

# Exoskeletons, Rehabilitation and Bodily Capacities

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[journals.sagepub.com/home/bod](https://journals.sagepub.com/home/bod)**Denisa Butnaru** 

Universität Konstanz, Germany

## Abstract

Motility impairments resulting from spinal cord injuries and cerebrovascular accidents are increasingly prevalent in society, leading to the growing development of rehabilitative robotic technologies, among them exoskeletons. This article outlines how bodies with neurological conditions such as spinal cord injury and stroke engage in processes of re-appropriation while using exoskeletons and some of the challenges they face. The main task of exoskeletons in rehabilitative environments is either to rehabilitate or ameliorate anatomic functions of impaired bodies. In these complex processes, they also play a crucial role in recasting specific corporeal phenomenologies. For the accomplishment of these forms of corporeal re-appropriation, the role of experts is crucial. This article explores how categories such as bodily resistance, techno-inter-corporeal co-production of bodies and machines, as well as body work mark the landscape of these contemporary forms of impaired corporeality. While defending corporeal extension rather than incorporation, I argue against the figure of the ‘cyborg’ and posit the idea of ‘residual subjectivity’.

## Keywords

cyborg, exoskeletons, phenomenology of the body, residual subjectivity, spinal cord injury, stroke

## Introduction

In a recent broadcast of *La Grande Librairie*, on France 5, the neuropsychiatrist Boris Cyrulnik asserted that ‘we are fascinated by transgressions’.<sup>1</sup> Current technological developments such as

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**Corresponding author:** Denisa Butnaru. Email: [denibutnaru@gmail.com](mailto:denibutnaru@gmail.com)

**B&S Online Forum:** <https://www.theoryculturesociety.org>

exoskeletons are specific markers of such transgressional phenomena. Mostly associated with science fiction, exoskeletons are presented as exceptional technologies and enjoy widespread media acclaim. They are commonly imagined to provide superpowers to their users, affording unprecedented possibilities for human bodies. A closer look at these types of technologies, however, suggests that the media's portrayal is still far from reality.

Exoskeletons are currently developed to cover needs related to motility in three areas: rehabilitation, industry and military. They have two main functions: to rehabilitate in cases where the human body has lost a certain motility capability (such as walking or grasping) and to assist the human body when the body is healthy. While rehabilitative uses of exoskeletons are commonplace, assistive or augmentative uses are more controversial. The presence of exoskeletal technology in some movies, especially in combat scenes, associates exoskeletons with the enhancement of corporeal strength.<sup>2</sup> Yet, exoskeletons used for rehabilitation are often described by their designers as training 'tools'. Like many other technologies, exoskeletons are not neutral. Due to their close proximity to the human body, they create specific challenges for both their designers and their users, who need appropriate training in order to use them. The implementation of exoskeletons is, therefore, accompanied by the creation of new habitus repertoires which contribute to the reinvention of 'techniques of the body' (Mauss, 1973), and with them, further corporeal phenomenologies.<sup>3</sup>

This article addresses the rehabilitative context in which exoskeletons are used to help humans with neurological impairments reappropriate bodily capacities. Here, exoskeletons have more success for several reasons. Unlike industrial or military applications, the use of an exoskeleton in a clinic or lab targets damaged anatomy so that it may regain partial and temporary motility (such as the capacity to walk or move one's arms and hands). In this article, I argue against the perspective that exoskeletons are considered to be enhancement technologies and intend to defend a view of bodily extension rather than bodily incorporation or embodiment. I will explore what challenges are faced in re-appropriating bodies and recasting motor capacities when using exoskeletons in rehabilitative environments and deconstruct the phenomenon of enhancement in concrete examples. The idea of enhancement is extensively promoted in a variety

of studies focusing on the relation between human bodies and technological gadgets, where tropes such as the ‘cyborg’ are used to portray augmentation (Clynes and Kline, 1960; Haraway, 1991; Westermann, 2012). As I will show, however, a fluid human–machine cooperation is an acknowledged challenge for many engineers developing exoskeletons (Georgarakis, 2020; Lotti et al., 2020).

Focusing on expert perspectives on exoskeletons in empirical qualitative data, I highlight how new corporeal forms resulting from the conception of exoskeletons create new frontiers for what bodies can do in rehabilitative environments. In so doing, exoskeletons attempt to engage human bodies in forms of re-appropriation. The empirical material is sourced from an ongoing qualitative research project in sociology beginning in 2014. The data include scientific presentations for academic or popularization purposes, 46 expert and narrative interviews and ethnographic fieldwork in laboratories and centres where exoskeletal devices are designed and tested.<sup>4</sup> The most common impairments rehabilitated with exoskeletons and evoked later on are cerebrovascular accident (CVA) and spinal cord injury (SCI).

I focus only on the third-person perspective of engineers. This decision is motivated by the fact that this technology is both work in progress and costly, and few patients have access to it. In my study, only seven individuals with motor impairments with whom I conducted narrative interviews used exoskeletons. All were men, aged between 25 and 65 years. Unlike other technologies, exoskeletons developed for medical purposes aim to modify damaged motility functions thought impossible to rehabilitate until recently. Consequently, exoskeletons contribute to the emergence of an unprecedented phenomenological corporeal potential. They alter first and foremost one’s ‘sense of agency’ as well as ‘sense of ownership’ (Gallagher, 2012: 132), central categories developed by current paradigms such as enactivism (Di Paolo, 2018; Gallagher, 2012; Thompson, 2007; Varela et al., 1991).

At first glance, correlating the third-person perspective of experts with the phenomenological paradigm may seem contradictory and open to obvious epistemological challenges, but such an attempt is not without precedent. Projects combining phenomenology and natural sciences (Carel and Meacham, 2013), the growing number of

studies in the field of embodied cognition (Dourish, 2004; Gallagher, 2017; Kyselo and Di Paolo, 2015) as well as postphenomenology (Ihde, 2002, 2009; Ihde and Malafouris, 2019, Selinger, 2006) suggest this is a promising approach. Because motility is one of the basic attributes of our experience of the world, exoskeletons have a clear impact on how impaired bodies are lived and experienced. Furthermore, my predilection for the phenomenological paradigm is supported by the fact that the views of experts are not completely separated from those of the users – on the contrary. The complete conception and design of these novel devices literally focuses on the changes of ‘own bodies’ and their experiential content, while including the very people for whom these technologies are designed in the research process. Unlike other studies about developments in robotics or medical technologies, my example is peculiar because the third-person perspective of the experts is strongly user-focused, meaning that engineers invent the bodies of the users together with these users as they develop exoskeletons. Their views reveal, therefore, how current phenomenologies of the body emerge in rehabilitative environments and what challenges are faced in the process of re-appropriating bodily capacities, and more generally of bodies *tout court*.<sup>5</sup> Because these technologies are meant to partially and contextually help the autonomy of affected persons, they also contribute to the advent of new forms of subjectivity. Among these is one that I name ‘residual subjectivity’.

After briefly presenting the current state of exoskeletons, I discuss the challenges in their application and use in cases of spinal cord injury (SCI) and cerebrovascular accident (CVAs) (more commonly known as stroke). Far from being a smooth practice, re-appropriation of bodies with motor impairments is a demanding process with many considerations. For example, not all bodies having these impairments may ‘work’ with exoskeletons. This empirical finding led me to conceptualize forms of ‘bodily resistance’ of the users. Re-appropriation processes include the techno-inter-corporeal production of bodies and machines where persons with impairments may use them. This is correlated to the process of ‘body work’ (Gimlin, 2002) and to the production of motor habits, which is what I attend to in later sections. Finally, I consider the concept of ‘residual subjectivity’ and highlight its relation to corporeal extension, relying on the previous categories.

## A Captivating Object

Exoskeleton technology was originally developed by the military. An

exoskeleton is an electromechanical structure worn by [an] operator and matching the shape and functions of [the] human body. It is able to augment the ability of human limb and/or to treat muscles, joints, or skeletal parts which are weak, ineffective or injured because of a disease or a neurological condition. [...] The exoskeleton works mechanically in parallel with [the] human body and can be actuated passively and or actively. (Anam and Al-Jumaily, 2012: 988)

Active actuation means that they function with batteries and are typically heavier. Passive exoskeletons, on the other hand, function with springs and are lighter. The three fields for which exoskeletons are currently developed are military, industry and medicine. Projects carried out for military applications, such as combat, promoted the conception of a body enhanced through use of an exoskeleton. Take, for example, the Tactical Assault Light Operator Suit, one of the well-known projects conducted by the Defense Advanced Research Projects Agency some years ago.<sup>6</sup> The constant use of a science fiction figure, namely Iron Man,<sup>7</sup> in various media referring to this project, or to military projects in general, reinforced this perception. Yet, programmes carried out in industrial environments to assist workers contradict this understanding and tend towards a more cautious narrative. From this perspective, exoskeletons are defined as gadgets or tools that assist rather than enhance the workers' capabilities while performing various tasks. They are designed to prevent eventual damage done to a person's body<sup>8</sup> due to the repetition of certain movements for a longer period of time. Technological projects in industry are the first to portray exoskeletons in terms of tools helping and protecting bodies rather than converting them into superheroes. This is a view I also defend. The third area where exoskeletons are produced and used, and which is the focus of this article, is medicine. In this domain, exoskeletons are almost considered a miracle technology because they represent an obvious revolution in rehabilitation. They help motor functions in the body, following an experience of neurological disorder. Among these, SCI and stroke are often the targets of rehabilitation with exoskeletons.

With respect to able bodies, exoskeletons might help the persons wearing them respond to context-related movement requirements; in the case of impaired bodies, exoskeletons act as a complement for a missing or damaged function in the body. In this sense, they are similar to prostheses, but, unlike prostheses or implants, they are not incorporated into the body. In other words, exoskeletons are designed to influence subjective phenomenological properties such as the 'sense of agency' or the 'sense of ownership' by extending the body. Prostheses are designed to be incorporated,<sup>9</sup> having more distinctive impacts on the corporeal feeling and being of the person wearing them.

Whether in non-rehabilitative or rehabilitative environments, exoskeletons vary significantly in form and conception. Some of them are bulky, such as those meant for persons with a SCI. In these cases, the exoskeleton must support both the body of the person wearing it as well as its own weight. Other exoskeletons are lighter, and function with strings mechanisms that support movement. This lighter exoskeleton type, sometimes called an 'exosuit', belongs to the category of soft wearables and mimics clothing.<sup>10</sup> Given their close proximity to the human body, these technological developments challenge the ways in which bodies are lived, impacting their phenomenologies. Despite their being referred to as 'tools'<sup>11</sup> by engineers and sometimes even by some patients, exoskeletons transcend this label in rehabilitative environments because they open possibilities of being a body previously thought to be incurable. For example, the fieldwork showed that individuals with a SCI, whose paraplegic condition would otherwise hardly improve (if at all), can use exoskeletons to experience verticalization of their bodies. In this respect, exoskeletons simultaneously represent a technological and a phenomenological revolution, because they modify (although for a short period of time) strongly damaged basic experiential functions: standing and walking. In so doing, they transform a motility-impaired body into a temporarily able one, for the duration of use in a clinic or lab, which makes exoskeletons extraordinary 'tools'.

Exoskeletons' modification of bodily conditions thought irreversible has generated significant media acclaim. Claire Lomas,<sup>12</sup> for instance, was paralysed from the chest down due to an accident, but some years ago managed to complete the London Marathon in seventeen days with an exoskeleton from the company ReWalk.<sup>13</sup> She is

often cited as an example of the success of robotic suits. Yet, despite this obvious progress in helping people who can no longer walk, rehabilitation exoskeletons are still works-in-progress and far from constituting body-machine fluid assemblages. They are even further from any figure of the cyborg, a prolific entity in cultural and body studies discourses (Coeckelbergh, 2017; Gray et al., 1995; Penley and Ross, 1991) during the past few decades. Vivian Sobchak, who herself has a leg prosthesis, criticizes the ‘metaphorical (and . . . ethical) displacement of the prosthetic’ (2006: 18). In her essay, ‘A Leg to Stand on: Prosthetics, Metaphor, and Materiality’, Sobchak asserts that the idea of prosthesis should be reconnected to real facts, rather than fictionalized. The facts observed in my fieldwork regarding the design and use of exoskeletons echo Sobchak’s position.

### **Bodies (Still) Against the Machines**

One of the difficulties faced by both engineers and users in the process of designing exoskeletons is the adjustment between the users’ bodies and the devices. What experts need to face very often in their projects is how users’ bodies respond to and often how they resist devices. Attaining fluid human-machine interaction that speaks to a successful re-appropriation of one’s own body with the device remains currently often a challenge, questioning views in phenomenology that argue for incorporation of objects. Some of these views argue, for example, that due to our kinaesthetic repertoire, we are predisposed to incorporate a variety of objects or extend our bodies through objects (De Preester and Tsakiris, 2009). This also includes technological ones (Malafouris, 2013; Schusterman, 2008). The fields of prosthetics and robotics are, in this respect, rich sources for analyses on body and embodiment, allowing reconsideration of notions such as ‘own body’, ‘body image’ or ‘body schema’ (Crawford, 2014; Sobchack, 2010; Tamari, 2017), with a long epistemological history not only in phenomenology, but also in psychoanalysis. As Daniel Black notes in ‘Where Bodies End and Artefacts Begin: Tools, Machines and Interfaces’, tools may be understood ‘as if they were themselves part of our own bodies’ (2014: 43). However, not all tools follow this rule.

My fieldwork experience shows that, despite being labelled as ‘tools’, exoskeletons used for rehabilitation do not fit Black’s

definition. The main goal that *both* experts and users aim to achieve in a rehabilitative environment, namely embodiment of this form of technology, or as some engineers name it, ‘transparency’ (Georgarakis, 2020), remains, for the time being, difficult. Exoskeletons challenge phenomenological possibilities of embodiment into the ‘body schema’ of their users, leading me to conceptualize a form of ‘bodily resistance’. Bodily resistance is acknowledged by all parties involved in rehabilitation with exoskeletons. It refers either to how the body of the user may not respond to the machine as it is expected or to how the user may find herself/himself with a medical condition that makes the training with the exoskeleton dangerous. Consequently, bodies that have experienced a SCI or stroke may resist the devices due to their fragility. This is an obvious challenge for engineers, as one of the major criteria they must respect in the design of these devices is the safety of use.

At the same time, the variation in bodies and injuries individualizes the strong subjective aspect of the users’ bodies. This may address, on one hand, the differences between the two types of neurological impairments; on the other, this may refer to differences among persons with the same category of impairment, which supports the view that techno-corporeal meanings and their developments are strongly anchored in people’s biographies (Williams, 1998). In this sense, although both categories of persons with a SCI or stroke may have walking problems, not all exoskeleton models may address their needs. Moreover, except for the specificities individualizing each type of impairment, as one of the interviewed engineers explained, one needs to differentiate between the contexts of use for exoskeletons and, correlatively, the body type which these contexts require:

The question is what goal you have in developing the exoskeleton. Stroke patients have an accident. After that, they have a recovery period. So, you can train. You can support recovery. This is one goal that the device could have. [...] But at some point, people don’t recover any further. They remain with problems. So, you can also make a solution that is more what they call an ‘assistive device’, that they have to use every day, for example. It’s not to train but to become functional. And that’s already different. You really have to know what you aim at. (Eng13CH: 40)

Indeed, aims are framed by contextual requirements and reduced corporeal resources. But they are also determined by degrees of severity of injury in people's bodies, which influences the concrete use of the devices. Especially, the extensive variety of other conditions that bodies with a SCI or stroke could have leads to the situation that not all impaired individuals are allowed to train with an exoskeleton. Machines, too, have their own requirements. As a consequence, if bodies cannot follow the 'scripts' (Akrich, 1992) of the devices, one can hardly have any successful interaction between the two. As one engineer explained, in cases where patients have contraindications, the use of the device is not recommended at all. For example, some patients may have strong spasticity: 'If the patient has severe spasticity or a joint which is impossible to extend, it is a contraindication. And it is not possible to train with the machine' (Eng10CH: 128).

Unlike prostheses, glasses or music instruments and various tools which are referenced in studies defending the incorporation and embodiment of foreign objects (Colombetti, 2016; Gallagher, 2005; Malafouris, 2013), exoskeletons in rehabilitative environments resist this process. This resistance is grounded in one's 'own body' as such, in the impaired person's specific condition and livability with the 'after' body: the body after the injuries occurred. In this vein, exoskeletons irrefutably trouble and interfere in a variety of phenomenologies of the body. When experiencing motor disorders, one's 'sense of agency' and 'sense of ownership' (Gallagher, 2012: 132) are deeply affected, involving radical changes in the person's motor intentionality (Merleau-Ponty, 2012 [1945]: 113–114). Jean Theurel, who leads a research programme on the use and application of exoskeletons at the *Institut national de recherche et de sécurité* in Nancy, France, emphasizes that using an exoskeleton is relatively difficult for the time being, regardless of whether the person using it is healthy or impaired. Unlike other tools or gadgets to which the human body is accustomed, current possibilities of incorporating an exoskeleton are minimal, and, if they exist, this occurs under very controlled conditions and with a lot of effort. As Theurel notes:

The big problem in robotics regarding the exoskeleton is motor intention. It's to search for the motor intention, for the brain code. I was telling you earlier that physiology is very interesting because we adapt

to everything. The brain adapts to everything. For instance, you jump on your ski. You don't have the same references anymore at all. It slides. [ . . . ] Generally, we know how to adapt to everything. You are warm, you start to sweat. Why? Because water will allow you to chill down. Generally, as soon as we are exposed to something, we adapt. However, the exoskeleton, as its own name indicates it, is 'exo'. It is not under this command of adaptation. Therefore, making it adapt to everything which a moving body may adapt to is senseless for the time being. Unless you connect it to the brain. (Jean Theurel, expert interview, translated from French: 152)

Rehabilitation robotics primarily seeks to avoid aggravating what bodies already cannot do, while preserving and building on some unaffected forms of ability. Experts categorize the latter as 'residual functions' (Riener, 2017), a category I discuss in a later section.

### **Techno-Inter-Corporeal Productions of Bodies and Body Work**

One of the functions that exoskeletons perform is that of a corporeal 'normaliser'. Although the main target remains motility, exoskeletons also have an impact on anatomical and biological functions of the body, such as blood circulation or bladder function. Interestingly, despite their being engineered for persons with impairments, exoskeletons are conceived starting from movement patterns of bodies which are able. This does not imply that people with impairments who are the target users are ignored. Often, persons with a SCI or stroke are included in the tests leading to the conception of the device, although before attaining to their final users, exoskeletons collect motor patterns from able subjects. Such a process entitles the qualification of these devices as both techno-corporeal and techno-inter-corporeal.

While the perspective of a body as an entity 'composed of' and hence made of 'detachable things' (Waldby, 2002: 240) is already well known in body studies, the example of medical exoskeletons demonstrates how the body works to *attach* things when experiencing missing functions. The specificity of attaching an exoskeleton to one's impaired body involves, as I argue, attaching along with the robot corporeal forms of ability of persons who are foreign to these very bodies. It is because they engage able bodies in the first place in their conception that I consider exoskeletons to be 'normalisers'.

Because a variety of corporeal profiles are mobilized in the process of creating the algorithm which is implemented in the robot, a form of datafied intercorporeality emerges. Such a phenomenon allows me to reconsider some categories from the phenomenology of the body. For example, the phenomenological concept of the body as object (*Körper*) (Merleau-Ponty, 2012 [1945]), which is the body as observed or perceived from a third person perspective (as it is in engineering science or, generally, in natural sciences), proves to be a derivation from subjective bodies (*Leib*). Remarkably, the extensions of impaired bodies by means of the exoskeleton imply an extension starting from parameters characterizing other bodies. Accordingly, the reciprocal production between the impaired body and the exoskeleton is based on a form of corporeal memory, a compilation of various healthy motility patterns saved inside the device. These patterns can be activated during the training process. In this line of thought, one may follow Andy Clark who claims that ‘humans and other primates are revealed as constantly negotiable bodily platforms of sense, experience, and [...] reasoning, too.’ (2008: 37). The body’s boundaries may be set, reset, compared and adjusted until a new form is available, which may be understood as a form of ‘other’ in the self (Butnaru, 2017) and thus, as an internal alterity production by means of external technological parameters.

The development and, implicitly, the use of exoskeletons find themselves embedded not in a strictly corporeal network; rather, as the empirical findings suggest, it is highly embedded in an intercorporeal one, where features of both ability and disability are called upon. In this process, bodies with impairment are caught in a loop, the edges of which are defined by healthy bodies. As one of the interviewees explains while discussing the example of SCI and describing why healthy subjects are needed in the conception of movement patterns for exoskeletons,

the goal is to get it as close to normal, but still functional for spinal cord injury. So, it’s just motors that move your legs for you. A normal person can get in it [in the exoskeleton], and then it will just move their legs, but if it does something wrong, then, the normal person could also move their legs to kind of prevent it. Or (laughing) they could also feel that it’s doing something weird, something that it shouldn’t be doing. (Eng1USA: 175)

In this vein, I understand the process of re-appropriating bodies with exoskeletons as a form of techno-inter-corporeal co-production. In its achievement, an innovative form of ‘body work’ is mobilized, one which follows clear steps and steady control. ‘Body work’ may refer in body studies to a variety of aspects. In a review of literature of this concept, Debra Gimlin differentiates between four categories of ‘body work’: (i) body/appearance work, (ii) body work/labor, (iii) body/emotion management and (iv) body-making through work (Gimlin, 2007: 353). Much in this classification refers to the area of work, in the sense of employment, and thus to how bodies are shaped by such environments, as well as to how they shape them in return. My use of this concept comes close partially to the ‘appearance’ work. A widely discussed case to exemplify this category is, for example, the phenomenon of cosmetic surgery (Gimlin, 2002, 2007; Jones, 2008) or those of body building and fitness cultures (Monaghan, 2001; Monaghan and Atkinson, 2014).

Body work in a rehabilitative environment with exoskeletons is deeply related to forms of practice that conjoin a multiplicity of epistemologies of the body. Its course engages both scientific and subjective phenomenological instances while reasserting the familiar by re-anchoring the body in a set of skills actualized by the device. With respect to cosmetic surgery, fitness culture and body building, the work on the body is related to personal choices that may be very explicit; though, in some societies, such as Korea or Finland, those who engage with these practices seek to respond to social norms regarding body images which are very recent (Kinnunen, 2010; Yeon Leem, 2017). Rehabilitation with an exoskeleton is, however, not necessarily a choice. Many persons with a SCI or stroke have restricted access to this type of care or no access at all, which makes the techno-inter-corporeal production of their bodies a challenge, and although access may be provided, the training sessions usually last between 30 to 45 minutes, which is why any bodily acquisition is relatively fragile. Unlike small objects which we may use in various contexts, including medical ones, exoskeletons are heavy and require tremendous corporeal literacy, necessitating extensive body work. Obviously, the acquisition of the needed corporeal literacy is made difficult by lacks in the anatomy of the people with motor impairments, a situation contradicting a widely accepted idea according to which the association between the human body and a machine leads

to the production of a 'hybrid infrastructure' or 'cyborg'. It is already an important achievement if an impaired person manages to have autonomy in using the robot alone in a lab or clinic, if one considers the case of non-static exoskeletons. These usually have crutches to help the patient balance during walking. To reach this competence depends, however, on many hours of training and on the condition of the patient's body. In this vein, exoskeletons engage their users in rehabilitative environments besides 'body work' in forms of 'work upon one's own body', the latter implying also the understanding that these gadgets are literally not for every 'body'. In this sense, exoskeletons are technologies of 'exclusion'. Accordingly, their impact on motility, disability and recuperation of damaged functions resulting from injuries to the spinal cord or brain needs to be understood as highly circumstantial and never permanently achieved. This makes corporeal re-appropriation in rehabilitative contexts where exoskeletons are used a form of 'body work in progress'.

One of the visible achievements of 'body work' with exoskeletons is their contribution in reinvesting the remaining anatomical but also the 'physical capital' (Bourdieu, 1984) of their users. In this dynamic, these devices target the achievement of a 'legitimate body' (Shilling, 1993: 144–145), a legitimization sanctioned by the variety of expert stances involved. Experts redefine motor capabilities, while simultaneously ensuring the function of translating what is natural into technological parameters. As Chris Shilling notes,

'body experts' are all involved in educating bodies and labelling as legitimate or deviant particular ways of managing and experiencing our bodies. This affects the recognition we have of our own body practices, and the body practices of others, as 'right' and proper or in need of control and correction. (1993: 145)

In such a process further forms of re-capitalization of experiential subjective resources emerge. In these, motor habits play a crucial role, as I show in the next section.

### **Recapturing Capabilities While Training Motor Habits**

Producing and designing motor capabilities with exoskeletons relies on the appropriation of new habits in the sensorimotor repertoire of one's own body. Often, experts invoke a central characteristic of the

brain, with regard to motor habit acquisition: neuroplasticity (Ramachandran, 2005). As Merleau-Ponty remarks, ‘habit expresses the power we have of dilating our being in the world, or of altering our existence through incorporating new instruments’ and ‘in the acquisition of habit it is the body that “understands” (2012 [1945]: 145). ‘To understand is to experience the accord between what we aim at and what is given, between the intention and the realization – and the body is our anchorage in a world’ (Merleau-Ponty, 2012 [1945]: 146). Such a phenomenological law defines our own bodies in general; yet, when confronted with severe forms of motility impairments such as those resulting from SCI or stroke, these resources need a recalibration. This is where exoskeletons intervene. The fact that the human body has capacities both to incorporate and extend its own skill repertoire (Durt et al., 2017; Fuchs and Froese, 2012) makes possible further adjustments with technological objects, a situation which obviously sustains corporeal re-appropriation. Like other technologies for rehabilitation, exoskeletons also follow this logic. However, some parameters contributing to visible achievements in the rehabilitation of motor impairments need to be respected. Among these is the training *intensity* of motor practice. Robert Riener, who is a well-known specialist in robotics, defines intensity related to three parameters: the number of repetitions of the movement pattern, the physical effort, and the cognitive effort (Riener, 2019). In order to actively contribute to corporeal re-appropriation of either damaged movement patterns or remaining ones, the training with the exoskeleton needs to simultaneously focus on all of them. In a presentation made in 2017 at University Medical Center, Neurozentrum, in Freiburg im Breisgau, Robert Riener explains some aspects of this process. In his view,

the longer you train, the faster you move, the more repetitions you can do. And this number of repetitions is an important variable or parameter in the gait training, or in physiotherapeutic training at all. But that’s not all. It’s also about the physical effort. You must be active. [...] And this afferent feedback, then triggers signals in the spinal cord, depending on the lesion. And this produces neuroplastic effects. [...]. And the more forces produced by the patients, the better is also the effect.

To integrate corporeal habits requires a steady presence of the machine so that the body manages to save what it learns and, more

importantly, to *maintain* motility models. Much in the process of re-appropriation of motility patterns is focused on preserving a steady level of what has been already achieved. Own bodies are articulated in terms of a collection of habit patterns, which involve the development of what Marcel Mauss named ‘techniques of the body’ (Mauss, 1973). Remarkably, such bodily techniques, responsible for both the creation and the preservation of movement patterns, are compared by some engineers to learning specific movements in sports. In this regard, Riener, whom I previously referenced, explained the following:

Some routine is good. You should train with some repetition. When you learn a tennis stroke, you should vary the movement, and if you have more variance in the movement, then you have a stronger effect. That’s the same kind of effect with these machines. (Riener, 2017)

And yet the reality of persons having a SCI or stroke is that, unlike sports, elite performance is not the goal. The target is to get as close as possible to the values characterizing what one used to be before the neurological impairment occurred, which often engages one’s own body in very complex procedures and skill negotiation forms. Interestingly, when engineers evoke the comparison with learning movements in sport, they denote an exceptional characteristic of the impaired body. In our ‘normal’, healthy state, the learning of movements is spontaneous. We do not reflect on how we move,<sup>14</sup> nor do we question the reality of our corporeality. This state has to do with what Drew Leder calls an ‘absent body’ (Leder, 1990). Training temporarily with an exoskeleton reminds the persons with impairments that this absence disappeared: this condition amounts to an ‘absent absence’ (Dalibert, 2016: 646). The body is therefore constantly present, and any attempt of recapturing former motor capabilities reinforces this presence.

During one of my participations in a training session, a patient was trying a leg exoskeleton for the first time. This exoskeleton belonged to the category of exosuits, which are lighter in conception, but also less powerful. One of the striking moments was to see that despite his first efforts to remain verticalized, and despite the help of the physiotherapist and the two engineers in the test room to achieve this position, his body could not sustain the effort. As a result, he often

had to sit or stop during the walking exercise and to bend over forward. This moment questioned not only whether the bodily profile of the person using the exoskeleton is compatible with the machine, but also what the person lacked in order to be able to use it with more autonomy, specifically exercise. This implies that, if training works, it is related both to what bodies still have as resources, which may be mobilized in the training process, but also to the duration of prior experience and practice with an exoskeleton. The comparison with sports practices becomes pertinent in this context, because similarly to sports, capabilities and abilities need regular training, maintenance and improvement. Additionally, just as in sports, achievements are temporary.

The exceptional status of the movement repertoire that persons with motor impairments need to learn and actualize regularly may be understood as a subculture of body practices (Hirschauer, 2004), with the caveat that unlike sportswomen and men, individuals with motor impairments do not aim to achieve performance exceeding what average bodies can do. The goal is to reach parameters of what a healthy body does. Learning how to make one's body efficiently work with a machine reorganizes the relation to one's 'sense of ownership' and 'sense of agency'<sup>15</sup> (Gallagher, 2012: 132). It means in particular that the person who uses the exoskeleton needs to stay physically and mentally concentrated during specific time intervals. As some engineers explain,

many patients have to undergo a long physiotherapy, many hours of physiotherapy. Especially right after a stroke or right after a spinal cord injury. They are in the hospital and they have to do many hours of physiotherapy. And they're not always motivated. You would think that they have to be motivated, because they want to get better. So, they have to have this intrinsic motivation, but it's not that easy. And, sometimes, they have to repeat the same exercises for a long time. It always depends on the person. Some have a strong will, and they will do it. But others don't. (Eng10CH: 26)

In order to increase training efficiency and motor habits, one of the projects which complements the practice of movements with exoskeletons is, for example, to do walking or grasping training while playing video games.<sup>16</sup> Video games are a recently introduced element in the re-appropriation of the movement repertoire of persons

with a SCI or stroke and may also play an active part in the amelioration of cognitive resources. To be engaged in virtual reality while training sharpens the awareness of the subject for what she 'can' do or for what she 'no longer can do' but potentially 'could do' again. As John W. Krakauer (2020), a neurologist engaged in research projects of recovery after stroke, notes in a discussion of one of his recent scientific developments, one of the advantages of using virtual reality for rehabilitation is that it allows one 'to do a lot and enjoy' what one is doing. In this line of thought, exoskeletons may interestingly use forms of 'dis-embodiment',<sup>17</sup> while aiming for de facto re-embodiment, appropriation and recapturing of motor habits. While targeting motor habits, they merge multiple phenomenologies of the body and reinvest both the relation and living of one's 'own body' in everyday practices. Yet, in order to achieve such a goal, the bodies of persons with SCI or stroke need to possess enough resources, which sets the basis for what I name 'residual subjectivity', a category that I will discuss in the following section.

### **Extending Bodies: Residual Subjectivities**

As outlined above, in order to obtain any visible achievements, one of the central issues in rehabilitative robotics is the detection of a patient's movement intention. While able bodies are naturally characterized by motor intentionality, the situation changes drastically in cases where there are strong motor deficiencies, such as those caused by a SCI or stroke. Despite an existing motor intention (one can think of walking, moving one's arm or even doing more complex movements like grasping an object with the hand), the material damage in the brain or the spinal cord makes the movement impossible. The role of exoskeletons is to respond these various forms of damage. Concretely, what exoskeletons do is to help the persons wearing them to perform some segments of movement related to what a body naturally could perform. In short, they briefly redimension bodily incapacities into capacities. For instance, with much effort and training, persons with SCI can walk with an exoskeleton over small distances, at reduced speeds. In allowing temporary ability, exoskeletons extend the body, which is what makes these devices similar to wheelchairs (Winance, 2006). In this sense, the body's extension becomes

a synonym for some forms of ability, such as walking or grasping small objects.

In order to achieve such results or any results at all, an essential condition for the use of exoskeletons is that the bodies of the impaired persons have rest functions. Redistribution of corporeal capacities may function only when the human body still has resources. These imply that there is an active part in one's own body which may be mobilized to use the exoskeleton, create further forms of ability and thus contribute to the process of corporeal re-appropriation. Hence, although there may be some exceptions, exoskeletons are mainly used by persons who have incomplete injuries. With respect to stroke, usually exoskeletons may be used by a larger variety of patients, unlike with spinal cord injuries where the resources of the body may be mobilized only above the lesion. In stroke, the affliction is asymmetric, the rehabilitation of the damaged half of the body being based on functions in the healthy half of the body. Due to a residuum of capabilities, new ones may be further forged. It is because the motor intentions produced with the device are grounded in rest motor intentions of one's own body that I speak of *residual subjectivity*.

To detect what rest functions may be mobilized for the interaction with the exoskeleton, experts may use biosignals such as electroencephalography or electromyography, information that provides the force that the device needs to support the user's body. Such a procedure is correlated further with the engagement of the impaired persons into a specific form of awareness, a 'bodily awareness' which is 'quite different from the perception that [they] have of the tool' and which further impacts the experience of one's own body 'not as an object, but as a field of activity and affectivity, as a potentiality of mobility and volition, as an "I do" and "I can" (Gallagher and Zahavi, 2019). Consequentially, persons with impairment start to develop a specific knowledge of their bodies and new capabilities, all while using the device and working with experts. It is in these forms of steady body work that they discover themselves as living bodies with residual capacities. That patients understand what they still can do is crucial for the remodeling of conceptions of ability and disability which takes place during and due to their use of the exoskeleton. Because of residual functions, people with motor impairments may engage in deconstructing forms of disability but

also of negative visibility. If one considers the example of body verticalization, which is one characteristic sanctioning one's belonging to the 'kingdom of the well', to recall a category introduced by Susan Sontag in her classic study *Illness as Metaphor* (1978), exoskeletons have an impact on this process. As Deborah Lupton notes, a disabled body is commonly a source of anxiety. In her view,

a body that does not function 'normally' or appear 'normal', or that is confined to a wheelchair or bed, is both visually and conceptually out of place, as evidenced by the lack of public facilities for people with disabilities or the elderly. (2012: 39)

Changes from sitting in a wheelchair to being verticalized may seem small at first sight; yet, they have a radical impact on how persons with motility impairments are perceived by others.

Despite rest functions which are active, an intentional dissymmetry may be, however, observed in the interaction between the body and the device. This refers to the fact that the machine cannot offer the same variety of movements a human body has, a view emphasized both by experts and users, and which draws attention to the limitations of exoskeletons, especially contextual and functional ones. Even if the devices allow the person wearing them to experience again some 'sense of agency' anew (for people who used to sit in a wheelchair for many years, this experience is crucial), this kind of motor intentionality remains very limited compared to what human bodies are naturally capable of. This is exemplified by the content of training sessions, in which the person with impairment follows mostly a clear pattern, and only that pattern. One can only walk if one wants to train the legs, the only variation being the occasional use of stairs. When describing what one potentially can achieve while using some current devices, one of the interviewees related that the possibilities are restrained. He said:

You could do two things with it [with the exoskeleton]. You could do A or B. You couldn't do something complex like reach a certain distance. But if you have invasive ones, where you could put electrodes directly in contact with the brain, you could do very complex things. (Eng1USA: 120)

Thus, while residual functions are crucial in elaborating further scenarios and possibilities of re-appropriation of one's own body, the great diversity of motor patterns that human bodies entail remains a challenge for what the technology can concretely transform. In order to cope with these current limitations, some training projects which include video games are a promising development, as such projects work towards overcoming the monotony of training only a few movement patterns and engage the user more actively in remodelling and transforming her or his corporeal capacities.

## Conclusion

To conclude, re-appropriating bodies in a rehabilitative environment while training with exoskeletons is a far cry from the idea of the 'cyborg'. Conversely, in order to obtain any visible and durable achievements, steady body work is engaged. Although concepts such as 'techno-body' (Andrieu, 2007: 35), 'hybridity' (Latour, 1993) or 'anthropotechnie' (Goffette, 2007) may pertinently describe a variety of technological advancements, boosting epistemological imaginaries, what the current perspectives of both experts and users in rehabilitative robotics show is that despite obvious possibilities of new phenomenologies of the body that exoskeletons open, any symbiosis between one's impaired body and the device remains a challenge.

There is no doubt that producing corporeal ability in chronic cases of impairment makes exoskeletons extraordinary devices. This attribute is also transposed onto the bodies that exoskeletons accompany and whose residual motor capacities they temporarily activate. In so doing, they directly challenge the distinction between the body as an object and the body as a subject, categories finding themselves at the core of a variety of phenomenological debates. As a concept, the 'extraordinary body' was defined some decades ago in disability studies by Marie Garland Thomson (Garland Thomson, 1997). In her study, one of the subcategories that she associates with 'extraordinary' bodies is 'physical disability' (1997: 5). Interestingly, it is this 'extraordinary' aspect that exoskeletons change for a short interval of time, while offering the persons wearing them novel experiences of living their corporeality, and by extension, sequential moments of corporeal re-appropriation.

Exoskeletons transgress the rules of bodies thought to be irretrievably disabled. They alter how persons with a SCI or stroke live their deficiency during the predetermined interval of their training, converting the value of the category 'extraordinary' from negative (mostly associated with physical disability) to positive (which characterizes ability). However, despite such a ground-breaking shift, exoskeletons remain far from being categorized as 'an object that can be absorbed into the body schema of its user' (Black, 2014: 43). Rather, they extend bodies, while allowing forms of corporeal transition from impairment to temporary forms of ability.

Thus, differently from what Ulrich Bröckling and Matthias Schöning defend while recalling a well-known categorization established by Helmuth Plessner between 'having a body' (*Körper haben*) and 'being a body' (*Leib sein*) (Bröckling and Schöning, 2004: 13), my empirical findings show that the natural borders of the body do not yet disappear. On the contrary: sometimes they may be very real, transforming one's own body into a form of corporeality that resists any cooperation project with technological devices. Unlike the oft-cited examples from classical phenomenology used to demonstrate the capacity of our body schemas to integrate foreign objects, such as the hammer (Heidegger, 1996: 64–65), the hat, the automobile or the cane (Merleau-Ponty, 2012 [1945]: 145), the body of SCI and stroke patients withstands exoskeleton incorporation, in spite of consequent hours of 'body work'. Indeed, exoskeletons may join the panoply of technologies which miraculously turn the ordinary of disability into the extraordinary of ability; yet, this happens for a very short time and under strictly controlled conditions. Exoskeletons remain, for the time being, technological 'companions' (Turkle, 2010) in moving one's arm, or in walking, offering temporary possibilities for corporeal re-appropriation and reversing for a brief interval the limit between abilities and impairments.

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### **ORCID iD**

Denisa Butnaru  <https://orcid.org/0000-0002-3161-270X>

### **Notes**

1. I refer to the broadcast of the TV show ‘La Grande Librairie’ presented by Francois Busnel, on 10 April 2019; available at: <https://www.france.tv/france-5/la-grande-librairie/la-grande-librairie-saison-11/944135-la-grande-librairie.html> (accessed 20 June 2019).
2. Combat exoskeletons are often named with respect to such movies as *Aliens* (1986), *Robocop* (1987; 2014), *Elysium* (2013) or *Edge of Tomorrow* (2014).
3. Many studies relying on phenomenological concepts drew attention to the impact the use of technologies have on how we experience our bodies (Coeckelbergh, 2019). Due to their resemblance to clothes, exoskeletons are technological gadgets which challenge a variety of sensorium forms. They also influence movement and consequently the way one experiences the relation to space, the experience of proximity and distance to objects and to other human beings.
4. The ethnographic fieldwork was carried out mainly in three countries: France, Germany and Switzerland. The interviewed experts include engineers, which are the greatest number, physiotherapists, ergonomists and salespeople for companies producing and commercializing exoskeletons, among which some were also trained engineers. They come from the formerly named three countries, but also from the

Netherlands, the United States and Canada. Many interviews were conducted at conferences or fair trade shows for exoskeletons. With the exception of those experts who agreed to explicitly be quoted in this article, all the other informants have been anonymized. Similarly, in accordance with the Codex of the German Society for Sociology, the names of the labs where the fieldwork was carried out shall not be divulged. When quoting the informants who are anonymized, I will use codes which refer to the following criteria: type of expertise, an ordinal numeral, indicating the place of the interview in the series to which it belongs, and the country, from which the expert comes. For example, the code 'Eng3GE' refers to the third engineer that I interviewed and who comes from Germany. Having used the software Maxqda to code my interviews, I will mention the number of the paragraph which I quote, after the code designating the interviewee.

5. According to Ezequiel Di Paolo, one of the crucial questions in the enactive orientation refers to: 'What is a body?' (Di Paolo, 2018: 72), a question which is also at the core of many views in sociology and anthropology (Gugutzer, 2006; Latour, 1993; Malacrida and Low, 2016; Shilling, 1993; Synnott, 1993).
6. See <https://www.bbc.com/news/technology-24474336> (accessed 10 April 2020).
7. See <https://www.defensenews.com/land/2018/05/24/iron-man-usso-com-1-year-from-putting-operator-into-powered-exoskeleton/> (accessed 10 April 2020).
8. In France, the SNCF (Société nationale des chemins de fer français) railway company, which encourages the development of exoskeletons for their workers, argues against the image of Iron Man and defends the category of a 'preserved' man. See <https://www.sncf.com/fr/reseau-expertises/direction-materiel/portraits-agents/yonnel-giovanelli-rencontre-papa-exosquelette> (accessed 10 April 2020).
9. For a phenomenological distinction between incorporation and extension see De Preester and Tsakiris (2009).
10. See, for example, the projects of the company Myoswiss in Switzerland: <https://myo.swiss/en/> (accessed 6 April 2020).
11. One of the interviewed engineers asserts clearly his view on exoskeletons being tools: 'they are "mobility tools, among other existing tools"; "something which partially assists the person on certain movement phases" (Eng16FR:124, translated from French).
12. See <https://www.independent.co.uk/news/science/bionic-woman-claire-lomas-is-first-woman-to-take-robotic-suit-home-8104838.html> (accessed 17 April 2020).
13. See <https://rewalk.com/>

14. In his study *Still Lives* (2004), Jonathan Cole evokes the experiences of 12 persons with spinal cord injury, all tetraplegics. With respect to two of them, he notes the following: 'Their spinal cord injuries reveal how our bodies normally enable us to make our way in the world with little attention to them. These two men can never forget the need to care for their bodies and so never forget their spinal cord injury. It continually imposes on their waking lives, conditioning their view of the world and their view of themselves' (Cole, 2004: 17).
15. The 'sense of agency' (SA) and the 'sense of ownership' (SO) are inter-related and both characterise pre-reflective aspects of self-awareness. However, between the two, the SA seems to hold a certain pre-eminence in granting more experiential coherence. The SA is more tightly connected to an intentional stance, whereas the SO is more fragmented and results by means of a constant aggregation of various experiences, among which are also agentic or agential ones. In Shaun Gallagher's view, the SA refers to 'the pre-reflective experience that I am the one who is causing or generating a movement or action or thought process', whereas the SO is understood as 'the pre-reflective experience that I am the one who is moving or undergoing an experience' (2012: 132). These two categories are fundamental in our constitution of a sense of selfhood. It is due to our SA that the SO becomes stronger. The SA allows our extension and expansion into the surrounding world, including both the presence of other humans or objects, and contributes to various forms of technological appropriation and integration.
16. Many projects on the development of exoskeletons include a virtual environment so that the person is engaged by a goal. Various games are proposed in which the patients are engaged in daily tasks so that what they train are motor patterns of daily life.
17. Don Ihde uses the concept of 'disembodiment' in his study *Bodies in Technology* (2002). The example he refers to in elaborating what he names 'a phenomenology of disembodiment' (2002: xviii) is that of virtual reality. My term of disembodiment obviously includes virtual reality but also the material presence of the exoskeleton, which disembodies in order to re-embodiment motor patterns.

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**Denisa Butnaru** is currently an assistant researcher at Universität Konstanz (Germany) and the PI of the project ‘Deviant Bodies. Extended

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Bodies' (BU 3417/2 -1), funded by the German Research Council (DFG). Her research focuses on contemporary transformations of human bodies by robotic technologies in medicine, industry and the military field from a sociological perspective. Further interests include recent developments of the phenomenological tradition (enactivism) and qualitative methodology in social sciences. She has edited the volume *Medial Bodies between Fiction and Faction* (Bielefeld: Transcript, 2020) and co-edited the volume *Corps abîmés* (PUL: Québec, 2013) with David Le Breton. She holds a PhD in sociology (2009) from Université de Strasbourg (France).