Technoethics and situated cognition: The case of exoskeletons

Leonardo Massantini, Alberto Pirni, Paolo Dario

Abstract: The paper presents a theoretical and ethical framework capable of describing the effects that exoskeletons (i.e., an emerging type of wearable technology) can have on users, especially on their embodiment. After an introductory framework, in section two we explain what exoskeletons are, focusing on occupational – or industrial – exoskeletons. Thus, we introduce and discuss the major opportunities and threats these technologies present from an ethical point of view, especially in the occupational sector. In section three, we further deepen the ethical challenges of exoskeletons, especially whether these technologies are *morally acceptable* or simply *individually accepted,* by relying on the theories of *situated cognition* and *affectivity*, which we integrate by introducing the concept of *body invasion*, derived from Slaby's *mind invasion*. By changing the embodiment of workers, wearable technologies such as exoskeletons might impose cognitive and affective repertoires that might go against the fulfilment of goals the user would otherwise choose for herself. Finally, we show why iterative design is not enough to address the ethical challenges posed by exoskeletons, especially when individual acceptance and moral acceptability are conflated.

Keywords: Technoethics, exoskeletons, situated cognition, body invasion, iterative design

1. *Introduction*[1]

In this paper, we analyze the theoretical and ethical problems deriving from the use of occupational exoskeletons (i.e., a form of wearable technology) by conducting an analysis derived from *situated cognition* and *situated affectivity* (also known as *4E theories* from the terms: *embodied, embedded, extended, enactive*). *Wearable technology* is an umbrella term that refers to many different devices that can be worn on the body to satisfy a variety of needs. For instance, we wear glasses to correct our sight and watches to reliably check the time. The most ancient form of wearable technology is clothes (see Spurrett 2024), which can be used to protect the body, to keep it warm, to signal social status and to modify body image and body expression. When people use the term wearable

[1] The authors wish to thank Nicola Vitiello, Simona Crea and Emilio Trigili for their guidance and effective contribution regarding technical aspects of exoskeletons.

philinq XIII, 1-2025, pp. 189-209 Submitted: 30 March 2025
ISSN (print) 2281-8618-ETS doi: 10.4454/philinq.v13i1.597 Accepted: 15 May 2025

technology, they usually refer to *smart devices* such as smartwatches or smart glasses, which employ sensors and wearable computing to access the internet, gather and elaborate data about the wearer's body and her environment and display information in a convenient way. Wearable technology however is not limited to clothes and smart devices, but also includes exoskeletons. Exoskeletons are devices worn on the body to protect it, enhance it, or restore its abilities. When these technologies employ motors, they are classified as wearable robots. Exoskeletons were initially developed in the 60's by the military.[2] Exoskeletons are now here and might soon change our world, not only in the military sector. Indeed, exoskeletons are expected to improve productivity through robotic human augmentation and to improve the life quality of people with disabilities by offering greater mobility and independence.

Exoskeletons represent an interesting topic for philosophical speculation for several reasons. First, these technologies present moral problems that need to be addressed. Moreover, since these are new technologies that have not been adopted on a large scale, there is the possibility to influence their design, development and deployment process. Not only that, exploring from a philosophical point of view a new technology that closely interacts with the human body could help us further expand our theories on the philosophy of mind. Philosophers often have a general understanding of the ethical and theoretical questions posed by the introduction of new technologies, however, they usually lack the technical knowledge to fully address them. On the other hand, engineers fully know the technical aspects but usually have only an introductory understanding of the philosophical aspects of these technologies. This paper aims to reduce the gap between these two fields. We then present the major opportunities and threats that these technologies present from an ethical point of view.

We will focus on occupational exoskeletons. This is because these kinds of exoskeletons are paradigmatically morally concerning, since they can be made mandatory by employers or through legislation.[3] In section three, we further ad-

[2] The birth of exoskeletons can be traced back to 1890 with N. Yagn's project of a robotic exoskeleton that was granted a patent (Kumar *et al.* 2019). After that, the idea of exoskeletons had an important revival in 1965 when General Electric started the development of an exoskeleton for an Army-Navy joint program (Kumar *et al.* 2019). That model, the Hardiman I was 680 Kgs in weight and was not energetically autonomous (Kumar *et al.* 2019). Indeed, the first energetically autonomous exoskeleton was developed in 2004 at the University of Berkeley (Kumar *et al.* 2019), thus starting the modern era of exoskeletons.

[3] One could argue that military exoskeletons are even more concerning, however analyzing military exoskeletons requires first an analysis on occupational exoskeletons, since the former can be seen as occupational exoskeletons used in military context. Even medical exoskeletons can be considered veiled by some degree of normativity, especially from the point of view of ableism. However, while

dress the ethical challenges of exoskeletons, especially whether these technologies are morally acceptable or if, in some instances, they are not necessarily morally acceptable but merely individually accepted. In doing this, we rely on the theories of *situated cognition* and *affectivity* (also called 4E theories), which we integrate by introducing the concept of *body invasion*, derived from Slaby's (2016) *mind invasion*.

Through the concept of *body invasion*, we will show that the introduction of wearable technologies such as exoskeletons could impose cognitive and affective repertoires that might go against the fulfilment of goals the user would otherwise choose for herself. In order to explain the concept of body invasion, we discuss the concepts of mind invasion (Slaby 2016), docile bodies (Foucault 1975), and habituation (Gallagher and Zahavi 2022; Merleau-Ponty 2012; Wehrle 2017). Finally, we show why iterative design is not enough to address the ethical challenges posed by exoskeletons and instead we need new solutions based on situated cognition and situated affectivity that can reshape the whole production process, development, adoption, commercialization and marketing. In other words, all the stakeholders should be examined from the point of view of a technoethics (i.e., an ethics of technology) founded on situated cognition and situated affectivity.

2. *Exoskeletons: An Engineering and Philosophical Matter*

2.1 What are Exoskeletons?

Exoskeletons have a great range of shapes, form factors and can vary greatly in the materials they adopt and functions they fulfil. Exoskeletons can range from devices that are worn all over the body, to devices that are worn only around a specific part of the body, for instance, only the upper part, only the lower part, only the left or right side, or even just a single articulation of a limb. Generally speaking, the construction of exoskeletons utilizes materials ranging from rigid carbon fibers and metals to more flexible and soft fabrics, incorporating technologies from simple passive systems to advanced designs equipped with sensors and actuators that respond to various kinds of inputs from the environment and from the users' movement (https://exoskeletonreport.com).[4]

one can relatively easily refuse to adopt certain medical solutions, especially if alternatives are offered, one cannot easily avoid complying with work regulations. If anything in the medical field the problem is not usually that these technologies will be made mandatory even for those who do not want to use them, but rather that they might not be available to those who actually want and need them.

[4] https://exoskeletonreport.com is an independent website whose objective is catalogizing all the models, prototypes and news in the fields of exoskeletons. The website has become an important source for experts in the field.

For what concerns the form factor, they can also be distinguished between single- or multiple-joint devices, or between powered or spring-loaded, the latter also called *passive* exoskeletons.[5] While active exoskeletons have actuators (i.e. electric motors), passive exoskeletons as the name suggests, only have passive systems such as spring-loaded mechanisms capable of accumulating and then restoring energy in specific phases of a task. An example here is one of the so-called *occupational exoskeletons*, which in most cases consist of devices which support either the upper-limb or lumbar region in strenuous and repetitive tasks.

Exoskeletons can be classified according to the field of application, where we can identify four main domains: occupational/industrial, medical, consumer market and military. In this paper, we will focus on *industrial or occupational exoskeletons.* These are designed to assist workers in their activities with the goal of reducing fatigue and mitigating the occurrence of work-related musculoskeletal disorders (WMSDs) resulting from work-related injuries (WRIs). These technologies have a relevant impact in supporting workers in repetitive actions (Spada *et al.* 2017). For example, they can be used for supporting workers in tasks of overhead manipulation and load lifting (Howard *et al.* 2019)[6] and their use shows promising results in the reduction of physical demands on the musculoskeletal system (Pacifico *et al.* 2020; Grazi *et al.* 2020; Lanotte *et al*. 2020). In the workplace, exoskeletons can be used not only as protection devices but also as devices that greatly improve workers' productivity. In particular, these technologies could improve endurance and increase the number of cycles completed while at the same time reducing error rates and time required to complete a job (Fournier *et al.* 2023).

2.2 Exoskeleton as a Source of Moral Opportunities and Moral Risks

Now that we have introduced exoskeletons, we should examine what specific moral challenges and opportunities these technologies pose. This exercise shall push forward the field of the ethics of exoskeletons. The moral opportunities and threats that exoskeletons pose depend on two major factors: the technology that the exoskeleton adopts and its field of application (in the case of the exoskeletons analyzed in this paper, the industrial sector). We will first consider the standpoint of the adopted technology, and we will consider moral opportunities in conjunction with moral risks because the latter is often the

[5] In active devices we have different moral implications. Passive devices do not offer positive energy, while active ones do. Powered exoskeletons have less success on the market, because they are bigger and more expensive. Recently, also semipassive exoskeletons have been developed.

[6] Currently there is no international classification of industrial exoskeletons. However, in many countries such as Italy if a technology is classified as PPE (i.e., personal protective equipment) it also becomes part of the mandatory equipment, such as helmets in construction sites.

other side of the coin of the former.

(i) Exoskeletons can *enhance, restore*[7] *or protect* the functionalities of the wearer's limbs. This significant, even life-changing, advantage also comes with a correlated risk: unforeseen *negative secondary effects on the body* (Pote *et al.* 2023; Maurice *et al.* 2018; Palmerini *et al.* 2014, Pirni and Lucivero 2013, Pirni and Carnevale 2014), which includes the risk of *secondary* injuries due to new forces applied to the body. Moreover, exoskeletons might interact negatively with pre-existing conditions.

(ii) From the viewpoint of *inclusivity*, exoskeletons are an opportunity to overcome gaps (such as ability or gender gaps) just as much as they can represent a risk to make those gaps even worse, for instance in the case in which an exoskeleton becomes widespread, but the models are not made to fit all body types. This comes with the risk of *excluding from experimentation or from market availability certain body types*, such as female bodies, disabled bodies, and bodies that are larger or smaller than average. Not only that, not designing exoskeletons with a variety of body types in mind might further increase the risk of *secondary* injuries, explained above (e.g., an exoskeleton might be less safe on a female body if it has only been tested on male bodies).

(iii) Exoskeletons can engender a sense of *empowerment* that positively affects the user's *body image.* The other side of the coin is that using exoskeletons might attract unwanted attention to users, or more generally, it may change how the user thinks they are perceived by others. For instance, the fact that a user needs an exoskeleton to perform certain tasks might have a negative impact on the perceptions of their social status (Butnaru 2024). The sense of masculinity of some users might be challenged when using technologies that impact someone's appearance and that highlight their bodies as vulnerable.

(iv) The fact that exoskeletons can engender a sense of *empowerment* comes with a further correlated risk, that of *dependency and withdrawal.* As Greenbaum (2016) notes, the fact that exoskeletons noticeably enhance the capabilities of the human body can cause dependency. Since these technologies are not always available to the user (e.g., because they belong to a company and not to the user), this can also cause withdrawal symptoms.

(v) Some models of exoskeletons can have sensors able to gather data on the user's activity. Sometimes, especially in the case of active exoskeletons, these sensors are necessary for the correct functioning of the exoskeleton itself.

[7] Of course, restoring the capability of a limb is typical of medical devices, while enhancing and protecting can be done not only by medical exoskeletons, but also by occupational, consumer and military exoskeletons.

In these cases, recording or sharing this data might not be necessary. In other instances, exoskeletons might collect and share data on the user's location, usage patterns, neural inputs, vital statistics and other information (Greenbaum 2016; Pote *et al.* 2023). While these data could be used to the advantage of the user, for example if she wishes to improve his or her performance, we should also be concerned about *privacy*.[8]

2.3 Moral Opportunities and Moral Risks of Occupational Exoskeletons

The moral opportunities and risks we have shown so far concern all types of exoskeletons independently of their field of application. Now we will add moral threats specific to *industrial* or *occupational exoskeletons*.

(vi) As said, the most relevant opportunity has to do with the protection of the worker from work-related injuries. This means that access to these technologies, insofar as they increase the safety of the worker, becomes a right of the worker.

(vii) As we noted, a great advantage of occupational exoskeletons is the expected increase in productivity and the expected decrease in fatigue. While currently workers have rights that limit work hours and set wages, it is not easy to predict how exoskeletons could impact these work limits and if regulations might differ between users and non-users of exoskeletons (Greenbaum 2016). The adoption of exoskeletons might also lead to employers demanding longer workdays with fewer and shorter breaks, thus *overworking* employees (Greenbaum 2016), thus negatively affecting the *psychological health* of workers. Workers might feel compelled to return to work quicker after injuries and, in turn, feel anxiety (Pote *et al.* 2023). Moreover, workplace norms and social pressure might compel workers to use exoskeletons even when they are not made mandatory by the employer (Maurice *et al.* 2018). Once again, this could cause anxiety in the worker.

(viii) A *further specific risk* is that of *continuous monitoring*. Being continuously monitored through the sensors that are installed on the exoskeleton might engender such anxiety in the work that could contrast with the very function of reducing physical stress at work (Maurice *et al.* 2018). Significantly, this differs from a mere concern for privacy, because the problem is not that of data and its value, but rather being the object of surveillance, that is to say, the fact that the workers become a mere object for someone else. When I am concerned about *privacy,* my data is what is ultimately at risk; in the case of *surveillance,* I risk losing my status as an autonomous subject.[9]

[8] Further general concerns which go beyond the scope of this paper are the environmental impact, unclear legal responsibilities and unsubstantiated ad claims.

[9] This is of course very close to Foucault's idea of the panopticon (1975). The relation between

2.4 Acceptability

Occupational exoskeletons are a promising technology that is not yet implemented on a large scale. As it is true for all new technologies that directly affect the body of users, the large commercialization of occupational exoskeletons can only take place if they are validated as *acceptable* technologies (Crea *et al.* 2021). Defining acceptability is complex, particularly because this term is often used in the field of engineering as a synonym for *acceptance* (see for instance Dario *et al.* 2001). Acceptability and acceptance have been defined in various ways and in a variety of fields, not only related to technology, but also law and new systems in general (Adell *et al*. 2014; Moesker *et al.* 2024). Therefore, fully accounting for acceptance and acceptability is well beyond the scope of this paper. In the field of ethics of technology, the discussion on acceptance and acceptability is relatively recent; despite this, there have been interesting attempts at defining and distinguishing these two concepts (Moesker *et al.* 2024). A common point drawn by many scholars is that acceptance is a descriptive notion that indicates if and to what degree the new technology is welcomed or tolerated, in some instances it even indicates if and to what extent the technology is actually used and therefore integrated into the routine of users (see Moesker *et al.* 2024; Oosterlaken, 2015, van de Poel 2016). Acceptability, on the other hand, is often described as a prescriptive notion that indicates if it is morally good or tolerable to employ a specific technology (see Moesker *et al.* 2024; Oosterlaken 2015; van de Poel 2016). Even though many scholars can agree on these starting points, they diverge on many aspects. For instance, there is no consensus on whether acceptance and acceptability should be independent or interdependent concepts. For the purposes of this paper, we will focus on what we call *individual acceptance* and *moral acceptability*. We define individual acceptance as the descriptive notion that indicates the degree to which the technology is entrenched and incorporated in the subject's physical, cognitive or affective activity or when the technology is not present, the degree to which the subject is willing to use it (see Adell *et al.* 2014). On the other hand, we define moral acceptability as the prescriptive notion that indicates whether, from a third-person standpoint, the technology is morally good or neutral. It is essential not to conflate these two notions, since the fact that a technology is individually accepted by a user does not necessarily entail that it is morally

wearable technology and the idea of the panopticon has already been analyzed (see for instance De Moya and Pallud 2020). Fully accounting for this aspect goes beyond the scope of this paper. While it is true that the presence of sensors might further cement discipline (a concept we examine later in this paper), we should also take into consideration that exoskeletons do not necessarily have sensors. While occupational exoskeletons that do not have sensors do not contribute significantly to surveillance, they can still be a means to body invasion (i.e., the concept at the core of this paper).

acceptable. Moreover, as van de Poel (2016) argues lack of acceptance of a technology is not enough to conclude that it is unacceptable. Similarly, as we will see in this paper, individual acceptance is not necessarily accompanied by moral acceptability. Since occupational exoskeletons offer significant moral opportunities, of course, making these technologies more morally acceptable is a desirable goal, but in order to do that, it is essential to further clarify the distinction between individual acceptance and moral acceptability.

3. *Body Invasion*

3.1 From Mind Invasion to Body Invasion

We will account for the moral dimension of occupational exoskeletons by developing the concept of *body invasion*, which we think could further the field of the 4E theories. This will also clarify why we should not conflate individual acceptance and moral acceptability, and it will also allow us to understand at a more fundamental level the moral risks and opportunities related to the use of occupational exoskeletons. Body invasion is to be framed within the debate of situated cognition and situated affectivity. These two concepts reflect the idea that the processes of the mind (e.g., cognition, affectivity, imagination, memory) are not bound exclusively to structures and processes located inside the *cranium* but can also be co-caused or even co-constituted by *extracranial* (i.e., located in the body or the environment) structures or processes (Stephan and Walter 2020). These theories are often referred to 4E theories, where the four Es stand for *embodied, embedded, extended and enacted.* The expression *embodied mind* means that at least some of our mental processes are co-caused or even co-constituted by processes or structures located in parts of the body that are located outside of the skull. For instance, when we use our fingers to count, we offload to a body part and to specific body gestures (i.e., the act of counting on fingers) some of the cognitive work that would otherwise only be carried out through more demanding processes, such as mental representation. However, the role the body plays is much more fundamental.[10] The body is not merely another object amongst other objects; it is rather the transcendental principle, the condition of possibility of all experience (Gallagher and Zahavi 2022; Merleau-Ponty 2012).

[10] In the theory of emotions, it is well established that the body plays a fundamental role. Emotions are fundamentally embodied phenomena because they are phenomena felt in the body. This point was clearly expressed by James, when is states that a disembodied emotion is a non-entity (Stephan and Walter 2020; James 1884).

As said, cognition is not only fundamentally embodied but also embedded and, according to some, extended in the environment. We have embedded cognition (or affectivity) when an external support is a co-cause of a cognitive (or affective) process (Stephan and Walter 2020). A classic example of embedded cognition is the use of pen and paper to do a calculation otherwise impossible. We have extended cognition (or extended affectivity) when an external support is a co-constituent of a cognitive process. The classic example of extended cognition is that offered by Clark and Chalmer (1998): Otto's Notebook. Otto is a person who has Alzheimer's disease, still in the early stages. He uses a notebook to store information he is not able to remember anymore, such as the directions to get to the location of an appointment.[11] Interestingly, Otto and his notebook become coupled to one another, that is to say, that the behavior of the former cannot be described without taking into consideration the behavior of the latter and vice versa. Otto changes the notebook by jotting down information on it, when he later consults the notebook, he acts according to the information he had previously stored in it. Otto and the journal, therefore, diachronically form a coupled system (i.e. Otto's mind), whose function cannot be described if Otto and the journal are not both taken into account.

At this point, one could think that the environment is nothing more than a set of resources we can use to fulfil our cognitive and affective needs. However, in recent literature, this idea has been criticized. Of course, the environment is hostile to us to some degree, and even when we actively change it to support our cognitive or affective tasks, it can still be *hostile* towards us in non-predictable ways. Slaby (2016) critiques the user/resource, which at the time, and partially even now, dominated the field of the theories of situated affectivity.

In the user/resource model, the user (usually an autonomous adult) intentionally engages with resources (e.g., tools or features of the environment) to satisfy her cognitive or affective needs (Slaby 2016). Slaby (2016) critiques this model as it overlooks significant political aspects such as the dynamic of reciprocal determination between the subject and her environment.[12] The environment, including technological tools, is not merely a set of resources that we can freely manipulate for our ends, but also plays a fundamental role of feedback loop which in turn modifies the subject (see Sterelny 2010). In this light, Slaby introduces the concept of *mind invasion* to indicate the influence

[11] Clark and Chalmers (1998) argue that from a functional point of view the information stored in the notebook acts as the information that is stored in the brain of a neurotypical person. In other words, the notebook is part of Otto's mind in virtue of the so-called parity principle.

[12] In a similar way, Aagaard (2021) critiques the so-called dogma of harmony, according to which in the 4E field, scholars tend to describe the relationship between humans and environmental resources, especially technology, as harmonious.

that the environment (which includes everything from infrastructures to institutional norms) can have on our personal affective processes and, therefore, on decision making. Mind invasion explains how individuals unconsciously adopt affective dispositions that are typical of certain environments, such as the workplace. These affective dispositions often have a normative value in the environment that engenders them, and this often goes to the detriment of mind invaded subjects and to the advantage of those who have a greater control over that environment (e.g. employers). A classic example of mind invasion is that operated through emails (see Slaby 2016). Emails can be used to extend our cognitive and affective capabilities. For instance, thanks to emails, we can reach out to a collogue to ask for her support when carrying out a task. The fact that other people are always available to us comes at the price that we also are potentially always available to others. Since our coworkers rely on us just as much as we rely on them, not being available for others might cause anxiety and stress. This is because not complying with other workers' expectations might come with considerable reprehension from them. This dynamic shows how a technology is not necessarily employed in the best interest of the user but can *hack* her mind, imposing an affective repertoire that goes to her detriment. We can further refine the notion of mind invasion so that it can be more aptly applied to technologies that act directly on the user's embodiment. In this sense, the notion of body invasion that we introduce in this paper must be considered as a specific subset of mind invasion and in no way does this notion indicate a sharp distinction between mind invasion and body invasion, or even worse, that there should be a dichotomy between body and mind. To develop the concept of body invasion we will analyze how technology (especially wearable technology such as occupational exoskeletons) changes the body both in the sense of an object that can be shaped externally and in the sense of a transcendental entity, that is to say, a subject that structures his or her own experience.[13]

[13] In phenomenological terms this distinction corresponds to the concepts of *Leib* and *Körper* (see Husserl 1952; Merleau-Ponty 2012). The latter refers to the body as an object. A dead body, a corpse, is a Körper, but also, a physician that is operating on a patient is interacting with a Körper. More generally, Körper is the body as something that can be analyzed and even modified objectively from a third person point of view. The Leib, or lived/living body, on the other hand, refers to the body as a subject, or more precisely indicates the body as a subject, or more precisely indicates the body as the condition of possibility of all the possible engagements the subject can have with the environment. My body, my Leib, is the inalienable point of view from which all my experiences are possible. Indeed, it is impossible for me to have experiences that do not stem from my body. The Leib however is not merely a point zero, it is not merely a mono-dimensional principle. The Leib allows for some kind of experiences and not others, because it has a specific structure that can be modified through one's life.

3.2 The Body as an Object: Docile Bodies

As we have stated above, a key point when addressing the moral standing of a new wearable technology is to determine if that technology is (or can be) morally acceptable. To clarify the distinction between moral acceptability and individual acceptance, we must understand how individual acceptance is achieved through the interaction with the body, both intended as an object and as a subject. Doing so will also further clarify the notion of body invasion. First, we will focus on the object as a body, and to do so, we will discuss the notion of Foucault's (1975) *docile bodies*. According to Foucault (1975), the body can become an object of the techniques that can change it, shape it, improve it, and make it more useful. In this sense, the body of the worker is a *docile body*, namely, a body that can be transformed and improved (Foucault 1975). The body of the worker is not valuable for its natural strength, it is valuable because it is improvable through the use of technology (Foucault 1975). In other words, the employer is not interested in whether the body of the worker is capable of lifting 100 kg or 150 kg. Instead, the employer is interested in whether the body of the worker can be shaped in such a way that it can follow the orders and the rules of the employer. At some points, some of the orders do not need to be given explicitly anymore, because they have been inscribed in the body of the worker. They have become a second nature to the worker, even though this second nature has been chosen for her rather than by her.

Indeed, the human body can become a machine, dividable into segments easier to understand and optimizable in their functions through innervations based on those analyses (Foucault 1975). In this way individuals also become easier to substitute. As Wehrle (2016) also highlights, once the body has been divided into parts and functions, discipline is what is used to control and improve the efficiency of the execution of gestures, movements and attitudes of those body parts. Control and discipline over the body (and therefore the individual) can only take place through the control of the spatiality and temporality of the individuals (Foucault 1975). Indeed, in Foucault's thought, the nature of power is inextricable from the spaces in which those powers are exercised. These spaces are structured in a way that allows for that power to be exercised. The factory is one of the places where this control can take place. For example, by assigning a space to each worker, it is easier to control them individually while working. Individuals are controlled not only through the structuring of space, but also of time. Temporal control takes place through the control of movements and gestures; the articulation of the limbs, their positions and the relations between them must be regulated. Supervisors must impose the best possible relations between these movements and the body (Wehrle 2016). A skill is designed in the way it should be executed, and then its practice is imposed on everyone (e.g. all the workers of a factory). This homogenization allows for comparison between all the workers, and it also allows for the coordination of a large number of workers. (Wehrle 2016).

From a Foucaultian point of view, the greatest risk connected to the introduction of occupational exoskeletons is that these technologies might become instruments of discipline. Indeed, a large-scale adoption will also imply a large-scale training, or, in Foucaultian terms, discipline. Exoskeletons are usually a technology that does not belong to the worker, but to the company. This means that workers do not have free access to these technologies, rather the access to them is disciplined by various rules: exoskeletons have a place where they have to be stored, they can only be accessed in some circumstances, sometimes they can only be used under supervision, they must be donned and taken off with precise procedures, they must be taken care of once they are removed. Most importantly, when they are worn, some movements are enhanced, while others are hindered. All of this is a clear demonstration that the use of an exoskeleton implies necessarily discipline. Discipline is subtle because it exercises control over the individual through her body, not by using violence or direct confrontation as is the case in slavery (Havis 2014). As we saw, discipline controls the body (its parts, its functions) by controlling movement and space. In the case of the adoption of the exoskeleton, even though there is still no violence, no direct confrontation, we go a step further from what Foucault envisioned. Rather than controlling the space around the body to shape the body, the exoskeletons are worn on the body and therefore directly affect the embodiment of the individual, and this, in turn, has significant phenomenological implications. As we will see next, one of the fundamental differences between the phenomenological method (especially in Merleau-Ponty) and the Foucauldian method is that while they both agree that the body both acts and is acted upon (though at different timescales) do not agree on the role of space (Crossley 1996). To Merleau-Ponty, space is created by habit and bodily engagement. To Foucault, space is what is structured to act upon the body (Crossley 1996).

3.3 The Body as a Subject: Habituation

We have just seen that occupational exoskeletons can become instruments of discipline, thus going against the best interests of the worker. However, the analysis conducted thus far is not enough to determine why the worker accepts the new embodiment that is imposed on him or her. Indeed, the analysis of body invasion also requires that we determine why the user accepts the new embodiment. While a new embodiment can be imposed on a body as if it were an object, the individual acceptance of this new embodiment can only be done by the body intended as a subject. Indeed, Foucault does not stress enough that the body is not simply a historically determined object; it is also a transcendental principle that structures experience itself (see Wehrle 2017). This means that, from a phenomenological point of view, a change in the embodiment is not simply a change in the individual; it is a change in the structure of all of her possible experiences. As we have seen, to Foucault, the organization of space and time is fundamental to changing the bodies of individuals and therefore the individuals themselves. From a phenomenological point of view, by acting directly on the embodiment of the worker through wearable technology, one can impose discipline not by changing the surrounding space, but by changing how the body generates its egocentric space. Indeed, as Merleau-Ponty (2012) shows in his phenomenology of perception, the body is not a fragment of space; on the contrary, it is the transcendental principle that allows the subject to have a space. All spatial experiences are possible to a subject through her embodiment, through the way in which she can interact with the world in a sensorimotor way. Changing the embodiment changes the way in which the subject can move, it changes her sensorimotor capabilities and therefore changes her egocentric space (see Pirni 2014). Embodiment, however, is not set once and for all; it changes over time, and it can even include tools. In this case, Merleau-Ponty would use the term *body schema*. This concept refers to the embodiment as a structured whole whose parts are related to each other in a way that constitutes the condition of possibility for any engagement in the world (2012). A change in the body schema takes place through the process of habituation, that is to say, the process of acquiring a new habit, for instance, learning a new skill such as dancing. Habituation is also the process through which resources become entrenched. Entrenchment, a term used in the 4E field, is the degree to which the external resource is incorporated, that is to say, the degree to which the resource changes the user (see Sterelny 2010), especially in their embodiment. Merleau-Ponty analyzes how we can change our embodiment through the repetitive use of tools. This is well shown in his example of the cane of the visually impaired person. He argues that the visually impaired person who has learned how to use the mobility cane does not intend the cane as an object anymore. Instead, the cane extends the embodiment of the subject, especially the sense of touch. As a matter of fact, when perception is enhanced through the use of the cane, perception is not located in the hand that holds the cane, but in the very tip of the cane, that is to say, the part that is doing the touching of the ground and of the other objects (Merleau-Ponty 2012).

The position of objects is given immediately by the scope of the gesture that reaches them and in which, beyond the potential extension of the arm, the radius of action of the cane is included. If I want to become habituated to a cane, I try it out, I touch some objects, and, after some time, I have it "in hand": I see which objects are "within reach" or out of reach of my cane. This has nothing to do with a quick estimate or a comparison between the objective length of the cane and the objective distance of the goal to be reached. Places in space are not defined as objective positions in relation to the objective position of our body, but rather they inscribe around us the variable reach of our intentions and our gestures. (Merleau-Ponty 2012: 144)

The new tool, in this case the cane, becomes transparent: the visually impaired person does not perceive the cane as an external object, but as an extension of her embodiment. This is not immediate, since the person has to learn how to use it first. The example of the visually impaired person can also be described in terms of individual acceptance. She learns how to use the new resource and, in doing so, she accepts the new resource in the sense that it becomes entrenched and incorporated in the subject's physical and cognitive activity. Individual acceptance is therefore the result of a process of habituation. The body is always open to learning new habits, to incorporating new elements (Wehrle 2017), but this process can be, in a way, hijacked, as is the case in body invasion. As Wehrle (2017) puts it: "'Discipline' can thus be understood as a form of forced habituation" (Wehrle 2017: 333). Body invasion can be the result of discipline imposed in the workplace through wearable technologies such as occupational exoskeletons.

As we have seen, body invasion involves the body both as a subject and as an object, but body invasion is also mediated by the affective relationship that we have. In some environments, other people implicitly or explicitly impose specific affective repertoires relative to the use of technologies. Similarly to what Slaby (2016) argues about mind invasion, coworkers and supervisors might enact, consciously or not, affective repertoires that impose on other workers to conform to a standard behavior. Such behavior can include the mandatory or encouraged individual acceptance of exoskeletons. In other words, coworkers and supervisors who have already accepted exoskeletons will likely behave in a way that makes it clear to new workers that using and accepting exoskeletons is not only expected, but also that not conforming to these expectations comes with negative affective interactions with other coworkers (e.g., reprehension and shaming).

3.4 Iterative Design

So far, we have shown that acceptance can be externally imposed. However, for this to truly take place, the body as subject—though shaped by its objective conditions—must itself accept the new embodiment. In other words, the subjective body must incorporate the new embodiment into its own subjectivity, understood as a meaningful way of engaging with the environment. Through an analysis based on 4E theories, phenomenology and Foucauldian structuralism, we have seen that individual acceptance of wearable technologies (especially occupational exoskeletons) can be described as the result of a process that is based on the incorporation and entrenchment of external resources through habituation. This means that a user who has learned how to use an occupational exoskeleton might feel at ease when using this external resource, but this fact tells us very little about whether the technology is morally acceptable. As said, individual acceptance can be defined as a possible or even necessary requirement for moral acceptability, but individual acceptance cannot ever be considered a sufficient requirement for moral acceptability, because the fact that a technology is individually accepted does not mean that it cannot go to the detriment of the user unbeknownst to him or her. In other words, the fact that a technology is accepted is not enough to determine that there is not a form of body invasion taking place. On the other hand, there can be no body invasion without acceptance.

A possible strategy to render technologies more morally acceptable might be iterative design. In this user-oriented approach, the involvement of the user – especially surveys on their experience – is present at various stages, including the creation of the first prototype and following reiterations (Dario *et al.* 2001). Surveys on users' experience can be extremely useful; however, they must be used carefully. Because of the process of habituation that the user must undergo when learning how to use the exoskeleton, the user, to a degree, must accept the technology. This means that the very process of iterative design requires periods of time in which the user must learn how to use the new prototype, and during these periods, habituation takes place. Interestingly, subsequent iterations can improve the time that is required to learn how to use the new technology, but this simply reduces the time that is required for habituation to take place. This means that on the one hand, the problems users indicate are problems that the designer must address, because they are so relevant that they cannot be bypassed by the process of habituation. If anything, these problems might be perceived as hinderances to the very process of habituation. On the other hand, the fact that the tester has no problem to report does not at all mean that the technology has reached a status of moral acceptability; it simply means that the technology has been accepted by the tester. In particular, users might be completely unaware of how body invasion can go to the detriment of subjects only over a long period of time during which expectations, practices and affective dispositions that can go to the detriment of the user are built. For instance, if I perceive the exoskeleton as a comfortable and empowering technology, I might not recognize that the exoskeleton is, at the same time, a technology that supports my affective sense of having to overperform. A sense that comes not only from the fact that the exoskeleton itself allows me to perform more, but also from the fact that other people around me, such as coworkers and supervisors, might have explicit or implicit expectations that I should overperform. Another important factor to consider is that the fact that exoskeletons are built for comfort is not a factor that goes exclusively to the advantage of the user. Comfort is simply a feature that allows the user to engage with the external resource, regardless of whether that interaction goes to the advantage or detriment of the user. For instance, a bed and a slot machine chair can be described as comfortable, but while in the former comfort is usually to the advantage of the user, in the case of the slot machine chair the comfort is exclusively directed at prolonging the activity of gambling, which statistically is against the user's best interest, for as long as possible (see Timms and Spurrett 2023).

4. *Conclusions*

In this paper, we have offered a preliminary introduction to the exoskeletons' domain, with a focus on their application in the industrial sector. We then showed how these technologies offer both significant advantages that must be preserved and risks that need to be mitigated through careful design. Importantly, while we should keep in mind that a new technology cannot ever have zero risks, it is still important to note that the major benefits that occupational exoskeletons can offer (i.e., preserving the health of the worker) are significant and can outweigh the risks. Through the use of 4E theories, phenomenology and Foucauldian concepts, we have shown at a more fundamental level, that the major risk that occupational exoskeletons - and similar wearable technologies - pose is that of *body invasion*.

Body invasion is a process through which external resources are used to modify the embodiment of users. While this new embodiment can offer some benefits to the user (e.g., an empowered body image, better performance and so on), it also goes significantly to the detriment (e.g., constant surveillance, increased anxieties towards performance and so on) of the user (e.g., the worker) and to the advantage of those who control the external resource (e.g., the employer). What is particularly deceptive about body invasion is that the subject might not be fully aware of (or at all) that such a process is taking place. This is due to the fact that in the very process of learning how to use the new technology, to some degree, the user must individually accept the technology through a process of habituation. Failing to do so would also imply failing to learn how to use the new technology and therefore failing to use it at all. Habituation does not only take place through practices imposed externally, but is also significantly reinforced by the affective relations that the users establish within the context in which the technology is used. For instance, when expectations of conformity and of productivity are not met, the worker might be reprimanded. This generates an anxiety that the worker thinks can be mitigated by further using the technology. The user, therefore, unconsciously accepts a technology that can go against her best interest. An external observer might wrongfully take this individual acceptance for moral acceptability. However, we should not draw the conclusion that if a technology is accepted, then some form of body invasion has taken place. Rather, we should say that while acceptance can take place through habituation, habituation per se is not necessarily a process that leads to body invasion. What determines if body invasion has taken place is whether the new embodiment goes also to the detriment of the subject (and to the advantage of someone else), whether she realizes it or not.

Finally, we showed that iterative design, insofar as it relies on the feedback of users, can be extremely useful in delineating what design features augment individual acceptance in users (i.e., the degree of ease with which the new wearable technology becomes entrenched and incorporated in the user). While this is a critical point, it is not enough to determine the moral acceptability of technology. Indeed, moral acceptability must consider a variety of factors such as physiological, psychological and affective aspects which the user might not realise in the short term. To mitigate risks related to the introduction of wearable technologies in the workplace, engineers should develop new solutions based on situated affectivity and situated cognition that can reshape the whole production process and rethink the role of all stakeholders.[14]

Leonardo Massantini
Sant'Anna School of Advanced Studies – Pisa
leonardo.massantini@santannapisa.it
leonardomassantini@gmail.com

Alberto Pirni
Sant'Anna School of Advanced Studies – Pisa
alberto.pirni@santannapisa.it

Paolo Dario
Sant'Anna School of Advanced Studies – Pisa
paolo.dario@santannapisa.it

[14] A preliminary version of some of the arguments developed in this paper was presented at the 2024 *Robophilosophy* conference "Social Robots with AI: Prospects, Risks, and Responsible Methods", 19-23 August 2024, Aarhus University, Denmark, and online; an abstract is available in Pugnaletto *et al.* (2025).

Funding

This research was promoted by the Ministero dell'Università e della Ricerca (Direzione Generale della Ricerca) within the Fit for Medical Robotics – Fit-4MedRob project (grant n° PNC0000007).

Author Contributions

All authors contributed to the study conception. The first draft of the manuscript was written by Leonardo Massantini and all authors commented on and integrated previous versions of the manuscript. All authors read and approved the final manuscript.

References

Aagaard, Jesper, 2021, "4E Cognition and the Dogma of Harmony", in *Philosophical Psychology*, 34, 2: 165-181. https://doi.org/10.1080/09515089.2020.1845640

Adell, Emeli, András Várhelyi, Lena Nilsson, 2014, "The Definition of Acceptance and Acceptability", in Regan, Michael A., Tim Horberry, Alan Stevens, eds., *Driver Acceptance of New Technology: Theory, Measurement and Optimisation*, Ashgate, Farnham: 11-22.

Butnaru, Dan, 2024, *Exoskeletal Devices and the Body: Deviant Bodies, Extended Bodies*, Routledge, London and New York.

Clark, Andy, David Chalmers, 1998, "The Extended Mind", in *Analysis*, 58, 1: 7-19. https://doi.org/10.1093/analys/58.1.7.

Crea, Simona, Philipp Beckerle, Michiel De Looze *et al.,* 2021, "Occupational Exoskeletons: A Roadmap Toward Large-Scale Adoption. Methodology and Challenges of Bringing Exoskeletons to Workplaces", in *Wearable Technologies*, 2: e11. https://doi.org/10.1017/wtc.2021.11.

Crossley, Nick, 1996, "Body-Subject/Body-Power: Agency, Inscription, and Control in Foucault and Merleau-Ponty", in *Body & Society*, 2, 2: 99-116. https://doi.org/10.1177/1357034X96002002006.

Dario, Paolo, Eugenio Guglielmelli, Cecilia Laschi, 2001, "Humanoids and Personal Robots: Design and Experiments", in *Journal of Robotic Systems*, 18, 12: 673-690. https://doi.org/10.1002/rob.8106.

De Moya, Jorge-Félix, Jessie Pallud, 2020, "From Panopticon to Heautopticon: A New Form of Surveillance Introduced by Quantified-Self Practices", in *Information Systems Journal*, 30, 6: 940-976. https://doi.org/10.1111/isj.12284.

Foucault, Michel, 1975*, Surveiller et punir: Naissance de la prison*, Gallimard, Paris; Eng. tr. by Alan Sheridan 1977, *Discipline and Punish: The Birth of the Prison*, Pantheon Books, New York.

Fournier, Daniel E., Marcus Yung, Kumara G. Somasundram *et al.*, 2023, "Quality, Productivity, and Economic Implications of Exoskeletons for Occupational Use: A Systematic Review", in *PLOS ONE*, 18, 6: e0287742. https://doi.org/10.1371/journal.pone.0287742.

Gallagher, Shaun, Dan Zahavi, 2022, *The Phenomenological Mind* (3rd ed.), Routledge, London and New York.

Grazi, Lorenzo, Emilio Trigili, Giulio Proface *et al.,* 2020, "Design and Experimental Evaluation of a Semi-Passive Upper-Limb Exoskeleton for Workers with Motorized Tuning of Assistance", in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 28, 10: 2276-2285. https://doi.org/10.1109/TNSRE.2020.3014408.

Greenbaum, Dov, 2016, "Ethical, Legal, and Social Concerns Relating to Exoskeletons", *in SIGCAS Computers and Society*, 45, 3: 234-239. https://doi.org/10.1145/2874239.2874272.

Havis, Daniel N., 2014, "Discipline", in Lawlor, Leonard, John Nale, eds., *The Cambridge Foucault Lexicon*, Cambridge University Press, Cambridge: 110-119.

Howard, John, Vladimir V. Murashov, Brian D. Lowe *et al.*, 2019, "Industrial Exoskeletons: Need for Intervention Effectiveness Research", in *American Journal of Industrial Medicine*, 63: 201-208. https://doi.org/10.1002/ajim.23080.

Husserl, Edmund, 1952, *Ideen zu einer reinen Phänomenologie und phänomenologischen Philosophie. Zweites Buch: Phänomenologische Untersuchungen zur Konstitution*, edited by Marly Biemel; Eng. tr. by Richard Rojcewicz and André Schuwer 1989, *Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy. Second Book: Studies in the Phenomenology of Constitution*, Kluwer Academic Publishers, Dordrecht.

James, William, 1884, "What is an Emotion?", in *Mind*, 9, 34: 188-205. https://www.jstor.org/stable/2246769.

Kumar, Vikash, Yogesh Vijay Hote, Shivam Jain, 2019, "Review of Exoskeleton: History, Design, and Control", in *2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), IEEE, Noida*: 677-682. https://doi.org/10.1109/RDCAPE47089.2019.8979099.

Lanotte, Francesco, Andrea Baldoni, Filippo Dell' Dell'Agnello *et al.*, 2020, "Design and Characterization of a Multi-Joint Underactuated Low-Back Exoskeleton for Lifting Tasks", in *8th IEEE RAS/EMBS International Conference for Biomedical Robotics and Biomechatronics (BioRob)*: 1146-1151. https://doi.org/10.1109/BioRob49111.2020.9224370.

Maurice, Pauline, Ludivine Allienne, Adrien Malaisé et al., 2018, "Ethical and Social Considerations for the Introduction of Human-Centered Technologies at Work", paper presented to *IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO), Genova, Italy.* https://hal.science/hal-01826487.

Merleau-Ponty, Maurice, 1945, *Phénoménologie de la perception*, Gallimard, Paris; Eng. tr. by Donald Landes 2012, *Phenomenology of Perception*, Routledge, London.

Moesker, Karen, Udo Pesch, Neelke Doorn, 2024, "Making Sense of Acceptance and

Acceptability: Mapping Concept Use in Energy Technologies Research", in *Energy Research & Social Science*, 115: 103654, https://doi.org/10.1016/j.erss.2024.103654.

Oosterlaken, Ilse, 2015, "Applying Value Sensitive Design (VSD) to Wind Turbines and Wind Parks: An Exploration", in *Science and Engineering Ethics*, 21, 2: 359-379. https://doi.org/10.1007/s11948-014-9536-x.

Pacifico, Ilaria, Alessandro Scano, Eleonora Guanziroli; *et al.,* 2020, "An Experimental Evaluation of the Proto-MATE: A Novel Ergonomic Upper-Limb Exoskeleton to Reduce Workers' Physical Strain", in *IEEE Robotics & Automation Magazine*, 27, 1: 54-65. https://doi.org/10.1109/MRA.2019.2954105.

Palmerini, Erica, Filippo Azzarri, Federico Battaglia *et al.*, 2014, *Guidelines on Regulating Robotics (D6.2)*, European Commission, viewed December 17, http://www.robolaw.eu/RoboLaw_files/documents/robolaw_d6.2_guidelinesregulatingrobotics_20140922.pdf.

Pirni, Alberto, 2014, "Corpo e mondo: Intorno all'idea di soggetto possibile nella contemporaneità tecnologica", in Danani, Carla, Benedetta Giovanola, Maria Letizia Perri, Daniela Verducci, eds., *L'essere che è, l'essere che accade. Percorsi teorici in filosofia morale in onore di Francesco Totaro*, Vita e Pensiero, Milano: 227-234.

Pirni, Alberto, Antonio Carnevale**,** 2014, "Technologies Change – Do We Change as well? On the Link between Technologies, Self and Society", in Pirni, Alberto, Antonio Carnevale**,** eds., *Investigating the Relationship between Future Technologies, Self and Society*, in *Politica & Società*, 2: 173-184. https://doi.org/10.4476/77098.

Pirni, Alberto, Federica Lucivero**,** 2013, "The 'Robotic Divide' and the Framework of Recognition: Re-articulating the Question of Fair Access to Robotic Technologies", in Koops, Bert-Jaap, Alberto Pirni, eds., Ethical and Legal Aspects of Enhancing Human Capabilities Through Robotics, in *Law, Innovation and Technology*, 2: 147-171. https://doi.org/10.5235/17579961.5.2.147.

Pote, Timothy R., Nicole V. Asbeck, Alan T. Asbeck, 2023, "The Ethics of Mandatory Exoskeleton Use in Commercial and Industrial Settings", in *IEEE*, viewed 17 December 2024, https://vtechworks.lib.vt.edu/handle/10919/114474.

Pugnaletto, Margherita, Leonardo Massantini, Alberto Pirni, Paolo Dario, Oliver Bendel, Nicola Vitiello, Danica Kragic Jensfelt, Simona Crea, 2025, "The Social Significance of Human Effort: What Parameters for a Positive Human-Robot Interaction in the Context of Industry 5.0?", in Seibt, Johanna, Peter Fazekas, Oliver Santiago Quick, eds., *Social Robots with AI: Prospects, Risks, and Responsible Methods*, *Frontiers in Artificial Intelligence and Applications*, 397: 655-662. https://doi.org/10.3233/FAIA241559, viewed 1 May 2025.

Slaby, Jan, 2016, "Mind Invasion: Situated Affectivity and the Corporate Life Hack", in *Frontiers in Psychology*, 7: 266. https://doi.org/10.3389/fpsyg.2016.00266.

Spada, Stefania, Lidia Ghibaudo, Silvia Gilotta *et al.*, 2017, "Investigation into the Applicability of a Passive Upper-Limb Exoskeleton in *Automotive Industry",* in *Procedia Manufacturing*, 11: 1255-1262. https://doi.org/10.1016/j.promfg.2017.07.252

Spurrett, David, 2024, "On Hostile and Oppressive Affective Technologies", in *Topoi*, 43: 821-832. https://doi.org/10.1007/s11245-023-09962-x.

Stephan, Achim, Sven Walter, 2020, "Situated Affectivity", in Szanto, Thomas, Hilge Landweer, eds., *The Routledge Handbook of Phenomenology of Emotions*, Routledge, London and New York: 299-311.

Sterelny, Kim, 2010, "Minds: Extended or Scaffolded?", in *Phenomenology and the Cognitive Sciences*, 9, 4: 465-481. https://doi.org/10.1007/s11097-010-9174-y

Timms, Richard, Spurrett, David, 2023, "Hostile Scaffolding", in *Philosophical Papers*, 52, 1: 53-82. https://doi.org/10.1080/05568641.2023.2231652.

Van de Poel, Ibo, 2016, "A Coherentist View on the Relation Between Social Acceptance and Moral Acceptability of Technology", in Franssen, Maarten, Pieter E. Vermaas, Peter Kroes, Anthonie Meijers, eds., *Philosophy of Technology after the Empirical Turn*, Springer, Dordrecht: 177-193, viewed 26 March 2025, https://doi.org/10.1007/978-3-319-33717-3_11.

Wehrle, Maren, 2016, "Normative Embodiment: The Role of the Body in Foucault's Genealogy. A Phenomenological Re-Reading", in *Journal of the British Society for Phenomenology*, 47, 1: 56-71. https://doi.org/10.1080/00071773.2015.1105645

Wehrle, Maren, 2017, "The Normative Body and the Embodiment of Norms: Bridging the Gap Between Phenomenological and Foucauldian Approaches", in *Yearbook for Eastern and Western Philosophy*, 2017, 2: 323-337. https://doi.org/10.1515/yewph-2017-0023.

Website, 2024, "What is an Exoskeleton?", Exoskeleton Report. Viewed 17.12.2024, https://exoskeletonreport.com/what-is-an-exoskeleton/#:~:text=Exoskeletons%20are%20wearable%20devices%20that,reinforce%20or%20restore%20huma.

Edizioni ETS
Palazzo Roncioni – Lungarno Mediceo, 16, I-56127 Pisa
info@edizioniets.com – www.edizioniets.com
Finito di stampare nel mese di luglio 2025