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DOI: 10.3217/978-3-85125-855-4-05

Simulating the Healthy Body: How Exoskeletal Devices Invent New Forms of Capability in Rehabilitative Environment

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Abstract. Exoskeletons are recent robotic developments in rehabilitation that draw attention to new ways of perceiving impairments. While simulating human walking or movements of the arms, exoskeletons redefine basic experiential parameters such as "motor intentionality" (Merleau-Ponty, [1945] 2012, p. 112-113; Pacherie, 2018), but also various forms of experiencing one's body as being abled. Hence, exoskeletons are markers of a partial transition from "I cannot" to "I can", which they perform through the simulation of healthy bodies. Although these changes take place mostly in the confined space of a clinic or lab, they are of major importance, and open the possibility to interrogate how the contextual use of exoskeletons in clinical environments changes the status of their users to "temporarily abled." In these new rehabilitative techniques, users are engaged in specific forms of "body work" (Gimlin, 2002; Gimlin, 2007). After first describing the current state of exoskeletal devices, I will analyze how healthy bodies are used as materials to provide models for impaired ones and discuss procedures of simulation based on a logic of "essentialization." In the next section, I will explore the specificity of "body work" with exoskeletons for rehabilitation purposes and how further conceptions of intercorporeality emerge due to the development of these novel technologies. I will support my arguments with excerpts from qualitative empirical material from sociological research conducted between 2014 and 2021 and correlate them to the phenomenology of the body.

1. Introduction

Recent robotic developments in rehabilitation such as exoskeletons draw attention to new ways of perceiving impairments and join the wider family of technological innovations in the medical field (Schlich, 2007). The main functions exoskeletons fulfill in medical environments are to assist and rehabilitate neurological conditions. In order to develop these possibilities, exoskeletons simulate motor patterns that characterize healthy human bodies, which identifies these gadgets as "translating" technologies for which simulation plays a crucial role. In this vein, exoskeletons simultaneously mediate and "intermediate" forms of motor capability, their aim being to capture motor patterns of healthy bodies in order to adjust or support impaired ones.

The first time when I had the chance to see an exoskeleton for rehabilitation in a clinic was in 2017 during a preliminary fieldwork visit. This device was intended to help people having experienced stroke and was conceived for arm training. What surprised me at first sight was the heaviness of the robot; yet shortly after discussing with one of

DOI: 10.3217/978-3-85125-855-4-05

the PhD students working in the lab and who explained me how the robot works and what the patients usually do in a training session, one understands that the device was hiding a world of corporeal possibilities hardly conceivable until recently. Stroke is just one of the examples of neurological affections that exoskeletal devices aim to respond to. Another one which exoskeletons aim to assist with is spinal cord injury. Regarding this type of injury, the devices I saw or tried myself were mainly developed for walking practice.

Exoskeletons for walking are either static, meaning that the device is immobile and functions like a fitness gadget, the impaired person being harnessed inside the device and having her or his legs moved by it, or they may be mobile. The first category of models is usually available in clinics and labs. The second type of models is intended both for training in clinics as well as for home use, in case users are autonomous enough. These exoskeletons usually function with crutches[1]. Whereas some exoskeleton models, especially the static ones are already on the market and have received certification, others that aim to provide more freedom and mobility for their users are often work in progress. Walking exoskeletons that have crutches are more restrictive; as a consequence, their users need to have a relatively good physical condition to manipulate the device. Nevertheless, one of the technical components in both types of devices that is crucial for the concrete practice is represented by sensors, which need to be very sensitive in order to capture remaining functions in the users' arms or legs and communicate this information to the robot so that the user may receive the needed support.

Because they simulate human walking or movements of the arms, exoskeletons impact basic experiential parameters such as "motor intentionality" (Merleau-Ponty, [1945] 2012, p. 112-113; Pacherie, 2018), but also various forms of "feeling" one's body as being able. This is a reason why they may be understood as technologies contributing to reformulate and reorganize specific phenomenological potentials on a more global level. Motor patterns may be described in very general terms; yet every user of exoskeletons has particular remaining motor resources, and often these differences that exoskeletons are designed to respond to may be challenging for a proper use of the device.

Simulation processes and procedures therefore relate to a very specific meaning with respect to my analyzed case. Unlike classical views in STS that conceive of simulation in relation to predictive practices (Heymann et al., 2017; Sundberg, 2010; Turkle, 1995; 2009), simulation mechanisms used in rehabilitative robotics enter other conceptions, the main goal of these projects being related to medical interests.

[1] The company Wandercraft from France developed an exoskeleton functioning without crutches for paraplegics, Atalante: https://www.wandercraft.eu/ (accessed 18/08/2021). However, this model is currently used only in clinics and hospitals.

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Different from such examples as goals in marketing or weather forecasting (Boumans, 2005; Daipha, 2015; Fine, 2007; Friedman, 2014), simulation characterizing the functioning of exoskeletal devices in rehabilitation gravitates around human bodies and their remaining possibilities to perform specific motor patterns. In this line of thought, exoskeletons are markers of a transition from forms of “I cannot”[2] to temporary forms of “I can” (Leder, 1990; Butnaru, 2018). The models used to train the impaired persons in clinics or labs are elaborated starting from healthy bodies which brings exoskeletons to simulate healthy movements while dis-simulating the specific impaired movements of their users. Due to the possibility of such a transformation, the interrogation of how the contextual use of exoskeletons in clinical environment changes the status of impaired persons into “temporarily abled” ones emerges, a phenomenon correlatively connected to the understanding of the clinical space (although for a short time) as one of corporeal normality.

The aim of this paper is to discuss the production of current forms of body cultures in rehabilitative environments where exoskeletons attempt to find their ways. My intention is to capture the dynamics of processes of simulation in this context while showing how new forms of motor capability are produced due to the use of this type of technology in the medical field. The simulation of a healthy body is crucial first for developing the technological device and second for the aimed achievements with impaired users.

After briefly describing the current state of exoskeletal devices, I will discuss what corporeal simulation means in the rehabilitative context. I rely on qualitative empirical material sourced from a sociological project started in 2014 and finished since recently.[3] The material comprises participations in scientific presentations and trade shows, narrative and expert interviews, as well as multi-sited ethnography in centers and labs where exoskeletal devices were developed, tested and used.[4] The

[2] Drew Leder discusses in his well-known study, *The Body Absent* (1990) the category of “I cannot” in relation to people’s capacity to intentionally decide anatomical processes. He notes: “Though I can lift my arm without any problem, I cannot in the same way choose to secrete a little more bile or accelerate my digestion” (Leder, 1990, p. 48). In case a person becomes a paraplegic following a spinal cord injury or has a half of the body paralyzed after a stroke, her or his body enters the realm of “I cannot”. It is due to the temporary and sequential modification of damaged walking or arm movement that exoskeletons act like translators towards forms of “I can”.

[3] The project’s aim was to inquire into the development and application of exoskeletal devices for both impaired and able bodies (industry and armed forces). In this paper, I only discuss one aspect related to the design of exoskeletons for rehabilitation purposes.

[4] For anonymization of the expert interviews, I used the following codes: Eng (engineer), a numeral showing the order of the interview in the series with that type of interview and an abbreviation of the country where the engineer was professionally employed at the time of the interview. For example, Eng1CH refers to the first interview I conducted in Switzerland. For narrative interviews I used the code: Reha (for rehabilitation), M if it is a male user and F if it is a female user, and then the country where

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impairment examples evoked later on for my analysis are spinal cord injury (SCI) and cerebrovascular accidents (CVA), more commonly known as stroke. I show what simulation aspects ground the conception and use of exoskeletal devices in rehabilitation, in which healthy motility patterns play a crucial role and how these further contribute to forms of body work and conceptions of intercorporeality, while correlating the empirical findings to the phenomenology of the body (Merleau-Ponty, [1945] 2012; Gallagher, 2012; Zahavi, 2019).

2. Wonder Objects

Because of their presence in science fiction movies, exoskeletons are often associated with enhancement, which is a first feature rendering these objects unusual or wondrous. However, the current reality of these devices is far from any pop culture figures of heroes using them. Currently, exoskeletons are developed for three fields: rehabilitation, industry, and armed forces. Their role is either to assist strenuous human motility patterns, which is why they are used by able people or rehabilitate but also assist people whose motor patterns are damaged and thus impaired. A peculiarity regarding exoskeletons' potential use in rehabilitation refers to two distinct cases: when impaired people have residual functions, which may improve due to practice with the device, one speaks of rehabilitation; in case that deficiencies are severe and the functions cannot be recovered, one speaks of assistance. I could experience concretely in my fieldwork why and how these devices bring the human bodies to practice what they could - walking but also moving one's arm after stroke - although this happened for a short interval.

Different from the fields of industry and military operations, exoskeletons in rehabilitation contribute to spectacular transformations. This is precisely because sometimes they enter worlds of heavy impairment, thought incurable until recently. Spinal cord injury and stroke are types of neurological affections that may have hard consequences for the people experiencing them. It is because of their exceptional and sequential impact on the motor deficiency of these category of persons that I categorize exoskeletons as "wonder objects." My use distances itself from any science fiction connotation and considers the impact that these technologies have on human bodies often living in pain. Besides the very phenomenological impact that exoskeletons induce, these devices are spectacular for a second reason: their changes in damaged bodies are unprecedented in the history of medical innovations and medical

the user comes from the number after the code of the interviewee refers to the paragraph. I analyzed the interviews with the software Maxqda.

DOI: 10.3217/978-3-85125-855-4-05

technologies. Such peculiarities reinforce the perception of exoskeletons as being "wondrous".

Both spinal cord injury and stroke have long represented strong challenges for both the people who experienced them as well as for medical personnel involved in their care. Exoskeletons reorient the focus on how these impairments can be medically transformed, and on another level, on the understanding of what human bodies can or cannot (anymore). In this sense, the bodies of people with (sometimes severe) impairments are transformed by these gadgets for short intervals of time into capable bodies, where capability means that they are partially able to perform sequences of movement. Take, for example, the experience of being verticalized after many years of sitting in a wheelchair or seeing one's image in a mirror while walking with an exoskeleton. These may seem to be unimportant details at first sight, especially for those who are healthy; and yet, for the people with spinal cord injury or stroke, walking or standing represents an alteration in their everyday lives with deep consequences, one that renders the experience of using an exoskeleton as an exceptional encounter. Although training with these devices may have a regularity in that the persons with spinal cord injury or stroke have consistently scheduled training sessions, these moments are marked by a temporary experience of what impaired bodies used to be able to perform in terms of motor repertoire. Due to this temporary character, exoskeletons retain their quality of being wondrous.

As one of the users recounted to me his first experience of using a walking exoskeleton after many years spent in a wheelchair, "the first steps, I would say, this was grandiose. When I sit in a wheelchair, I am the impaired person; when I stand up with an exoskeleton and I walk, then I belong back in society. Then, I am not impaired anymore" (RehaM3GE: 211; 213) (my transl. from German). In this line of thought, exoskeletons operate a clear mutation between ability and impairment, which actually starts at an invisible level. The wonder exoskeletons elicit happens both outside but especially inside the body of their users[5]. One of the interviewed engineers recounted to me about the impact of the initial use of a static exoskeleton for one of the observed patients, an impaired woman who re-experienced standing up again after many years

[5] In a recent broadcast of the magazine 28 Minutes on the TV channel Arte, Dorine Bourneton who is a paraplegic aerobatic pilot explicitly drew attention to what exoskeletons change. Her comments on her experience with the exoskeleton Atalante from the company Wandercraft, resonate with reactions of users I met during my research. She said: "First time that I got inside the exoskeleton, I told myself that this is how it should be. This is real life. This is how one should live. It is standing up. (La première fois que je me suis mise dans l'exosquelette, je me suis dit : c'est comme ça ; c'est la vraie vie. C'est comme ça qu'il faut vivre. C'est être debout.) (my transl. D.B.) And later on she evokes the quality of exoskeletons of "repairing the inside" (se sentir réparé de l'intérieur). See: https://www.arte.tv/fr/videos/103696-032-A/28-minutes/ (access 19.08.2021).

DOI: 10.3217/978-3-85125-855-4-05

of sitting in a wheelchair with whom the engineer worked during a study on this type of device. The engineer said:

> "Many patients report good psychological effects. Because they are always sitting in the wheelchair. And now, that they see that they are standing and walking, even if it is the machine that walks them, just the fact of seeing themselves upright is super beneficial for their well-being. Actually, some years ago, when I did a study here with [name of exoskeleton], I had a patient with spinal cord injury who didn't walk for like thirteen years. And when I put her in the [name of exoskeleton] she cried out of joy, and she told me to take a video for the children. So, it was really touching. And she is not the first. Many people actually, even if they know they cannot walk anymore, they require [name of exoskeleton] training just for the well-being. Because psychologically, it's good for them just to have this hour when they can stand up" (Eng13CH: 165).

The described surprise indeed transforms these gadgets into "wonder objects." Though the "wonder" may be very real, to achieve concrete success, complex procedures nevertheless must be elaborated and many hours of preliminary tests are required, which inscribes exoskeletons in specific forms of career of becoming one's "own body" after impairments occur. Among these, simulation, which in my analyzed case refers to the implementation of models of walking or moving one's arm in healthy bodies into the algorithm of the robot, plays a central role. Simulation already characterizes some practices related to the medical field as for example the education of specialists in surgery (Prentice, 2005; Prentice 2013). Yet besides educating experts of human bodies, current forms of digitally mediated simulation redefine and reinvent boundaries between models of bodily ability and models of bodily impairment and this is where exoskeletons intervene. They act, therefore, as an interface between healthy bodies and impaired ones. Interestingly, they engage their users into specific forms of experiencing their bodies in that if in general the human body is our primary site in the world because it situates us, when a person with neurological impairments uses an exoskeleton, her or his body becomes re-situated.

On another level, what these devices do is to challenge and reconfigure the landscape of contemporary "cultures of prediction" (Heymann, Gramelsberger and Mahony, 2017) that, different from technological cultures where exoskeletons are developed, have a much longer existence. Unlike other "cultures of prediction," which as Heymann et al. define as "cultures of power and, hence, transformative forces, which are all the more effective as they are often black-boxed, hidden, and invisible" (2017, p. 7), in my observed examples the main aim of simulation processes and procedures is to contribute to the development of medical epistemologies and practices. In my discussed example, although simulation obviously belongs to "cultures of prediction", its explicit purpose is to overcome corporeal damaged capacities. As I

DOI: 10.3217/978-3-85125-855-4-05

will detail in the following sections, simulation of healthy bodies relies on two central processes, which are interrelated – body essentialization and body work, both of which allow to further theorize phenomenological concepts.

3. Extending Cultures of Simulation: How Exoskeletons Intervene in Rehabilitation

3.1. Healthy Bodies and Their Simulation(s): Essentialization and Safety Procedures

Different from other simulation techniques involving quantification and contributing to the legitimization of various political, economic, or scientific decisions—weather forecasting is one of these examples (Fine, 2007)—exoskeletons integrate simulation to respond to other needs. If the former techniques may be associated with the development of "technologies of distance" (Porter, 1995: IX), exoskeletons may be understood as contributing to forge the field of "technologies of proximity" (Butnaru, 2021). The quantification procedures leading to their design, although impersonal at first sight, aim at finding solutions for a variety of human bodies and their motor impairments. Accordingly, exoskeletons contribute to the emergence of unprecedented forms of "idioculture"[6] inside the realm of medical robotics. Besides these, they also transform conceptions of impairment and bodily capacities, having a clear impact on the very subjective experiences of their users. These reasons grant exoskeletons a deep phenomenological potential. Alone, their influence of the "motor intentionality" (Merleau-Ponty, [1945] 2012, p. 112-113; Pacherie, 2018) of their users, associated with one's "sense of agency" (Gallagher, 2017), represent important aspects of transforming bodies thought irremediably damaged into bodies that sequentially regain motor functions. Clearly, associating quantification and simulation in engineering cultures with the fine grained details of each and every human body for which these devices are designed not only seems a complicate and intricate enterprise, but it also is de facto. And yet, interestingly, it is due to processes of simulation, that new phenomenological experiences are invented and, if enough practice with the device is possible, sometimes durably maintained.

[6] According to Gary Alan Fine, the category of "idioculture" refers to "a system of knowledge, beliefs, behaviors, and customs shared by members of an interacting group to which members can refer that serves as the basis of further interaction. Members recognize that they share experiences, and these experiences can be referred to with the expectation that they will be understood by other members" (Fine, 2007, p. 69).

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Among the mechanisms contributing to the simulation process in the conception of exoskeletal devices, besides the classical procedures of counting, measuring, compiling and not less importantly datafying and quantifying, one specific procedure I observed in my fieldwork was that of “essentializing” bodies. Generally, simulation mechanisms characterize a variety of forms of “cultures of prediction,” to stay with the above-mentioned concept. However, different from other areas for which charting capacities of human able bodies serves the purpose of predicting and controlling, what I observed in my fieldwork was that engineers engage in processes of data accumulation, which essentialize human capacities according to the intended correction of damaged motor capacities. Simulating healthy bodies representationally results in a very reduced “silhouette” that engineers name the “stick figure.” The stick figure may be understood as a computational translation of living bodies, which further construes the process of the simulation of healthy bodies for exoskeleton design in terms of what I identify as “body essentialization.”

“Body essentialization” first covers a very material aspect: able test subjects are invited to visit labs and centers and allow experts to gather information about their physiological and anatomical characteristics. Because very often it is easier to work with doctoral students or master students who are themselves involved in the team designing exoskeletons, it is these able people whose body values are collected. One of the advantage in using healthy subjects who are experts in engineering science is that they may quickly identify whether there are problems with the device. A second aspect of “body essentialization” involves the datafication of specific values characterizing the bodies of the test subjects. This epistemic procedure of capturing focused characteristics helps in concentrating the constitution of an algorithm for a particular aspect, as for example the metabolic cost. Interestingly in this process of essentialization the focus is on building a model which although composed of very specific values of people’s healthy bodies aims at a general application. The final aim is that the “collected capacities” composing the algorithm may be further transposed onto the impaired subjects by means of the device. In my observed examples of spinal cord injury and stroke, this refers to motor patterns of arms or legs and their correlated intentions.

In a study discussing how virtual reality simulators contribute to professionalize surgeons in their developing skills to perform minimal invasive interventions, Rachel Prentice proposes the concept of “body objects.” In her view, these objects refer to “representation of human bodies as they have been engineered to inhabit computers” (2005, p. 847). As she further details:

> “Body objects also are narrow: because the computer requires specific mathematical descriptions to calculate a line or determine a trajectory, body objects cannot be loosely described in ways humans understand intuitively. Body objects are

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representations of bodies articulated graphically and haptically, so humans can understand them, and mathematically, so computers can understand them" (ibid.).

Recording motor values and characteristics of healthy bodies for exoskeletons design is highly focused on very specific properties, which further partitions and simplifies the reality of human bodies. However, what the peculiarity of my example shows is that, if one stays with the previously evoked vocabulary of representations, the end product one perceives after a laboratory test is carried out to the end is very far from typical representations in anatomy and physiology. Actually is quite the contrary. Stick figures are minimal representations of human bodies that serve different purposes in the process of shaping skills. And yet, despite seeking such forms of necessary reduction and simplification, stick figures are essential stages in body simulations. Apart from forging understanding of how healthy subjects move, stick figures contribute to shape specific "epistemic cultures" (Knorr Cetina, 1999), the engineering ones. Simplification itself is a necessary procedural step in engineering sciences, the aims of which are functional and oriented toward solving problems. This is a feature that obviously differs from medical sciences, mostly confronted with complexity. As one of the engineers recounted to me when I asked him about the logic behind conceiving exoskeletons for rehabilitation:

"The problem was that the people with disabilities after spinal cord injury could not move. And there is a technology to stimulate muscles. You can electrically, artificially stimulate muscles and this way they can move their limbs. But the control is not by the brain but by a machine which has to be programmed. And the challenge was to stimulate the muscles in that way that the people can move and that the people can move in a functional way. So, part of the hardship to stimulate is to know how to stimulate the muscles in order to get a meaning for movement. It has to stimulate the body in a dedicated right way to get a functional movement. I had to think about how movement works, how the muscle contracts, how we can model the human mathematically, because this can help to simplify the strategy. That was a given goal. And then, as an engineer you always try to formulate the problem, and then, to find solutions for the problem. You formulate subproblems and you try to find subsolutions. And again and again. You get new questions on the way to the goal which has to be solved. That is the task of the engineer: to look ahead and solve single technical problems. It's always a technical problem, a small technical problem. It's not so much the overall problem of the disability. Of course in the very beginning, you see the day and the people. But then, soon, you go to the subproblem in order to solve it. It's becoming technical and less social […]" (Eng1CH: 24).

That bodies engineered to inhabit computers in the form of stick figures and contributing further to processes of rehabilitation and assistance of people with motor impairments are elaborated from healthy people is a logic that may surprise at first

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sight. Yet, as the above interviewed engineer explained to me, the role of healthy people whose body values contribute to shape the algorithm for the robot, besides providing the very fleshy material and motor patterns, is to help detect anomalies or malfunctions of the devices. The simulation of healthy bodies for the rehabilitation of impaired ones reaches therefore a more involved level. What the simulation procedure does, besides "shaping" impaired bodies and training them to re-appropriate lost or damaged "body techniques," is play a safety role. Because impaired users, who usually have paralyzed limbs as well as sensation and perception deficits, cannot assess if the exoskeleton is working properly and thus aiding their bodies, healthy subjects instead provide this information to engineers. They may thus help in preventing malfunctions and injuries that impaired persons would otherwise ignore. As such, healthy test subjects have a critical role in guaranteeing the safety of use of these novel devices because they have the ability to warn when the devices function incorrectly. As I was explained by one of the users himself an engineer participating in a program for exoskeleton development at the time of the interview:

> "If a normal person can get in the exoskeleton, then it'll just move their legs. But if the exoskeleton does something wrong, then, the normal person could also move their legs to prevent it. Or, they could also feel that the machine is doing something weird that it shouldn't be doing. And able persons are more readily available. There are very few spinal cord injured people around. We have to set up appointments with the physical therapist and then get them to sign consent forms. So it's just easier to try it on people who are available" (RehaM2USA: 177).

Following this description, exoskeletons may be understood as "healthy bodies collectors", while essentializing them and transforming these very bodies into sentinels. As technological objects, not only do exoskeletons have the function to literally objectify healthy motor patterns; in addition, they conjoin a multiplicity of bodily experiences, scientific visions, and conceptions about health and impairment, and thus advance a further perspective of simulation practices that demarcate contemporary cultures of rehabilitation and medical ones. In this attempt, exoskeletons highlight how simulation in rehabilitative robotics relies on multiple levels of collaborative work to repair bodies and, as I will show in the following section, contribute to advance new understandings of how material corporealities are actually made (Gimlin, 2007; Shilling, 2005) in contemporary worlds of rehabilitation.

The body experiences of the healthy test subjects, the expertise of medical professionals, and those of the users as insiders of their impairments in the final stages of design, makes simulation a plural architecture. Its multilayered articulation further forges the limits of knowledge claims about human bodies in these very contexts, where the final aim is the long-lasting care and maintenance of achieved motor patterns, though this remains an open and unfinished project. Attaining the category

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of what Sherry Turkle names “fluent users of simulation” (Turkle, 2009, p. 10) is for the time being a difficult enterprise, as not all impaired users may benefit of training with exoskeletons. One reason is that neurological injuries concretely lead to a strong variety of profiles. Another reason is that fluency of use relies on many hours but also conceptions of “body work” and forms of intercorporeality, aspects that I will discuss in the next section.

3.2. Body work with exoskeletons and novel forms of intercorporeality

The main aim of designing and applying exoskeletal devices in rehabilitation is to transform forms of “I cannot” in human damaged bodies into forms of what I name temporary “I can”. The category of “I can” is a classical one in the phenomenological tradition (Husserl, 1989; Merleau-Ponty, [2012] 1945; Leder, 1990). If the “I can” in preliminary Husserlian definitions referred mainly to the possibilities entailed by the egological consciousness (Husserl, [1928] 1973), in later elaborations of this concept they were related in particular to the field of phenomenology of the body. The “I can” extended to embed our dispositions to act and interact (Gallagher, 2017). Our embodiment is the precondition of our active engagement in a variety of experiences, performing actions, or interactions with other people. As Shaun Gallagher notes in a recent study while discussing mainly perceptual experience with respect to the phenomenological potential of “I can,”

> “what it’s like to experience the color red or green is not just an abstract state of phenomenal consciousness – it is affected by, and it affects our postural readiness to act, which may be experienced as a feeling of discomfort or awkwardness, or alternatively, a feeling of extreme readiness pertaining to engaging in a particular action. Whatever we call such phenomena – qualia, hyletic experiences, somaesthetic factors – they delimit our perception and action possibilities, as well as our cognitive possibilities” (Gallagher, 2012, p. 97).

Exoskeletons in rehabilitative environments do not explicitly aim to transform perceptual skills, but motor ones, and more specifically motor-impaired ones. However, their impact on one’s own bodily capacities to act and interact are obvious, one of the first experiential layers exoskeletons modify being one’s “sense of agency.” According to Shaun Gallagher, the “sense of agency” refers to “the pre-reflective experience that I am the one who is causing or generating a movement or action or thought process” (Gallagher, 2012, p. 132).

One’s being paralyzed delimits a specific sphere of “what it is like,” “knowing how,” or being able or unable to. Obviously, what prevails in this situation is the “I cannot” or “I no longer can” (Leder, 1990, p. 83), the main role of exoskeletons being to achieve a durable impact on these aspects. Such transformations mostly take place in the confined space of a clinic or a lab at present, since users mostly have the possibility of

DOI: 10.3217/978-3-85125-855-4-05

working with an exoskeleton in these type of environments. Consequently, the capability produced by means of using exoskeletal devices is delimited both in time and space and usually carried under the supervision of such professionals as physiotherapists, although circumstantially engineers may assist to training sessions for the purpose of assessing the device's performance and its improvement. These limitations lead to conceive of exoskeletons as sequential bodily producers. Within the algorithmic forms conditioning these very productions, the simulation of healthy bodies, is central and at the source of specific forms of "body work." The process of building up temporary abled bodies in the confined spaces of specialized institutions involves precisely many hours of "body work," a type of "work" far surpassing the phenomenological sphere of one's own body. According to Debra Gimlin, who discussed this category in a classical study in which she analyzed cosmetic surgery (Gimlin, 2002), "body work" is crucial because it is related to work on the self. As she mentions,

"the self that is enacted through the body is both a social construction and, at least at the level of cultural understanding, a distinctively individual possession. […] The body is fundamental to the self because it serves to indicate who an individual is internally, what habits the person has, and even what social value the individual merits" (2002, p. 3).

Clearly, the fact that exoskeletons are for the time being not widespread technologies impacts the generalization of self transformations. Yet as the findings in my fieldwork show, for some people with impairments, training with an exoskeleton even for only a thirty to forty-five minute session in a clinic strongly impacts the value of their bodies (Butnaru, 2021), and if one follows Gimlin's strong correlation between bodies and selves, also of their selves.[7] In the line of understanding selves as a collection of capabilities, skills, and a variety of forms of expertise, exoskeletons indeed rearrange them and enact them anew, despite limitations of accessibility, further limitations defined in terms of time and space, and their being obvious marks of dependency. Under these circumstances, the rehabilitation time and its sites become a synonym for reinventing one's own body and some of its phenomenological dispositions. What the fieldwork experiences show is precisely that during the training time experiences of former capability are actualized in bodies heavily impaired. Interestingly, this is a process deeply anchored in experiences of simulating other human bodies, and more specifically in entering, traversing, and copying the patterns of these very bodies, categorized as healthy, which are solicited to build up the

[7] The category of "self" is a very complex and debated one in phenomenology, as well as in social sciences. I will not enter the debates that oppose these two fields. My position is that selves are embodied, which is what has been defended in recent studies in phenomenology (Gallagher and Zahavi, 2008; Gallagher, 2011; Gallagher, 2017; Zahavi, 2005).

DOI: 10.3217/978-3-85125-855-4-05

algorithm. It is this feature that makes exoskeletons and their contained simulations specific intercorporeal instances.

The articulation of simulation in rehabilitative worlds with exoskeletons and its correlated body work (or forms of body work, since there is not one or only one form of body work) is based on the conjunction of experiential patterns of human motility that need appropriate codification and translation for the conception of the algorithm inside the robot. Translation is a necessary step in processes of simulation (Prentice, 2005, p. 854). As Konrad and Cepera note, “with computer simulation in general and agent-based modelling and simulation (ABMS) in particular, the complex reality of a system can be reduced to formalised and simplified rules” (2019: 242). One of the difficulties raised by “body work” with exoskeletons is this precise contradiction between the perspective behind simulation procedures that aim at generality, which characterize usually the third person perspective of experts and the specificity of the human bodies the exoskeleton needs to accompany, briefly put their very phenomenologies.

Within these fluctuations between material and immaterial patterns where simulation actually attempts to find its justification, the aim is not mere copying or reintegrating former “techniques of the body” (Mauss, [1934] 1973) that were damaged. Rather, what is sought refers to the elaboration of areas of subjectively articulated body knowledge that need to be invested anew, and where simulated motor patterns of healthy bodies are expected to overlap. This logic justifies the active existence of “body work” in rehabilitation centers and clinics provided with exoskeletal devices. Whereas “body work” may embrace a variety of forms (Gimlin, 2007; Shilling, 2005), among which are those discussed in Gimlin’s work (2002; 2010) whose empirical example concerns interventions in cosmetic surgery, that concretely and “fleshly” mark the limit between a “before” and an “after” of the human body, the “body work” with exoskeletons follows another type of logic. First, the “body work” with exoskeletons in clinics and labs is based on a consistent number of hours of practice that the bodies of the users need to withstand. Second, different from surgical interventions that usually happen once, the “body work” in rehabilitation is conceived of as happening for longer periods of time, the aim being the maintenance of skills or motor patterns, or the amelioration of anatomical functions. And third, besides the temporal and iterative aspects that underline that what exoskeletons do to the bodies they accompany is never completely achieved, the “body work” in this case is conditioned by undamaged possibilities that the bodies of the users may retain. This third aspect actually highlights the huge gap between the expected achievements and what the technological objects

DOI: 10.3217/978-3-85125-855-4-05

may currently offer[8]. As one of the interviewed engineers commented on this discrepancy regarding facts and expectations,

> "there has been a lot of hype around exoskeletons, you know. Because it is quite impressive to see people that cannot move their legs to be able to stand up. But […] there is a mismatch between what they hope to achieve and what is the reality right now. You know, ideally, in a few years, then things will get a lot better" (Eng14CH: 320).

Contrary to the use of other technologies for motor impairments such as wheelchairs (Winance, 2006; 2010), which are much more common and more immediately associated with the assistance of motor deficiencies, the use of exoskeletons and their correlated "body work" follows specific licenses. Interestingly, because of the generality of simulated motor patterns of healthy bodies, the aim is to cover the widest possible range of corporeal profiles. And still, simulation of healthy bodies may act as a selective factor. By this I mean that not all the people having spinal cord injury or stroke may have enough corporeal resources to enter the algorithmic copies of healthy bodies that the robot actualizes during the training sessions in the clinic or lab. Thus, simulating healthy bodies is a process related to forms of dis-simulation (Shin, 2021), by which I mean that despite the explicit goal of adjusting and improving injured functions of the human body, the current state of these technologies offers only partial answers for the needs of their projected users, not to say that literally exoskeletons are not "usable" by each and every body. One of the interviewees with a spinal cord injury concretely mentioned this detail in one of the interviews. He said:

> "Ideally, the target for exoskeletons is a young population, people who are not in the wheelchair for a long time, and who didn't develop bad habits. Because after a few years in a wheelchair, one develops bad habits. For instance, bones which are stiff, no possibility to move, lie down completely. So, for some people verticalization is not possible anymore and thus there is an incompatibility with the machine" (RehaM9FR: 211) (transl. from French).

Besides the very type of body, another limitation is, for example, the severity of injury of the users. If people with spinal cord injury or stroke cannot sustain the effort that the

[8] In a recent study *Robo sapiens japanicus* (2018), Jennifer Robertson briefly discusses her experience of one of the Japanese exoskeletons for rehabilitation from the company Cyberdine, namely Hybrid Assistive Limb (HAL) (Robertson 2018: 163-167), and notes that for the time being the use of this type of exoskeleton is relatively "challenging" (Robertson 2018: 167). Obviously Robertson's perspective comes from a person who is able and who has healthy motor functions and she pertinently notes the difficulties caused by the lack of fluidity between the movements of the robot and those specific to human bodies. Despite these difficulties there are some users who manage to regularly use some exoskeleton models, yet after many hours of training. It is in this context that I elaborated the category of "body work", a type of work which is highly specific and hence phenomenological, because each and every human body and each and every experienced injury are different and are different to compare.

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device imposes on them during a training session, this becomes as the engineers name it, a “contraindication,” which results in either the limitation of “body work” or its complete interdiction. Capability forms may indeed be recuperated and sustained with exoskeletal devices in cases of spinal cord injury and stroke, provided that they exist as residual functions, a condition which is usually assessed by medical doctors. As one of the interviewed engineers explained to me, when I asked her about the limitations in “body work” that exoskeletons may impose, she said:

“We have some contraindications both for upper and lower extremity devices. One of the main contraindications is osteoporosis. If the patients have problems because the [name of exoskeleton] is an exoskeleton which really moves the legs of the patient and, so, the legs might be weak, then the legs may get fractures. So, this is really important because if the therapist trains a patient with severe osteoporosis it might happen that, I don't know, there is a problem. And the patient maybe stumbles with the foot on the treadmill and the tibia breaks. […] So, the therapists always have to take care that if the osteoporosis is too severe, maybe a [name of exoskeleton] is not the best treatment” (Eng10CH: 114).

The production of temporary forms of capability takes place therefore in a circuit where the exoskeleton acts as a corporeal translator at the core of which both simulation and dis-simulation procedures of healthy bodies mangle. This observation makes exoskeletons new adherents to what Andrew Pickering defined as the “mangle of practice,” a “dialectic of resistance and accommodation” (Pickering, 1995, p. xi) with a specificity: exoskeletons collect human bodies in the form of models[9], which further on are used as corporeal instruments for rehabilitation of neurological impairments. In this procedure of both scientific and subjective experiential translation that sequentially reforms the very possibility of how impaired bodies may materially experience themselves, novel forms of intercorporeality (Merleau-Ponty, [1945] 2012) emerge. Here the materiality of human bodies enters algorithmic procedures, which speak for their immateriality for the purpose of re-creating healthy motor patterns around rather than inside damaged ones. The simulation happens around the body of the user because unlike other medical technologies that are literally situated inside human bodies in order to help, adjust, or correct anatomical or physiological functions, exoskeletons are currently “exo,” not “endo”, although what they aim to impact is the “endo” aspect. They entail an algorithmic intercorporeality that is later at disposal for rehabilitation, facilitating some of forms of “body work” I previously evoked and with them the manufacture of temporary motor ability in rehabilitative environments. These processes identify current cultures of simulation and essentially rely on forms of

[9] For a discussion on models and their function as mediating instruments, see *Models as Mediators* (1999) Mary S. Morgan and Margaret Morrison (eds.). Cambridge: Cambridge University Press.

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distributed ownership and agency, despite their aiming at yielding subjective “sense(s) of agency” (and partially ownership) (Gallagher, 2005; 2012; 2017).

That intercorporeality is a general characteristic of how human beings act and interact with one another is an assumption with a long conceptual history to which the phenomenological paradigm I previously evoked made an extensive contribution (Zahavi, 2005, p. 147-163). However, the logic of collecting motor patterns from healthy bodies for the purpose of helping impaired ones elucidates that intercorporeality needs to be newly defined. One of the dimensions where intercorporeality may currently gain more prominence is provided by the current cultures of simulation and “multiple ownership(s)” (Leach, 2005) to which exoskeletons doubtlessly belong.

4. Conclusion

In keeping with this narrative, exoskeletons appear to promise the re-anchorage of deficient manners of acting and performing tasks, but also the transformation of corporeal characteristics thought to be permanently unrecoverable into actual possibilities. That is why I named them “wonder objects.” While surfing the possible and the feasible, exoskeletons permanently switch between forms of “I can” and “I cannot” or forms of “I no longer can,” to retain the terminology of Drew Leder (Leder, 1990). In these fluctuations, what these devices ultimately do is redraw forms and possibilities of how living with severe forms of impairments has transformed in the past decade and attribute further meanings to procedures of simulation.

Whereas the role of simulating practical scenarios may be reversible in some situations—take, for example, learning to fly a plane, or the formerly evoked example of the education of surgeons—the role of simulation in rehabilitation with exoskeletons reinvests this strategy and consequent conceptions of what it is like to experience back temporarily lost capacities. As Theodore M. Porter noted in a well-known study, *Trust in Numbers*, “any domain of quantified knowledge, like any domain of experimental knowledge, is in a sense artificial. But reality is constructed from artifice” (1995, p. 5). The corporeal productions that exoskeletons aim at bring this perspective to a further level. In their settings of action, explicitly delimited by time and space, rehabilitation exoskeletons re-articulate human bodies with impairments through human healthy bodies in an algorithmically sanctioned intercorporeal play. In doing so, they contribute to renegotiate corporeal boundaries beyond the experiential potential of human bodies.

DOI: 10.3217/978-3-85125-855-4-05

Acknowledgements

I would like to thank my two anonymous reviewers for their helpful comments as well as to Michaela Jahrbacher and Nicki Lisa Cole for the organization of the peer-review process. My warmest thanks to Melissa Reed and Lena Kolb for their support both during and after my writing this paper.

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