

Research Article

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Exoskeletons for all: The interplay between exoskeletons, inclusion, gender, and intersectionality

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Abstract: In this article, we investigate the relation between gender and exoskeleton development through the lens of intersectionality theory. Exoskeleton users come in a wide variety of shapes, sizes, and genders. However, it is often the case that wearable robot engineers do not develop such devices primarily on the premise that the product should fit as many end users as possible. Instead, designers tend to use the one-size-fits-all approach – a design choice that seems legitimate from the return of an investment viewpoint but that may not do as much justice to end users. Intended users of exoskeletons have a series of user criteria, including height, weight, and health condition, in the case of rehabilitation. By having rigid inclusion criteria for whom the intended user of the technology can be, the exclusion criteria will grow in parallel. The implications and deep-rootedness of gender and diversity considerations in practices and structural systems have been largely disregarded. Mechanical and robot technology were historically seen as part of a distinct male sphere, and the criteria used today to develop new technology may reflect the biases that existed in another time that should no longer be valid. To make this technology available for all, we suggest some tools to designers and manufacturers to help them think beyond their target market and be more inclusive.

Keywords: exoskeletons, gender and technology, intersectionality, inclusive design, exclusion, data bias, access, discrimination

1 Introduction

Robotic technology is increasingly present in the health-care sector. Robots perform useful tasks for humans and assist humans in performing tasks by processing and acting upon the information collected by several sensors. They can be a powerful tool for assisting people with illnesses or disabilities because they can supplement the work provided by the health-care professionals – both in medical treatment and in rehabilitation – and support people in prevention programs [1]. Robots may be helpful in lessening the burden of care assistants by performing automated tasks. In this respect, the European Parliament [2] discuss how care robots might “free caregivers from tedious work and allow them to devote more time for diagnosis and better-planned treatment options” and thus make doctors’ work more efficient [3]. Recent findings also suggest that artificial intelligence (AI)-powered diagnostic tools in some cases can outperform physicians in the diagnosis of probabilities for disease and conditional interdependencies [4].

The use of technology in medical care is becoming more prevalent. This includes devices, integrated platforms, and services aimed at promoting the well-being of users, patients, and formal and informal caregivers; and the use of technology that allows people with health impairments to be more independent, thus improving their quality of life [5]. Robot-mediated gait training is one example of a technology that helps patients with reduced gait function [6]. In the 1990s, body weight-supported treadmill training with manual assistance was developed to improve walking function for patients with neurological impairments [7,8]. However, walk rehabilitation process was (and it is still) very costly and labor intense – it usually requires a team of two to five people. Robot technology has been proven to be an effective method for rehabilitation, requiring only one therapist to supervise a training session [9].

Despite the apparent benefits of such technology, research on care robot technologies suggests that their

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implementation is not straightforward, and new ethical, legal, and social concerns arise from the human–robot interactions [10–12]. Some authors argue that robot technology, especially when coupled with AI, “can be used to foster human nature and its potentialities, thus creating opportunities; underused, thus creating opportunity costs, or over-used and misused, thus creating risks” [13], suggesting that adoption is inevitable and that the current debate no longer focuses on the question of whether robot technology has an impact on society but on whether and to what extent this impact is going to be positive or negative.

Seeing technology as a social construct and not a natural force that arrives in society can help us understand how technology is being produced, implemented, and used in the “social construction of technology” [14]. It can also help illuminate the intricate relationship between the user and producer and the potential coproduction that happens in that relation [15,16]. For instance, one essential concern is how different individual users’ attributes might lead to their exclusion from technology. This critique has been around for decades, thanks in particular to the feminist understanding of technology, and remains quite unexplored in the context of robot technology. In this sense, technology – including robots – is not created in a vacuum. They arise as a result of – and reflect – human needs and ingenuity; they create new relationships between humans and also transform the way we see the world [17].

Disability studies seek to challenge the view that disability is synonymous with human failing [18] by creating space to explore the multitude of complexities of people who are disabled [19]. Within disability studies, exoskeletons are quite a new topic of inquiry, but they have received some attention notably by Lajeunesse et al. [20], who give an account of exoskeletons used for spinal cord injury patients, and Goggin [21], who argues that exoskeletons can lead to novel forms of mobility opportunities for their users.

In this article, we investigate the interplay of inclusion and gender perspectives and exoskeleton development from the lens of intersectionality. Exoskeleton users come with a wide variety of individual attributes, shapes, and sizes. However, wearable robot engineers do not usually develop such devices primarily on the premise that the product should fit as many end users as possible. Instead, designers tend to rely on the one-size-fits-all approach – with some adjustment possible. Such a design choice seems legitimate from a return of an investment viewpoint, but it may not do as much justice to end users. Intended users of exoskeletons have a series of user criteria, including height, weight, and, in the case of

rehabilitation, health condition. When the inclusion criteria for whom the intended user of the technology are rigid, the exclusion criteria are necessarily just as rigid.

We draw on feminist scholarly understandings of gender and technology to better understand how people adapt to technologies such as exoskeletons. We use the concept of intersectionality to see how people with disabilities are not just “disabled” but hold, as every human does, a wide variety of other identities. Furthermore, we explore whether being disabled can lead to double or multiple levels of exclusion, disregard, or discrimination. The implications and deep-rootedness of gender considerations in technology practices have been disregarded in the development of exoskeleton technology. Mechanical and robot technology were historically seen as part of a distinct male sphere and the criteria used today to develop new technology may reflect the biases that existed in another time that should no longer be valid. To make exoskeletons available – and enabling – for all, we suggest some tools to help designers and manufacturers think beyond their target market, be more inclusive, and avoid discrimination.

2 Gender, technology, and intersectionality theory

“Gender refers to psychological, social and cultural factors that shape attitudes, behaviours, stereotypes, technologies and knowledge” [22]. As a social construct, gender relates to, but is not identical to, sex, which is biologically and physiologically determined. Just as gender is in a context flux and negotiation – e.g., gendered understandings of the body or who can drive a car – so is technology. To better understand how a technology such as exoskeleton can be understood on the social, nontechnical level – for example, by zooming in on the inclusion and exclusion of users – gender perspectives can inform the understanding of what exoskeletons can and cannot do for different groups of people.

Feminist scholars stress that technology has for too long been part of the male sphere and thus inevitably reflects inevitably certain biases, as discussed by Wajcman [23], who argues that gendered power relations mediate the development of technology because “technology is always a form of social knowledge, practices, and products. It is the result of conflicts and compromises, the outcome of which depends primarily on the distribution of power and resources between different groups in society”. She argues that this could be achieved by looking at how technology is being made and used by male

power and interests. Technology is not created in a vacuum, as can be seen through the concept of “situated knowledge” [24], which focuses on the interrelation of “thinking with” both epistemologically, ontologically, ethically, and politically. In a semiotic materialist notion, situated knowledge helps to go beyond the “god trick god trick of seeing everything from nowhere” [24], showing how knowledge is not neutral, but socially constructed. In her “Cyborg Manifesto,” Haraway [25] takes the interweaving of technology and gender on a slightly different perspective, by introducing the cyborg concept into technofeminism:

A cyborg is a cybernetic organism, a hybrid of machine and organism, a creature of social reality as well as a creature of fiction. Social reality is lived social relations, our most important political construction, a world-changing fiction [...] The cyborg is a matter of fiction and lived experience that changes what counts as women’s experience in the late twentieth century. This is a struggle over life and death, but the boundary between science fiction and social reality is an optical illusion.

In contemporary society, the cyborg concept is so commonly used that the theoretical conceptualization must be explicitly mentioned when writing about cyborgs. People using exoskeletons integrate their bodies with a robotic device in a seamless manner, becoming in a way an actual cyborg. Scholars like Berg and Lie [26] continued the feminist technoinquiry by discussing the question, “do artifacts have a gender,” continuously unwrapping the black boxes of technology in a gendered framework, using gender theories to understand technology.

One theory within gender studies that addresses how people are made of a wide variety of personal attributes is intersectionality theory, which can be used to give a more comprehensive understanding of bias and direct and indirect discrimination based on individual (and sometimes clashing) identities. Intersectionality theory illustrates how gender discrimination and other forms of discriminating (e.g., racism, homophobia, xenophobia) may interact and strengthen each other, as defined by Crenshaw [27], who first used it to describe the double-discrimination Black women face:

Black women are regarded either as too much like women or Blacks and the compounded nature of their experience is absorbed into the collective experiences of either group or as too different, in which case Black women’s Blackness or femaleness sometimes has placed their needs and perspectives at the margin of the feminist and Black liberationist agenda.

Intersectionality can be defined as “the interaction between gender, race and other categories of difference in individual lives, social practices, institutional arrangements, and cultural ideologies and the outcomes of these

interactions in terms of power” [28]. Intersectionality perspectives have been included in a variety of topics on a structural level, such as psychology [29] and mainstreaming studies [30]. On a more individual level, McCall [31] discusses how different personal attributes make us up as people and individuals and makes each individual belong to multiple societal subgroups. All of these together contribute to the creation of identity politics [32].

This theory has also received criticism. Nash [33], for example, problematizes: “the lack of a defined intersectional methodology; the use of black women as quintessential intersectional subjects; the vague definition of intersectionality; and the empirical validity of intersectionality.” In our contribution, we do not seek to remedy these four valid criticisms regarding the theory, as we have found it to be a useful theoretical perspective to show how several identities overlap and create complex understandings of people having more than just one identity, leading them to being subject to systems of oppression and even discrimination. There has, however, been scholarly attempts to justify/refine intersectionality into a more operable theoretical tool [31,34]. We draw on the abovementioned feminist scholarly understandings of gender and technology to better understand how we as humans adapt to and are made to better or worse use technologies such as exoskeletons.

3 Methods and typology of exoskeletons

The use of exoskeletons in rehabilitation is a relatively new research field, with the most important technological developments happening within this past decade. However, several research groups and clinics across the world have made notable advances in understanding the benefits that patients have when using this novel technology. Exoskeletons have the potential to revolutionize the rehabilitation context completely. Exoskeletons provide health benefits, including improvements in gait function, body composition, aerobic capacity, bone density, spasticity, bowel function, and quality of life [6,35]. Moreover, exoskeletons allow a freer and more natural movement while walking than that provided by body weight-supported treadmill training. Exoskeletons offer much independence in a variety of everyday settings such as shopping malls, local parks, and movie theaters [6]. Exoskeletons also provide excellent help in repetitive-intensive gait training interventions [36] and help patients combat several chronic health-related consequences that are likely to affect persons with a spinal cord injury [37].



Figure 1: Indego therapy; photo courtesy of Parker Hannifin Corporation, USA.

Over the years, these devices are becoming less and less bulky. See an example in Figure 1.

Evidence concerning the rehabilitation of stroke patients is somewhat weaker, with fewer extensive studies to provide evidence. A recent scoping review found only seven pre-post clinical studies and four controlled trials, although it concluded that exoskeleton-based gait training in patients with subacute stroke had meaningful improvement when compared to traditional therapy [36]. These studies show that exoskeletons can be used safely in gait training in a clinical environment [38]. However, there is still a lack of research in certain key areas, including their use outside of a clinical setting [39] and especially relating to social science and humanities perspectives, on their impact on the daily life of the user from a nonmedical point of view. Although tests on exoskeletons show the potential for significant medical, technological, and social improvements for patients, there is still little understanding of how this technology will be implemented efficiently.

Several types of exoskeletons exist in the market and in research settings to date, with a varying degree of com-

plexity, weight, and applications. The Lokomat (Hocoma, Switzerland) involves patients using body weight support on a treadmill. Motorized braces move the patients' legs through trajectories that imitate standard gait patterns. Other robot devices include stepping machines like the Gait Trainer (RehaStim, Germany) and the G-EO, which uses movements similar to those of elliptical machines (Reha Technology AG, Switzerland). Another example is KineAssist (HDT Global, USA), which uses body weight support around the pelvis and a treadmill reacting to the patient's movements [40].

For this study, we investigate those wearable robots connected with the H2020 Cost Action 16116 on Wearable Robots,¹ that is, on physical assistant robots that “physically assist a user to perform required tasks by providing supplementation or augmentation of personal capabilities” [41]. Although there is confusion whether or not these devices can be considered medical devices [12], a “prescription device that is composed of an external, powered, motorized orthosis

¹ <https://wearablerobots.eu/>

that is placed over a person's paralyzed or weakened lower extremity limb(s) for medical purposes" is recognized as a medical device by the FDA. Moreover, what matters is the intended purpose of the device, something reinforced by art. Section 1.3 of the European Union Regulation of Medical Devices that stresses that "devices with both a medical and a non-medical intended purpose shall fulfil cumulatively the requirements applicable to devices with an intended medical purpose and those applicable to devices without an intended medical purpose" [42].

In the following section, we compile several examples of exoskeletons available in the market and analyze their different results. For our selection, we combined a nonsystematic online search with the Google search engine, using the key words: "'marketed' AND 'exoskeleton'"; "'exoskeletons' AND 'for' AND 'sale'"; "'buy' AND 'an' AND 'exoskeleton'" to seek companies currently selling exoskeletons. This showed that lower limb (as opposed to upper limb) products from large, respected companies dominated the online presence. The results were varied and lacked consistency in the amount of information freely available online, making the compilation and visualization of these products in a single chart difficult. The majority of companies did not have technical information online, forcing potential clients to contact them for further inquiries. Although this is a good strategy for marketing purposes, it presented a significant obstacle in our research and data collection.

As a second step, therefore, we sought further details by directly contacting the companies using their online contact forms. Unfortunately, the majority of the companies did not reply. After careful thought, we present the information we found online from mid-/large-sized companies (Table 1). Although our sample is limited, it is rich in results; it identifies and illustrates a trend that seems to replicate in different domains. In this regard, we included "EksoWorks" in the chart to complement our understanding of the impact that the physical embodiment of current exoskeletons has on constraining the access to technology by design.

4 Results

The section below includes three available commercial products: the US-based Ekso Bionics,² Indego,³ and

Cyberdyne from Japan.⁴ Considering the available information online, we focused on EksoHealth for gait training, Indego for therapy, and HAL for well-being. Rewalk⁵ is a major player in the market; however, they do not have any technical information online and did not respond to our requests for information, so they are excluded. Other excluded robots include Twice from Switzerland⁶ and MarsiBionics from Spain,⁷ both of which have yet to begin mass production of exoskeletons. In Table 1, we look at some specific technical information concerning the device and the users.

We can deduce some results from Table 1. The majority of the companies have both physically impaired patients and people without a medical condition as intended users (e.g., workers who perform physically demanding labor). Concerning the weight parameter, we see that the upper weight limit from HAL and Ekso is 100 kg. The average body weight for an American male is 91 kg.⁸ While fully clothed, which adds another kilo or two, many users on the heavier side would be excluded from the possibility of using the exoskeletons. Indego allows for slightly more, with 113 kg as the maximum weight. Similarly, the minimum limit for weight can also cause a problem, as HAL requires users to weigh at least 40 kg. This could be problematic in countries like Madagascar or Bangladesh, where the average weight of women is about 49 kg [43].

Concerning the height parameter, we observe that Japanese Cyberdyne starts at 150 cm, followed by Ekso Bionics at 152 cm and Indego at 155 cm. The World Population Review [44] reports that the country with the shortest average human height (Indonesia) has an average height of 62.2 inches (157 cm). This implies that many Indonesians would be too short to use these devices. There are many other populations – such as Filipino women [45] – who could likely be prevented from using the devices. There are also categories other than nationality – e.g., individuals with dwarfism – that would similarly exclude potential users. Although some companies are investigating pediatric orthoses (Hocoma,⁹ for instance,

² <https://eksobionics.com/>. Although its website is not forthcoming about its headquarters, it is a US-based company that additionally has a significant presence in the EU and Asia. <https://www.bloomberg.com/profile/company/EKSO:US>

³ <http://www.indego.com/indego/en/home>

⁴ <https://www.cyberdyne.jp/english/>

⁵ <https://rewalk.com/rewalk-personal-3/>

⁶ <http://twice.ch/>

⁷ <https://www.marsibionics.com/?lang=en>

⁸ See Froehlich-Grobe et al. [46] for data on self-reported height and weight of the average wheelchair user. The reason why American males were chosen in the example here is because they represent one of the most overweight and richest countries in the world.

⁹ <https://www.hocoma.com/solutions/lokomat/modules/#Pediatric-Orthoses>

Table 1: User and device characteristics for some commercially available exoskeletons from Ekso Bionics, Indego, and Cyberdyne

Parameter	Exoskeletons		
	Ekso Bionics	Indego	HAL, Cyberdyne
Intended user/ health condition	EksoHealth is for patients, and EksoWorks is for workers	Indego personal offers users with spinal cord injury a new level of independence at home and in the community. Indego therapy is a lower limb powered exoskeleton which enables therapists to offer task-specific and intensive gait training	HAL for Well-Being Lower Limb type Pro is a wearable robot designed for inducing the improvement in physical function in the lower limb, for the wearer with chronic conditions
User height range	5'–6' 4" (152–193 cm)	Height range: 5'1"–6'3" (155–191 cm) Maximum hip width: 16.6" (42.2 cm) Femur length: 14"–18.5" (35–47 cm)	S size: 150–165 cm, upper leg length 36–38 cm, lower leg length 35–38 cm M size: 160–175 cm, upper leg length 38–41 cm, lower leg length 37–41 cm L size: 170–190 cm, upper leg length 40–45 cm, lower leg length 39–45 cm XL size: 180–200 cm, upper leg length 43–48 cm, lower leg length 42–48 cm
Supported weight	Maximum weight: 220 pounds (100 kg)	Maximum weight: 250 lb (113 kg)	Minimum weight: 40 kg Maximum weight: 100 kg
User age	N/A	N/A	N/A
Intended use	EksoHealth is to gait train. EksoWorks is for workers for fatigue reduction for overhead manufacturing, assembly, and construction	Personal or medical	Personal
Device size	Adjustable hip width and abduction	Hip width range: 13.3"–16.6" (34–42 cm) Upper leg length range: 14.6"–19.3" (37–49 cm) Lower leg length range: 16.5"–21.7" (42–55 cm)	S/M/L/X
Device weight	55 lbs. (25 kg), but patients bear only their own weight	Personal: 26 lbs. (12 kg) Medical: 39 lbs. (18 kg)	Double-leg model: 14 kg Single-leg model: 9 kg
Shoe size	N/A	N/A	23.0, 24.0, 25.0, 26.0, 27.0, 28.0, 29.0, 30.0 cm
Gender considerations	N/A	N/A	Hip width: male size: 28–36 cm and female size: 32–40 cm
Price	Not available for personal use	To be consulted	To be consulted

offers pediatric orthoses for persons with femurs between 21 and 35 cm), there are not currently any mainstream items, further excluding children and youth. Even in such situations, age is not a common or a specific parameter that companies take into account. They focus more on femur length or hip width. Populations can also be excluded for being too tall – men in the Netherlands have an average height of 183 cm, suggesting that Cyberdyne's device, which can accommodate a maximum height of 200 cm, would be the only device that is broadly available to many Dutch users.

Concerning the weight of the device, Ekso Bionics proves to be the most massive (25 kg); but on their website, the

company stresses that patients bear only their weight. Indego is 12 kg for personal use and a bit heavier for medical purposes (18 kg). HAL reports being in between, with a device weight of 14 kg. (We are not considering the 9 kg single-legged device because the others are double legged.) Other results suggest that HAL from Cyberdyne is the only company offering the possibility to adjust the shoe size. The same company also has a gender specification, that of the hip width. For men, the size is 28–36 cm, whereas for women it is 32–40 cm. Pricewise, the majority of the companies do not have their prices online and force potential buyers to contact them directly for more information.

5 Discussion

In this section, we apply a feminist critique through an intersectional lens in order to better understand the social context of the individual relating to exoskeleton technology. Based on the results, we have selected three individual attributes – height, weight, and age – that affect how a user may be included or excluded from using exoskeleton technologies. We also include discussion of matters of socioeconomic status (relating to the price of the exoskeletons) as critical inclusion/exclusion criteria.

5.1 Exoskeletons for all?

Height and weight are the two most important parameters for exoskeleton use, but the technological fit for the standard user might also lead to exclusion. As Wajcman [23] writes on the topic of hay bales which require workers to be able to lift precisely 50 kg in the particular weight of the standard hay bale: “male workers use their bodily and technical effectivity to design machinery and machine tasks to constitute themselves as the capable workers and women as inadequate.” Similarly, exoskeletons have been given a certain standard measure at one point in their design and development history. As we can see, devices may support from 100 to 113 kg of maximum weight. This excludes users who have a weight under or over the weight limits. Intended users of exoskeletons have a series of user attributes that developers need to bear in mind for effective development and implementation. Most important of those is the health condition of the user, which excludes a large number of users who do not have the body strength required to use the exoskeleton. In an industry, this would exclude those workers required to use these devices for work; in a rehabilitation context, this could impede patients from accessing a technology that may benefit them. Although health condition-oriented exoskeletons seem to help realize the goals of personalized medicine, they also seem to highlight the need to develop exoskeletons for the other conditions, whichever those may be, pressuring developers and health-care systems to provide an equal and fair access to health-care technological solutions.

It is not only the weight of the technology but also the embodied technological adoption through the users’ body weight that matters for successful domestication of exoskeleton technology. As seen in the comparison, users of these exoskeletons can never weigh less than 40 kg, nor more than 113 kg. If they do so, they are excluded from

use. This is problematic, as there are several issues with weight in contemporary societies. Malnourishment and starvation are causing massive health pandemics in the global south, and the global north faces the opposite problem of obesity and overeating. Both of these global demographic weight trends are increasing at both ends of the spectrum and causing multiple health issues. In turn, this can make gait treatment and rehabilitation difficult as the users might not be within the weight limits of the technology. The weight limit is both a social construct and a result of technological constraints. To build an exoskeleton that supports heavier patients would lead to having heavier, clunkier, and more cumbersome devices which could then be in conflict with users of decreased arm strength (some of whom might be barely able to use the current system now).

Another aspect that seems to be highly problematic on a structural level is the price of exoskeletons. We did not find the exact price of the exoskeletons of the companies we analyzed due to the lack of the companies’ transparency. However, some articles suggest that the price range of exoskeletons varies between US\$30,000 and US\$200,000, which suggests that patients in emerging and developed countries cannot afford to obtain such a solution for their condition [47]. Although there may be many exoskeleton solutions out in the market, their use largely remains limited to the rehabilitation center or wealthy patients. It is an undeniable fact that disadvantaged people are recurrently excluded from the benefits of technological development. At an extreme, in some capitalist economies only the rich can afford to live when contracting a severe disease, whereas the poor who, due to their socioeconomic situation, cannot afford medicines would die in a worst-case scenario. In more egalitarian societies like the Nordic European countries, it is the state’s responsibility to provide good minimal equal health care for all citizens. However, exoskeletons currently are not seen as “necessary enough” for patients to have their own, due primarily to the high cost of the technology. Also, there is little evidence on the social impact of using the technology.

One essential unaddressed issue is whether there is enough competition to cover all market needs at affordable prices. At the moment, providers try to suit as many users as possible from a cost perspective, not specializing in specific minority targeted audiences. If some companies created exoskeletons just for children, while in healthy competition with other providers, would that create more affordable solutions? For some other considerations, private actors might not be in a position to afford developing technologies that cover the

whole market, thus prompting the question of public support or mandatory requirements for certain features – e.g., language support for indigenous people who might not speak the official/majority state language but whose developers might not have the resources (or profitability) to include in their original design.

5.2 Technological bias as user exclusion

Technological biases reflect how technology embodies social knowledge, practices, and products. Although we cannot claim to know if the exoskeletons in question are “being made and used by male power and interests” [23], there are certain gender biases that can be seen through target users. Going back to Berg and Lie’s [26] feminist techno-inquiry of artifacts’ genders, we can likewise prompt the question: “do exoskeletons have a gender?” By this, we do not mean the physical exoskeleton itself, as it is not gendered in the same way as a social robot or a chat program that may be given male/female design choices [48]. Instead, we wonder what the design script of the exoskeleton implies symbolically for the intended user. Here gender theories can help better understand user exclusion, and especially intersectionality can be fruitful.

To give an intersectional account of the user of exoskeletons, we need to look at who the intended user is, but, more importantly, who she is not. By looking at the technology user criteria, there are specific attributes a user must fit within. She cannot be too tall or too short, and she cannot be too overweight or underweight. She must be healthy enough to be able to strap on the technology if she is to use it by herself. These choices will necessarily exclude many users who could, for example, find themselves being too young and healthy normally be required to use a wheelchair for life but too tall to be able to walk with an exoskeleton. Disabled people – already a minority in society – are not just “disabled” but hold, as every human does, a wide variety of other identities. How can this, especially in regard to disabled people, lead to double or multiple levels of exclusion, discrimination, or disregard? Are exoskeleton users more in control of their life when using exoskeletons? And, revisiting the concept of coproduction [16], are the users involved in coproduction processes of the technology?

As Haraway [25] prompts with her Cyborg concept, one novel way of thinking about the exoskeleton user is precisely as a cyborg where humans and machines merge as cybernetic organisms; and although this sounds quite futuristic, we already see the start of this through

exoskeleton use. Through active inclusion, by understanding and eliminating exclusion criteria, more people could and should have the opportunity to walk again if that is their wish and the technology allows it. By looking at the rigid inclusion criteria for whom the intended user of the technology can be, we can thus also see whom the intended user is not meant to be.

5.3 Intersectional users of exoskeletons

For a better understanding of the exoskeleton users, we argue that it is imperative to see the users as unique and actively engage with their multiple identities. People come from all walks of life, have diverse genders, ages, socioeconomic backgrounds, upper arm strength, weight, and height. For a good development and implementation usage of exoskeleton technology, it is important that producers, health-care technology providers, health-care staff, and formal and informal caregivers be aware of patients’ unique individuality. As of now, technology seems to treat users as black boxes: the input and the output are known, but not what happens in the black box. We propose that, instead, technology should understand the user attributes and the effects it has on them. Unboxing the “user-as-a-black-box” can serve as an argument for a better sociotechnical understanding of the user as a technology–human hybrid – as people using exoskeletons integrate their bodies with a robotic device become a sort of cyborg. Making developers and designers aware of the effect technology has on users may confront them with the responsibility they have. The following chart provides a list of inclusive design choices that designers and manufacturers could consider when designing exoskeletons, which we term “inclusive design choices for exoskeleton design” (Table 2).

By considering these and other related issues when building, testing, and receiving feedback on the technology, creators, designers, and technology developers can increase the usability of their technology by better including a myriad of users – not only those who fit within the relatively high threshold standards. This may also help realize the dignity of the users, which should be central to how manufacturers design and build these robotic devices [50]. Going back to Haraway’s [24] situated knowledge, she describes how “bodies as objects of knowledge are material-semiotic nodes. Their boundaries materialize in social interaction.” In this case, this relates to how the producers’ way of selecting and excluding which “bodies that matter.” The ones that need the technology the most could risk being the

Table 2: Inclusive design choices for exoskeleton design

Human feature	Technology solution
Height considerations	Make exoskeletons that can accommodate very tall people as well as short people, e.g., children, or persons with dwarfism
Weight considerations	Make sure exoskeletons can support overweight and underweight people. This is especially important since a disproportionate amount of people in wheelchairs are overweight because of their more sedentary life
Correlated condition considerations	Make buttons in different patterns, so that green-red color-blind people can easily operate them without the fear of pushing the wrong-colored button. Create buttons with different textures for blind people and add auditory response sensors
Capability considerations	Make the exoskeleton as easy as possible to put on and operate with minimal upper body strength required, so that the users who are also minorly impaired in their upper body but severely impaired in their lower body can benefit from the technology
Gender and sex considerations	Be aware of bodily differences between men and women and ensure that the exoskeleton design is not a result of a man-only team, designing for men. A diverse group of employees or users should be involved at all levels and also be included in the target user group
Cultural considerations	People from different sociocultural backgrounds might relate to robotic technology in widely different manners. Acceptance rate and levels of trust differ, and what might work well in one region might not be ideal in others. Therefore, be sure to include a robust sociotechnical perspective in the development and testing of the technology to better understand how to adhere to different cultural values
Inclusivity considerations	Think about the importance of including typically marginalized communities such as the LGBTQ+ in the development of technology to avoid discrimination and reinforcing the existing biases [49]. Be inclusive-by-design and remember that any inclusion criteria may represent exclusion criteria for other communities. Careful reflection on these aspects when developing technology – including exoskeletons – can benefit both society and the individual

ones that are not able to use it due to, for example, being a couple of kilos or centimeters over or under the limits. Since the technology – and the knowledge put into development and redevelopment – is situational, and sociomaterially constructed, inclusive criteria can better inform the production and also the use of exoskeletons.

5.4 Limitations and further studies

The limited public availability of information concerning exoskeletons limited this study. The majority of large, international companies do not have specific information online. Additionally, given that there are currently only a few companies developing exoskeletons, the data were dependent on a few selected available companies that could provide the data. Following Nash's (2008) critique of intersectionality, the lack of a specific, defined intersectional methodology is also a potential issue, but here we have used it more as a conceptual tool. Additionally, we do not seek to give an empirical validity of intersectionality, as our data material does not include user studies. However, this could be a focus on further studies. Future studies may also cover a growing area of application, i.e., exoskeletons for

work purposes. Exoskeletons may improve and support the working conditions of staff performing demanding physical tasks, such as lifting patients. Overall, exoskeletons may help reduce fatigue in difficult jobs, such as manufacturing, assembly, and construction. More in-depth studies are also needed to investigate the coproduction that producers have with end users regarding exoskeletons.

6 Conclusion and further recommendations

By having rigid inclusion criteria for whom the intended user of the technology can be, exclusion criteria will grow in parallel. This holds for exoskeletons and may lead to discriminatory scenarios. By integrating a deeper understanding of how users of exoskeleton come in a wide variety of attributes, shapes, sizes, gender, and wealth, and that there is no general "one-size fits all," exoskeleton technology holds the potential for being more inclusive. To make this technology available for all who need it, designers and producers must also think beyond their target market. However, how this extra mile of inclusive

design should be implemented is not within the scope of this article. Some potential solutions could be to give incentives for technology producers to also include users who do not fit the standard frames of the technology, thus realizing and providing “exoskeletons for all.”

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References

- [1] E. Broadbent, N. Kerse, K. Peri, H. Robinson, C. Jayawardena, T. Kuo, et al., “Benefits and problems of healthcare robots in aged care settings: a comparison trial,” *Australas. J. Ageing*, vol. 35, no. 1, pp. 23–29, 2016, DOI: 10.1111/ajag.1219.
- [2] European Parliament, Civil Law Rules on Robotics European Parliament resolution of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics (2015/2103(INL)), 2017. Available: <http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P8-TA-2017-0051+0+DOC+PDF+V0//EN>.
- [3] M. Butter, A. Rensma, J. V. Boxsel, S. Kalisingh, M. Schoone, M. Leis, et al., Robotics for healthcare: final report, 2008. Available: <https://repository.tudelft.nl/view/tno/uuid%3Abeddf38c-e88c-4d2a-8394-e7234d9b3e8a>.
- [4] S. Razzaki, A. Baker, Y. Perov, K. Middleton, J. Baxter, D. Mullarkey, et al., “A comparative study of artificial intelligence and human doctors for the purpose of triage and diagnosis,” *arXiv preprint arXiv:1806.10698*, 2018.
- [5] P. Sale, M. Franceschini, A. Waldner, and S. Hesse, “Use of the robot assisted gait therapy in rehabilitation of patients with stroke and spinal cord injury,” *Eur. J. Phys. Rehabil. Med.*, vol. 48, pp. 111–121, 2012.
- [6] A. S. Gorgey, L. L. Goetz, and R. Sumrell, “Exoskeletal assisted rehabilitation after spinal cord injury,” *Atlas of Orthoses and Assistive Devices*, 5th ed., Elsevier, 2019, pp. 440–447, DOI: 10.1016/B978-0-323-48323-0.00044-5.
- [7] A. Wernig and S. Muller, “Laufband locomotion with body weight support improved walking in persons with severe spinal cord injuries,” *Paraplegia*, vol. 30, pp. 229–238, 1992, DOI: 10.1038/sc.1992.61.
- [8] E. Høyer, B. Normann, R. Sørsdal, and L. Strand, “Rehabilitation including treadmill therapy for patients with incomplete locked-in syndrome after stroke; a case series study of motor recovery,” *Brain Injury*, vol. 1, pp. 34–45, 2010, DOI: 10.3109/02699050903471805.
- [9] G. Colombo, M. Joerg, R. Schreier, and V. Dietz, “Treadmill training of paraplegic patients using a robotic orthosis,” *J. Rehabil. Res. Dev.*, vol. 37, pp. 693–700, 2010.
- [10] C. Holder, V. Khurana, F. Harrison, and L. Jacobs, “Robotics and law: key legal and regulatory implications of the robotics age (Part I of II),” *Comput. Law Secur. Rev.*, vol. 32, pp. 383–402, 2016, DOI: 10.1016/j.clsr.2016.03.001.
- [11] R. Leenes, E. Palmerini, B. J. Koops, A. Bertolini, P. Salvini, and F. Lucivero, “Regulatory challenges of robotics: some guidelines for addressing legal and ethical issues,” *Law Innov. Technol.*, vol. 9, pp. 1–44, 2017, DOI: 10.1080/17579961.2017.1304921.
- [12] E. Fosch-Villaronga, *Robots, Healthcare and the Law: Regulating Automation in Personal Care*, Routledge, 2019.
- [13] L. Floridi, J. Cowls, M. Beltrametti, R. Chatila, P. Chazerand, V. Dignum, et al., “AI4People – An ethical framework for a good AI society: opportunities, risks, principles, and recommendations,” *Minds Mach.*, vol. 28, pp. 289–707, 2018, DOI: 10.1007/s11023-018-9482-5.
- [14] W. E. Bijker, T. P. Hughes, and T. J. Pinch, Eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, MIT Press, 1989.
- [15] M. Etgar, “A descriptive model of the consumer co-production process,” *J. Acad. Mark. Sci.*, vol. 36, pp. 97–108, 2008, DOI: 10.1007/s11747-007-0061-1.
- [16] S. Jasanoff, Ed., *States of Knowledge: The Co-production of Science and the Social Order*, Routledge, 2004.
- [17] E. Fosch-Villaronga and B. Özcan, “The progressive intertwinement between design, human needs and the regulation of care technology: the case of lower-limb exoskeletons,” *Int. J. Soc. Robot.*, 2019, DOI: 10.1007/s12369-019-00537-8.
- [18] D. Goodley, *Disability studies: an interdisciplinary introduction*, Sage, 2016.
- [19] S. L. Snyder, B. J. Brueggemann, and R. G. Thomson, Eds., *Disability Studies: Enabling the Humanities*, Modern Language Association of America, 2002.
- [20] V. Lajeunesse, C. Vincent, F. Routhier, E. Careau, and F. Michaud, “Exoskeletons’ design and usefulness evidence according to a systematic review of lower limb exoskeletons used for functional mobility by people with spinal cord injury,” *Disabil. Rehabil. Assist. Technol.*, vol. 11, pp. 535–547, 2016, DOI: 10.3109/17483107.2015.1080766.
- [21] G. Goggin, “Disability and mobilities: evening up social futures,” *Mobilities*, vol. 1, pp. 533–541, 2016, DOI: 10.1080/17450101.2016.1211821.
- [22] C. Tannenbaum, R. P. Ellis, F. Eyssel, J. Zou, and L. Schiebinger, “Sex and gender analysis improves science and engineering,” *Nature*, vol. 575, pp. 137–146, 2019, DOI: 10.1038/s41586-019-1657-6.
- [23] J. Wajcman, *Feminism confronts technology*, Penn State Press, 1991.
- [24] D. Haraway, “Situated knowledges: the science question in feminism and the privilege of partial perspective,” *Feminist Studies*, vol. 14, pp. 575–599, 1988.
- [25] D. Haraway, “A manifesto for cyborgs: science, technology, and socialist feminism in the 1980s,” in *Feminism/Postmodernism*, L. J. Nicholson, Ed., Routledge, 1990.
- [26] A. J. Berg and M. Lie, “Feminism and constructivism: do artifacts have gender?,” *Sci. Technol. Hum. Values*, vol. 20, pp. 332–351, 1995.
- [27] K. Crenshaw, “Mapping the margins: intersectionality, identity politics, and violence against women of color,” *Stanf. Law Rev.*, vol. 43, pp. 1241–1299, 1990.

- [28] K. Davis, "Intersectionality as buzzword: a sociology of science perspective on what makes a feminist theory successful," *Feminist Theory*, vol. 9, pp. 67–85, 2008, DOI: 10.1177/1464700108086364.
- [29] E. R. Cole "Intersectionality and research in psychology," *Am Psychologist*, vol. 64, pp. 170–180, 2009, DOI: 10.1037/a0014564.
- [30] R. K. Dhamoon, "Considerations on mainstreaming intersectionality," *Polit. Res. Q.*, vol. 64, pp. 230–243, 2011, DOI: 10.1177/1065912910379227.
- [31] L. McCall, "The complexity of intersectionality," in *Intersectionality and beyond: Law, Power and the Politics of Location*, E. Grabham, D. Cooper, J. Krishnadas, and D. Herman, Eds., Routledge-Cavendish, 2008.
- [32] N. Yuval-Davis, "Intersectionality and feminist politics," *Eur. J. Women's Stud.*, vol. 13, pp. 193–209, 2006, DOI: 10.1177/1350506806065752.
- [33] J. C. Nash, "Re-thinking intersectionality," *Feminist Rev.*, vol. 89, pp. 1–15, 2008, DOI: 10.1057/fr.2008.4.
- [34] F. Ferrando, "Is the post-human a post-woman? Cyborgs, robots, artificial intelligence and the futures of gender: a case study," *Eur. J. Futur. Res.*, vol. 2, p. 43, 2014, DOI: 10.1007/s40309-014-0043-8.
- [35] C. B. Baunsgaard, U. V. Nissen, A. K. Brust, A. Frotzler, C. Ribeill, Y. B. Kalke, et al., "Exoskeleton gait training after spinal cord injury: an exploratory study on secondary health conditions," *J. Rehabil. Med.*, vol. 50, pp. 806–813, 2018, DOI: 10.2340/16501977-2372.
- [36] J. Mehrholz, S. Thomas, C. Werner, J. Kugler, M. Pohl, and B. Elsner, "Electromechanical-assisted training for walking after stroke," *Cochrane Database Syst. Rev.*, vol. 5, p. CD006185, 2017, DOI: 10.1002/14651858.CD006185.pub4.
- [37] J. J. Eng, T. Lam, and D. R. Louie, "Research team gait speed using powered robotic exoskeletons after spinal cord injury," *J. Neuroeng. Rehabil.*, vol. 12, p. 82, 2015, DOI: 10.1186/s12984-015-0074-9.
- [38] J. Eng and D. Louie, "Powered robotic exoskeletons in post-stroke rehabilitation of gait: a scoping review," *J. Neuroeng. Rehabil.*, vol. 13, p. 53, 2016, DOI: 10.1186/s12984-016-0162-5.
- [39] P. H. Chen, R. H. Wang, R. L. Wang, D. J. Liou, and J. S. Shaw, "Gait disorders in Parkinson's disease: assessment and management," *Int. J. Gerontol.*, vol. 7, pp. 189–193, 2013, DOI: 10.1016/j.ijge.2013.03.005.
- [40] A. Esquenazi, and M. Talaty, "Robotics for lower limb rehabilitation," *Phys. Med. Rehabil. Clin. N. Am.*, vol. 30, pp. 385–397, 2019, DOI: 10.1016/j.pmr.2018.12.012.
- [41] International Organization for Standardization, "ISO 13482: 2014 Robots and Robotic Devices – Safety requirements for personal care robots," Available: <https://www.iso.org/obp/ui/fr/#iso:std:iso:13482:ed-1:v1:en:term:3.15>.
- [42] European Union Medical Device Regulation, <https://www.medical-device-regulation.eu/2019/07/04/mdr-article-1/>.
- [43] World Data, "Average Sizes of men and women," Available: <https://www.worlddata.info/average-bodyheight.php>.
- [44] World Population Review, Average Height by Country 2020, 2020. Available: <http://worldpopulationreview.com/countries/average-height-by-country/>.
- [45] B. Lozada, "Filipinos second-shortest in Southeast Asia," *Inquirer.net*, April 25, 2014. Available: <https://globalnation.inquirer.net/102688/filipinos-second-shortest-in-southeast-asia>.
- [46] K. Froehlich-Grobe, D. E. Nary, A. VanSciver, R. A. Washburn, and L. Aaronson, "Truth be told: evidence of wheelchair users' accuracy in reporting their height and weight," *Arch. Phys. Med. Rehabil.*, vol. 93, pp. 2055–2061, 2012, DOI: 10.1016/j.apmr.2012.05.005.
- [47] E. Abdelkarim and S. M. Brahim, "Development and control of a low cost Exoskeleton system with an interactive HMI designed for paraplegic children," *Int. J. Sci. Eng. Res.*, vol. 10, pp. 1326–1331, 2019.
- [48] R. A. Søraa, "Mechanical genders: how do humans gender robots?" *Gend. Technol. Dev.*, vol. 21, pp. 99–115, 2017, DOI: 10.1080/09718524.2017.1385320.
- [49] A. Poulsen, E. Fosch-Villaronga, and R. A. Søraa, "Queering Machines," *Nat. Mach. Intell.*, vol. 2, p. 152, 2020, DOI: 10.1038/s42256-020-0157-6.
- [50] L. Zardiashvili and E. Fosch-Villaronga, "“Oh, dignity too?” Said the robot: human dignity as the basis for the governance of robotics," *Minds Mach.*, 2020, DOI: 10.1007/s11023-019-09514-6.