Wearable technologies as extensions: a postphenomenological framework and its design implications

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Abstract

Wearable technologies are increasing both in number and variety enabling new ways for collecting personal data, as well as novel interaction modalities. Even though the Human-Computer Interaction (HCI) community has widely explored the potential applications of wearables, its theoretical contribution on this research field has been far from impressive. Most scholars and designers seem to rely on a series of dominant assumptions that look at wearables "from the outside" by focusing on their "external properties." When these assumptions are fully embraced at design-time, however, they may cloud opportunities for designing for the "internal aspects" of our everyday experience. In this article, I propose a theory that looks at wearables "from the inside," giving a theoretical backdrop to all those wearable designs that pay attention to the internal aspects of interaction. By adopting a postphenomenological approach, I conceptualize wearable devices as "extensions" of our intentionality and introduce the "extension relation" to explain how wearables may alter how we relate to the world. In doing so, I propose a series of design considerations that aim to trace future research lines for all those wearables that are currently designed from an "externalistic" perspective.

Keywords: Wearable systems, wearable devices, personal data, activity trackers, smart watches, self-tracking, phenomenology, postphenomenology, HCI theory, quantified self

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1 INTRODUCTION

Wearable devices are increasing both in number and variety enabling new ways for collecting personal data, as well as novel interaction modalities. The Human-Computer Interaction (HCI) community has widely explored the potential applications of wearable technologies, both creating prototypes in domains as diverse as sport (Kosmalla et al., 2016), health (Cibrian et al., 2020), and learning (Garcia et al., 2018), and studying the adoption of such technologies in people's everyday practices (e.g., Fritz et al., 2014). This research interest has paralleled the spreading of commercial wearables among a larger population (IdTechEx 2020).

Surprisingly, despite the popularity of the term "wearable" among practitioners and researchers, the theoretical contribution of the HCI community to this research field has been far from impressive. By and large, it has been noted that the lack of theorization in HCI stems from the tendency to put practitioners' needs above those of researchers (Kostakos, 2015). However, "the claim that practice in general, and especially in a multifaceted and complex field as HCI, can be relied upon for systematic knowledge accumulation has already been dispelled" (Tractinsky, 2018: 136), as practice-based research suffers from several limitations, such as the difficulty to abstract and generalize context-specific findings (Parush, 2006). As Tractinsky (2018) pointed out, the breadth and depth of knowledge required in HCI cannot be mastered based on practical experience alone.

I argue that a theoretical investigation and development of the notion of wearable is needed. This article is an attempt in that direction. More precisely, I think that in HCI there are two different "ways of thinking" about wearable technology, offering two tacit conceptualizations of wearables, which correspond to two different "points of view" on technology. The first one is now completely affirmed, connects with the logical positivist position (e.g., Carnap, 1928; Kitchener, 2004), which sees the world as a series of observable facts, and conceptualizes wearable devices as objects focusing on their external properties seen from a third-person perspective. The second one is still emerging, relates to the phenomenological tradition (e.g., Heidegger, 1927; Husserl, 1973), which values a first-person perspective on technology, and experiments on the experiential and expressive properties of wearables, exploring their internal opportunities. I will call these two different ways of thinking about wearables the "externalistic thought style" and the "internalistic thought style."

These two thought styles are not impervious to one another: for instance, wearable devices that are designed on the basis of the externalistic thought style do not prevent people from using them in an internalistic way. However, thanks to the spreading of commercial smart watches, activity trackers, and wearables aimed at collecting "objective data" to be "used" for purposes as diverse as wellness, health and sport, we are currently witnessing a growing popularity of wearable devices designed on the ground of the externalistic way of thinking and the tacit conceptualizations that it brings along. These conceptualizations, which date back to engineering approaches do design, are pragmatically useful, because they target objective and identifiable variables that can be directly tackled by technology, allowing for the development of instruments that appear to be immediately useful for a specific goal (e.g., collecting step data to make more physical activity). Nonetheless, by becoming dominant, the externalistic way might lead designers to forget that the internalistic properties of wearables are also worth pursuing as explicit design goals.

In this article, I propose a theoretical framework, as an extension of postphenomenology, which aims to give a theoretical backdrop to HCI research inspired by the second way of thinking, i.e., the internalistic account. In fact, the first-person conceptualizations developed within HCI (e.g., Svanæs, 2013) have never been explicitly and thoroughly applied to wearables, leaving the "view from within" with respect to this technology undertheorized. Postphenomenology builds upon the study of human-

world relations that the major phenomenological philosophers have been doing (e.g., Husserl, Merleau-Ponty, Heidegger) and thinks of technological artifacts in terms of mediation, i.e., they help to shape (mediate) our relations to the world (Rosenberger & Verbeek, 2015). With respect to phenomenology, which grounded most of the first-person accounts of technology in HCI, postphenomenology allows to better identify the multiple effects that wearables may have on the ways through which we relate to the world. Fallman (2011) pointed out its potentialities to provide well-grounded conceptual tools for HCI, where it has been used to analyze the design of new artifacts (e.g., Wakkary et al., 2018), as well as existing projects and applications (e.g., Ohlin and Olsson, 2015).

A theorization of wearables that extends postphenomenology is important for two reasons.

On the one hand, by being constantly in contact with our "being" and potentially being employed in every contexts of the daily living, wearables appear a "special" kind of technology, capable of impacting on how we subjectively relate to the world to a greater extent than many other devices, without requiring any "invasive" integration into our bodies (differently from e.g., prostheses). The seminal conceptualizations developed by Ihde and Verbeek (e.g., Ihde, 1990; Verbeek, 2008), who founded the postphenomenological tradition, were not thought to be applied to wearables and thus may not be sufficient to pinpoint all the modalities through which this technology affects our experience. Therefore, by building upon their work, I will introduce a new kind of human-technology-world relation, the *extension relation*, to remedy shortcoming of the existing relations in postphenomenology for understanding wearables. This theoretical work may contribute to the affirmation of the wearable internalistic thought style within HCI, providing an explicit understanding of how we may experience the world *through* wearables, grounding designs that focus on "internal opportunities."

On the other hand, a perspective that attempts to look at wearables "from the inside" may move to the foreground alternate aspects of technology, opening novel possibilities for research on even those wearables that are traditionally framed in the externalistic thought style. At present, there are almost no externalistic wearables, like activity trackers and smart watches, that are designed by explicitly taking "internal insights" into account. This may be obvious, as each thought style hardly draws inspiration from other thought styles. However, it may also be due to the lack of an internalistic theoretical framework specifically developed for the wearable domain, which could be directly applied to design. Another main goal of this article, therefore, is to inspire HCI research on those wearables that are traditionally developed under the externalistic way of thinking.

To summarize, my contribution to HCI aims to be twofold. First, after introducing a definition of "wearable" and unfolding the current dominant perspective on wearable technology, I will propose a theoretical scaffold for the wearable internalistic thought style, which extends postphenomenology by introducing the "extension relation." This framework allows us to analyze existing wearable designs giving theoretical substance to the internalistic design choices, emphasizing that they are worth pursuing in their own right.

Second, I will suggest a series of design considerations as implications of the theory to be applied to wearables conceived within the externalistic thought style. The suggestions show how the framework can be used by HCI researchers and practitioners to explore design opportunities for making current externalistic wearables more internalistic, better supporting "internalistic uses" of the technology.

In other words, in this article I try to give a preliminary answer to questions like: What are the dominant theoretical assumptions that currently inform the design of most wearable technologies? How can we theoretically ground an alternative, internalistic, way of thinking about wearables? What lesson can we draw from this theorization to the design of the most popular, externalistic, wearable devices?

2 WHAT ARE WEARABLES?

Even though wearable technologies can be retraced to the invention of wristwatches in the 16th century (Amft & Lukowitz, 2009), the modern conception of wearables is tied to the appearance of the system to predict roulette wheels of Edward Thorp and Claude Shannon (Thorp, 1998) and the head-mounted display of Hubert Upton to aid lip reading in the 1960s. In fact, if we look at the definition of wearable technologies provided by Steve Mann in the 2nd Edition of The Encyclopedia of Human-Computer Interaction, we see that "*wearable computing is the study or practice of inventing, designing, building, or using miniature body-borne computational and sensory devices. Wearable computers may be worn under, over, or in clothing, or may also be themselves clothes*" (Mann, 2012).

Mann's definition focuses on the computational and sensing capabilities of devices that are *worn* by the person and parallels that of Thad Starner, who defines wearable computing as "*an effort to make computers truly part of our everyday lives by embedding them into our clothing (e.g., shoes) or by creating form factors that can be used like clothing (e.g., sunglasses)*" (Starner, 1996), stressing that wearables may simply have forms that are suitable to be worn by the individual. In this article, I will build on a definition of wearables that takes into account both Mann's and Starner's descriptions: I define wearable technologies (or wearable computers, wearable devices, or simply wearables) as *body-borne computational, sensory, and interactive devices, materials and fabric that may be worn under, over, or in clothing, may also be themselves clothes, or can be used like clothing*. This definition excludes both portable devices like handheld and laptop computers, which are "carried" but not worn by the person, as well as technology that is inserted into the body, e.g., replacing missing body parts or sensorial capabilities through body implants. Another exclusion relates to devices like medical smart patches and biosensors that do not provide the individual with any interaction opportunity.

However, my definition still includes a wide variety of technologies. These may be characterized by a spectrum on the extremities thereof we can identify, on the one side, devices that apparently do not really change our ways of interacting with technology, if compared with other portable devices, and are not aimed at affecting our perception and action in the world; on the other side, technologies that manifestly alter our interaction experience if compared to non-wearable technology, potentially modifying our sensing, understanding, and acting in the world. In the first side of the spectrum, we find devices like smart watches and activity trackers, which provide an interaction and information experience almost identical to that of smart phones, but just on a smaller, wrist-worn screen. In the second side of the spectrum, we find technologies like Augmented Reality (AR) head-mounted displays, as well as audio-based AR that alter, augment or diminish a person's visual or auditory perception of reality, possibly even without the person being aware that it is happening.

These two types of wearables seem to correspond, at least partially, to the two ways of thinking about wearable technology I sketched in the Introduction. Devices like activity trackers appear to be designed on the basis of the externalistic thought style. Instead, technologies like full-body suits or AR glasses embed the "spirit" of the internalistic account: they explicitly search new ways of altering a person's perception and expression. The growing popularity of activity trackers has somehow clouded the opportunities for modifying the human experience *through* technology in the wearable discourse. If we look at the most popular commercially available wearables, as well as the amount of research that revolves around trackers, the externalistic way of thinking appears dominant.

A goal of this article, therefore, is to put in the foreground the internalistic account, by providing a theoretical framework that points out how wearables affect our experience. This could contribute to its affirmation and be used to inspire the design of even those wearables that are currently developed within the externalistic frame. In the following Section, I will first briefly outline the theoretical

assumptions encompassed by the externalistic thought style, explicating the way it conceptualizes wearable technologies, and point out how it differs from the internalistic thought style.

3 A TAKE FROM THE OUTSIDE AND A TAKE FROM THE INSIDE

Two diverse "thought styles" can be identified in the wearable domain, an *externalistic thought style*, which focuses on the external aspects of the wearable and the "user," and an *internalistic thought style*, which pays attention to the "internal aspects" of experience and sees wearables as a means for enhancing or altering action, perception and cognition. A *thought style*, is a concept coined by Ludwik Fleck (1979) which later inspired Thomas Kuhn's concept of paradigm (Kuhn, 1970) and refers to what "determines the formulation of every concept." Thought styles are not dependent on one clear definition but are a consequence of a way of thinking that is socially influenced and have been usefully employed to characterize the conceptualization of interfaces within HCI (Janlert & Stolterman, 2015).

I elaborated on these two thought styles on the basis of more than 6 years of research on wearable technologies and activity trackers, in which I empirically studied a variety of people using wearables (through observation and semi-structured interviews), designed new technology for displaying wearable data, organized international workshops discussing with wearable researchers, as well as reviewed scientific literature on wearables.

More precisely, in a first diary study conducted in 2014, I recruited 14 participants with no previous experience in using wearable and self-tracking technologies (Rapp & Cena, 2015; Rapp & Cena, 2016). Seven of them had to use an activity tracker (Jawbone Up) up to one month (while the other seven had to use a set of tracking apps), self-observe, and report daily their experience with the device on a diary. At the end of the study, they were interviewed using semi-structured interviews. The study findings emerging from a thematic analysis (Braun & Clarke, 2006) showed that most of the participants perceived the device as an "object" put "on" their body sometimes interfering with their body movements and daily tasks. Moreover, some of them saw the data collected by the wearable as removed from what they considered their true "self", being such data too abstract and siloed within different visualizations. A participant, for example, reported that they felt "distant" from the information collected by the device, which was "cold" and "anonymous". Participants found it difficult to engage in sense-making activities, likely due to their lack of motivation and expertise in analyzing quantitative information: in fact, the wearable's focus on analytical representations did not support them in developing meanings around their data.

These findings led to the attempt to explicitly design for the internal aspects of the experience, developing a system which integrates information (e.g., sleep, heartbeat rate, steps) coming from different commercial wearable devices and tracking apps into a unique visualization that is meant as an extension of the person's body (Rapp et al., 2018). When the person stands in front of the screen, the system wakes up a data-driven reflected image of the person's body, as if the person were looking into a mirror, "embedding" their own data, which are represented through different colors and visual effects that dynamically change the body-reflected image. This image was aimed at providing a meaningful and integrated representation of data that were originally siloed among different devices. A qualitative user study, consisting in the observation of the system usage and semi-structured interviews with 24 participants (16 with no previous experience in using wearable and tracking technologies and 8 with previous experience in using such technologies), highlighted that the system was able to support people's sense making of and identification in their own data.

In 2017 and 2018, I then conducted two semi-structured interview studies with a total of 30 amateur

and professional sportspeople of different disciplines, who habitually used a variety of wearable technologies (e.g., Garmin fēnix 3 HR, Suunto Spartan, Suunto Ambit3 Vertical, Garmin Swim) during their sports activities (Rapp & Tirabeni, 2018; Rapp & Tirabeni, 2020). Through open and axial coding techniques (Strauss & Corbin, 1990), I found that amateur athletes, who still do not profoundly know their own body, allow the device to regulate their body "from the outside", completely relying on the exact and "objective" data provided by the wearable. Elite athletes, instead, who have an in-depth understanding of their own body processes and limits, stressed the need to distinguish when it is appropriate to count on the device (e.g., during trainings) and when it is needed to trust only the body sensations (e.g., during races). For them, the data provided by the wearable should not be uncritically accepted as "objective measures". Rather, they need to be integrated into the "subjective body knowledge" that the athlete must develop. To this aim, they construct meaningful data interpretations with their coaches, which allow them to make wearable data "more internalistic": for instance, they review the data together and connect those that might be relevant (e.g., because they present anomalies) with the subjective body sensations experienced during the training. This study highlighted how externalistic wearables are designed to convey an external perspective on the body: however, certain individuals are able to use them in an "internalistic way."

In 2018, I also conducted a systematic literature review of 57 papers on wearable technologies for sport (Mencarini et al., 2019) using a Grounded Theory Literature Review method (Wolfswinkel et al., 2013), which highlighted that most designs in this domain are focused on technological advancements and design matters like "data accuracy" and "wearability", which encompass an external view of the person's body, knowledge, and "world". The review also emphasized the lack of research on wearables explicitly addressing the "empowerment" of athletes, augmenting e.g., their strength or perceptions, as well as extending the kinds of movements that they are able to perform. Other literature reviews conducted by other researchers in other domains (e.g., Reeder & David, 2016 in the health context) point to similar trends.

Some of the preliminary insights coming from these studies were discussed with wearable researchers in three different workshops in top-tier international conferences (Rapp et al., 2015a; Rapp et al., 2015b; Hilviu & Rapp, 2015; Rapp et al., 2016; Rapp et al., 2017). This discussion made me further aware of the need to pursue internalistic matters as explicit design goals in the wearable domain.

Starting from this background knowledge, I recognized the externalistic thought style as dominant in the wearable discourse and then proceeded through problematization (Alvesson & Sandberg, 2011): according to Foucault, problematization is an "*endeavour to know how and to what extent it might be possible to think differently, instead of what is already known*" (Foucault, 1985: 9). Such an endeavor questions the presuppositions that researchers make about a subject matter in order to develop a theory about it (Alvesson & Sandberg, 2011). I thus identified and articulated the dominant style's ontological, epistemological, and methodological assumptions, by decomposing them into their constituent concepts following common method in philosophical analysis (Beaney 2003). I then circumscribed an alternative assumption ground (Alvesson & Sandberg, 2011), i.e., the internalistic thought style. Finally, I theoretically developed this alternative perspective by building on and extending postphenomenology, which offers a variety of theoretical tools for grounding an internalistic approach to technology but, as it stands, is not capable to fully account for all the peculiarities of wearables. This theoretical development has been further grounded in the analysis of several design artifacts, as common in postphenomenology (e.g., Verbeek, 2005) and theoretical HCI works (e.g., Kirsh, 2001; Janlert & Stolterman, 2010, 2015; Svanæs, 2013).

The wearable thought styles I identified connect with the wider third- vs. first-person HCI discussion on technology, which already captures several differences between these different approaches. The

third-person perspective assumes that "users" can be described and understood with the same tools and theories that we use to study other objects in the world (Svanæs & Barkhuus, 2020) and embraces a techno-centric approach to design; whereas the first-person perspective focuses on the subjectivity of the interaction and explores "experiential" design methods, putting the human and its experience at the center of the design process (e.g., Winograd and Flores, 1986; Ehn, 1988; Dourish, 2001; Svanæs, 2013; Höök et al. 2016, 2017, 2018; Rapp & Tirassa, 2017). Here, therefore, I only point out the key assumptions that specifically lie behind the conceptualization of wearables, while referring the reader to this HCI debate (see e.g., Svanæs & Barkhuus, 2020; Bødker, 2006) for deepening wider implications (e.g., about their different conceptions of science).

3.1 The wearable externalistic thought style

The externalistic thought style assumes three main conceptualizations of wearables, namely as *objects*, *repositories*, and *instruments*. These conceptualizations are fully embraced by most of currently available wearable technologies (see e.g., Seneviratne et al., 2017; Shin et al., 2019; Mencarini et al., 2019; Iqbal et al., 2016; Reeder & David, 2016): they are especially evident in smart watches and activity trackers, namely devices used for tracking people's physiological and mental states, which dominate the current market of wearables (IdTechEx, 2020; Vandrico, 2020; Seneviratne et al., 2017).

First, wearables are thought as independent material *objects* designed to be placed "on" the individual's body, detachable entities similar to everyday body accessories. This is visible in the theoretical debate on *wearability*, i.e., "*the physical shape of wearables and their active relationship with the human form"* (Gemperle, et al., 1998), which focuses on "external matters," like weight distribution (Zeagler, 2017) and the comfort "*afforded by a body-mounted object*" (Dunne & Smith, 2007). In this perspective, the most pressing design need becomes that of finding the best form factor and body location where the wearable should be placed, in order to increase accessibility to interaction (e.g., Curmi et al., 2017; Kosmalla et al., 2016), or enhance the device sensing capabilities (e.g., Feeken et al. 2016; Chen et al. 2014). Khalaf et al.'s (2020) framework of wearable input devices, for instance, suggests that designers pay attention to body locations and mobility, types of interactivity, and output modalities when designing new wearables: these factors are aimed at increasing accessibility and wearability. The objectification of the device parallels the objectification of the person's body, which is studied from the outside in its material and functional features, like its shape, size, and movements, and becomes parceled, scattered among the body parts where the wearable can be put on.

Second, wearables are seen as *repositories* of objective data. Developers put a great effort in finding more effective sensing techniques transforming what the person "is" into a series of quantifiable parameters that can be automatically detected by sensing the person's "outside" (e.g., movements and physiological parameters, Tag et al., 2017; Quiroz et al., 2013). Wearable data can be then used to increase the person's self-knowledge (Li et al., 2010), in line with the "Quantified Self ideology", which accompanied the rise in popularity of activity trackers (Marcengo & Rapp, 2014; Rapp & Cena, 2014). This "knowledge" consists in objective numbers and appears exact (Lupton, 2014), unless the wearable in charge of collecting the data is inaccurate. This explains the many concerns for accuracy in wearable research (Mackinlay, 2013; Yang et al., 2015) and the employment of stats, graphs, and analytical visualizations for representing the data (e.g., Epstein et al., 2014; Gouveia et al., 2016). Moreover, knowledge coming from wearables becomes fragmented because data are often siloed within a specific device or service provider (Li et al., 2011) and the different parameters sensed (e.g., the number of steps taken, the blood pressure levels) are thought as stand-alone quanta of knowledge that atomize the wholeness of the individual in favor of a specialized understanding of their singular

aspects.

Finally, wearables are conceived as *instruments* for achieving certain objectives. An instrument is something that we use for acting in the world, pushing it toward some more desirable evolution. In this perspective, wearable devices are thought as multi-purpose instruments that can be employed across different environments. This leads developers to pay great attention to the varying contexts where the wearable can be used (e.g., Chatzopoulos et al., 2017; Kubo et al., 2017). Here, contexts are conceived as stable states of an objective world that has the same value and meaning for every individual (Dourish, 2004; Gilbert et al., 2017). Once a relevant world state is detected and encoded by the device, the very same system's response is delivered independently from what the person sees in it. Moreover, the goals that the instrument allows to achieve are tied to the device's sensing capabilities. This can be observed in wearables providing the person with recommendations of some kind (e.g., Bächlin et al., 2009; Spelmezan, 2012): the target goal is defined on the basis of the collected data (e.g., sleep data) and suggestions on how to reach the goal are limited to that particular domain (e.g., sleep behavior). In this perspective, the world is objectified and fragmented into delimited contexts, which can be easily managed by the wearable: how such contexts are connected to a "wider world" is not considered.

To summarize, the wearable externalistic thought style both objectifies and fragments phenomena at design-time. On the one hand, the person, the device, and the world in which they interact, are conceived as quantifiable and stable objects that can be automatically detected and recorded. On the other hand, this style favors a specialized account of the person's body, knowledge and world that ultimately refers to the single parameters monitored by the wearable.

3.2 The wearable internalistic thought style

In the internalistic thought style, wearables are seen as a means for enhancing or altering action, perception and cognition and are tightly connected with the human being. In other words, this style focuses on the potentialities of wearables in directly affecting "the human" and in integrating with their sensory and intellectual experience. Wearables may transform the body into an information processing technology (Hogle, 2005), which ultimately challenges one's sense of identity (Barfield & Williams, 2017), and develop the person's physical or cognitive abilities (Leigh et al., 2017).

Conceptualizations based on this style were paradoxically more popular among the works of wearable precursors and pioneers. Licklider (1960), for instance, envisioned "man-computer symbiosis," a subclass of man-machine systems in which human brains and computing machines are coupled very tightly; while Starner et al. (1998) highlighted that wearable computers allow a close association with the person, stressing that they have the potential to experience the life of the individual in a first-person sense. Mann (1998) emphasized that wearables may augment, diminish, or otherwise alter the human perception, as well as blur the boundaries between remembering and recording (Mann, 1997); whereas Starner et al. (1997) stressed that wearable systems may augment the person's memory and provide them with a different thinking modality.

These early conceptualizations, however, were soon clouded by the consolidation of the externalistic thought style and the spreading of wearables conceived as objects, repositories, and instruments. Explicitly theorizing about the internalistic perspective on wearables becomes thus pressing, in order to both give full account of works that are currently carried out within the internalistic frame and propose an alternative to wearable externalistic assumptions.

In fact, on the one hand, wearables inspired by the internalistic thought style are currently designed by scholars to e.g., yield sensory alterations (Karpashevich et al., 2018); convey knowledge to be

experienced without conscious interpretation (Brueckner & Freire, 2018); augment the act of remembering by tying memories to specific places (Matassa et al., 2013); communicate enhanced visceral sensations (Neidlinger et al., 2017); or express emotions in an embodied way (Du et al., 2018). This line of research, nonetheless, appears to lack a theoretical scaffolding that may move internalistic works in the foreground.

On the other hand, despite the enthusiastic market predictions, current externalistic wearables are facing some difficulties in sustaining user engagement over time (Maddox 2014; Lazar et al., 2015): research reports that one third of the Americans that purchased a tracker abandoned it after only six months of use (Ledger and McCaffrey 2014; Harrison et al., 2015), and that people trying a wearable may become disengaged due to problems in integrating it into their everyday life (Rapp & Cena, 2016; Lazar et al., 2015). An alternate way of conceptualizing wearables may provide insights to integrate and even magnify what has been done under the externalistic account.

In sum, a thorough theoretical work is still in need to develop an alternative take on wearables, unfold its implications, and open up design opportunities. To this aim, I will adopt a postphenomenological approach, putting in the foreground the experience of being human and the mediating effects of technology, exploring the concept of wearables as "extensions." By building on the work of Ihde and Verbeek, I will introduce a new kind of mediation, the "extension relation," to remedy shortcoming of the existing human-technology-world relations in postphenomenology for understanding wearables.

4 WEARABLES AS EXTENSIONS

I will first introduce how wearable technologies can be characterized neither as objects, nor as repositories, nor as instruments, but as *extensions* of the human subject engendering a specific kind of mediation: the *extension relation*, which is meant to theoretically ground the wearable internalistic thought style. This relation widens those human-technology relations identified by Ihde and Verbeek, by building on a more comprehensive notion of intentionality, i.e., the *extended intentionality*, which takes into account the perceptual and the conscious ways through which we relate to the world, as well as the "world" itself. The extension relation shows that wearables may extend the intentionality itself, increasing the human opportunities for bodily and consciously appraising the world, as well as for acting in this world.

Then, I will deepen the conceptualization by focusing on the three fundamental constituents of the proposed notion of extended intentionality: the motor intentionality, the conscious intentionality, and the "world" towards which the intentionality is directed. In so doing, I will show how the extension relation may extend all these constitutive elements of intentionality.

Finally, I will show how this theoretical scaffold can be applied to understanding existing wearables and generating design opportunities that could be worth exploring by the HCI community, in order to make externalistic wearables more "internalistic."

It is worth to notice that I do not want to propose a new "general theory of technology." Rather, I want to focus on wearable devices. Although, this theoretical work could be in principle applied to other technologies as well, I do not pursue any unifying framework that can embrace and account for all technological artifacts. Nor I want to define a "complete" or "ultimate" theory. Rather, I want to highlight how theorizing several aspects of the way we relate to ourselves and the world may be relevant for wearable design. I am aware that other equally relevant aspects, such as the emotional nature of the experience, are not adequately discussed here. Likewise, some features of wearables could not be fully accounted in this limited space.

Finally, I do not want to convey the idea that there is a subject-object dichotomy that is reified in an "opposition" between the internalistic and the externalistic thought styles. Subject-object dichotomy is sharply criticized both in phenomenological and postphenomenological thinking, where the split between subject and object is replaced with an intentional relation between them (Rosenberger & Verbeek, 2015). Rather, the internalistic and externalistic thought styles are not impervious to one another. Nor the externalistic thought style forecloses the interiorities that are explicitly valorized in the internalistic account. Even though they are explicitly designed to support externality, externalistic wearables do not preempt the person's active construction of meaning: the person can always turn exact quantities into meaningful representations, going beyond the assumptions that drove the development of the wearable at design-time. Elsden at al. (2016), for instance, discovered that people may develop a variety of meanings around quantitative records of their past, while Ha et al. (2020) highlighted that certain individuals may use the virtual rewards delivered by activity trackers to deepen their understanding of the current activity level and fitness routines. Likewise, Gross et al. (2017) found that people may treat tracking devices as if they were creativity support tools, by connecting self-tracking with digital photo authoring. These studies suggest that externalistic design mindsets are not preemptive of internalistic, or fairly imaginative, user experiences. Therefore, in the following, rather than championing the internalistic thought style over the externalistic thought style, I want to suggest that researchers and designers shift from a merely externalistic thinking at design-time to the exploration of internalistic opportunities, which are worth pursuing as explicit design goals in their own right. The theory that I propose is precisely aimed at supporting such kind of design.

4.1 The extension relation

Postphenomenology is heavily inspired by the phenomenological emphasis on experience and subjectivity, building on and reinterpreting the foundations of phenomenology. Postphenomenology sees phenomenology "as understanding the relations between human beings and their world" (Rosenberger & Verbeek, 2015). In fact, the study of human-world relations is what all major phenomenological philosophers have been doing, by conceptualizing them in terms of consciousness (Husserl), perception (Merleau-Ponty), and being-in-the-world (Heidegger) (Verbeek, 2005). Postphenomenology builds upon and expands these conceptualizations of human-world relations, focusing on how technology *shapes* such relations. This active role of technology in altering our relations to the world is called *mediation* in postphenomenological terms.

In order to investigate the mediating role of technologies, postphenomenology analyzes various types of relations between humans, technologies, and world (Verbeek, 2015). Ihde identifies four basic forms of technological mediation (Ihde, 1990). *Embodiment relation* is the mediation of technologies that alter the individual's perceptual involvement with the world. In this form of mediation, an individual's experience is reshaped through the device, with the device itself in some ways taken into the person's bodily awareness. For instance, a person looks through the eyeglasses upon a transformed world, and the eyeglasses can be conceived as a part of their perceptual experience. In the *hermeneutic relation* (hermeneutic means "to interpret") the individual experiences a transformed encounter with the world via the interpretation of the technology itself. For example, by looking at a wristwatch, they interpret its display and gain a transformed access to the time of day: the display is an analogous to a text and they must read what it shows through a hermeneutic process. *Alterity relations* are those in which our interaction with technology assumes the form of person-to-person interaction. Finally, *background relations* are established when an individual does not use a device directly but nonetheless it shapes their experiential surroundings, like the running of a refrigerator.

Building on the seminal work of Ihde, I argue that these kinds of relations are insufficient to characterize the mediating role of wearables. Rather, this role should be framed in what I call the *extension relation*. The term extension, here, expresses a greater "flexibility" with reference to similar terms: prosthesis (Tan, 2003; Cranny-Francis, 2008; Barfield & Williams, 2017), for instance, implicitly conveys the underlying assumption that technology replaces or restores body functions or needs to be physically integrated into the body. Extension, instead, remains open to different interpretations about what is extended and how it is extended.

Before developing this concept further, it is needed to say that the idea of wearables as extensions is not new in the history of thought about technology. Technical artifacts have been seen as extending the human organism by amplifying bodily and/or mental abilities (Lawson, 2010; Brey, 2000; Kapp, 2018), augmenting the *means* by which human intentions are realized (Brey, 2000), and enhancing human's willingness (Rothenberg, 1993). The idea of cyborg (Clynes & Kline, 1960) refers to being incorporating exogenous components extending their self-regulatory control function. Engelbart (1962) thought electronic technology as a means for extending the capability of human intellect. Clark (2003) claimed that we naturally use a variety of nonbiological elements to extend our cognition, while Mueller et al. (2020) emphasized that technology may extend the experienced human body. Mann (1998) stated that wearables can be a true extension of the wearer's mind and body, whereas Svanæs and Solheim (2016) literally built wearable "body extensions" for the stage.

A thorough theoretical investigation of "human-wearable-world relation" as extension, however, is still missing. What is the nature of this relation? What is extended and how? To answer these questions, I have to introduce the notion of intentionality, a basic notion in phenomenology that also grounds most of the theorization in postphenomenology (Rosenberger & Verbeek, 2015). The concept has been developed by Husserl, albeit it has a long history in philosophy, from Meinong to Brentano. Intentionality does not refer to people's "intentions," rather to a characteristic feature of our mental states and experiences, especially evident in what we commonly call being conscious or aware: as conscious beings we are not merely affected by things, but we are also conscious of them, of our own self and other persons, of abstract and imagery objects, and, by and large, of everything we bring before our minds (McIntyre & Smith, 1989). When I think of a dog, my thought is a thought "of" a dog. Each mental state or experience is a representation of something other than itself giving one a sense of something: this representational character of perception and consciousness, its being of or about something else, is intentionality (McIntyre & Smith, 1989). Ihde introduced a technological dimension in this phenomenological tradition of understanding human–world relations: humans do not experience the world directly, but always *via a mediating artifact* which helps to shape a specific relation between humans and world (Verbeek, 2008).

The theoretical framework that I propose elaborates on the notion of intentionality to develop Ihde's work, by affirming that wearables can be framed within the extension relation, in which wearables *extend human intentionality*. I call the intentionality involved in the extension relation *extended intentionality*. This intentionality is constituted of three different aspects, the *motor intentionality*, the *conscious intentionality*, and the *"world"* towards which the intentionality is directed, allowing us to understand the various ways in which wearable technology transforms the opportunities for us to relate to the world.

First of all, the extended intentionality has different "levels" corresponding to the different ways through which we appraise the world. The first level is that of *motor intentionality*, that is a primary, pre-reflected way of experiencing the world, which happens before the constitution of intentional acts in the consciousness and corresponds to bodily perception. The second level is that of *conscious intentionality*, which is made of "higher-order" intentional acts, corresponding to e.g., imagining,

desiring, and thinking. Wearables may extend both these levels of intentionality increasing the human opportunities of bodily and consciously relating to the world, thus enhancing how we perceive, think of, imagine, remember, and so on.

Moreover, the extended intentionality always refers to an "object." This is a representation at which the intentional act is directed. It may be a percept in the case of motor intentionality, or a meaning in the case of conscious intentionality. The object, however, is never given as an isolated entity that can be fully appraised by the person. Rather, it is always immersed in something wider, in a "world" that gives the possibility for every manifestation of the object. The idea of "objects" and "world" are originally included in the notion of intentionality itself and have nothing to do with the realist position that splits the reality in subjective ideas and objective facts. In a postphenomenological perspective, "*subject and object cannot have a separate existence. The human subject is always directed at objects: we cannot just "see," "hear," or "think," but we always see, hear, or think something. Similarly, the objects "in themselves" will probably exist, but it does not make much sense to think about them, because as soon as we do that, they become things-for-us, things as disclosed in our relations with them*" (Rosenberger & Verbeek, 2015: 11). The objects and the "world" towards which intentionality is directed, therefore, are always objects-for-us and world-for-us. Wearables may also extend them, by expanding the entities of which this world is made and widening the person's opportunities for acting in this world.

Figure 1 summarizes the theoretical framework that I briefly introduced here and that I will extensively develop in the following Sections. The extension relation enacted by wearables intervenes on the extended intentionality by shaping all its constitutive elements, that is the motor intentionality, the conscious intentionality, and the "world" towards which the intentionality is directed. Extension here means that wearables transform and increase the opportunities for us to relate to the world at perceptual, conscious, and action levels.

FIGURE 1 HERE

The extension relation extends postphenomenology to account for the specific kind of human-technology-world relation engendered by wearables. In fact, the extension relation differs from those identified by Ihde. In Ihde's perspective, the unique form of technology relation that somehow truly *extends* the way we connect with the world is the embodiment relation. However, in Ihde's reading glasses, embodiment relation introduces a "fixed alteration" of the perception (e.g., a better focus on the read text), which does not entail a complete and dynamic integration of the technology into our

perceptual apparatus. The embodiment relation and the reading glasses point to technology as a "passive" filter, failing to grasp the complex and intimate intertwining of humans and wearables, which merges their "action" and points of view into a novel way of perceiving the world. Differently from reading glasses, wearables may be able to proactively and dynamically change the person's perception, transparently merging with their perceptual capabilities and multiplying their perceptual opportunities thanks to their computational capabilities: for instance, certain AR glasses may dynamically alter how the person sees depending on the changes happening in their internal states or in the environment, as if they were a new organ completely integrated into the person's perception acting for the realization of the mutable organism's goals and desires, while offering multiple perceptual modalities.

More importantly, Ihde's embodiment relation focuses on perceptual experiences (i.e., the motor intentionality), while ignoring "higher-order" ways that we have for appraising the world (e.g., by *knowing* it, or by *remembering* it), namely the conscious intentionality. The person's conscious modalities are rather included in the hermeneutic relation: here, nonetheless, the action of technology is not to extend such ways of experiencing the world, rather to transform the world into a text that the person can interpret. This hermeneutic relation can be useful to understand technology like smartphones, tablets, desktop computers, and even externalistic wearables, in which the person's focus is not on the world experienced *through the technology*, but on the technological instrument and the information it prompts. However, its explicatory power for internalistic wearables appears weaker: it may account for the data representations that wearables are able to display but is less able to explain how such devices may alter e.g., how we remember, think, imagine, and desire.

Finally, Ihde's relations do not account for how the person's world may be extended. While the reading glasses merely change the perceptual focus on the world, AR wearable glasses may introduce new "entities" in this world (e.g., by displaying virtual objects that integrate with the "real world"). The notion of extended intentionality that grounds the extension relation, instead, includes both the perceptual and conscious ways that we have to relate to the world, as well as the world towards which intentionality is directed, allowing for a better understanding of the mediating role of wearables.

Veerbek (2015) precisely pointed out that Ihde's typology is insufficient to characterize the different relations engendered by recent technologies. He emphasized that there are configurations of humans and technologies that are more intimate than an embodiment relation, like a brain implant. He thus proposed the cyborg relation, where technology is not merely embodied; rather, it merges with the human body into a new, hybrid being (Verbeek, 2008): "*Instead of organizing an interplay between a human and a nonhuman entity, this association physically alters the human*" (Verbeek, 2008, p. 391). Cyborg relation highlights the strict connection between humans and technologies, which is a key characteristic of the extension relation as well. However, cyborg relation requires a physical fusion between human and technology and is more suitable for implants and prostheses than wearables.

Moreover, cyborg relation builds on what Verbeek calls cyborg intentionality, an intentionality that is partly constituted by technology and that has two radical forms, the composite intentionality and the hybrid intentionality. While the former assumes a cooperation between the human being and the technology each with a different intentionality[1], thus still seeing the device and the person as separate entities, *hybrid intentionality* is a form of intentionality "beyond the human," pointing to a material fusion between body and technology. In this form of intentionality, however, Verbeek not only misses the fact that a strict integration between human and technology does not necessarily require a physical fusion, as it happens in wearables; but also, he still focuses the intentionality on the perceptual level,

[1] For instance, the intentionality of a sound recorder reveals aspects of sound that cannot be perceived by the intentionality of the human being. When this intentionality is added to human intentionality composite intentionality comes about (Verbeek, 2008).

leaving apart both its conscious level and the "world" towards which it is directed.

The extension relation, instead, does not require any physical merge between the device and the person being capable to account for technologies that are simply "worn" and not incorporated by the person. Moreover, it builds on a more comprehensive notion of intentionality, the extended intentionality, that does not focus merely on perception, but also considers our conscious intentional acts and the "world-for-us," showing how these three elements are extended by wearables through the extension relation.

In the next three Sections, I will deepen the three basic constituents of the extended intentionality to explain how the extension relation engendered by wearables unfolds. After each Section, I will analyze a series of design artifacts to show the explanatory power of the framework, as well as list a series of design considerations that point out its generative power, sketching possible future research directions for the design of externalistic wearable technologies.

5 MOTOR INTENTIONALITY

We have seen that within the wearable externalistic thought style the device is seen as an independent object: the person's body is conceived as an object among others as well, quantifiable and divisible into autonomous parts. The extended relation, instead, refers to the notion of *motor intentionality*, which is a level of the person's intentionality that builds on a conception of body and perception dating back to Merleau-Ponty's (1962) subjective body ("leib") (Svanæs, 2013, 2016).

Motor intentionality is directed towards otherness at the body level and is meaningful, whereby meaning is still not articulated at the order of reflective thoughts: it entails a notion of perception in which the world is taken up in an active moment of meaning constitution (Merleau-Ponty, 1962; Bullington, 2013). This "body meaning" provides us with habitual functioning that establishes appropriate relations with the world without needing any prior reasoning, as a form of pre-reflexive understanding (Gallagher & Zahavi, 2008).

Motor intentionality, therefore, happens before the constitution of intentional acts in the consciousness and allows us to bodily relate to the world. The interesting thing is that it involves not a single sensorial channel or body part, but the whole body and its entire sensorial field (Merleau-Ponty, 1962). When an individual holds a hammer in their hands, for example, they are automatically coordinated with the rest of the body, which takes part in the perception of the tool as a holistic entity.

The extension relation highlights that wearables may extend the motor intentionality, which means that they may alter the person's whole sensorial field, increasing their perceptual opportunities. This extension may be characterized by an integration of human and technology that is almost completely *transparent*[2] (Van Den Eede, 2011; Liberati, 2016): the wearable becomes part of the person's perceptual apparatus and can dynamically change how they hear, see, and feel. This integration, nonetheless, does not require any material fusion, because it is realized not at the physical level but at the motor intentionality level.

In the case of wearables, the extension relation may take multiple forms, as the device may offer multiple potential transformations of a person's bodily-perceptual encounter with the world. Unlike eyeglasses, which offer the same perceptual alteration to everyone when they are worn, the

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[2] This conception of transparency may remind Heidegger's description of the withdraw of the ready-to-hand tool, such as in his account of the hammer (Heidegger, 1927). However, where Heidegger's account is a critique of the entire history of Western metaphysics, in postphenomenology transparency is put toward the pragmatic description of particular human-technology relations, where the particular degree to which a device should be considered transparent may depend on the specific technology (Rosenberger & Verbeek, 2015).

computational capabilities of wearables may differently and dynamically transform the perception of the world depending on the goals, context, usage modalities, and the person's characteristics. In postphenomenological terms, wearables are *multistable* mediators of human perception, capable of supporting multiple alterations of the motor intentionality. In this sense, they may produce a variety of *perceptual variations* in order to convey different perceptual possibilities that a phenomenon can exhibit while experienced from different vantage points (Ihde, 2009).

However, every technology filters certain sensations while enhancing others and in doing so it excludes certain perceptions of reality while promoting others (O'Brien, 2017). In postphenomenology, this is called its *magnification/reduction structure*: binoculars, for instance, enable an individual to see over a distance, at the detriment of the visual awareness of her surroundings (Ihde, 1990). This means that the wearable not only produces the "desired change" in our perception, but also always entails other changes, some of them taking on the quality of "tradeoffs," a decrease of a sense, layer of context, or area of focus (Rosenberger & Verbeek, 2015).

To summarize, differently from the externalistic thought style, which sees the body as objective and fragmented, the extension relation builds on a conception of the body as fundamentally subjective and holistic. Wearables may extend the person's motor intentionality, namely our pre-reflective and bodily way of relating to the world, allowing us to experience it transparently through the technology. In so doing, they may magnify and reduce at the same time our experience, also potentially offering multiple "perceptual modalities." This conceptualization parallels in part the somaesthetic appreciation design in HCI, which emphasizes the living, perceptive body subjectivity and focuses people's sensitivity on their own somatics (Höök et al., 2016, 2018; Alfaras et al., 2020). This design approach builds on somaesthetics theory which draws attention to the importance of our bodily movements as part of our ways of being and highlights how learning body awareness is as important as educating our minds (Höök et al., 2016). However, the extension relation at the motor intentionality level focuses not only on the design opportunities for encouraging the person to be closer to their own body, but also for altering and widening the bodily modalities through which we experience the world. Moreover, it highlights the necessary side-alterations that each modification of the sensorial field operated by technology brings along.

5.1 Wearable technologies for the extended motor intentionality

The conceptualizations surfaced above open new opportunities and challenges for HCI. The properties of the extension relation at the motor intentionality level, which refer to technology transparency, the magnification/reduction structure, and multistability, not only provide a theoretical scaffold for all those wearables that are framed in the internalistic thought style; they also may inspire the design of those wearables that are currently developed within the externalistic thought style.

In order to see how the extension relation at the motor intentionality level may ground an internalistic approach to wearable design and generate design suggestions for externalistic wearables, we can now compare two different kinds of wearables: sensory augmentation and simulation wearables, which can be ascribed to the internalistic style, and activity trackers, which represent the externalistic style.

Wearable simulations and sensory augmentation wearables aim to evoke, through a combination of sensations, novel perceptual experiences (Gibb et al., 2015) and "enhance" our sensorial field. These wearables may enable people to experiment ill-health conditions at work (Gibb et al., 2015) and to "sense" information that are commonly not available for us, like feeling orientation information gained by the magnetic field (Nagel et al., 2005), or seeing ultraviolet radiation on the body (Zhang et al.,

2013). We may focus on two examples of this kind of wearables: i) Force Jacket, which is an array of pneumatically-actuated airbags and force sensors that provide feel effects such as punch, hug, and snake moving across the body (Delazio et al., 2018); and ii) TreeSense (Liu & Qian, 2017), which is a tactile experience of being a tree, where wearables trigger novel tactile sensations that are not "naturally" possible (Fig. 2).

FIGURE 2 HERE

If we use the extension relation to analyze these wearables, we see that they are specifically addressed to extend our motor intentionality *transparently* integrating novel perceptual modalities into our perceptual apparatus and providing novel full-body experiences. Both the designs encompass a first-person conception of the body, subjective and holistic. ForceJacket, for instance, uses vibrotactile and variable force feedback for the upper body and arms to make the person experiment an entirely new perceptual experience, which is not limited to the body parts impacted by the device, but reverberates to the wearer's whole body (Delazio et al., 2018).

In so doing, these wearables actively intervene on the *magnification/reduction structure* at the motor intentionality level, by modifying the balance of the person's sensorial field. ForceJacket and TreeSense magnify the sense of touch altering the person's body perception though haptic feedback. As a consequence, the visual focus on the body is reduced: by amplifying the tactile perception the person loses sight of their real body image and can believe to have a different body simulated in a Virtual Reality (VR).

The concept of *multistability* further allows us to see how these wearables may dynamically alter the person's body sensations producing different perceptual modalities depending e.g., on their goals. ForceJacket provides different body experiences in accordance with the objective of the person, e.g., feeling to be a muscular hero while playing a videogame, or simulating heartbeat effects to control their sense of anxiety or fatigue when running. Treesense (Liu & Qian, 2017) elicits a variety of *perceptual variations* allowing the person to experience what it feels like to be a tree from a seedling to its full-size form, to its final destiny, thus providing the experience from multiple points of view.

By contrast, activity trackers rely on the conception of the objective and fragmented body, seeing technology as a means to provide objective data about it. To this aim, they make use of visual feedback that favors the conscious and rational interaction with the device, and, to a lesser extent, of auditory and haptic feedback in the form of on/off vibration (Culbertson et al., 2018), verbal instructions (Pan et al., 2018), or simple acoustic stimuli (Umek et al., 2015), which nonetheless rely on a "rational" language

as well. Let's take as examples two popular activity trackers available on the market (Fig. 3): the Apple Watch and the FitBit.

FIGURE 3 HERE

These devices are not designed for becoming *transparent* extensions of the person's entire sensorial field. The Apple Watch provides an interaction experience almost identical to that of an iPhone (to which it may refer as a supplementary display/tool), but on a wrist-worn screen, in which the person can have access to a variety of "instruments" (the apps) among which those in charge of collecting body data play a relevant role. The FitBit collects almost exclusively body data and gives minimal information on its display, while referring to the smartphone for supplementary interaction. Both the wearables are collectors and conveyors of data, turning the person's sensations into a text to be read. Certainly, people can always use this "text" in an "internalistic way". For example, a person can use the wearable to prevent an excess of fatigue while doing physical activity: they may learn how to "read" the instrument for understanding when they are pushing too much, as if it were a new perceptual channel able to detect the sense of exertion. Nonetheless, these trackers are not explicitly aimed at extending perceptual experiences; rather, they communicate information exploiting a specific sensorial channel.

The *magnification/reduction structure* in these devices does not point to an amplification of an aspect of the motor intentionality, but to a magnification of rationality, in terms of rational examination of numeric data, stats, and graphs. Both the Apple Watch and the FitBit rely on "glanceable" numbers directly prompted on the wearable screens, while more in-depth analysis can be carried out through the correspondent mobile apps, which provide a variety of analytical tools like filters and graphical summaries. In other words, here the pre-reflective meanings that the body commonly constructs to relate to the world are not intentionally supported by design. This does not mean that the person cannot develop body meanings by using these technologies: for instance, an athlete can become more aware of their heartbeat by constantly comparing those body signals that are tied to a specific level of their heart rate with the fixed measures prompted by the device (Rapp & Tirabeni, 2018). Rather, it means that these wearables are not purposefully designed to magnify specific body signals.

The Apple Watch and the FitBit also do not exploit the *multistability* of technology with reference to motor intentionality. Even when a haptic feedback is given, for instance by the Apple Watch in the

form of a vibration, this is not meant to dynamically modify the perception of the person's body or "world," like in simulation wearables, rather to communicate precise information *about* the body. There is no interest here in inducing *perceptual variations*.

Given the differences illustrated above, what inspiration can we draw from the internalistic thought style to the design of externalistic technology like activity trackers? The conceptualization of the extended relation at the motor intentionality level suggests that we focus on making externalistic wearables more *transparent*, integrating them into the person's sensorial field, more capable of amplifying certain body signals, taking into account the *magnification/reduction structure*, and more *multistable*, multiplying the perceptual variations that may help people learn from their own body.

As for *transparency*, activity trackers may consider opportunities for being integrated into the person's sensorial apparatus in order to provide them with novel full-body experiences. The extension relation at the motor intentionality level emphasizes that technology can become part of the person's perceptual apparatus affecting their sensorial field as a whole. This could be achieved by leaving the communication channel always open, exploiting phatic cues, rather than punctual messages, in the form of continuous variations in the material/sensorial qualities of the wearable: this would mirror the individual's body changes and establish an enduring exchange between the person and the device. Having the sensorial stimulation always active would make it more transparent, by intertwining the continuous feedback coming from the wearable with those signals naturally coming from our body. For instance, activity trackers could use continuous haptic feedback to feed body data back to the person: in so doing, they could employ pre-rational interaction modalities conveyed by e.g., heat, stiffness and roughness alterations of the material support of the wearable, rather than relying on a tactile-based "rational" language, where the mapping of sensations to meanings may be abstract or arbitrary, as it happens in haptic icons (Azadi & Jones, 2014) and reminders (e.g., in the Apple iPhone).

As for the *magnification/reduction structure*, researchers could design activity trackers aimed at increasing the person's body awareness amplifying certain body signals, which they may be not aware of. Activity trackers could include biofeedback functionalities (e.g., Frey et al., 2018; Neidlinger et al., 2019) to magnify proprioceptive sensations, like the level of fatigue and respiration, by recommending that the person pay more attention to such sensations when they are undergoing a change. Design could learn from "expert people" (e.g., expert patients) what subtle body signals are important (e.g., in certain chronic conditions) and then focus "novices" on such signals, in order to allow them to better recognize their symptoms. The magnification/reduction structure points out that when certain sensations are amplified, others, at the same time, are narrowed. For instance, magnifying the perception of certain aspects of the person's body may remove them from their context in the whole body. These are not a sort of "optional side-effects": each magnification always brings along a correspondent reduction. The extended relation then stresses that researchers and practitioners should always take into account how their designs necessarily entail downsides and learn how to recognize them.

Finally, as for *multistability*, trackers could induce perceptual alterations activated according to the person's context, goals, and characteristics. The concept of multistability with reference to motor intentionality precisely points to the opportunities for designing for different objectives, persons, and environments at the body/perceptual level. For instance, a health activity tracker paired with AR glasses could differently modify the individual's perception of food: if they have hypercholesterolemia, by coloring "dangerous" foods in red; while if they are simply following a low-fat diet, by using different shades to highlight foods that have different levels of fat. People using activity trackers could also be engaged in multiple perceptual variations to "learn" directly from their body, rather than from the acquisition of exact knowledge. MusicJacket, for instance, is a wearable system that allows novice musicians to learn to play musical instruments, by supporting the teaching of good posture and bowing

technique through vibrotactile feedback (van der Linden et al., 2011). What would it mean, then, to make an amateur athlete perceive their body as it is perceived by an elite? Trackers could allow the person to experiment different degrees of physical resistance (e.g., by expanding inflatables wired in their garments and connected with the tracker) as they were experienced by other (maybe more "expert") people, in order to learn specific body gestures connected with e.g., certain sports practices (e.g., a golf swing), or health conditions (e.g., the correct posture).

6 CONSCIOUS INTENTIONALITY

In the wearable externalistic thought style the wearable is conceived also as a repository of objective data patterns: in this sense, the person's knowledge is understood as objective and fragmented. The extension relation, instead, points to the notion of *conscious intentionality*, which entails a conception of knowledge as constructed by the subject.

To us, in fact, the world shows itself not only through our motor intentionality, which is pre-reflective, but also in and through consciousness. Conscious intentionality corresponds to the high-order level of extended intentionality and is constituted of different intentional acts. The definition of intentional acts dates back to Husserl and has a central role in postphenomenology: intentional acts have two basic parts, one is the quality of the act, whereas the other is the matter of the act (Husserl, 1984). Quality distinguishes the act phenomenologically from acts of other kinds: for example, remembering something is different, in phenomenological terms, from the experience of imagining something. In other words, we have different subjective experiences depending on the kind of act we are engaged with: remembering the day of our graduation is "qualitatively" diverse from imagining it in the future, or pursuing it as a goal.

The matter of the act, instead, gives the act its specific representational character: it varies in acts that represent different "objects" (which object is represented) and in acts that represent the same object in different ways (how the object is represented). For example, I can imagine a horse or a unicorn, in this case the act has two different matters with reference to its object. Otherwise, I can think of Cesar as the conqueror of Gaul, or as the dictator assassinated by Brutus: in this case the matter varies in relation to how the object Cesar is represented. The matter, therefore, corresponds to the *meaning* of the intentional act, the conscious representation toward which the act is directed (Nikolić, 2016).

These meanings, which are articulated at the order of consciousness, however, are not objective, but constituted subjectively (or intersubjectively) through the interpretation of what is happening (Rapp & Tirassa, 2017). In this perspective, knowledge is not absolute, but depends on the knower who produces it. What the subject knows are meaning-laden entities, and these are construed by the subject itself (Selvi, 2011). As long as the subject constructs new knowledge, such knowledge affects how the meanings will be constructed later on. In other words, our past experiences impact how we currently understand the world, the meanings we ascribe to it, and the "entities" that are relevant to us. Here, knowledge is seen as a whole, as sense making is affected by the entire previous knowledge that has been built, whereby new knowledge needs to be integrated into previous one.

The extension relation points out that wearables may extend the conscious intentionality, by altering both the quality and the matter of the person's intentional acts.

On the one hand, by constantly providing "inputs" that are not commonly available to the individual, in forms that can be as diverse as their computational and representational capabilities allow, wearables may *transparently* change our high-order ways of appraising the world, increasing the opportunities of how we imagine, desire, remember, think (i.e., the *quality* of our intentional acts). Engelbart's idea of

augmenting the human intellect (1962), as well as the pioneering conceptualizations of wearables as opportunities for creating novel remembering (Mann, 1997) and thinking (Starner et al., 1997) modalities find full place here. While in Ihde's hermeneutic relation the person's consciousness is directed *at technology* (Verbeek, 2008), as an object to be interpreted, here, in the extension relation, conscious intentionality works, like the motor intentionality, *through technology*, being thus extended by the wearable.

On the other hand, a wearable may allow us to construct new meanings (the *matter* of our intentional acts), helping us integrate them into our previous knowledge. Like a thermometer that reveals a certain aspect of the environment (i.e., its temperature) through a representation that transforms our knowledge of it (Verbeek, 2005), a wearable may provide different views of the world potentially integrating into the meanings we subjectively construct, thus modifying how we build our knowledge.

The concepts of multistability and magnification/reduction structure also apply here. Wearables may be multistable with reference to conscious intentionality because they are capable of affecting multiple intentional acts in diverse ways, as well as providing different representations of the world. Moreover, the amplification they produce in an aspect of our consciousness always parallels other changes, which may assume the form of undesired alterations, in terms of decreased opportunities of knowing, imagining, and so on.

To summarize, the extension relation at the conscious intentionality level allows us to look at wearable technologies from a different angle with respect to the externalistic thought style, which sees wearables as collectors of objective and fragmented knowledge. This conceptualization, instead, looks at wearables as technologies that extend both the person's ways of consciously relate to the world and the opportunities for constructing meanings from a subjective and holistic points of view.

6.1 Wearable technologies for the extended conscious intentionality

The main features of the extension relation at the conscious intentionality level, which refer to the opportunities for extending both the quality and the matter of the intentional acts, give theoretical substance to those internalistic designs that explore possibilities of enhancing our consciousness, as well as provide insights for pushing externalistic wearable design towards a greater consideration of how we subjectively produce our knowledge. We can better see how this theorization may put in the foreground the peculiarities of wearables designed within the internalistic thought style, by comparing them against those developed within the externalistic perspective. To do so, we can focus on wearables that alter our conscious ways of appraising the world and the activity trackers we introduced in Section 5.1.

Wearables explicitly addressed to "augment" our conscious capabilities were popular among the pioneers of wearable technology and are still explored in current internalistic research. Let's take as examples a seminal work on wearables developed in the 70ies and a proof-of-concept of a recent device (Fig. 4 and Fig. 5): the Remembrance Agent is a wearable system that augments the person's memory and thought, by suggesting combinations of information, as a constant "brain-storming" system (Starner et al., 1997; Rhodes, 1997); Lucid Loop, instead, aims to produce an altered states of consciousness experience where people may practice lucid dreaming awareness via biofeedback and VR (Kitson et al., 2019).

FIGURE 4 HERE

If we use the extension relation to examine these wearables, we see that they are designed to extend our conscious intentionality primarily by transparently altering the *quality* of our conscious intentional acts. The Remembrance Agent, for instance, constantly provides timely information associated with the current person's situation through an overlay display. If the person is holding a conversation with a colleague at a conference, for example, the wearable might bring up relevant associations based on the notes that the person is taking. As the system "thinks differently" from the person, it might propose associations that the person might never assemble themselves (Starner et al., 1997). In so doing, the wearable provides a different way of combining ideas that may change how the person thinks. The device may also alter the individual's memory, by e.g., reminding the wearer that the person they are talking to has actually been met before (Rhodes, 1997), thus increasing the opportunities for remembering. In so doing, the Remembrance Agent shows its multistability, being able to affect multiple intentional acts (thinking and remembering) in diverse ways. Likewise, Lucid Loop brings the experience of dreams into the consciousness simulating lucid dreaming (i.e., being aware that one is dreaming while in a dream) without having to be asleep. This wearable literally aims to create a novel intentional act, that of lucid dreaming, which normally people are not able to experience.

FIGURE 5 HERE

These wearables also potentially extend the matter of our intentional acts. By contextually reminding us episodes that we may have forgotten, for example, the Remembrance Agent not only alters our memory function, but also allows us to develop different meanings, more grounded in the past and integrated with our previous knowledge. The Remembrance Agent may continuously watch what the person types and reads and send this information to a search engine that prompts the person's old emails and notes they wrote, which are relevant to their actual context. In doing so, the person may be able to connect the meanings they are currently developing with those they produced in the past. This would allow to enrich the person's sense-making process by supporting the reinterpretation of their actual situation on the basis of their past experiences.

Instead, the Apple Watch and the FitBit do not purposefully aim to extend *the quality* of our intentional acts, by multiplying our ways of e.g., thinking, imagining and remembering. Rather, they prompt analytical representations of the world to feed the collected data back. This design choice favors the analytical thinking: by magnifying rationality when the person wants e.g., to understand or remember or imagine future projections of their data, they leave apart other design opportunities that may support other conscious modalities to relate to the world. Both the Fitbit and the Apple Watch, for instance, visualize current data about the steps taken in a numerical form, display the person's past physical activity through trends/statistical reports, and encourage people to "imagine" how they will be in the future numerically, by e.g., allowing them to set a future objective in terms of numbers (e.g., the daily steps) to be reached in the future. Of course, people may go beyond their externalistic design, enacting an "internalistic use" of them: for instance, they may appropriate data records to form highly personal accounts of their pasts, thus using quantitative information to produce rich memories (Elsden et al., 2016). However, the decisions made at design-time are thought to support a different use.

In fact, these devices are meant to turn also the *matter* of our intentional acts towards greater "objectivity." The Apple Watch (and the FitBit) and the correspondent mobile apps are designed to hoard a variety of numeric data about e.g., the steps taken, the heartbeat, and the calories consumed, which "objectively" represent what the person is, but cannot be reworked or annotated through the device. In this perspective, data are given, rather than constructed by the person and integrated into their previous knowledge (Drucker, 2011). This said, these devices do not prevent people from developing meaning. Again, the person may engage in an internalistic use of activity trackers: they may recontextualize the collected data into qualitative narratives, making sense of quantitative information to understand something new about their "self" within a process of identity construction (Nafus & Sherman, 2014). However, activity trackers are not explicitly designed to this aim.

The conceptualization of the extension relation at the conscious intentionality level precisely focuses the designers' attention on how wearables developed within the externalistic thought style may be deliberately turned into more internalistic designs. This conceptualization suggests that we consider how both the quality and the matter of the person's intentional acts could be extended by the device, by purposefully designing for multiple and even altered conscious modalities and by making wearable data more subjective.

As for the *quality* of the intentional acts, designers may take into account how data collected by a tracker may be differently "appropriated" by the person: conscious intentionality points out that there exist different intentional acts with different "qualities," each of which presents specific peculiarities that should be considered by design. This would enable to design for the different "modalities" of our consciousness, as well as to experiment ways to alter these modalities (changing e.g., *how* we remember, desire, imagine, etc.).

For instance, if the person is "remembering something," the data gathered by an activity tracker could

be navigated in a "memory mode." In doing so, research could explore different alterations of the memory itself enacted by design. Kalnikaitė et al. (2010), for instance, showed that visual cues promote detailed memories, whereas locational information supports inferential processes. The wearable, then, could aim to make the individual's memory not only more "powerful" by giving them an external support on which memorizing information (e.g., Iwamura et al., 2014), but also e.g., more "visual" by providing them with pictures taken in the past, or more "visceral" by leveraging sensorial channels like smell and taste, with the aim to make the person relive an emotional experience. The same collected data set could then be framed differently, and different functionalities provided, if the person is desiring something, or is reflecting on their present situation, or is imagining an alternative condition, thus exploiting the device's multistability. In the first case, the wearable could use the data set to strengthen the person's desire to succeed. For example, an athlete has become demotivated after losing a race and starts doubting that they will win the championship. The wearable, then, might display their achievements and conceal those occasions in which the athlete failed, by moving failures into a remote past (altering the "true" chronology of the data), in order to enhance the athlete's self-confidence and reinvigorate their desire. Instead, when the person is reflecting on an episode that has just happened, the device could display data referring to events that present similarities with the present situation, eliciting an analogical way of thinking. Lastly, if the person is imagining themselves in a different condition, the wearable could develop simulations of alternative situations based on the data set, opening up their imagination by concretizing and expanding its possibilities (using e.g., graphical representations like avatars instead of numbers). The notion of magnification/reduction structure may help researchers consider the side-alterations of such amplifications. For instance, when the person is more able to remember the "images" of their past, is a loss of capacity of rationally reasoning on their memories implied? In sum, the extension relation highlights that we consciously appraise the world in different ways, that each way has its phenomenological peculiarities, and that designers may explore opportunities to alter such ways and/or tailor the interaction to them.

As for the *matter* of the intentional acts, the personal data collected by the tracker could be made more "subjective" fitting the person's sense-making process. The extension relation emphasizes opportunities for wearables to construct new meanings. The wearable could shift from displaying objective statements (e.g., "When you sleep more you do more physical activity"), to prompting "first-person questions" opening up the interpretation process (e.g., "Why do I seem happier when I eat more?"). Reflecting on (and trying to answer to) these questions would allow the person to develop their personal meanings on the basis of the elicitation prompted by the device. Then, when the person wants to explore trends in their data, the device could thread both the questions and the related data together using first-person narratives, which may give a more holistic perspective on them. Here, the person may become the main "character" of the narrative and data may be connected to past situations that the character has lived (e.g., "Last night I went to bed earlier than the other days. Did I feel more tired? I remember that the same happened one month ago. Was I in the same situation?). These strategies would better reflect how we develop knowledge through our conscious intentionality: while the first-person presentation of data would mirror the fundamental subjectivity of sense making, the narrative form would account for our tendency to integrate each information into a wider body of knowledge. Moreover, the system could display data-based stories of fictional characters, which may be in the same "data situation" of the individual but living it in ways that the person does not expect, in order to elicit alternate ways of understanding. Extending the matter of the individual's intentional acts means, therefore, to increase the points of view through which they may look at a single phenomenon, multiply the meanings that they may consider, and allow them to construct novel interpretations. In other words, it means to explore how we can transform the sense-making process, extending its possibilities.

7 WORLD

As we have outlined in the previous Sections, we relate to the world by making sense of it both at the perceptual level and at the conscious level. The motor intentionality and the conscious intentionality are always "of" or "about" something else: this "something else" (the percept or the meaning), however, is never an isolated entity, but is always embedded into something wider.

An object, for instance, is perceived with some characteristics, like particular colors, a certain shape, and so on. However, the object always has hidden faces, which are not directly "seen" in the object (Husserl, 1939). One of these faces, for instance, is the inner horizon of the object which refers to what the object conceals according to the subject's spatial position: we cannot see the machineries inside the door's keyhole, but they play a relevant role in the constitution of the object "door" (Liberati, 2016). The outer horizon, instead, relates to the aspects of the object that are "out" of it but related to it, namely to what lies in its background, pointing to the fact that the object cannot be separated from the environment in which it is inserted (Liberati, 2016; Liberati & Nagatki, 2015).

However, the object is also always embedded into something wider than its background. This is a "world," which concerns the entire experience of the subject in its wholeness. The perception of an object always comes with anticipations and expectations and the object always shows itself as something known and in a way that suggests some actions related to it. The world is the "ultimate" horizon in the sense that it is the way the object gives itself as part of the totality where the individual lives: despite its not-manifestability, the world contributes to the constitution of the object, because it gives the framework for the object, the ground, the way every object is perceived (Liberati, 2016; Liberati & Nagatki, 2015).

This world is a fundamental constituent of the extended intentionality, as it is the wholeness in which the aboutness of the intentionality is embedded. Objects are not mere things that exist in isolation but belong to a whole that precedes and gives sense to them. It means that the object, the material out of which it is made, the other objects that are connected with it, the person, and the environments in which it has a place are related to each other in a totality that is pre-given. It follows that it is not possible to circumscribe a certain context to a limited set of environmental features.

The extension relation at the world level points to the fact that the world, which is a constituent of the extended intentionality, can be extended by wearables as well. On the one hand, this means that wearables may *extend a world* (that of the people who wear them) because it becomes transparently embedded with new objects. This is particularly evident in those AR wearables that present to the person virtual objects that are intertwined with the real environment. In this perspective, those individuals who do not wear these devices do not live in the same world as the people who wear them, because they experience a "weakened" version (without the augmented objects) of the extended world (Liberati, 2016; Liberati & Nagatki, 2015). On the other hand, this means that wearables may *extend our possibilities of action* upon and within the world: in other words, action capabilities of the person are changed as a result of the mediation operated by the technology (Kaptelinin & Nardi, 2012). New entities imply not only new opportunities for interaction with such entities but also e.g., for communicating with others. This is notable in those wearable designs that allow the person to extend their capabilities of self-expression by modifying their aesthetics, like smart clothing. Here, the individual's possibilities of acting within the world are extended by enhancing their communication means, as new "invisible entities," like emotions, are moved to the "visible."

This idea of world has nothing to do with a stable catalogue of elements to be looked at objectively, as

the world of the externalistic thought style is. Rather, this world is the world we experience, a world-for-us of common use objects that is *originally* endowed with meaning provided by the subject. Our way of looking at the world is thus fundamentally subjective, or better inter-subjective. This happens not only because meanings are often inter-subjectively constructed. But also because we are characterized by an inherent openness to others that prevents every experience being entirely private: I perceive objects that are something in principle perceivable by others in the same situation as myself (Moran, 2013). In other words, the experience of the world is constituted by the harmonious intertwining of different subjectivities (Husserl, 1973).

To summarize, differently from the externalistic thought style, which conceives the world (and thus context) as a series of stable and objective environmental states, the extension relation refers to a world that is subjectively appraised and extendable through technology. Moreover, it emphasizes that the focus of the device cannot be narrowed to well-delimited contexts, cut off from the wider person's world. The idea that context is not merely the sum of the physical features of the environment can be retraced to the HCI first-person perspectives on technology. Svanæs (2001), for instance, highlighted that what is context and what is interface in a given system depend on the person's intention and focus, and not on the physical action/world itself. Likewise, Dourish (2004) emphasized that the determination of contextuality is not one that can be made a priori but is an emergent feature of the interaction. Kirsh (2001) stressed that context is a structured amalgam of informational, physical and conceptual resources going beyond simple facts. The approach that I surfaced here is surely inspired by such prior conceptualizations. However, it stresses more the subjectivity and malleability of the person's world that can be altered by technologies like wearables.

7.1 Wearable technologies for the extended world

The extension relation with reference to the world points to opportunities for extending the person's world, as well as for acting within such world. This conceptualization may both ground those internalistic wearable devices that aim to increase the individual's possibilities of action and self-expression, as well as give insights about how we can design externalistic wearables on the basis of a subjective, holistic, and extendable notion of world. To this aim, we may compare internalistic wearables that extend the individual's possibilities of self-expression with the activity trackers introduced in Section 5.1.

Jewelry-like wearable devices (Silina & Haddadi, 2015; Versteeg et al., 2016), smart clothing and e-textiles (e.g., Vande Moere & Hoinkis, 2006) may provide an externalization on the body of inner expression, non-verbally communicating internal states of the wearer to those they encounter (Ju, 2016). They may augment the body natural language (Hartman et al., 2015), make visible the body activity level (Colley et al., 2018), and enhance emotion expression (Fusakul, 2002; Jarusriboonchai et al., 2020). As an example of these internalistic wearables, we can focus on the Emotional Wardrobe (Stead et al., 2004), one of the first smart clothing for self-expression, which represents emotions through the interface of technology (Fig. 6). This wearable design identifies emotions on the basis of physiological signals and displays them on the surface of the clothing using color-change electroluminescent panels. If we use the extension relation to analyze its features, we see that the device may extend both the person's possibilities of acting within the world and the person's world itself.

As for the first point, the wearable allows the person to express internal states that are commonly not visible extending their capabilities to communicate with others. Here, the role of the body in making

visible the person's emotional states is empowered through a dialogue between the body and the garment creating the emotional aesthetics of the wearer. Moreover, the verbal language through which we express and explain our emotional states beyond the body may now be substituted by the visual language of the wearable. In so doing, our possibilities of acting within the world are extended: our emotions can now reach a wider audience thanks to the visibility of the garments; furthermore, they can be communicated even when we feel that we are not able to express them through the verbal language.

FIGURE 6 HERE

As for the second point, the Emotional Wardrobe also extends the person's world. It moves the invisible to the visible making personal emotions available to others: in so doing, it creates new entities of the world that can be intersubjectively perceived, influence other people's actions and be interacted with. In this sense, it acts as those wearables that are aimed at "creating" new objects through AR (e.g., Lindlbauer & Wilson, 2018, Gupta et al., 2020). The Remembrance Agent analyzed in Section 6.1, for instance, is also thought to mesh the virtual world with the real world, creating a sort of physically-based hypertext (Starner et al., 1997): the objects of the physical world are extended by being connected to information that is not circumscribed to the "local context" in which they are physically situated (e.g., through links based on analogies generated by the wearable). Moreover, the world itself can be extended by the "materialization" of newly created virtual entities transparently intertwined with the person's "real" world.

Instead, activity trackers like the Apple Watch and the FitBit are thought for a personal and private use. Collected data can be shared or streamed online, but their visibility in "the material world" is addressed to the person who wears them. They are not meant to extend our capabilities of self-expression. In the Apple Watch, which pays attention to matters of fashion and personal aesthetics, the possibilities of communicating something about the wearer given by design revolve around the mere choice of the color and the material of the wearable.

Furthermore, these devices focus on the possibilities of capturing the objective features of the world, without explicitly attempting to extend such world through technology. They rely on an objective and local context, whereby the device's actions are circumscribed to the information that the wearable is able to collect. The Apple Watch, for instance, may send a variety of reminders, acting as a sort of trainer (e.g., to remind the person to stand up when they sit for more than 50 minutes): however, the messages sent are exclusively based on the particular kind of data connected to the target goal (e.g., the movements of the body for increasing the person's movements) and have a narrow applicability (e.g., they suggest that the person should move more). People, of course, are always free to "appropriate" the wearable's actions adapting them to other contexts: for instance, they may use the device's reminders on doing more physical activity to lower their blood pressure, a data that is not captured by the device. In this way, they may employ the device in a chronic illness context, which was not wired into its design: the device would help them attend to their own everyday habits, which might impact their blood pressure, supporting them in engaging the world in ways that allow them to battle against an undesired condition. Nonetheless, these internalistic uses are not deliberately sought at design-time.

The extension relation at the world level emphasizes that externalistic wearables can be made more internalistic by integrating the aesthetics dimension into their designs, as well as by "creating" new objects that may extend the person's world.

As for the first design opportunity, the extension relation shows that technology may *multiply our possibilities of action* within the world, by e.g., increasing the person's capabilities of self-expression. Through their aesthetics, trackers may transform the gathered information about the person into "intersubjective entities," making them visible to others and thus increasing our communication means. Dynamic graphical patterns displayed on the tracker's "outside" (e.g., on the bracelet) or embedded in the person's garments may make visible their internal states, like degree of fatigue, and provide a supplementary means of expression. Externalistic wearables could also embed communication features to enable physical activity in group, where the tracker becomes a supplementary way for coordinating the group activity according to the physiological parameters of its members, communicated through changes in the device's appearance, e.g., color, luminosity, or shape. Furthermore, wearables like smart watches could be designed in order to adapt their aesthetics to different social contexts, by changing the way they look for fitting different social situations and increasing the person's possibilities of self-expression.

As to the opportunities for *extending the person's world*, data collected from activity trackers may be transformed into objects that can permanently populate the world of wearables' wearers. The extension relation shows that the world is malleable and subjective and can be widened by technology. Design opportunities may come from data materialization, which represents new modes of incorporating wearable data into the person's lifeworld (Lupton, 2017). The HCI community recently transformed digital data into 3D printed physical artifacts, like flowers and rings (Khot et al., 2014), and chocolate treats (Khot et al., 2017), or suggested that they are transformed into dynamic virtual objects (Rapp, 2018). Rather than providing pre-defined shapes based on the individual's data, as proposed by these previous works, the person could be allowed to define their own "material language," endowing the newly created objects with personal meanings. The person could be provided with a system that allows to create shapes to be 3D printed and to define the meaning of the dimensions used in the creation process. For instance, one person could ascribe the deepness of their sleep to the object sharpness, and their "sleep agitation" to the patterns of its spikes; whereas another individual could assign the "sense of tranquility" to the former dimension and the kind of dreams they had to the latter (as they interpret some data patterns as moments in which they had bad/good dreams). By manipulating each dimension and combining different data, the person would develop their own language, constructing meanings

that represent their own understanding of the data while materializing them. This would also make the "created extension of the world" subjective, like the world we commonly experience. A further example: an athlete could create a set of objects representing their exertion data, the form thereof would represent the subjective qualities of their feeling (e.g., their pain, tiredness, or other aspects beyond the physical domain, such as happiness and memory); then they could put them onto "a board" to create a sort of physical diary of their trainings, which may communicate in a glance (or in a touch) a variety of meanings and be used to share such data with others (e.g., by donating the objects). Such objects would contribute to expand the athlete's world as long as they interact with them (e.g., by carrying the objects with them, showing them to others).

A final suggestion relates to the opportunities for connecting "objects" with the wider world. The Remembrance Agent exemplifies a wearable that intertwines the physical local context with information that pertains to other domains. Likewise, the context that activity trackers consider could not be tied to the device's target domain. This would acknowledge the nature of the world involved in the extended intentionality, which pinpoints that each entity or fact is always connected with a wholeness going beyond the local context in which the entity/fact is situated. Therefore, when the tracker acts as a trainer or recommender, it may abandon its domain-dependency: to suggest an objective with reference to the number of calories to be consumed per day, the device could take into account not only the number of steps taken and the hours slept, which are likely monitored by the device, but also e.g., the fact that the person uses food as an emotional regulator, that when they are with their friends they usually drink more alcohol as they feel that it improves their sociability, and so on. Each person's "life domain," even far away from the target domain of the device, might then contribute to the recommendation process. This would mean to widen the kind of data collected by the device and to explore novel means to engage the individual in reporting their interpretations.

8 DISCUSSION

In the previous Sections, I proposed the idea of wearable technologies as extensions, introducing the extension relation as a development of postphenomenology, in order to remedy shortcoming of the existing human-technology-world relations in postphenomenology for understanding wearables. In fact, the relations developed by Ihde and Verbeek, the major postphenomenological thinkers, are insufficient to characterize the mediating effects of wearable technologies.

The extension relation shows that wearables may extend human intentionality and, at the same time, defines a more comprehensive notion of intentionality with respect to those proposed by Ihde and Verbeek. The extended intentionality takes into account the motor and the conscious intentionality, as well as the world toward which the intentionality is directed: a wearable can in principle extend all the constituents of the extended intentionality, by altering how we bodily and consciously relate to the world, as well as the entities embedded in such world and our capabilities to act within it. Instead, Verbeek's hybrid intentionality grounding the cyborg relation, as well as Ihde's intentionality implied by the embodiment relation, exclusively focus on the bodily ways through which we appraise the world and cannot account for the alterations that wearables may engender on our consciousness and our world. Consciousness is tackled by Ihde only within the hermeneutic relation, in which the action of technology is meant not to extend consciousness, but to turn the world into a text that can be interpreted. Moreover, even at the perceptual level, the extension relation points to a tighter and more dynamic integration of humans with technology than Ihde's embodiment relation: the perceptual alteration induced by wearables is not fixed as in the eyeglasses, but intrinsically multistable due to their computational capabilities, potentially introducing a variety of perceptual variations in accordance

with the person's goals and internal states. Differently from the cyborg relation, this integration does not require any physical fusion, because the merging of the perceptual apparatus of the person and that of the wearable is realized at the motor intentionality level and not at the material level.

These conceptualizations differ from the assumptions lying behind the wearable externalistic thought style, which conceptualizes the person's body, knowledge, and world as objective and fragmented (Table 1). The extension relation emphasizes that our ways of bodily and consciously appraising the world, as well as the world itself, are fundamentally subjective and cannot be understood as a mere sum of disconnected parts. Moreover, this postphenomenological approach shows that the mediating effects of wearables have a transformational character, which moves to the background the problem of our use of technology and how it may help to achieve our goals. In so doing, it presents similarities with attempts of going beyond exclusively utility-driven and pragmatic results when designing and studying technology, which characterizes much work that belongs to the third wave HCI (e.g., Harrison et al., 2007; Raptis et al., 2017). With respect to the first-person based approaches based on phenomenology developed within HCI, the proposed framework allows to capture the fundamental and multiple alterations that wearables induce in our relations to the world.

TABLE 1 HERE

The framework may be useful to analyze existing internalistic technologies, as we have seen in the previous Sections, due to its explanatory power: it provides a theoretical explanation of the various mediating effects of wearables, pointing out how they transparently alter fundamental aspects of our experience and uncovering their necessary "side-effects," implied by their magnification/reduction structure. Moreover, the framework can be used by HCI researchers and practitioners to identify design opportunities when applied to the examination of externalistic wearables. Its generative power lies in its capability of identifying areas of intervention for making externalistic wearables more internalistic, producing insights on how to complement and even magnify what has been developed within the externalistic frame until now. Figure 8 summarizes the main features of the framework, how they differ

from the assumptions of the externalistic thought style, and the design considerations reported in the previous Sections.

It is worth to mention that the framework also entails "political" consequences in relation to wearables that differ from those implied by the externalistic thought style. For instance, the externalistic frame conceptualizes wearables as repositories of data. These data are conceived as separate from the individual, so that they can be used or even owned by "third-parties," like service providers (Orlosky et al., 2019), organizations controlling their employees (e.g., Moore & Robinson, 2015), or teachers monitoring their students (Lupton, 2015). This might entail the idea of a sort of "dataveillance" (Lupton, 2016), in which not only the person's privacy is at risk, but also their ownership on parts of their extended self (Rajan, 2012). The extension relation, instead, sees wearable data as inalienable from the individual who intrinsically owns them, as they were integrated aspects of their subjectivity: in so doing, it fundamentally challenges the idea of considering wearable data as "a means to be used by others" for e.g., surveillance and control, or objects of value that can be sold on the market.

A final point worth to be discussed relates to the idea of interface encompassed by the extension relation. By conceptualizing the wearable as an object and repository, the externalistic thought style sees the interface of the device as a shell that filters relevant information from the outside through its sensors and shields what is contained inside (the data). Instead, the conceptualization of wearables as extensions advances a different concept of interface, as *organic faceless interaction*, which I think it could be useful to explore in theoretical terms more in depth.

8.1 Interface

In reviewing the different interpretations of the concept of interface, Janlert and Stolterman (2015) identify four main *thought styles*: a surface of contact between matching objects, a boundary of an independent object, a means for controlling (operating, checking, steering) an object, and a means for expressions and impressions, a target of interpretations and affectations. The analysis of these thought styles leads them to a realization of the crucial role of surface in contemporary understanding of interaction.

If we look at wearables through the lens of the externalistic thought style, the interface they rely on can be mainly ascribed to the idea of the boundary of an independent object. The device is a detachable object enclosed in its material shell, which has the task of filtering important information from the environment and safeguarding the collected data. Here, the role of the surface is fundamental, as it embeds the device's sensing capabilities, is in charge to make the person feel comfortable, and displays what is contained "inside" the device.

However, when we shift the focus from the externality of the object to the internality of the subject, wearable technologies' interfaces can be looked under a different light: instead of a boundary of an independent object, their interface may be conceived as a case of *faceless interaction*, namely interaction that transcends traditional reliance on surfaces. Janlert and Stolterman envision three potential directions for the development of faceless interactions: the first one leads to "things," that is the traditional surface-bound interfaces disappear and the resulting artifacts can be interacted with in similar ways to traditional things; the second one leads to "beings," which means that digital artifacts become more behavioral and intelligent; the last one leads to "fields," i.e., an interaction that is not done with a clear direction to any particular artifact or object, whereby the person becomes an inhabitant, traveling through a field of interactive forces.

I think that wearables may represent a fourth direction of development of faceless interaction, not foreseen by Janlert and Stolterman, that of the "organisms," whereby the interface is somehow internalized and the device is designed to perfectly couple the internal dynamics of the person's body/mind/world. This kind of interface may be retraced to the idea of "symbiotic interface." In 1960 Licklider (1960) envisioned a kind of interaction involving very close coupling between the human and the electronic members of the partnership. Sixty years later Farook and Grudin (2016) proposed the notion of human-computer integration, whereby the engagement of the interaction is conceived as an ongoing partnership. A symbiotic relationship, nonetheless, is an association of mutual benefit between different kinds of entities (Clark, 2003). In these terms, this idea does not distance itself from the externalistic assumption of wearables as objects: devices can be designed to better collaborate with the person, being capable of taking into account e.g., their work and interests as a partner does (Farook & Grudin, 2016), but the kind of integration implied clearly maintains the partners conceptually separate.

A different interpretation of the term "integration" is proposed by Britton & Seeman (2017): drawing on cyborg imagery, they look at the merging of human and machine in which the boundary between biological organism and technological artifacts are breached. In doing so, they take such merging literally, focusing on technology that are materially embedded into the body. However, on the one hand, this idea of integration leaves out those devices that are not physically inserted in the person's body, like wearables. On the other hand, it sees the interface as a matter of material integration, overlooking the more fundamental integration with our subjective experience.

Mueller et al. (2020) revisited the notion of integration adding to Farook and Grudin's symbiotic integration the notion of fusion: an integration in which devices extend the experienced human body or in which the human body extends devices. They emphasize that humans perceive through fusion systems by embodied mediation. This conceptualization of interface recalls Verbeek's cyborg relation that I mentioned in Section 4.1. On the one hand, fusion is thought to refer not only to wearable technologies but also, and especially, to those devices that are physically merged with the individual's body, thus emphasizing the importance of material integration into the body. On the other hand, by focusing on embodied mediation and perception, fusion overlooks those mediations that extend the person's conscious intentionality, as well as their world.

The authors also introduce the idea of human-technology assemblage, a unique entity made up of the person and the technology that allows us to ask "how the agency is distributed" or describe "*the type of integration by measuring the amount of physical or cognitive coupling between user and interface*" (Mueller et al., 2020: 4). This is the kind of integration that most fits the opportunities offered by wearables, but still lacks a theoretical elaboration on what is assembled and how the assemblage is realized. It appears, in fact, that the assemblage integrates the human with the machine at the physical level rather that at the intentionality level, i.e., it happens at the level of our "surfaces" rather than at that of our fundamental ways of relating to the world. For instance, considering the distribution of agency between human and technology reveals that they are still thought as separate entities, which may be strictly coupled but maintain their independency.

I thus propose that we conceptualize the wearable's interface as *organic faceless interaction*, whereby the "surface" of the device disappears in favor of a merging of the "points of view" of the person and that of the device. Thinking of wearables as extensions precisely means that the device is no more an external, autonomous object, but is under the control and coordination of the person, as if it were a novel "organ" harmonizing with their subjective bodily and conscious ways of acting. As a new organ, the wearable also provides the organism with new opportunities for action, in the sense of extended person's possibilities of self-expression and action within the world, and even the potentiality of extending the person's world itself.

By building on the notion of extension relation, and focusing on the extended intentionality, the notion of organic faceless interaction points to a way of interacting with machines that fits in our "natural" ways of perceiving, understanding and acting, making it impossible to separate the organism from the computer at the intentionality level, that is the level of our fundamental relation to the world. As designers find ways to integrate more tightly what is prompted by the device and what is naturally perceived by our senses and understood by our consciousness, as well as what constitutes our world, the idea of interface as a surface will vanish. This would not even take the form of an "integration" or "assemblage," which are still realized at the surface/physical level, but an organic merge of the human and the artifact points of view realized at the intentionality level.

8 CONCLUSION

In this article, I attempted to outline a theoretical framework for conceptualizing wearable technologies from a postphenomenological perspective. I first identified a dominant way of conceptualizing wearable technologies, which I called the externalistic thought style, highlighting how it tends to look at phenomena "from the outside." Here, wearable devices are seen as objects, repositories, and instruments, whereas the person's body, knowledge, and world become fragmented and objectified. Then, I identified an alternative thought style, which I called internalistic, that views wearables "from the inside" and explores opportunities for altering the person's ways of appraising the world. This thought style, however, is still undertheorized in the wearable discourse and within HCI.

Therefore, building upon Ihde's and Verbeek's work, I attempted to give a theoretical backdrop to those wearable designs that are currently developed within the internalistic thought style by introducing the extension relation: this relation widens the existing human-technology-world relations in postphenomenology by building on a more comprehensive notion of intentionality, the extended intentionality. The extension relation points out that wearables may extend how we bodily and consciously relate to the world, as well as the world toward which the intentionality is directed. In doing so, I examined a series of existing wearables to show the explicatory power of the framework, as well as proposed a series of design considerations that aim to trace future research lines for externalistic wearables making them "more internalistic": these considerations show the generative power of the framework and may be taken as design hypotheses in need of further testing to disconfirm or strengthen their validity. Finally, I tried to preliminary theorize the kind of interaction that this conceptualization entails, developing the idea of organic faceless interaction.

This said, I certainly overlooked important aspects (e.g., emotions) that could be relevant for the wearable technology field. Likewise, I am aware that certain kinds of wearables may be here not fully addressed. However, I did not want to propose an ultimate theory capable of covering all the different aspects of wearable design. Rather, I wanted to start theoretically scaffolding an alternate perspective on wearable technology, which may put in the foreground the internalistic experience of interaction and complement what has been previously done under the externalistic thought style. I am convinced that this kind of analysis, even in this "incomplete" form, could be of value to the HCI field both from the theoretical and design perspectives.

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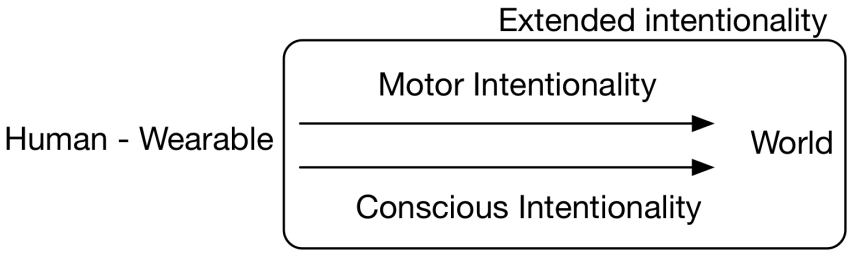

Figure 1. The extension relation. The human is integrated with the wearable, which extends all the three constituents of the extended intentionality, i.e., the motor intentionality, the conscious intentionality, and the world toward which the intentionality is directed.

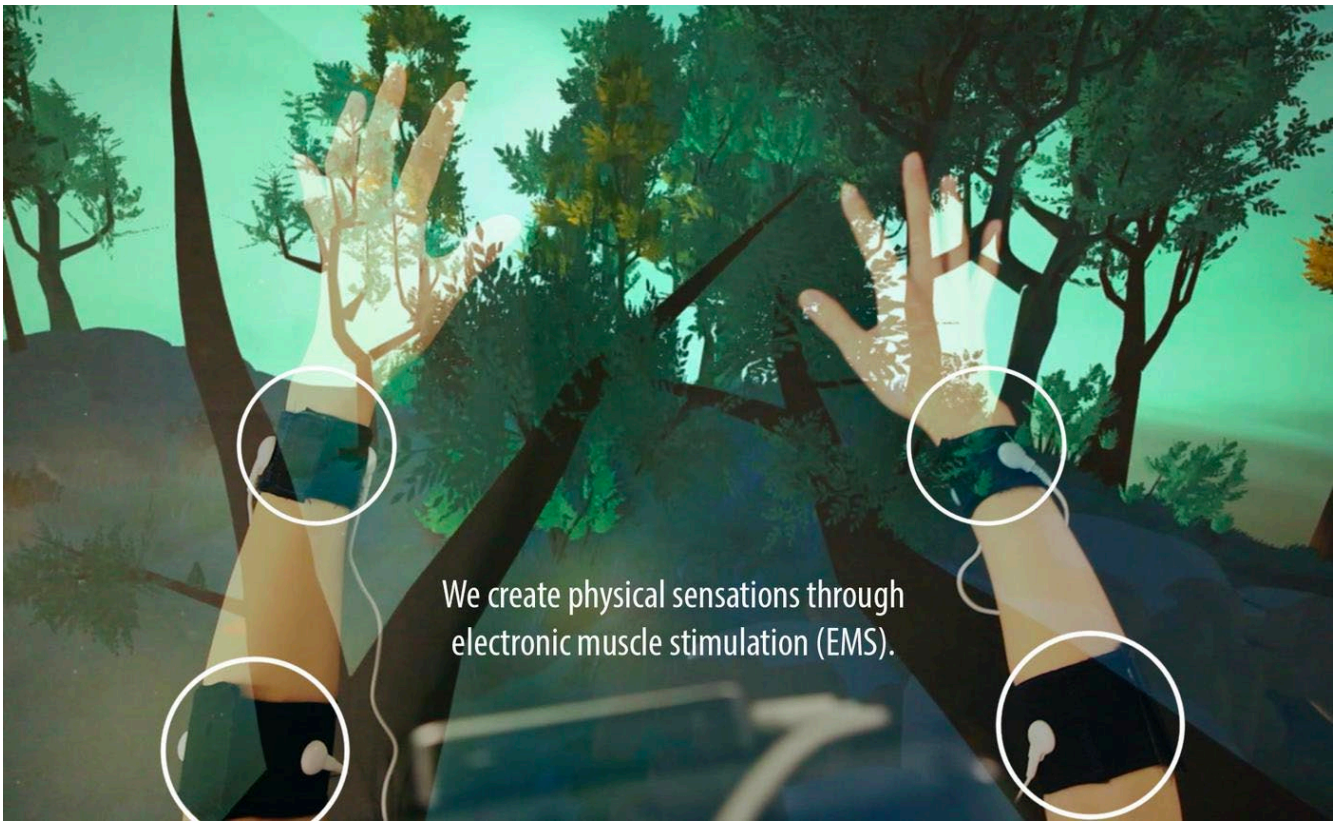

Figure 2. Photo by Xin Liu and Yedan Qian (2017) displaying TreeSense. Credit Liu & Xian (2017), Attribution 4.0 International (CC BY 4.0) (https://www.media.mit.edu/posts/tree-treesense/).

Figure 3. Photo by Andres Urena on Unsplash (unsplash.com) showing an Apple Watch and a FitBit Charge. Credit Andres Urena (Unsplash).

Figure 4. The heads-up display for the wearable platform. Reprinted by permission from Springer Nature: Springer Nature, *Personal Technologies*, The wearable remembrance agent: A system for augmented memory, Rhodes, B. J., Copyright (1997) by the publisher.

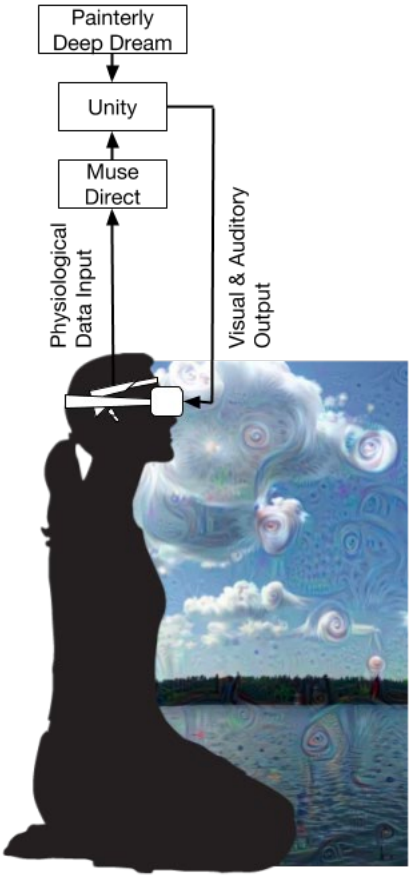

Figure 5. Lucid Loop system schematic Kitson et al. (2019). Reprinted by permission from the author Alexandra Kitson. *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems (CHI EA '19), ACM*, Lucid Loop: A Virtual Deep Learning Biofeedback System for Lucid Dreaming Practice, Kitson, A., DiPaola, S., and Riecke, B. E. (2019). Copyright (2019) by the authors.

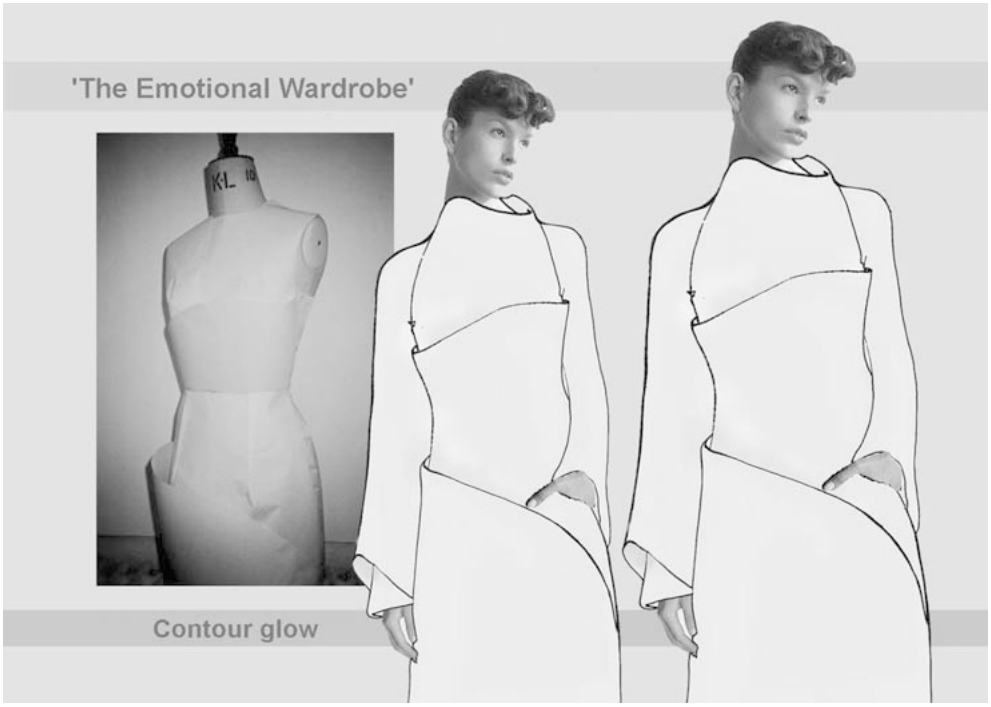

Figure 6. The emotional wardrobe design. Reprinted by permission from Springer Nature: Springer Nature, *Personal and Ubiquitous Computing*, The Emotional Wardrobe, Stead, L., Goulev, P., Evans, C., Mamdani, E., Copyright (2004) by the publisher.

Table 1. Main features of the theoretical framework compared against the assumptions of the externalistic thought style

Theoretical assumptions of the externalistic thought style	*Design-related aspects of the externalistic thought style*	*Theoretical pillars of the extension relation*	*Design considerations for designing externalistic wearables based on the extension relation*
Wearables as objects imply that: - The body of the person is conceived as a material support for the device and thus turned into an object - The body is dispersed among the different locations that ensure the best sensing opportunities	**Wearables as objects focus design on**: - Wearability and the material properties of the device - The device's sensing capabilities and ergonomic/comfort features	**Wearables as extensions of motor intentionality imply that**: - The wearable may extend how we perceive by transparently integrating into our perceptual apparatus - The wearable necessarily produces side effects, through its magnification/reduction structure - The wearable may introduce perceptual variations through multistability - Body perception is fundamentally subjective and involves the entire sensorial field	**Wearables as extensions of motor intentionality may focus design on**: - The possibility of making technology more transparent, by producing continuous body stimulation - The possibility of amplifying internal sensations of which the person may be not aware of while considering potential side effects - The possibility of eliciting perceptual variations to help people "learn" directly from their body
Wearables as repositories imply that: - Knowledge is objectified, being made up of exact data collectable by the device - The knowledge provided by the device is scattered among the different parameters monitored	**Wearables as repositories focus design on**: - Accuracy in order to increase the exactness of the collected data - Visualizations in which each data source is considered autonomously	**Wearables as extensions of conscious intentionality imply that**: - The wearable may extend the quality of the intentional acts, altering how we e.g., remember, think, desire. - The wearable may extend the matter of the intentional acts, supporting people produce subjective meanings - Knowledge is constructed by the subject and is always integrated into previous knowledge	**Wearables as extensions of conscious intentionality may focus design on**: - The possibility of modifying how we e.g., remember or think and of designing for the person's diverse conscious modalities - The possibility of making wearable data more subjective, by displaying first-person questions and narratives
Wearables as instruments imply that: - The world considered by the device is objective and has the same value for all the persons - The world of the wearable is limited to the immediate surroundings of the parameters that it is able to collect	**Wearables as instruments focus design on**: - A one-size-fits-all approach, in which the same objective context is used in the same way for all the persons - Recommendations that are circumscribed to a single "life domain"	**Wearables as extensions of world imply that:** - The wearable may extend our ways of acting within the world, multiplying e.g., our possibility of self-expression - The wearable may extend the person's world by embedding new entities in it - The "world" is a world-for-us and cannot be fragmented into delimited contexts	**Wearables as extensions of world may focus design on**: - The possibility of increasing the person's capabilities of self-expression modifying the wearable's aesthetics - The possibility of creating "data objects" to be embedded into the person's world - The possibility of providing recommendations that take into account the person's wider world