation to the ongoing development of this technology. Design teams must understand the difficulties faced by potential users in order to ameliorate them with successful designs.

Therefore, further research is needed to identify the aspirations and concerns of potential users of exoskeleton technology in order to inform the design and technical development of this innovative technology. The authors also wish to encourage research groups that have achieved the commercialization of their exoskeleton technology to publish their findings from focus groups investigations.

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Conflict of Interest

None

Table 1 – Design Specifications of Commercially Available Exoskeletons

	Weight	Battery Life	Cost	Method of Control	Function

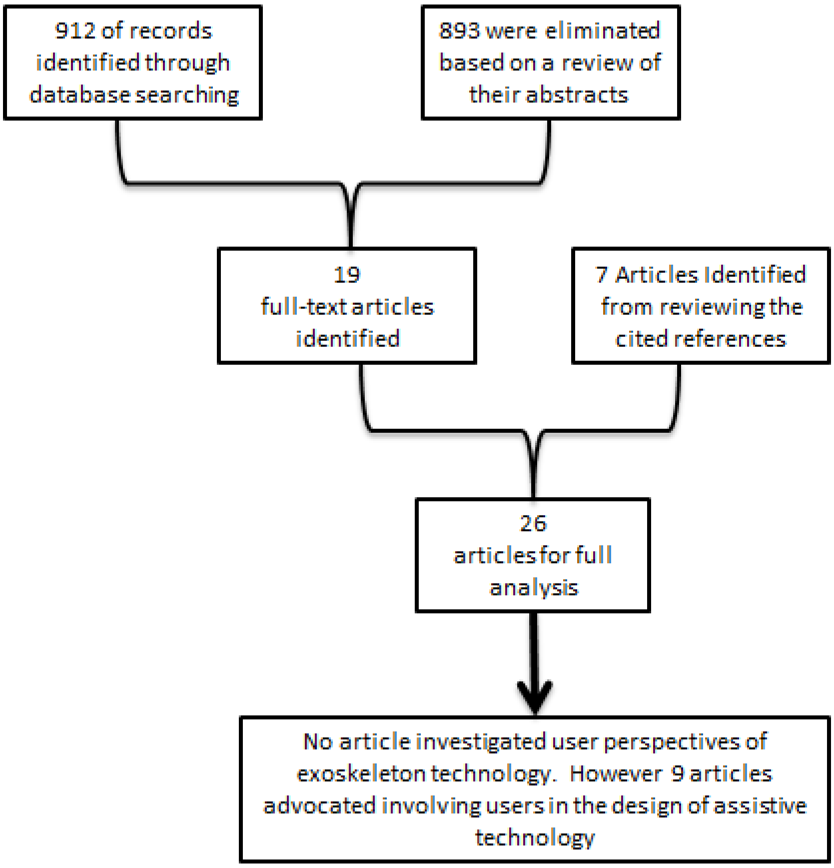
Ekso™ (13)	23 Kg	Up to 4 hours	£52,000 - £73,000	• Battery-powered motors • The user's forward lateral weight shift initiates a step • Operated by therapist, progressing to independent use of buttons on crutches or Zimmer Frame	• Medically supervised standing & walking
ReWalk™ (47)	25Kg	3:15 hours of continuous walking	£49,500 (excluding £5000 training fees)	• Computer-based control system and motion sensors • Sensors recognise a change in body position and trigger the desired hip or knee movement to initiate a step forward • Users must have the ability to use hands and shoulders to facilitate walking with crutches	• Standing • Ambulation indoors & outdoors • Stair climbing
REX® (48)	50Kg	1 hour	£80,000	• Joystick to control • Powered by interchangeable battery pack • No need for crutches or walking aids	• Standing • Walking on flat ground and slopes • Stair climbing

Table 2: Results from Database Search

Key Search Terms	Results

Exoskeleton* & User Perspective*	11
Exoskeleton* & User Experience*	37
Exoskeleton* & Experience	69
Robot* & User Perspective*	283
Robot* & User Experience*	94
Exoskeleton* & Qualitative & Rehab*	31
Robot* & Qualitative & Rehab*	250
Technology & Qualitative & Rehab* and (spinal cord injury)	40
Technology & Qualitative & Rehab* and (stroke)	74
Technology & Qualitative & Rehab* and (neuro*)	23
Total Articles	912

Figure 1: Flow Diagram Detailing Literature Review Process


912 of records identified through database searching
893 were eliminated based on a review of their abstracts
19 full-text articles identified
7 Articles Identified from reviewing the cited references
26 articles for full analysis
No article investigated user perspectives of exoskeleton technology. However 9 articles advocated involving users in the design of assistive technology

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