A Critical Examination of Virtual Reality Technology in the Context of the Minority Body

Kathrin Gerling
Department of Computer Science, KU Leuven
Leuven, Belgium
kathrin.gerling@kuleuven.be

Katta Spiel
HCI Group, TU Wien
Vienna, Austria
katta.spiel@tuwien.ac.at

ABSTRACT

Virtual Reality (VR) holds the promise of immersing people in virtual worlds. However, initial work on the relationship between VR and disability suggests that VR is a body-centric technology that poses barriers for disabled users. We supplement this work with a theoretical analysis of immersive VR through the lens of Surrogate Body theory, a concept from media theory for the structured examination of interactive media in use. Leveraging Critical Disability Studies, particularly the theory of the Minority Body, we explore the assumptions about bodies inherent in VR, and we reflect on implications of these assumptions when disabled people engage with the technology. Our findings show that VR is an inherently ableist technology that assumes a 'corporeal standard' (i.e., an 'ideal', non-disabled human body), and fails to adequately accommodate disabled people. We conclude with implications for HCI research on VR, and discuss design approaches that foster inclusive technology development.

CCS CONCEPTS

• **Human-centered computing → Accessibility theory, concepts and paradigms**; **Virtual reality**.

KEYWORDS

Disability Studies, Surrogate Body Theory

ACM Reference Format:
Kathrin Gerling and Katta Spiel. 2021. A Critical Examination of Virtual Reality Technology in the Context of the Minority Body. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 8–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3411764.3445196

1 INTRODUCTION

Virtual Reality (VR) technology holds the alluring promise of immersing people in virtual worlds. Concepts such as *presence* (i.e., the feeling of being transposed into another environment than the immediately physical one) [39] or *immersion* (i.e., the acceptance of rules governing fictional worlds) [62] aim to capture the unique experiences people can and hope to make with these technologies [22]. Even though virtual experiences allow people to experiment with experiences otherwise inaccessible to them (e.g., flying [21]), they still have to engage with the material setup of instruments facilitating entrance into these virtual worlds. Yet, accessibility of the latest generation of consumer VR for people with disabilities[1] – people with minority bodies in relation to the general population [6] – routinely comprises an afterthought, denying them access to potentially enriching virtual experiences that are set to become a mainstream activity and will drive innovation for years to come.

The Human-Computer Interaction (HCI) research community has begun to address this issue through the development of dedicated VR systems for disabled people – largely, but not exclusively, as a medically driven corrective experience (cf. for example, [16, 27, 36, 44]). In the context of physical disability, previous work has explored accessibility issues experienced by people with limited mobility [28, 42]. However, while effective at identifying basic barriers to VR use, we argue that these projects only scratch the surface of challenges and opportunities associated with physical disability and Virtual Reality: Mott et al.'s work strongly focuses on practical accessibility of the current generation of VR hardware [42] (e.g., putting on the headset and cable management, using controllers including hard-to-reach buttons), and Gerling et al. narrowly focus on how wheelchair users engage with VR games [28]. By prioritizing technical accessibility, these examples do not take into account the complexity of the relationship between a specific body and VR technology, the wider context in which disabled people experience VR, and the assumptions that VR technology makes about people's bodies.

We expand on these initial findings through theoretical analysis of the relationship between physical disability (i.e., limited mobility) and access to Virtual Reality. The core questions that we seek to answer are: 1) *Which assumptions about people's bodies are inherent in the current wave of VR?* 2) *How do these assumptions affect the access to VR for people with physical disability?*, and 3) *What are the implications of these assumptions for Human-Computer Interaction (HCI) research on VR?*

We follow Mankoff et al.'s approach of building on disability studies as a lens for technology exploration [37], and leverage surrogate body theory [63] – a concept from media theory that has previously been applied to interactive technology [57] – as a means of deconstructing the relationship between people's bodies and VR technology. Thereby, we provide focus points for the design of inherently accessible VR, which we illustrate with testimonies of disabled people on their use of VR, and examples regarding the

CHI '21, May 8–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05.
https://doi.org/10.1145/3411764.3445196

[1]Our paper uses a mix of identity-first and person-first language. Different groups of people and different cultures appreciate different terminology. For a detailed discussion of language in the context of disability, please see [3].

design and development of VR technologies that have begun to prioritize the experiences of people with physical disability.

Our work makes the following three contributions: (1) We provide a theoretical examination of consumer VR for people with physical disability with focus on core qualities of VR, and expose it is an inherently ableist technology. On this basis, we highlight challenges for the HCI research community in moving forward to create more accessible approaches to VR. (2) We apply surrogate body theory to a specific case study of interactive technology with the goal of reflecting on its design, demonstrating the epistemological value of adapting this theory as a lens to analyse interactive media. (3) We provide an example of the situation of accessibility research in disability studies [37], and highlight how its combination with the analysis of accounts of the testimony of disability can contribute to findings produced by empirical work [66], allowing us to challenge the fundamental assumptions based on which technology is designed.

While we have seen tremendous improvements in approaches toward the accessibility of immersive technology in the last years (e.g., with Microsoft's and Logitech's accessible gaming initiatives [61]), we need to recognize that the frontier of technical innovation is constantly shifting: VR technology now represents the cutting edge of immersive technology, with core accessibility challenges broadly unaddressed. Our work highlights this issue, and offers a starting point for reflection for the HCI research community specifically and engineers of entertainment technologies more generally.

2 RELATED WORK

Our work draws on (Critical) Disability Studies to analyze VR technologies. At this backdrop, we provide an overview of the main models of disability and highlight perspectives from critical disability studies. We then consider these together with existing definitions of Virtual Reality and the role of presence and immersion in this context. To appropriately position our work in relation to existing approaches, we summarize previous work within the HCI research community that seeks to explore VR and disability.

2.1 Theories of Disability

How we understand and view disability is shaped by theories and models that have developed over time; consequences for the perception of disability and the specific situatedness of lived experiences as a part of society vary widely. We focus here on two classical distinctive approaches – the medical model and the social model of disability – as well as their construction of disabled bodies and discourses thereof as they are discussed within critical disability studies. For a more comprehensive overview of the potential of disability studies in the context of technology development, please consider Mankoff et al.'s work [37, 58].

2.1.1 The Medical Model. The medical model propagates an individualistic view on disability, and "defines disability as a property of the individual body that requires medical intervention" [51, p.325]. As such, it adopts an impairment-centric perspective focusing on the perceived 'deficits' of disabled bodies, laying the foundation for medical intervention, i.e., rehabilitation, or, ultimately, the cure of disability. In the context of technology, viewing disability through the lens of the medical model has in the past supported the development of interventions that facilitate therapy and rehabilitation, an area of research particularly relevant within the Human-Computer Interaction research community. Likewise, medical views can be leveraged to inform the design of assistive technology [37]. However, critics of medical models suggest that they make the inherent assumption that disabled bodies are less valuable than non-disabled bodies [6], and that the strong focus on rehabilitation of disability ultimately renders disabled identities as undesirable, with parts of the disabled community strongly rejecting the idea of cure, which is viewed as an attempt to erase not just disability but also the disabled person (see [17] for a detailed discussion of the difficult relationship between disability and cure).

2.1.2 The Social Model. The social model of disability adopts the view that disability is not a trait of an individual, but the result of oppressive societal structures that are not tailored to the needs of people with impairments [48]. In this context, impairments are understood as physical limitations. Shakespeare and Watson offer a detailed discussion of the *disability* vs *impairment* distinction, with the relative dismissal of the individual experience of impairment and questions of identity being core weaknesses of the social model [49]. Critical Disability Studies tend to support the social model, and more widely challenge the notion of how disability is constructed, adopting disability as 'the space from which to think' while emphasizing socio-cultural conceptions, its intersectional and political dimension, ultimately exposing disability as a form of oppression with material consequences [29, p.632]. Particularly with respect to disabled bodies, Garland-Thomson suggests the perspective of "extraordinary bodies", and argues that what is cast as 'corporeal insufficiency and deviance' in reality is not a property of the person, but a consequence of societal structures that prioritize non-disabled bodies [24] – what Garland-Thomson calls "the 'normate' –the corporeal incarnation of culture's collective, unmarked, normative characteristics" [25, p.10]. As such, she defines disability as "the attribution of corporeal deviance – not so much a property of bodies as a product of cultural rules about what bodies should be or do" [24, p.6]. Likewise, Campbell criticizes "Ableism [as a] a network of beliefs, processes and practices that produce a particular kind of self and body (the corporeal standard) that is projected as the perfect, species-typical and therefore essential and fully human" [15, p.44]. This 'corporeal standard' is a narrowly defined non-disabled body, in turn affording that the disabled body is viewed as a 'diminished state of being human', ultimately rendering disability as a 'tragedy' needing to be avoided, limited and erased whenever possible [ibid]. Or, as Shildrick puts it, "To be perceived as differently embodied, however, is still to occupy a place defined as exceptional, rather than to simply be part of a multiplicity of possibilities" [50, p.2]. This aligns with other, post-modern models of disability that emphasize the relevance of the lived experience of disability, offering a broad foundation for the development and situation of technology in the context of disability [37]. One example of such models is the concept of the minority body proposed by Barnes, who defines being disabled as "simply something that makes you a minority – it is a way of having a minority body" [6, p.78], that can, depending on the situation, be either something that is good or, or something that is bad.

In our work, we draw on Barnes' theory in combination with other perspectives from critical disability studies to situate and explain our analysis of Virtual Reality and their preparedness for disabled bodies. Making this connection allows us to understand the (in)accessibilities of VR technology on a basic level, and appreciate the value of disability studies to examine how we design technology not just considering the experience of a disabled person with a specific artefact, but also fundamentally questioning the assumptions that VR technology – a technology that, we argue in the following section, is inherently body-centric – makes.

2.2 Virtual Reality

Virtual Reality (VR) has historically been defined in terms of the hardware setup, i.e., it has been described as a system that uses a Head-Mounted Display (HMD) and motion-sensing technology in combination with a computer to let people experience virtual worlds [60, p.3]. However, as the technology evolves, experience-centric definitions have moved into the foreground, examining *how* people can experience presence and immersion in the virtual world [60].

2.2.1 Understanding Presence and Immersion and the Role of the Body in VR. Presence and immersion refer to the experiential qualities of VR with respect to people entering and engaging with virtual worlds. Bowman and McMahan offer a useful explanation of relationship between presence and immersion on the basis of Slater's work [52]. They refer to immersion as the "objective level of sensory fidelity a VR system provides", which they summarize as the technical quality of the system, for example, display resolution of the HMD, field of view, and frame rates - see [12, p.3]. To some extent, this understanding contradicts the wider definition of immersion that is applied in other fields that examine interactive media (e.g., games research [32] or media theory 3.1.1). In contrast, they define presence as "a user's subjective psychological response to a VR system" [12, p.3]. Hence, presence emerges if sensory immersion is achieved by means of adequate performance of VR hardware. Biocca and Delaney further elaborate on the phenomenon of presence, which they define as "a point at which our perceptual systems are so immersed in the simulation that the user already begins to feel some of the sense of 'being there"' [8]. Likewise, Slater and Wilbur elaborate that this immersion spans emotional, spatial, motoric and cognitive elements [54], which all contribute to a perceptual illusion [53] that create a "sense of being there", i.e., presence [65]. However, despite trying to shift away from the focus on hardware-centric perspectives, many researchers still acknowledge the mediating role that hardware plays in people's experiences of VR, i.e., the relevance of bodily immersion in a virtual world. On a basic level, Lombard and Ditton postulate that presence is the "illusion that a mediated experience is not mediated", depending on the quality of the interaction between people and hardware system (e.g., responsiveness, degree of user control, mapping of controls - elements which relate to Bowman and McMahan's definition of immersion [35]. Likewise, Held and Durlach comment on the "obtrusiveness of medium", which can be an an issue for the experience of presence if hardware takes up a dominant perceivable part in the overall interactive experiences and breaks the illusion of immersion within a virtual world [30]. Along these lines, it is useful to consider the aspiration of the medium with respect to involving people's bodies in the virtual environment. Here, Biocca and Levy postulate that if you compare VR with reading a book "[...] this book has stretched in all directions and wrapped itself around the senses of the reader" [9, p.135]. This once more highlights the immsersive nature and close relationship between bodies and VR hardware required to optimize the experience of VR. As such, this raises questions for the involvement of disabled bodies in VR that relate to the design of VR hardware, and the quality of experience that people with disabilities can gain access to.

2.2.2 Virtual Reality and Disability. Previous work has explored the possibilities of virtual realities to address autism [14], to provide therapy in the context of cognitive impairment [45], and to support rehabilitation of physical disability [11]. Also see [55] for a recent literature review of *VR in healthcare* that predominantly identifies applications in the context of disability. More relevant recent research has addressed access concerns around VR for people with specific disabilities, e.g., Zhao et al. developed *SeeingVR*, a toolkit to improve access to VR for people with low vision [68]. Furthermore, there have been many efforts to create auditory or haptic VR systems for people who are blind, e.g., Canetroller is a device that replaces traditional VR controls with a cane, facilitating navigation of virtual spaces [67]. Specifically exploring the role of physical disability, initial work by Mott et al. has addressed the concerns of individuals with limited mobility when interacting with VR [42]. The results of a user study with 16 participants were refined into seven barriers to VR [42, p. 7] that predominantly relate to characteristics of VR hardware (e.g., system setup, adjusting the head-mounted display, and working with the controllers). Likewise, Gerling et al. examined the design of VR games for wheelchair users with focus on adaptation of user input, highlighting that people using wheelchairs were concerned about accessibility barriers, but perceived VR as a futuristic and desirable technology, with results of an empirical study showing that VR can be made accessible through adjustment of interaction paradigms [28].

In our work, we illustrate how theoretical reflections on the relationship between Virtual Reality as an immersive technology, and people with physical disability can explain and further support these initial empirical findings, providing a wider platform for reflection on the implications of the current design of consumer VR for the engagement of people with physical disability.

3 A THEORY-LED ANALYSIS OF VIRTUAL REALITY TECHNOLOGY IN THE CONTEXT OF DISABILITY

In this section, we introduce Surrogate Body Theory [63] and its application to interactive media [57] and illustrate Barnes' theory of the Minority Body as our lens for analysis [6]. We then detail our analysis approach and present our findings on the relationship between physical disability and VR.

3.1 Theoretical Background: Surrogate Body Theory and the Theory of the Minority Body

Here, we summarize Surrogate Body Theory [63], a perspective from Media Theory that can help understand how people immerse themselves in media content, and we elaborate on Barnes' theory of the Minority Body [6] as a means of defining disability in the context of our work.

3.1.1 Surrogate Body Theory. Originating from Film Studies, specifically Cinema Studies, Voss' theory postulates that viewers lend the affective expressiveness of their body to the film and intersubjectively embody the so-called *surrogate body* [63]. In this affective engagement through aesthetic distancing and the acceptance of the rules governing the fictional narrative sees Voss the potential for immersion [62].

Building on the original surrogate body theory, Spiel and Gerling extended the work to immersive aspects of play [57]. The authors identified that beyond *affect*, in digital games, players additionally lend *actions* to the surrogate body. They analyzed six different contexts of play and illustrated a range of parameters defining play contexts:

- the physical *distance* between players and hardware ranging from large to inverted,
- the expressive potential for embodied *affect* ranging from constrained to expressive,
- the type of *actions* that can be lend to the game ranging from abstract to direct,
- the *environmental* factors of play (e.g., portable, communal or private),
- the given opportunities for *multiplayer* scenarios with others participating in parallel, variably or as bystanders, and
- the forms of *bodily involvement* in lending actions as restricted, limited to specific body parts or fully embodied

Because the authors cover a breadth of playful experiences, each one of them is only briefly analyzed through the lens of the surrogate body. For VR specifically, the authors provide a short description of the generic context, assessing that VR technology operates *immediately* on a player's body, somewhat *constrains* affect, offers *adapted* actions, can be played in *home* as well as *dedicated* environments, offer *bystander* options for others and *restrict* bodily involvement [57]. In our paper, we use the basic approach to illustrate an additional in-depth analysis of VR as one specific interactive technology and within the specific use context of physical disability. Hence, while the theory informs our work we also refine the previous assessment by Spiel and Gerling.

3.1.2 Minority Body Theory. Barnes defines being disabled as "simply something that makes you a minority – it is a way of having a minority body" [6, p.78]. The author suggests a value-neutral model of disability that regards disability as mere-difference without making a general judgment of value or well-being of the individual (echoing Shildrick's perspective on physical disability as 'multiplicity of possibilities' [50]). However, by suggesting that overall, the value is neutral, the model can facilitate the exploration of what Barnes terms features that result in a *local* or *global good* or *bad*, i.e., disability can "sometimes be bad for you [...] and can also, in different combinations, be good for you" [6, p.88]. According to Barnes, this can depend on extrinsic or intrinsic factors, recognizing the importance of wider society and the individual lived experiences of disability. Applying this theory to engagement with technology, it suggests that how disability affects individuals depends on societal structures – including the shape of the system – along with the general lived experience of the individual and their experience of a technical system they interact with. As an example, a disabled person could lead a rich and satisfying life (*global good*), but experience access barriers when interacting with entertainment technology such as video games (*local bad*). Here, the relationship between disability and the occurrence of local goods and bads can be a helpful tool in examining the impact of society and environment on the well-being of disabled people. Concretely, with this work, we seek to explore the existence of structural access barriers in VR technology.

3.2 Method

We engage in a theory-led analysis of VR technology, which we interpret in the context of accessibility implications for physically disabled people. Our interpretative and theory-led analysis takes an approach similar to that by Spiel and Gerling illustrating the application of surrogate body theory to playful technologies, focusing on its six main categories for analysis, i.e., spatial distance between users and hardware, bodily involvement, actions lent, embodied affect, the spatial environment, and multiplayer (which we interpret as multi*user*) [57]. For each of these categories, we explore the assumptions about bodies that underpin the design of the technology, and then review VR technology in the light of physical disability. We recognize the heterogeneity of bodies, and therefore primarily highlight instances where VR expects the corporeal standard in an attempt to identify potential issues for people with physical disability: defining all variations of minority bodies in the sense of listing impairments (as often attempted by accessibility work by illustrating the range of impairments that research participants live with) would be a futile and non-productive task when considering our core research question. We include testimony of disabled people to illustrate our points. The testimonies were collected in the context of a survey [28] in which we explored perspectives of disabled people on VR either based on their own hands-on experience or through engagement with reports about the technology. For example, this included the individually preferred setting in which the technology would be used as part of being asked to imagine or report how the technology would be approached, and implications for integration of movement-based interaction paradigms that may need to be more nuanced. Inclusion of testimony to contrast theoretical work is common in the field of disability studies, and also leveraged by Barnes in her work on the Minority Body [6]. Likewise, some work within the HCI and accessibility community follows a similar approach, for example, Bennett and Rosner work with stories to explore the disabled experience in the context of design [7]. Further, some of the authors are and identify as disabled, which implicitly informs our analysis.

We adopt the current generation of consumer VR hardware supporting six Degrees of Freedom (6DoF) user tracking as a starting

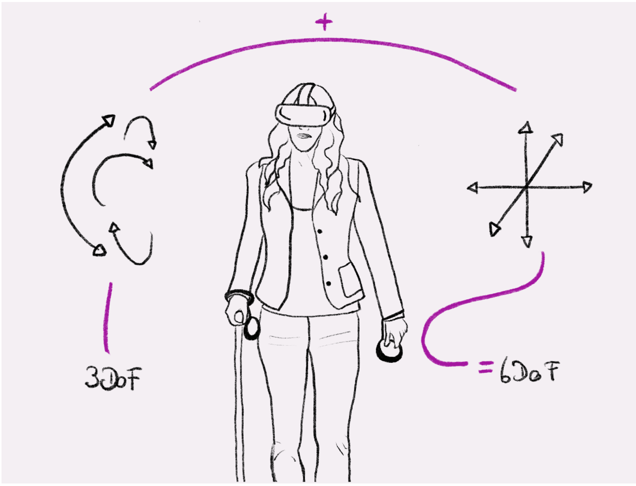

Figure 1: Illustration of Degrees of Freedom (DoF) of VR. Head tracking provides 3DoF, body tracking (moving forward/backward, moving to sides, moving up and down) provides another 3DoF, resulting in a 6DoF system.

point for inclusion in our analysis (see also, Figure 1), i.e., we focus on systems that maximize bodily involvement, in principle enabling people to move through the room [2]. This includes systems such as the Oculus Rift, Playstation VR, and HTC Vive that all combine a head-mounted display (HMD) with handheld controllers and optical movement tracking, and the Oculus Quest that employs similar strategies, but offers camera-based hand tracking to replace handheld controllers. Systems such as Google Cardboard that facilitate fewer degrees of freedom are not included in this analysis, and we likewise do not include alternative VR implementations such as caves as both commercial development and academic research strongly emphasize HMD-based versions of 6DoF VR as described above. While not our primary focus, we do make reference to software implementation of interaction techniques where relevant, but do not limit ourselves to a specific application context of VR. The main analysis was carried out by the first author of the paper, and results were discussed with the second author.

3.3 Results

We present our analysis per element of Surrogate Body theory. Within each subsection, we structure our findings as follows: (1) a general description of the design of VR technology with respect to the specific element and an examination of the assumptions that its design implies about human bodies, and (2) implications for people with physical disability, illustrated with reflection on potential accessibility barriers along with testimony of disabled people and how they experience or perceive VR.

3.3.1 Spatial Distance Between User and Hardware. The physical distance between bodies and system hardware is something that VR technology seeks to eradicate, which is in line with the idea that VR systems immerse all human senses to achieve the feeling of presence.

Description of VR Technology and assumptions that its design implies about the human body. The current generation of consumer VR systems achieves this through a combination of devices: (1) A head-mounted display that serves both in terms of output (conveying visual and auditory information) and integrates additional sensors to support input (e.g., head tracking through motion sensors, hand tracking through integrated cameras). (2) Two handheld controllers to support gesture-based input (unless system supports hands-free tracking of arms, hands and fingers, e.g., Oculus Quest) and input through buttons. Some handheld controllers also support haptic feedback (e.g., vibration). (3) Positional tracking devices – often optical systems – that support the determination of location and pose of a person within a dedicated interaction space (e.g., the HTC Vive Lighthouses). To enter VR, people subject themselves to the system by attaching relevant devices to their bodies, and limiting their radius of movement to the interaction space that is defined by the technology (see also, Figure 2). To engage with these systems, people need to use both arms and hands to hold two controllers, and are expected to precisely push sometimes small buttons with their fingers. Some controllers provide haptic feedback (i.e., vibration) that is directly transferred to the hands. In the case of hands-free tracking systems, people need to be able to gesture with their arms, hands, and fingers. Additionally, many headsets are reasonably heavy (e.g., 470g/1lbs for Oculus Rift, and 555g/1.2lbs for the HTC Vive [5]), which puts additional strain on the spine [26].

Implications for people with physical disability. With respect to people with physical disability, the core question is whether the reduction of distance between a body and the system hardware is achieved so that the body merges into the surrogate body, or if there are system characteristics that interrupt this process. For example, a person with a fine motor impairment might find the buttons of VR controllers difficult to press and a person with a spinal cord injury might find currently available headsets uncomfortable to wear, both instances resulting in increased perceived distance. This suggests a higher risk of poor fit of VR hardware for people with physical disability than for non-disabled bodies, that will in turn affect the perceived distance between a person and the hardware. Likewise, it is important to recognize the presence of assistive devices (e.g., canes, crutches or wheelchairs) in the lives of people with physical disability. For example, holding two controllers may not be suitable if a person also uses a cane, interacting with the controllers may not be possible while propelling a manual wheelchair, and the headset may not comfortably fit with the layout of the headrest of a powered wheelchair. All of these elements contribute to increased physical distance between a body and the hardware: either because actual physical distance is (temporarily) increased, e.g., when placing controllers in lap to propel wheelchair, or because union between body and surrogate body is interrupted by uncomfortable, overly present hardware. Some of the aspects that exacerbate the issue of overly present hardware (e.g., the need to manage cables of a VR headset) become less relevant as technology becomes more performant (e.g., wireless data transmission capabilities of latest generation of VR headsets) while other issues remain. Finally, wheelchair use in particular has implications for the size of interaction space required; here, systems support adequate play area sizes (e.g., the HTC Vive system allows for an up to 10x10m

Figure 2: The physical distance between a body and a VR system is extremely short, with a direct connection between the body and input/output devices.

Figure 3: In 6DoF VR systems, people lend actions extensively; this can include the entire body. Here, a person is engaging in mid-air pointing.

area), however, this aspect also needs to be viewed in the light of the space that is available in the physical environment (see section 3.3.6).

These observations are present in testimony of physical disability and the (anticipated) use of VR, calling for a new approach to their design: When reflecting on previous experiences with VR, or imagining potential future use of VR hardware, disabled people highlighted a number of accessibility barriers in relation to the accommodation of physical disability that would prevent them from effective system use, including the following:

> "*Well, the obvious is that you need to hold the controllers but also need to use your hands to move a chair. [. . .] VR is not calibrated for someone sitting down and having to use their hands to move their body position.*" (male, 37, manual wheelchair, experience with Oculus Rift and Google Cardboard)
>
> "*[The headset] looks too heavy to sit on my head for too long.*" (male, 40, not used VR before)

This suggests that the expectations that VR hardware places on someone's body can turn a mere-difference of the minority body into what Barnes terms a 'local bad' of disability [6, p. 86]: it expects a bodily shape closely resembling the 'corporeal standard', otherwise resulting in a partially or fully inaccessible experience that is not sufficiently attuned to a minority body, detracting from the experience of presence because the heightened obtrusiveness of hardware is unsuitable (see Held and Durlach for a detailed discussion of the importance of unobtrusiveness of VR hardware [30]).

3.3.2 Bodily Involvement. Bodily involvement refers to the degree to which the system allows for the involvement of a human body in interaction. Here, the surrogate body in play predominantly focuses on the options that the hardware setup offers to players (e.g., desktop computing being predominantly limited to hands, [57, p. 401]); in this section, we explore how this aspect is realized in VR.

Description of VR Technology and assumptions that its design implies about the human body. The involvement of the body in VR can be explored through examination of which body parts are required for basic system interaction. Figure 4 provides a sketch that highlights which body parts are commonly involved: The head carries the HMD; head movement adjusts the view within the virtual world, implying that the neck and spine also need to

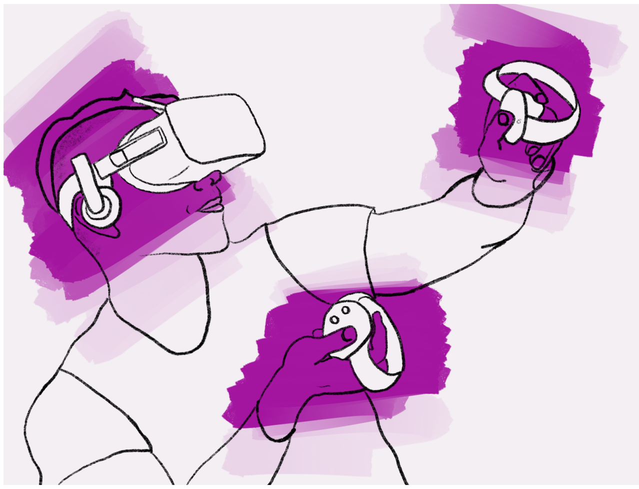

Figure 4: Body parts directly involved with VR hardware: the head and - in controller-based systems - hands.

be considered in interaction as they provide support. Upper body movement involving hands, arms and shoulders is necessary to interact via handheld controllers or hands-free gesture-based input. For systems that implement forms of locomotion, people further need to be able to move through the room and involvement therefore extends to the lower body and legs (i.e., systems assume that people have the ability to walk); systems that support seated interaction may still require extended upper body movement involving the trunk (e.g., leaning to the side or turning). As such, bodily involvement in the current generation of VR technology is extensive, and can span the entire human body depending on the actions that need to be lent (see section 3.3.3).

Implications for people with physical disability. Because the expectation that VR technology has in terms of bodily involvement is extensive, it can therefore create accessibility barriers for people who lend their body differently to the system. For example, many wheelchair users would find bodily involvement of the legs or the trunk unsuitable, people who interact with one arm would not appreciate the expectation of VR for people to involve two arms, and individuals who experience pain might find it difficult to involve large parts of their body over longer periods of time. While these examples may seem obvious and there are of course many more nuanced examples of how physical disability is difficult to reconcile with the bodily involvement expected by VR technology, our examples do illustrate the extent to which normative assumptions about how human bodies will be able to support interaction are ingrained in VR technology.

Testimony supports that this expectation is problematic for disabled users. When reflecting on their bodies and what the full-body interaction paradigm of VR would afford, they offered the following comments that are valuable points for discussion in the context of our work:

> "*I am not too good with my arm strength, reaching high is hard.*" (male, 35, experience with Oculus Rift, HTC Vive, Google Cardboard)

> "*My balance is poor and that affected my ability to play fully. [. . .] A lot of body movement is difficult, whether is chair or on couch.*" (male, 25, experience with Sony Playstation VR)

Beyond highlighting the difficulty of bodily involvement, testimony also hints at the complexity of the relationship between bodies and VR technology: while the description of bodily involvement is fairly straightforward in terms identifying relevant body parts, the consequences of this involvement for accessibility and experience are intertwined with the specific expectations of VR systems in terms of interaction (i.e., software implementation of interaction paradigms and other application-level requirements such as mechanics in the case of games). While we conclude here that the general view on bodily involvement suggests that VR technology anticipates the 'corporeal standard' in that people are expected to use two arms, legs, and their head and trunk to experience VR fully, we argue that the full demand of VR technology on a body only becomes clear once we also take into account the actions that need to be lent, an analysis which we offer in the following section.

3.3.3 Actions Lent. The principle of 'lending actions' assumes that people lend their actions to an interactive system in a bid to establish a connection with the medium and to merge into the surrogate body. Here, the concept facilitates the analysis of the interplay between VR hardware and specific interaction paradigms. It becomes possible to determine the full demand that systems place on people's bodies by exploring the actions that need to be lent: we can consider the demands that emerge from the combination of VR technology with interaction paradigms that are implemented in specific applications, allowing us to explore the perspective of VR technology on bodies 'in action'.

Description of VR Technology and assumptions that its design implies about the human body. It is important to note that like many other full-body technologies, VR explicitly defines actions that people are expected to lend (e.g., pushing buttons or performing gestures), often demanding very specific actions that can be detected by the technology (e.g., camera-based tracking). Here, we illustrate this symbiosis by means of two actions that VR systems expect people to lend, (1) mid-air pointing and (2) locomotion.

(1) Mid-air pointing is one of the most common referential gestures in VR [47], which is leveraged to indicate a location within the virtual environment. Typically, people are expected to extend and hold out their arm in the air (see Figure 3, often in combination with additional controller input (e.g., to confirm a selection or carry out further action on an object); depending on implementation, mid-air pointing can be limited to a specific arm. In terms of range of motion, applications often exploit all degrees of freedom and expect overhead input in combination with upper body turns. For example, if a first-person shooting game implements mid-air pointing to aim at enemies that spawn in front of, behind, or above the player, systems expect rapid responses along with the ability to point calmly and steadily, penalizing erratic (as defined by the technological setup) movement. To stick with the previous example, a player in a first-person shooting

game would miss the enemy if not pointing accurately or quickly enough.

(2) Locomotion refers to techniques that are leveraged to enable people to move through a virtual world, and include these that require full-body involvement along with techniques that predominantly rely on controller input [10]. Here, main approaches focus on walking within confines of the play area or in place (thus requiring people to stand up and move their legs), teleportation (a variant of mid-air pointing to rapidly progress through virtual space that needs to be carried out repeatedly throughout interaction [13]; see previous paragraph for analysis), or using buttons and or joystick input that predominantly requires fine motor interaction [18]. Research involving non-disabled participants shows that methods that maximize bodily involvement are usually perceived as more comfortable, with sedentary input leading to higher rates of simulator sickness and lower perceived presence [23].

Implications for people with physical disability. Reflecting on these two paradigms through the lens of the minority body, a number of potential access barriers need to be considered. For example, if one specific arm must be used for mid-air pointing, this can be challenging for people who prefer to use their, potentially differing, stronger arm. If actions need to be lent rapidly yet calmly, this can be challenging for individuals with tremor. If pointing must be supported with trunk movement (e.g., turning), accessibility for people with spinal cord injury may be reduced. Likewise, locomotion through walking may not be suitable for people with different gait; anyone who uses an assistive device when moving may also find the paradigm inaccessible. Teleportation still requires people to extensively use their arms and in some instances stand up; here, sedentary controller-based input may be more accessible for some people (despite potential negative implications for the experience of VR). Finally, if all these actions are to be lent for longer periods of time, they may become increasingly difficult to produce, and result in pain for some people, with fatigue only cursorily addressed by current research, and previous research exploring full-body interaction (e.g., in the context of games) treating fatigue as a design element that mediates engagement rather than an access barrier [43, p. 2195]. Hence, having a minority body is yet again associated with a higher chance of disability resulting in a local bad: the principle of lending action is overwhelmingly aligned with the idea of a corporeal standard that can fulfill system demands precisely in the way developers envisioned both in a single instance and over time.

This is also reflected in testimony that comments on demands inherent in interaction schemes implemented in full-body VR games, and makes reference to VR control schemes:

> "*While I enjoy the VR from the perspective of the eyes, the rest of my body does not fit with motion control schemes of VR. Hence unless there is a choice to use something more static and less physically active I rule out the game. Feels like the movement to a more real experience in terms of control schemes removes my chance to participate in such games.*" (male, 37, experience with Oculus Rift and Sony Playstation VR)

Figure 5: When lending affect to a VR system, people may respond with their whole body due to the embodied nature of the technology.

3.3.4 Embodied Affect. In VR, lending bodily affect extends to an entire body within the boundaries that are defined by the system, i.e., the process of lending affect is limited by what Spiel and Gerling call "responses [that] might interfere more dramatically with the game" as they would be misinterpreted by tracking technology [57, p. 402].

Description of VR Technology and assumptions that its design implies about the human body. Previous research has demonstrated that VR is a technology with potential to evoke a strong affective response in people due to the immersive nature. At times, this may induce emotional responses that extend into physical reactions specifically among players (e.g., see [28, p.3]). In contrast to the actions that need to be lent, these affective responses are not clearly defined by the system and individually embodied. Thus, VR offers the unique potential of evoking strong responses while giving them freedom of expression (see Figure 5).

Implications for people with physical disability. Generally, we argue that physical disability can be regarded as mere-difference with respect to the principle of lending affect: assuming that an individual's experience within the virtual world is adequate, the evoked affective response does not depend on external factors that relate to system design. However, one point for attention is the risk of discomfort and injury as a result of affective responses leading to unplanned physical movement (e.g., raising one's arms or moving backwards). For example, a person who combines VR hardware with the use of a cane for stability may lose balance when an unexpected event occurs in the virtual world. Likewise, because the use of assistive devices is not accounted for in currently available systems, entanglement between them and VR hardware (e.g., wires) may be problematic particularly when people seek to lend affect. In this case, the high level of bodily involvement might create a local bad for disabled people.

These challenges are further reflected in testimony, with the general public perceiving VR as a technology that evokes strong physical reactions which may interfere with bodily needs during

Figure 6: The spatial environment needs to account for the presence of assistive devices and alternative modes of engagement.

periods of engagement where unexpected events occur. For example, the following testimony describes the respondent's thoughts on preferences and needs with respect to content of interactive VR applications, suggesting that surprising elements commonly employed to engage users - for example in games that seek to scare players - would not be suitable in her context of use: "*One other thing I wanted to mention is that, especially with chronic pain, you develop all sorts of guarding behaviors to protect your body parts with pain.*" (female, 30, experience with HTC Vive)

This shows how the loop of *lending action* (3.3.3) and *lending affect* (3.3.4) extends to an entire body, and places physical demands on it, which – in the case of lending affect – are not explicitly defined by the VR system. This means that careful consideration is required when developing VR applications to ensure that all people with physical disability can engage safely.

3.3.5 Multiuser. In their initial work on the Surrogate Body in play, Spiel and Gerling argue that the immersive and perhaps isolating nature of the current generation of consumer hardware predominantly supports VR as a single player experience [57, p. 403], something which is supported by previous work on VR games for wheelchair users [28].

Description of VR Technology and assumptions that its design implies about the human body. As such, whether VR provides a single or multi-user experience makes no bodily assumptions as such, with preferences for single- or multi-user experiences reported as varied in previous research (see [28]). The perhaps biggest assumption that is made in the context of single-user engagement with VR is that everyone can set up the VR system on their own, which in some cases requires more extensive bodily involvement than interaction within VR. Subsequently, people are expected to place the headset on their head, adjust straps to ensure a good fit, manage wires (if present), and pick up the controllers while already wearing the headset.

Implications for people with physical disability. Because the setup routines require full upper-body flexibility, they will not be suitable for all people with physical disability. Previous work argues that design for interdependence could help resolve this barrier (i.e., designing VR systems in a way that people with physical disability can receive support from others when setting them up [42, p. 12]). However, we argue that while this approach may in the short term resolve access barriers, it ultimately contributes to disability manifesting as a local bad: if people with physical disability depend on the help of others to set up a system that is ultimately intended to provide single user experiences, it does not lead to meaningful interdependence, but increases potentially undesired dependency on other people for the purpose of basic access to the VR system as presence of others will always be required at the entry into a virtual world.

3.3.6 Spatial Environment. Generally, consumer VR is geared toward home use, but is increasingly finding its way into work spaces, educational institutions, and leisure (e.g., theme parks or VR arcades). As such, the **assumptions that the design of VR technology implies with respect to bodies** are limited to the idea that human bodies inhabit spaces that can be fitted with the technology and affording the relevant background requirements such as a stable network condition or enough space to move comfortably. However, this deployment setting, while seemingly a simple undercurrent, can have impactful implications for people with physical disability.

Implications for people with physical disability. The primary intended setting for engagement with VR - a person's home - results in disability manifesting as mere-difference, suggesting that barriers to VR use of a disabled person would be comparable to these of a non-disabled person (e.g., affordability and space requirements of systems). However, these may be compounded by the use of assistive devices, e.g., using VR while simultaneously using a powered wheelchair may change space requirements, and while these could be accommodated by current systems, some living spaces may not afford sufficient space. Additionally, it is worth asking more detailed questions about *where in the home* people with physical disability typically engage with interactive media. Current VR systems expect people to create dedicated, empty spaces, although people with physical disability might not find setups suitable that expect them to submit their bodies to the hardware, requiring them to sit on chairs that allow for upper body movement, or remain standing throughout interaction. Instead, a person who uses a wheelchair some of the time may want to play standing up on some days, but might prefer to sit on a couch (with limited opportunity for upper body movement) on other days, and a person with chronic pain might find it more comfortable to engage with VR while lying in bed, making it difficult to engage in extensive upper body movement (if at all). Currently, the suitability of VR systems for alternative settings depends on associated software (see section 3.3.3). Hence, play space setups for consumer VR hardware assume ability attributed to the corporeal standard, i.e., suggest that people need to stand up for extensive periods of time, casting disability as a local bad. In other instances however (e.g., if it is possible to interact with an application while seated), certain groups of people with physical disability may experience disability as mere-difference as demands in terms of spatial environment are well-aligned with their needs (see, for example, Figure 6).

Testimony supports the need for further exploration of requirements in terms of spatial environment. When asked about alternative interaction paradigms that involve the assistive device, one participant declined and specifically outlined the need for alternative play spaces within the home that accommodate their needs:

"*I'd be using it from bed, so no definitely not [interested in wheelchair movement].*" (42, agender, has not used VR before)

4 DISCUSSION

We set out to examine the assumptions that underpin the design of the current generation of consumer VR with respect to people's bodies, and how these assumptions affect the access options for people with physical disability to VR. To support our critical analysis, we presented a detailed overview of disability theory, a description of state of the art VR technology, and introduced Surrogate Body theory [57, 63] as a lens for structured theoretical analysis. Our results show that the design of the current generation of VR technology prioritizes non-disabled people both in terms of hardware and interaction paradigms that are supported. Hence, our analysis suggests that VR – in its current shape – does not attend to the experiences of people with physical disability, who are likely to encounter accessibility barriers that negatively affect their experiences with VR, an assumption that is backed by the testimony that we provide. Here, we discuss these core findings, and derive implications for HCI research on VR to encourage technologists and designers to be more mindful and explicit about the choices they make and the ramifications for the bodies they include or exclude through those choices. Additionally, we discuss on the potential of Surrogate Body theory to structure reflection on interactive technology, and we delineate the wider role of theoretical analysis in accessibility research.

4.1 VR Technology as a Proponent of the Corporeal Standard

Our analysis shows that the design of consumer VR technology places a strong focus on non-disabled bodies with respect to bodily involvement, the shape that interaction paradigms take (i.e., *actions* and *affect* lent to the system), and the lack of consideration for the integration of assistive devices or the need of people to engage with VR in a variety of environments: for most dimensions of the surrogate body, physical disability results in a *local bad*, limiting the accessibility of the current generation of consumer VR technology – presumably with jarring consequences to presence [39] and immersion [62]. Linking these findings back to the original definitions of presence and immersion in VR, it is likely that disabled people will be more aware of the hardware while engaging with a virtual world due to its alignment with non-disabled bodies, and our analysis has demonstrated that VR hardware does not *wrap around disabled bodies* for the same reason (see 2.2.1). We therefore conclude that the current design of VR technology propagates the 'corporeal standard', and VR therefore needs to be regarded as an ableist technology that is designed in a way that does not account for the experiences of disabled bodies.

The strong implicit focus on non-disabled bodies is also reflected in prominent research lines within the HCI research community, focusing on optimizing the VR experience for said 'corporeal standard'. Here, 'accessibility' is often understood as improved access for non-disabled persons (e.g., [4] on movement modalities), and while features such as seated interaction are explored that would benefit the disability community (see [38]), applications predominantly target non-disabled people and do not report inclusion of disabled people within system evaluations. Likewise, certain areas of ongoing VR research - by definition - neglect people with physical disability, e.g., much of the research on full-body support for locomotion techniques for VR prioritizes walking over other modes of movement without reflecting on exclusionary consequences (e.g., see [10]). Instead, much of the work that does address physical disability is applied, and specifically focuses on matters related to specific impairments, rather than seeking to address fundamental questions around the design of VR technology for people with physical disability and the complexity of the experience. For example, VR is applied to simulate wheelchair use [34] or to support occupational therapy and rehabilitation [11, 19]. Likewise, there is a body of work that seeks to make experiences that are inaccessible in the real world accessible through VR (e.g., drumming [33] or skiing [28]), a perspective which is also reflected in Mott et al.'s exploration of VR accessibility for people with limited mobility [42]. However, the structured contribution of these case studies to the general accessibility of VR for people with physical disability remains limited, broadly identifying but not (yet) addressing the complexity of VR access for people with physical disability. Hence, the design of VR technology binds the potentially immersive experiences that can be made with this technology to specific embodiments, although this is only explicitly done for people with physical disability whereas the non-disabled corporeal standard is largely implicit even if ever present.

4.2 Strategies for the Design of Virtual Reality Technology for People With Physical Disability

While our work does not seek to provide detailed design recommendations for VR for people with physical disability, it serves as an opportunity for reflection on assumptions that the designers of the technology make about bodies. We offer starting points for reflection that might help identify some shortcomings of the technology. Here, we reflect on the challenge of developing new VR systems, and explore implications of the choice of design strategy of virtual reality technology for people with physical disability that can help remove bias toward the corporeal standard.

4.2.1 Appreciate Diversity of Bodies as Starting Point for Design. Our findings suggest that VR technology commonly adopts the 'corporeal standard' as a starting point for design, in turn only catering to minority bodies as an afterthought. Recent academic work recognizes shortcomings associated with this approach [28, 42], but continues to focus on existing VR systems rather than returning to the drawing board. However, if we accept that ableism is deeply ingrained in the current generation of VR systems and subscribe to HCI's widespread philosophy of user-centered design [1], we

Section	Strategy	Technological	Bodily	References
4.2.1	Appreciate Diversity	Reflect Continuously on Exclusions Created by VR Systems	Account for Disabled Bodies from the Start	[1]
4.2.2	Challenge Status Quo	Consider Speculative and Future-Looking Approaches	Prioritize (Minority) Bodies over Technological Constraints	[20, 46]
4.2.3	Individualized Designs	Develop Hardware in a Modular Fashion, Provide Adaptive Interaction Paradigms	Involve Disabled Communities Equitably in Design	[31, 40]

Table 1: Strategies for the hardware design of Virtual Reality technologies along technological and bodily considerations with references for further consultation.

must reject them as starting point for the design of accessible VR: if disabled bodies were not taken into account throughout system development and design (both with respect to hardware and software), it will not be possible to create truly engaging experiences simply by adjusting what was originally designed for non-disabled bodies. Instead, we need to start design efforts from scratch, allowing designers and developers to fully appreciate the diversity of bodies and experiences, while adequately involving the disabled community in the shaping of these new VR systems. Centring disabled bodies from the beginning comes with the additional potential of creating technologies that not only allow people with minority or majority bodies alike to make and share similar experiences, they might also lead to novel interaction approaches and experiences.

4.2.2 Adopt Design Approaches That Challenge The Status Quo. In an effort to move beyond fixing existing VR technology, one opportunity lies in the adoption of design approaches that challenge the status quo. Commonly, the HCI research community focuses on user-centered design where systems are designed in consultation with a specific target audience, or participatory design as a means of direct and equal co-creation. However, more recently there has been discussion within the HCI research community that often, despite claiming a co-creative approach, projects often do not start from scratch, but are already invested in certain elements [56], e.g., commercially available VR hardware. Here, speculative approaches offer an alternative that encourages to look beyond the status quo. Such design approaches have previously been leveraged in HCI, but also at the intersection of disability studies, gender studies and critical race theory (e.g., [46]). Therefore, we believe that speculative design [20] that seeks to design for desirable futures could also benefit disabled people's use of VR, re-imagining the technology in an inclusive and welcoming shape.

4.2.3 Invest in Individualized Designs. Finally, our results highlight the diversity of bodies and use cases of VR, echoing previous findings by [41]. One might argue that adequately designing for every body (echoing notions from Universal design) needs to address cross-cutting complexities between hardware, interaction techniques, and representation. While we recognize these challenges, we highlight that individualized designs already occur at scale: charitable organizations such as SpecialEffect [2] have made tireless efforts in supporting disabled people to gain access to immersive media through highly tailored, custom-designed interface solutions, demonstrating that individualized designs are in fact possible although they require a combination of professional and/or lived expertise. This raises the question why technology developers (often with more extensive financial means) do not make these considerations on their end (and are not required by law to do so), but instead rely on disabled people and on the third sector to address the issue, accepting further dependency of disabled people on charity (see [31, 40] on issues with a charity model of disability).

[2]https://www.specialeffect.org.uk/

4.3 Strengthening the Role of Theoretical Analysis in Accessibility Research

Theoretical analysis of technology within HCI, as exemplified in this paper by the application of Surrogate Body theory [57] and the theory of the Minority Body [6] to VR, complements empirical work that addresses the accessibility of interactive systems. Williams and Gilbert highlight that exposure and examination of implicit biases and societal stigmas is imperative for the ethical and just development of technology [64]. Our work offers an opportunity to explore the design of technologies and their implications (not just but also for disabled people), and enables a shift of perspective away from post-hoc evaluation of system design (and its shortcomings) to an a-priori examination of ingrained but implicit assumptions. Theoretical analysis can serve as an intermediate means of evaluation that ensures only suitable technology is tested with the intended target group [37], reducing the burden on (in our context) disabled communities that result from the ever-growing need of HCI research for continuous user involvement. We do not advocate for theoretical research to replace empirical work, but to substitute where necessary, and complement where possible. Particularly in the context of accessibility research, user involvement remains paramount to ensure accurate representation of disabled experiences [7]. In our work, this is why we decided to supplement our analysis with testimony; however, in the next step, future work seeking to develop accessible VR should explore nuances with people with physical disability.

5 LIMITATIONS AND FUTURE WORK

Our analysis of Virtual Reality and physical disability is by no means all-encompassing, and needs to be viewed in the light of limitations that require future work. Most importantly, our work only focuses on physical disability and limited mobility, and does not address other shapes that bodies can take (e.g., neurodivergence or sensory disability) which might have contradicting implications for the engagement with VR technology. Likewise, we do not address issues that emerge at the intersection of disability, gender, and race, aspects that will further impact how a general public perceives VR. We also need to recognize that our attempt of reviewing VR technology against a corporeal standard does not seek to capture the individual lived experiences of people with physical disability in VR, but rather provides general insights into where the relationship between bodies and technology can be problematic. Likewise, VR is a complex, multi-layered technology, and in some instances we only offer illustrative examples. Here, future work could provide more in-depth analyses particularly with respect to the software elements of VR, exploring groups of interaction techniques and their specific implementation in a given VR system, highlighting the important role that the design of applications plays in ensuring accessibility of VR for people with physical disability. Likewise, our work currently does not tie analysis to one specific use case; future work should explore accessibility requirements in settings such as entertainment, work, or education. Along these lines, future work could also examine how our findings extend to different implementations of VR hardware (e.g., 3DoF systems such as Google Cardboard or Samsung Gear that are more accessible from a financial perspective). From an analytical perspective, limitations of the theory of the Surrogate Body carry through into our work: while the theory offers an excellent starting point for our analysis in terms of examining the interplay between VR systems and people's bodies on a physical level, cognitive aspects of interaction are implicitly included in the concept of *lending affect*. Therefore, wider implications of the role of embodiment and disability are not included in this analysis; the relationship between bodies, hardware, interaction techniques, and *representation of bodies* in virtual worlds therefore needs to be examined by future work.

6 CONCLUSION

Virtual Reality is rapidly becoming a mainstream technology with wide availability of consumer hardware, and applications in education and training, healthcare, and entertainment, offering a wide range of enriching and immersive experiences. However, our theoretical analysis of VR on the basis of Surrogate Body theory [57, 63] in combination with the theory of the Minority Body [6] demonstrates that the current generation of this technology is overwhelmingly designed for the corporeal standard, and does not account for the needs and desires of disabled people. Thereby, a significant part of the population - including people with physical disability - is denied access to a technology that pushes the boundaries of innovation. Starting from the understanding that VR is underpinned by ableist assumptions that lead to the design of inaccessible technology, we reflect on implications for HCI research and sketch avenues for future work that re-imagines VR as an individual technology that accommodates bodily diversity. To those who claim that this is a Utopian and overly labour-intensive endeavour, we would like to respond: We need to recognize that both within research and industry, we still engage in the creation of disabling and exclusive body-based technologies (not just in the context of immersive systems [59]), only to make additional efforts later in patching up a persistent oversight. This suggests a general need to move from a paradigm of '*improving for*' or '*making accessible for*' to the perspective of '*creating for*', accounting for the diversity of bodies from the very start of system development, and placing duty for engaging in this process with the stakeholders who seek to reap the benefits of the systems they design. Thus, we argue that it is time that we take our responsibility as technology developers and Human-Computer Interaction researchers: Too often, we act as though we are surprised by the inaccessibility of technology, while perhaps we should have been able to draw this conclusion at the very beginning of the design process. We invite you to pause, and take a moment to question the structures and views that led to this situation in the first place, and how, as a research community, we can do better in the future.

ACKNOWLEDGMENTS

This work was supported by a KU Leuven Starting Grant – STG/17/034, and the Austrian Science Fund (FWF) through a Hertha-Firnberg Scholarship – T 1146-G.

REFERENCES

[1] Chadia Abras, Diane Maloney-Krichmar, and Jenny Preece. 2004. User-Centered Design. In *Berkshire Encyclopedia of Human-Computer Interaction, Volume 2*, William S. Brainbridge (Ed.). Berkshire, Great Barrington, MA, 763–768.
[2] Ridvan Aksu, Jacob Chakareski, and Vladan Velisavljevic. 2019. Displacement Error Analysis of 6-DoF Virtual Reality. In *Proceedings of the 13th International Conference on Distributed Smart Cameras* (Trento, Italy) *(ICDSC 2019)*. Association for Computing Machinery, New York, NY, USA, Article 11, 6 pages. https://doi.org/10.1145/3349801.3349812
[3] Erin E. Andrews, Anjali Forber-Pratt, Linda R. Mona, Emily M. Lund, Carrie R. Pilarski, and Rochelle Balter. 2019. SaytheWord: A disability culture commentary on the erasure of "disability". *Rehabilitation Psychology* 64, 2 (05 2019), 111–118.
[4] L. ap Cenydd and C. J. Headleand. 2019. Movement Modalities in Virtual Reality: A Case Study from Ocean Rift Examining the Best Practices in Accessibility, Comfort, and Immersion. *IEEE Consumer Electronics Magazine* 8, 1 (2019), 30–35.
[5] ArsTechnica 2020. *The Ars VR headset showdown—Oculus Rift vs. HTC Vive*. Retrieved September 10, 2020 from https://arstechnica.com/gaming/2016/04/the-ars-vr-headset-showdown-oculus-rift-vs-htc-vive/
[6] Elizabeth Barnes. 2016. *The minority body: A theory of disability*. Oxford University Press.
[7] Cynthia L. Bennett and Daniela K. Rosner. 2019. The Promise of Empathy: Design, Disability, and Knowing the "Other". In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3290605.3300528
[8] Frank Biocca and Ben Delaney. 1995. *Communication in the Age of Virtual Reality*. Lawrence Erlbaum Associates, Hillsdale, NJ, USA, Name of chapter: Immersive Virtual Reality Technology, 57–125.
[9] Frank Biocca and Mark Levy. 1995. *Communication in the Age of Virtual Reality*. Lawrence Erlbaum Associates, Hillsdale, NJ, USA, Name of chapter: Communication Applications of Virtual Reality, 125–156.
[10] Costas Boletsis. 2017. The New Era of Virtual Reality Locomotion: A Systematic Literature Review of Techniques and a Proposed Typology. *Multimodal Technologies and Interaction* 1, 4 (2017). https://doi.org/10.3390/mti1040024
[11] I. Bortone, D. Leonardis, N. Mastronicola, A. Crecchi, L. Bonfiglio, C. Procopio, M. Solazzi, and A. Frisoli. 2018. Wearable Haptics and Immersive Virtual Reality Rehabilitation Training in Children With Neuromotor Impairments. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 26, 7 (2018), 1469–1478.
[12] D. A. Bowman and R. P. McMahan. 2007. Virtual Reality: How Much Immersion Is Enough? *Computer* 40, 7 (2007), 36–43.
[13] Evren Bozgeyikli, Andrew Raij, Srinivas Katkoori, and Rajiv Dubey. 2016. Point & Teleport Locomotion Technique for Virtual Reality. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play* (Austin, Texas, USA) *(CHI PLAY '16)*. Association for Computing Machinery, New York, NY, USA, 205–216. https://doi.org/10.1145/2967934.2968105
[14] L. Bozgeyikli, A. Raij, S. Katkoori, and R. Alqasemi. 2018. A Survey on Virtual Reality for Individuals with Autism Spectrum Disorder: Design Considerations. *IEEE Transactions on Learning Technologies* 11, 2 (2018), 133–151.

[15] Fiona AK Campbell. 2001. Inciting Legal Fictions-Disability's Date with Ontology and the Abieist Body of the Law. *Griffith L. Rev.* 10 (2001), 42.

[16] Tanvir Irfan Chowdhury, Sharif Mohammad Shahnewaz Ferdous, Tabitha C. Peck, and John Quarles. 2018. "Virtual Ability Simulation" to Boost Rehabilitation Exercise Performance and Confidence for People with Disability. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology* (Tokyo, Japan) *(VRST '18)*. Association for Computing Machinery, New York, NY, USA, Article 129, 2 pages. https://doi.org/10.1145/3281505.3283386

[17] Eli Clare. 2017. *Brilliant imperfection: Grappling with cure.* Duke University Press.

[18] Noah Coomer, Sadler Bullard, William Clinton, and Betsy Williams-Sanders. 2018. Evaluating the Effects of Four VR Locomotion Methods: Joystick, Arm-Cycling, Point-Tugging, and Teleporting. In *Proceedings of the 15th ACM Symposium on Applied Perception* (Vancouver, British Columbia, Canada) *(SAP '18)*. Association for Computing Machinery, New York, NY, USA, Article 7, 8 pages. https://doi.org/10.1145/3225153.3225175

[19] Iris Dimbwadyo-Terrer, Fernando Trincado-Alonso, Ana de los Reyes-Guzmán, Miguel A. Aznar, Cesar Alcubilla, Soraya Pérez-Nombela, Antonio del Ama-Espinosa, Begoña Polonio-López, and Ángel Gil-Agudo. 2016. Upper limb rehabilitation after spinal cord injury: a treatment based on a data glove and an immersive virtual reality environment. *Disability and Rehabilitation: Assistive Technology* 11, 6 (2016), 462–467. https://doi.org/10.3109/17483107.2015.1027293 arXiv:https://doi.org/10.3109/17483107.2015.1027293 PMID: 26181226.

[20] Anthony Dunne and Fiona Raby. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming.* The MIT Press, Cambridge, MA, USA.

[21] Horst Eidenberger and Annette Mossel. 2015. Indoor Skydiving in Immersive Virtual Reality with Embedded Storytelling. In *Proceedings of the 21st ACM Symposium on Virtual Reality Software and Technology* (Beijing, China) *(VRST '15)*. ACM, New York, NY, USA, 9–12. https://doi.org/10.1145/2821592.2821612

[22] Laura Ermi and Frans Mäyrä. 2005. Fundamental components of the gameplay experience: Analysing immersion. *Worlds in play: International perspectives on digital games research* 37, 2 (2005), 37–53.

[23] Julian Frommel, Sven Sonntag, and Michael Weber. 2017. Effects of Controller-Based Locomotion on Player Experience in a Virtual Reality Exploration Game. In *Proceedings of the 12th International Conference on the Foundations of Digital Games* (Hyannis, Massachusetts) *(FDG '17)*. Association for Computing Machinery, New York, NY, USA, Article 30, 6 pages. https://doi.org/10.1145/3102071.3102082

[24] Rosemarie Garland-Thomson. 1997. *Extraordinary Bodies: Figuring Physical Disability in American Culture and Literature.* Columbia University Press.

[25] Rosemarie Garland-Thomson. 2002. Integrating Disability, Transforming Feminist Theory. *NWSA Journal* 14, 3 (2002), 1–32. http://www.jstor.org/stable/4316922

[26] Bernie Garrett, Tarnia Taverner, Diane Gromala, Gordon Tao, Elliott Cordingley, and Crystal Sun. 2018. Virtual Reality Clinical Research: Promises and Challenges. *JMIR Serious Games* 6, 4 (17 Oct 2018), e10839. https://doi.org/10.2196/10839

[27] Franca Garzotto, Mirko Gelsomini, Daniele Occhiuto, Vito Matarazzo, and Nicolò Messina. 2017. Wearable Immersive Virtual Reality for Children with Disability: A Case Study. In *Proceedings of the 2017 Conference on Interaction Design and Children* (Stanford, California, USA) *(IDC '17)*. Association for Computing Machinery, New York, NY, USA, 478–483. https://doi.org/10.1145/3078072.3084312

[28] Kathrin Gerling, Patrick Dickinson, Kieran Hicks, Liam Mason, Adalberto L. Simeone, and Katta Spiel. 2020. Virtual Reality Games for People Using Wheelchairs. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3313831.3376265

[29] Dan Goodley. 2013. Dis/entangling critical disability studies. *Disability & Society* 28, 5 (2013), 631–644. https://doi.org/10.1080/09687599.2012.717884 arXiv:https://doi.org/10.1080/09687599.2012.717884

[30] Richard M. Held and Nathaniel I. Durlach. 1992. Telepresence. *Presence: Teleoperators and Virtual Environments* 1, 1 (1992), 109–112. https://doi.org/10.1162/pres.1992.1.1.109 arXiv:https://doi.org/10.1162/pres.1992.1.1.109

[31] S. Hibbert and S. Horne. 1996. Giving to charity: questioning the donor decision process. *Journal of Consumer Marketing* 13, 2 (1996), 4–13. https://doi.org/10.1108/07363769610115366

[32] Charlene Jennett, Anna L. Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. 2008. Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies* 66, 9 (2008), 641 – 661. https://doi.org/10.1016/j.ijhcs.2008.04.004

[33] Jacob Jewel and Tony Morelli. 2019. Using Virtual Reality to Create an Inclusive Virtual Drumming Environment. In *Universal Access in Human-Computer Interaction. Theory, Methods and Tools*, Margherita Antona and Constantine Stephanidis (Eds.). Springer International Publishing, Cham, 569–577.

[34] N. W. John, S. R. Pop, T. W. Day, P. D. Ritsos, and C. J. Headleand. 2018. The Implementation and Validation of a Virtual Environment for Training Powered Wheelchair Manoeuvres. *IEEE Transactions on Visualization and Computer Graphics* 24, 5 (2018), 1867–1878.

[35] Matthew Lombard and Theresa Ditton. 1997. At the Heart of It All: The Concept of Presence. *Journal of Computer-Mediated Communication* 3, 2 (09 1997). https://doi.org/10.1111/j.1083-6101.1997.tb00072.x JCMC321.

[36] The-Kiet Lu, Edwin Foo, Bala S. Rajaratnam, and Kannappan. 2013. Configurable Augmented Virtual Reality Rehabilitation System for Upper Limb Disability. In *Proceedings of the 7th International Convention on Rehabilitation Engineering and Assistive Technology* (Gyeonggi-do, South Korea) *(i-CREATe '13)*. Singapore Therapeutic, Assistive & Rehabilitative Technologies (START) Centre, Midview City, SGP, Article 19, 4 pages.

[37] Jennifer Mankoff, Gillian R. Hayes, and Devva Kasnitz. 2010. Disability Studies as a Source of Critical Inquiry for the Field of Assistive Technology. In *Proceedings of the 12th International ACM SIGACCESS Conference on Computers and Accessibility* (Orlando, Florida, USA) *(ASSETS '10)*. Association for Computing Machinery, New York, NY, USA, 3–10. https://doi.org/10.1145/1878803.1878807

[38] Mark Mcgill, Aidan Kehoe, Euan Freeman, and Stephen Brewster. 2020. Expanding the Bounds of Seated Virtual Workspaces. *ACM Trans. Comput.-Hum. Interact.* 27, 3, Article 13 (May 2020), 40 pages. https://doi.org/10.1145/3380959

[39] Alison McMahan. 2003. Immersion, engagement and presence. *The video game theory reader* 67 (2003), 86.

[40] Jenny Morris. 1991. *Pride against prejudice: A personal politics of disability.* Womens PressLtd.

[41] M. Mott, E. Cutrell, M. Gonzalez Franco, C. Holz, E. Ofek, R. Stoakley, and M. Ringel Morris. 2019. Accessible by Design: An Opportunity for Virtual Reality. In *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. 451–454. https://doi.org/10.1109/ISMAR-Adjunct.2019.00122

[42] Martez E. Mott, John Tang, Shaun K. Kane, Edward Cutrell, and Meredith Ringel Morris. 2020. 'I just went into it assuming that I wouldn't be able to have the full experience' Understanding the Accessibility of Virtual Reality for People with Limited Mobility. In *Proceedings of ASSETS 2020*. ACM, New York.

[43] Florian Mueller and Katherine Isbister. 2014. Movement-Based Game Guidelines. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 2191–2200. https://doi.org/10.1145/2556288.2557163

[44] Prajwal Paudyal, Ayan Banerjee, Yijian Hu, and Sandeep Gupta. 2019. DAVEE: A Deaf Accessible Virtual Environment for Education. In *Proceedings of the 2019 on Creativity and Cognition* (San Diego, CA, USA) *(C&C '19)*. Association for Computing Machinery, New York, NY, USA, 522–526. https://doi.org/10.1145/3325480.3326546

[45] Meelad Sayma, Remco Tuijt, Claudia Cooper, and Kate Walters. 2019. Are We There Yet? Immersive Virtual Reality to Improve Cognitive Function in Dementia and Mild Cognitive Impairment. *The Gerontologist* (10 2019). https://doi.org/10.1093/geront/gnz132 arXiv:https://academic.oup.com/gerontologist/advance-article-pdf/doi/10.1093/geront/gnz132/30130831/gnz132.pdf gnz132.

[46] Sami Schalk. 2018. *Bodyminds Reimagined: (Dis)ability, Race, and Gender in Black Women's Speculative Fiction.* Duke University Press, Durham and London.

[47] Valentin Schwind, Sven Mayer, Alexandre Comeau-Vermeersch, Robin Schweigert, and Niels Henze. 2018. Up to the Finger Tip: The Effect of Avatars on Mid-Air Pointing Accuracy in Virtual Reality. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play* (Melbourne, VIC, Australia) *(CHI PLAY '18)*. Association for Computing Machinery, New York, NY, USA, 477–488. https://doi.org/10.1145/3242671.3242675

[48] Tom Shakespeare. 2013. *Disability rights and wrongs revisited.* Routledge.

[49] Tom Shakespeare and Nicholas Watson. 2001. *Exploring Theories and Expanding Methodologies: Where we are and where we need to go (Research in Social Science and Disability, Vol. 2).* Emerald Group Publishing Limited, Bingley, USA, Name of chapter: The social model of disability: An outdated ideology?, 9–28.

[50] Margrit Shildrick. 2012. *Critical disability studies.* Routledge London.

[51] Tobin Siebers. 2013. Disability and the theory of complex embodiment—for identity politics in a new register. *The disability studies reader* 4 (2013), 278–297.

[52] M. Slater. 2003. A Note on Presence Terminology. *PresenceConnect* (2003).

[53] Mel Slater. 2018. Immersion and the illusion of presence in virtual reality. *British Journal of Psychology* 109, 3 (2018), 431–433. https://doi.org/10.1111/bjop.12305 arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/bjop.12305

[54] Mel Slater and Sylvia Wilbur. 1997. A Framework for Immersive Virtual Environments Five: Speculations on the Role of Presence in Virtual Environments. *Presence: Teleoper. Virtual Environ.* 6, 6 (Dec. 1997), 603–616. https://doi.org/10.1162/pres.1997.6.6.603

[55] Aaron J Snoswell and Centaine L Snoswell. 2019. Immersive Virtual Reality in Health Care: Systematic Review of Technology and Disease States. *JMIR Biomed Eng* 4, 1 (26 Sep 2019), e15025. https://doi.org/10.2196/15025

[56] Katta Spiel, Christopher Frauenberger, Os Keyes, and Geraldine Fitzpatrick. 2019. Agency of Autistic Children in Technology Research—A Critical Literature Review. *ACM Trans. Comput.-Hum. Interact.* 26, 6, Article 38 (Nov. 2019), 40 pages. https://doi.org/10.1145/3344919

[57] Katta Spiel and Kathrin Gerling. 2019. The Surrogate Body in Play. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 397–411. https://doi.org/10.1145/3311350.3347189

[58] Katta Spiel, Kathrin Gerling, Cynthia L. Bennett, Emeline Brulé, Rua M. Williams, Jennifer Rode, and Jennifer Mankoff. 2020. Nothing About Us Without Us: Investigating the Role of Critical Disability Studies in HCI. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3334480.3375150

[59] Katta Spiel, Fares Kayali, Louise Horvath, Michael Penkler, Sabine Harrer, Miguel Sicart, and Jessica Hammer. 2018. Fitter, Happier, More Productive? The Normative Ontology of Fitness Trackers. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI EA '18)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3170427.3188401

[60] Jonathan Steuer. 1992. Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication* 42, 4 (1992), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x arXiv:https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1460-2466.1992.tb00812.x

[61] TheVerge 2020. *Logitech's Adaptive Gaming Kit is a cheaper way in to accessible gaming.* Retrieved September 10, 2020 from https://www.theverge.com/2019/11/18/20970294/logitech-adaptive-gaming-kit-xbox-controller-microsoft-accessibility-gamers-with-disabilities

[62] Christiane Voss. 2008. Fiktionale Immersion. *montage AV* 17, 2 (2008), 69–86.

[63] Christiane Voss. 2013. *Der Leihkörper: Erkenntnis und Ästhetik der Illusion.* Wilhelm Fink Verlag.

[64] Rua M. Williams and Juan E. Gilbert. 2019. Cyborg Perspectives on Computing Research Reform. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3290607.3310421

[65] Bob G. Witmer and Michael J. Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence: Teleoperators and Virtual Environments* 7, 3 (1998), 225–240. https://doi.org/10.1162/105474698565686 arXiv:https://doi.org/10.1162/105474698565686

[66] Anon Ymous, Katta Spiel, Os Keyes, Rua M. Williams, Judith Good, Eva Hornecker, and Cynthia L. Bennett. 2020. "I Am Just Terrified of My Future" — Epistemic Violence in Disability Related Technology Research. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI EA '20)*. Association for Computing Machinery, New York, NY, USA, 1–16. https://doi.org/10.1145/3334480.3381828

[67] Yuhang Zhao, Cynthia L. Bennett, Hrvoje Benko, Edward Cutrell, Christian Holz, Meredith Ringel Morris, and Mike Sinclair. 2018. Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3173574.3173690

[68] Yuhang Zhao, Edward Cutrell, Christian Holz, Meredith Ringel Morris, Eyal Ofek, and Andrew D. Wilson. 2019. SeeingVR: A Set of Tools to Make Virtual Reality More Accessible to People with Low Vision. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300341