HCI, Disability and Sport: A Literature Review

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Equitable access to sport for disabled people remains challenging, and technology is often viewed as a way of addressing barriers. However, little is known about how disability is approached in such research and the purpose of sport that is afforded to disabled people. We address this issue in a review of 60 publications in the field of Human-Computer Interaction. We leverage Template Analysis in combination with Mueller and Young's lenses on virtues of sport to also explore the experiential side of sports technology for disabled people. Our results are threefold: (1) We show that disability shifts the intended purpose of sports technology away from leisure to health, and that technologies such as exergames are viewed as an opportunity to replace real-world sport to address barriers and increase motivation. (2) We highlight that in(ter)dependence plays a strong role in technology development, but that disabled people are not extensively involved in research. (3) We show that virtues beyond health as per Mueller and Young do apply to existing work, but that value frameworks need to be re-worked in the context of disability, placing a stronger emphasis on sport as leisure, and the enriching role that technology can play.

CCS Concepts: • **Human-centred computing → Accessibility**;

Additional Key Words and Phrases: Disability, sport, literature review, virtues

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1 Introduction

Sport is a popular leisure activity, and provides many benefits, including improved health, social bonding and plain enjoyment [24, 127, 145]. Yet, despite many efforts to ensure equitable access to sport as leisure (e.g., see Article 30 of the **United Nations Convention on the Rights of Persons with Disabilities (UNCRPWD)** [1]), disabled people frequently experience barriers to sport and are forced to forego benefits [15, 57].

The **Human-Computer Interaction (HCI)** community has suggested leveraging digital technology to increase access to sport and to foster the inclusion of disabled people in physical activity (e.g., [4, 39]). However, little is known about how disability is approached in such work and the purpose of sport that is afforded to disabled people: whether systems primarily focus on health outcomes (as observed in other work exploring accessible technology [133, 148]), whether disabled

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people play an active role in the development of sports technology (which remains an issue in accessibility research more widely [75]) and whether technology also supports an experiential perspective on sport as engaging leisure and source of pleasure [143]. A holistic perspective on sport may complement health as the primary purpose [101], possibly better representing disabled people's values, preferences and interests [148].

To address this knowledge gap, we provide a systematic review of the literature in the field of HCI, disability and sport. Thereby, we seek to provide an overview of existing research efforts, while pairing it with a critical perspective on the way disabled people are involved in and addressed by research and the purpose of sport that is offered to disabled communities for its role as leisure. In this context, we draw upon Mueller and Young [101]'s *10 Lenses to Design Sports-HCI*[1], which provide us with an experience-centric lens on sports technology that prioritises virtues, i.e., '*desirable disposition[s], [...] tendenc[ies] to do the right thing in the right time and place*' [101]. By leveraging Mueller and Young [101]'s lenses, we emphasise the relevance of the experiential domain also in the context of disability, thereby moving beyond predominantly health-oriented perspectives on sport and disability (see Section 4.3).

Through this research approach, we seek to answer the following **Research Questions (RQs)**:

RQ1: What is the perspective of HCI research on disability and sport, and what kinds of contributions are made by existing work?
RQ2: How does existing work relate to Mueller and Young [101]'s 10 Lenses to Design Sports-HCI, and how would the lenses need to be expanded to facilitate the design of equitable and enriching sports experiences for disabled people?

Our approach comprises a systematic retrieval of literature, followed by a thematic synthesis. We follow the PRISMA 2020 [108] guidelines for reporting, and leverage Template Analysis [137, Chapter 25] for a qualitative analysis of 60 publications in line with our RQs.

Our results are grouped into three main areas: (1) perspectives on disability and sport expressed through research focus and technological artefacts, (2) involvement of disabled people in technology design and evaluation and (3) the virtues and experiential dimension of sport. Results show that besides efforts to design exergames and technologies for independent and community sport, health is a main focus of research, taking priority over other aspects such as enjoyment. Additionally, various communities are unequally represented and in some cases, research still relies on non-disabled stakeholders, highlighting the need for broader inclusion of disabled communities in research. Yet, though there is a substantial bias towards health-based motives, our analysis leveraging Mueller and Young [101]'s framework shows that certain virtues are also considered in sports technology for disabled people, including lenses such as pleasure, humility or oneness. Expanding beyond the framework, we further note that aspects of community play a central role in the corpus and, thus, need to be incorporated in the discussion about the experiential side of sport and disability.

Our article makes the following four main contributions:

(1) We provide an overview of the state of the art in SportsHCI for disabled people, and we highlight that health is a dominant motivation of research despite a lack of consultation of disabled communities. However, there are efforts to design for the experiential side of sport, centring exergames and the connections between people.
(2) We further detail the conceptions of disability in the context of sport, and we outline how technology promotes different perspectives, i.e., the medical and social model of disability.

[1]In this article, we will, however, use the term SportsHCI as recently employed in [26] to refer to this research community.

(3) We add an analysis of virtuous aspects in sports technology for disabled people that showcases the potential of research towards experience-based objectives and suggest avenues for expanding existing frameworks.
(4) We provide a structured overview of opportunities for future work for sports technology in HCI that addresses broad groups of disabled people and moves beyond medical perspectives on disability and sport.

Our work seeks to add to the growing body of research in accessibility and SportsHCI, providing reflections on the matter that we hope inspires work in both communities.

2 Background

To lay the foundation for our review, we address the general concept of sport, outline perspectives from disability studies and contextualise these within sport. Further, we summarise research in SportsHCI, including Mueller and Young [101]'s framework which we use as lens for the analysis in this review.

2.1 The Concept of Sport

The concept of sport can be viewed from different perspectives. The most basic one discusses it from the angle of physical activity, which Caspersen et al. [16] define as '*any bodily movement produced by skeletal muscles which results in energy expenditure*'. This physical activity can then be approached from a range of angles, e.g., occupational physical activity or physical activity in the context of leisure [16, 60], where people engage in physical activity for recreational reasons.

Defining sport, however, entails a more complex discussion about its philosophy. For instance, Suits [135] situates it within the concepts of (non-digital) *games* and *play*, and relates amateur performances to the intersection of sport and play and professional athletics, such as the Olympic Games, to the one of sport and games. Likewise, Parry [109] elaborates on the definition of sport and base their essay on Olympic sports, seeking to derive values that shape the concept of sport in general, such as formal competition. Specifically when viewing sport through the lens of professionalisation and competition, the boundaries between work and leisure are blurred [19].

In the context of disability, sport can also be viewed as leisure or competition (e.g., see [74] and events such as the Paralympics [132]), but it often carries a health-related component in the context of therapy and rehabilitation (e.g., [82]), an aspect which we address in more depth in the following section. Moreover, the varying physical abilities of disabled people may require a nuanced perspective on the concept of sport that allows us to question normative definitions, and instead, focus on individual accounts.

2.2 Models of Disability Revisited in the Context of Sport

To further explore sport in the context of disability, existing models of disability offer a useful lens. Thereby, different perspectives on disability can be described, for example, leveraging the medical, psychological, social or human rights model of disability. Brittain and Beacom [14] provide a particularly suited summary of how these can be applied to different aspects of Paralympic sports (also see Table 1).

The *medical model* views disability as pathological: Using medical language, disability is described as an illness that is not *normal* and needs to be cured. Marks [79] relates to disability in the context of this model as 'any restriction or lack of ability to perform an activity in the manner or within the range considered *normal* for a human being' (also see [139]). While it can offer a useful lens in a healthcare context, this model is criticised for its application outside thereof. For instance, various facets of the Paralympic Games are criticised [13, 114]: The existence of both Olympic

Table 1. Four Models of Disability in the Context of Sport Adapted from [14] and [79]

Model	Meaning	Application in sport
Medical model	Disability is the lack of ability resulting from impairment to perform an activity within the range considered normal for a person [139].	Paralympic movement
Psychological model	Cognitive factors shape disability. The *dis*ability of the individual results from failure to adjust to their impairment [79].	Lacking motivation for exercising to improve symptoms
Social models	Disability is not caused by impairment but by the social barriers that people with impairments come up against in every arena [129].	Accessibility of sports facilities
Human rights model	The UNCRPWD and its eight principles guide how disability is understood, what actions need to be taken and how damage for disabled people can be undone [1].	The right of participation in sport

and Paralympic Games promotes a segregation between disabled and non-disabled people [9, 93]. The Paralympic Games focus on impairments and, in their classification, rely on pathology and communicate medical views of disability [14]. They further support a misrepresentation of disabled people [13], e.g., as role models who can achieve goals despite what is framed as deficit, hiding the lived experiences of many individuals in the community [69].

Similar to the medical model, the *psychological model* also views disability from the perspective of the individual, but accounts for the 'cognitive and emotional factors shaping illness or disability' [79]. In particular, it focuses on the individual and their 'failure to adjust, and overcome an impairment' which still puts the burden on the disabled individual [79], e.g., when assuming their lack of motivation impedes the improvement of the impairment-related symptoms with sport.

Contrary to these individual perspectives, the *social model* describes disability as a result of environmental and social barriers rather than a characteristic of the individual [129]. In the context of sport, such barriers can be inaccessible sports facilities (e.g., a lack of wheelchair access due to stairs), or a design of sports activities not suited for disabled people (e.g., loud music at a fitness studio may be difficult for autistic people). Combining multiple perspectives, the *biopsychosocial model* incorporates these different facets: Engel [27] asserts that biological, psychological and social factors need all to be considered to understand disability.

Brittain and Beacom [14] ultimately relate sport to the *human rights model* of disability. This model originated from the eight principles of the UNCRPWD [1]. Specifically, it views participation in sport as usual activities of citizenship. Instead of categorising it as 'special needs', it discusses physical activity as a human right [20, 90].

Consequently, these perspectives manifest in the design of sports technology, e.g., by leveraging it as a rehabilitation tool or facilitator of inclusion. This underlines the relevance of an extensive analysis of publications that critically reflects upon how we view sports technology when designing for disabled people.

2.3 HCI Research on Technology and Sport

The HCI research community has addressed sport from a variety of perspectives. Here, we provide an overview of existing research targeting broad audiences without an explicit focus on disability. Through examples, we highlight research directions regarding the type of sport and its purpose, including recently proposed conceptual frameworks. We close with virtuous sports technologies and Mueller and Young [101]'s framework which we will further discuss in the review.

2.3.1 Developing and Evaluating Sports Technology. HCI research broadly explored sports technology for non-disabled persons. For example, systems were developed for endurance disciplines like running [100], cycling [144] or swimming [62, 80] but also team-sports like handball [55, 73], basketball [17] or cricket [59], and adventure sports or sports with smaller audiences, such as climbing [56], skiing [46] or martial arts [18]. There is a broad range of goals that these systems claim to achieve, including socialising among athletes, providing assistance during training, improving the performance of athletes or making a sport safer: Mueller et al. [98, 100, 102] introduced systems that focus on social aspects of sport, such as exercising together remotely. Jensen et al. [55] developed a system that helps handball players train their ball-throwing skills using an interactive installation. Slackliner, another training assistant, helps people practice their balancing skills on a slackline [67]. Kiss et al. [62] developed swimming goggles that display the current orientation in the pool to the swimmer, helping them to maintain a straight line and swim at a faster pace. Such contextual information can also contribute to a safer experience. Niforatos et al. [106] proposed a smart skiing helmet that presents the skier with additional cues to detect when someone is approaching from behind, and thus, aims to minimise accidents on crowded slopes.

Further, sports technology can also be discussed through the lens of games. Many sports already contain playful elements, especially team sports, such as basketball, handball or the European and American games of football. While these games usually do not require technology to be played, exergames, i.e., games that deliberately require physical effort [98], on the other hand, depend on it. However, in contrast to traditional sports, exergames are usually only a suitable choice for light and medium energy expenditure, and thus, may not be a tool for intense exertion [81, 110].

Concerning specific user groups, HCI research has previously engaged in the development of systems for distinct audiences. For example, a large body of work has explored technology to motivate physical activity among older adults [33], and game-based systems in particular have been examined as an opportunity to engage children in physical activity [11, 125]. Research outcomes suggest that certain user groups benefit from adaptations, but that individual backgrounds need to be taken into account (e.g., in the case of older adults and their perspectives on technology to motivate activity [150]), an aspect that is also relevant in the context of disability.

2.3.2 Frameworks for the Design of Sports Technology. The SportsHCI community proposed frameworks and discussed various aspects of sports technology, guiding both technology design and analysis. Such frameworks address general sports technology [113], as well as more specific systems such as wearables [141], exergames [103] or acoustic devices [122]. Some discuss specific types of sport, such as cycling [88]. Other frameworks assess sports technology within its broader purpose: Foundational work by Elvitigala et al. [26] crafts grand challenges in the field of SportsHCI, including an argument for the inclusion of disabled people in research on sports technology.

Leveraging a philosophical perspective on sport, Mueller and Young [101] contribute a framework that comprises a set of lenses to reflect on the design of virtuous sports technology [101, 104]. They draw upon a philosophical account to explore the design of sports technology and how people

Table 2. Overview of the 10 Lenses Suggested by Mueller and Young [101]

Lens	Short description in [101]	Example in sport
Reverie	Appreciate a void	A walk in the woods
Pleasure	Finding pleasure in exertion	Enjoying achievements
Humility	Become humble	Among superior athletes
Sublime	Enjoy the stimulation that comes from fear	Open water swimming
Oneness	Be more aware of one's own body	Yoga
Sacrifice	Value sacrifice as a chance for a simpler existence	Intense training
Beauty	Bring beauty into the world through movement	Dance choreography
Pain	See benefit in pain	Boxing
Consistency	Foster consistency for life	Regular exercise
Perseverance	Welcome patience	Comeback after injury

will use it, reflecting on research efforts in sports science that seek to foreground experiential qualities of sport (e.g., see [112] on pleasure and physical activity). Here, the assumption is that technology can serve a predefined purpose, but may also shape the way sport is experienced [26]. Mueller and Young [101] explicitly distance themselves from a health-related focus on sport, i.e., the improvement of personal fitness and the prevention of negative health outcomes, and instead focus on a broader range of experiences that sport can provide (see Table 2 for an overview).

Overall, the lenses highlight virtuous aspects of sport, and the authors draw implications for the design of interactive technology. Applying their framework allows us to examine the purpose of sports technology beyond health, focusing on experiential aspects of the activity.

3 Method and Corpus

We document our corpus construction process using the PRISMA 2020 [108] method and describe how we apply Template Analysis [137, Chapter 24] for the analysis of the corpus to answer the RQs. To provide additional context for the analysis, we also add a description of the corpus regarding publication history and outlets, and we present key characterisations, including a summary of the communities of focus and types of technologies discussed.

3.1 Corpus Construction

Following the PRISMA reporting guidelines [108], we describe the main phases of the corpus construction process (see Figure 1 for the core of that process).

3.1.1 Identification. Records were identified from the ACM Digital Library Guide to Computing Literature[2] database. We opted for this database in line with previous work (e.g., [134, 138]) as it covers many venues relevant to HCI. We ran a search query on the abstract, title and author keywords of each publication since pilot queries on the full texts yielded too many false-positive results. The search keywords were sport- ('sport', 'athlete', 'physical activity') and disability-related ('accessibility', 'disability', 'impairment', 'assistive technology'). We selected the sport-related keywords upon a pilot search that involved snowballing on publications that were previously known to us. At this stage, we decided to exclude the term *exercise* as it produced a large amount of false-positive results, while relevant publications also made use of other terms (e.g., *sport* or *physical activity*) and therefore still showed up in our search. To only retrieve disability-related publications, we included

[2] https://libraries.acm.org/digital-library/acm-guide-to-computing-literature

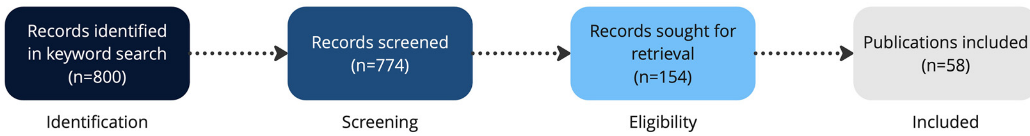


Fig. 1. Depicting the core of the PRISMA [108] record selection process.

the search terms proposed by Mack et al. [75] in their literature review. To combine both parts, our search query comprised two components, separated by an *AND* operator (see Appendix A). This final query was run on 26 October 2023, and yielded 800 results, including 26 duplicates.

3.1.2 Screening and Eligibility. Before screening, both authors discussed the characteristics of papers that would be included in the final corpus. When compiling a list of **Inclusion and Exclusion Criteria (IC/EC)**, we did so through our original exploration of the concept of sport (see Section 2.1) and the RQs. This translated into the following IC/EC criteria:

We included items that

- make a contribution in the context of sport (IC 1)
- include disabled people explicitly in their target group (IC 2)
- focus on interactive technology (IC 3)

We excluded items whose context of the contribution

- views sport solely in an instrumental, for instance, medical way, e.g., in the context of rehabilitation or therapy (EC 1)
- is watching, listening to or supporting sport in a way that does not require any involvement in the activity itself, e.g., provides blind people audio descriptions of football games (EC 2)
- is not a sport that requires substantial physical skill or effort, ensuring that this was reviewed against the community of focus and the context (e.g., acknowledging that chess can induce substantial effort for people with limited mobility and may therefore, in certain contexts, be considered a sport requiring physical activity) (EC 3)
- is exclusively technical and does not take HCI into account, e.g., machine learning algorithms for improved Paralympic athlete classification systems (EC 4)

Further, we excluded items that

- are neither a full paper, journal article, short paper, nor extended abstract (e.g., books that do not present original work or magazine articles) (EC 5)
- we could not retrieve a full text for even after contacting the authors (EC 6)

First, we screened for EC 5 and excluded 186 items. Then, the first author read the title and abstract of the remaining 588 items and excluded those items that did not match any of the criteria. If exclusion could not be decided by only considering these parts of an item, it was marked for further reading, i.e., the first author then read as much of the item as necessary to decide if it could be included in the final corpus or not. During this process, IC 3 and EC 4 were added as some of the items in the selection did not make a contribution in HCI, i.e., the actual interaction with technology was not addressed. Additionally, EC 1 was rephrased to not only exclude items that made their contribution in health-related areas, but any item that only views sport as instrumental. This, for instance, includes a paper by Hey et al. [49] that focuses on educational aspects during the development process of assistive sports technologies but does not focus on how disabled people use and experience them. After the final criteria were adjusted, the first author once more applied these criteria to the items already screened.

A decision for inclusion was made for 53 items. Thirteen items that could neither be included nor excluded in this phase were marked as *to be discussed*. The second author then read the full text of these items as well. A decision on the inclusion was made after both authors discussed the items, ultimately including five of them.

3.1.3 Included Items and Other Sources. A selection of 58 items was compiled during the screening process described above. In some of these items, the authors referred to previous publications in the context of the same project. We found two such publications [5, 91] that qualified for the IC and EC, but were not identified with our search query. Following a discussion among both authors, the items were added to the corpus as consulting previous research would help answer the RQs for a given project with higher confidence. Thus, the final corpus includes 60 items (also see Table B1 in Appendix B).

3.2 Corpus Analysis

Our understanding of disability and sport is informed by frameworks such as the models of disability described by Marks [79] and Brittain and Beacom [14] as well as Mueller and Young [101]'s 10 lenses, and we further established an understanding of the definition and purpose of sport for disabled people (see Section 2.1). In that, our approach was guided by existing concepts which we included as *a priori themes* in the analysis. The notion of *a priori* themes is described by King who presents Template Analysis as a flexible technique to do Thematic Analysis [137, Chapter 24]. In the following, we summarise this technique and outline how we employed it in the analysis of the corpus regarding RQ1 and RQ2.

3.2.1 Template Analysis. Template Analysis is usually guided by *a priori* themes that can be informed by underlying theoretical frameworks (such as [79] or [101]) or researchers' experience in a field. In an early phase, an initial template is developed by assigning codes to a subset of the data, e.g., 15% of the items in the corpus. During that phase, the initial template is modified iteratively, i.e., (*a priori*) themes may be inserted, deleted or merged and the template's structure and scope may change. After this phase, all the data are analysed and changes to the template are still possible. King therefore describes this approach as a combination of deductive and inductive techniques [137, Chapter 24]. He argues its distinction from Braun and Clarke's initial proposal of their style of Thematic Analysis [12] by outlining the flexibility of the coding structure, the use of *a priori* themes and the use of an initial template.

In the application of this technique for RQ1 and RQ2, we started with a discussion on *a priori* themes that was guided by theoretical frameworks, such as [14, 79], and [101]. The first author then proceeded with the initial coding of the items in the corpus, applying the *a priori* themes. For example, the theme *medical perspective on disability* [14] was further developed into more specific codes, e.g., *sport as treatment of underlying conditions* and *deficit-based language* were inserted into the initial template. In contrast to such deductive themes, others were developed inductively. For example, codes related to games were folded into *accessible virtual environment in exergames* and *exergame against sedentary lifestyle* and then inserted into the template. Following the development of this initial template, to ensure quality checks, both authors discussed its content and adapted it for the coding of the whole corpus. During the entire process, we further developed the template and regularly discussed the interpretation of themes. In case of changes to the template, the first author re-applied it to the corresponding parts of the corpus.

3.2.2 Positionality Statement. Carrying out qualitative analysis requires the researcher(s) not only to reflect on the applied method but also on their individual positionality and how it influences their work. To give the reader a better grasp of our position, we provide the authors' backgrounds that shaped this part of the contribution. This includes a reflection on our privileges, experiences with

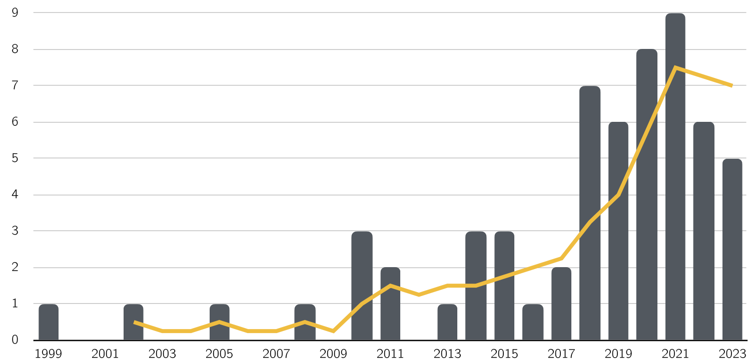


Fig. 2. Histogram of publication years for all items in the corpus. The trendline shows a moving average over 4 years.

marginalisation, relation to sport and the theoretical lenses that further influence our perspective on this work.

Both authors were born and exclusively worked and lived in countries that can be categorised as western, educated, industrialised, rich and democratic [47, 71], and they do not belong to an ethnic minority. They identify themselves as physically disabled and neurodivergent, but in general, they consider themselves privileged. This also influenced their perspectives on disability, particularly, their subscription to the human rights model of disability. Both regularly engage in physical activity and live in environments that facilitate this, i.e., cycling, swimming, climbing, or walking. The first author has done different sports in the past when they did not have a disability; however currently, they are exercising with a physical impairment. They associate physical effort with the definition of sport but acknowledge that this can vary depending on the athlete's abilities. Despite exercising for physical health playing an important role in the life of the first author, they also assign other meanings to it, such as fun, mental recreation and social factors. In contrast to them, the second author does not engage in structured sports activities and instead integrates physical activity into their daily life as they are not particularly fond of sport as a hobby.

3.3 Corpus Description

The following sections describe key characteristics of our corpus. Section 3.3.1 outlines the publication history and outlet venues. The then following parts characterise the corpus regarding the types of research (Section 3.3.2), sport (Section 3.3.3), types of technologies (Section 3.3.4), as well as the communities of focus (Section 3.3.5). We acknowledge that these parts reflect the perspectives of the first and the second authors. If available to us and applicable, we leveraged categories from related work. For all characteristics, the process was the same: The first author suggested a categorisation. In some cases, both authors discussed the assignment of publications to increase confidence.

3.3.1 Publication History and Outlets. This section presents the results of a computational analysis of the final corpus with 60 papers spanning 25 years from 1999 until October 2023. Figure 2 shows that there was an overall trend of increasing numbers of publications in the last decade. The years 2022 and 2023 (until October), however, show a downward trend in publications that could be explained by researchers and disabled people adapting to the COVID pandemic (cf. [36]).

The items included in the corpus were published at 24 different outlets. Table 3 shows the most popular ones ranked by their share of the corpus. With 18.3% of all items, ASSETS was the preferred conference followed by CHI and HCII with each 13.3%, respectively. In addition to ASSETS, ICCHP, which also has a focus on accessibility, was the fourth most popular outlet for researchers in the

Table 3. List of Publication Outlets Appearing At Least Twice in the Corpus

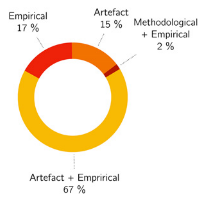
Acronym	**Name**	#	%
ASSETS	International ACM SIGACCESS Conference on Computers and Accessibility	11	18.3
CHI	CHI Conference on Human Factors in Computing Systems	8	13.3
HCII	International Conference on Human-Computer Interaction	8	13.3
ICCHP	International Conference on Computers Helping People with Special Needs	6	10.0
AH	Augmented Human International Conference	3	5.0
DIS	Designing Interactive Systems Conference	3	5.0
CHI PLAY	Annual Symposium on Computer-Human Interaction in Play	3	5.0

field of HCI, disability and sport (10%). Finally, AH, DIS and CHI PLAY (each 5%) also appeared more than once in the corpus. Except for one journal article, all items were published at conferences. With 40 publications (66.7%), for the majority of items, ACM was the responsible publisher, followed by Springer (26.7%) and IEEE (3.3%). Concerning conference papers, we included both full papers and extended abstract formats, because they represent the research landscape, and especially preliminary work representing a focus on research is published on these tracks.

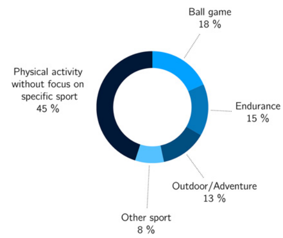
3.3.2 Contribution Types. We applied the taxonomy by Wobbrock and Kientz [149] and categorised the publications in the corpus accordingly (see Figure 3(a)). Overall, 82% introduced an artefact. The majority of these additionally provided an empirical contribution (82% of artefact contributions), for instance, as an artefact evaluation study (e.g., [53, 54]); 17% had no artefact and only an empirical contribution. One paper [115] described how participatory design could be leveraged to design a tennis ball for blind players and, thus, also provided a methodological contribution.

There were various kinds of user studies which were often heterogeneously described, including pilot studies (e.g., [44]), preliminary studies (e.g., [29]) or studies with a more rigorous method and analysis outlined (e.g., [53, 61, 87]). Further, there exist extensive and short documentations of user studies. For instance, Torrado et al. [140] report on a three-step user-centred process including expert interviews, focus groups and a pilot study. However, they do not detail their methods nor do they provide a detailed analysis of the results. On the other hand, Mason et al. [87] also conducted multiple studies and offer detail on method and analysis. Due to this plurality of methods and documentation, we argue that classification requires much interpretation and strongly underlies the subjectivity of both authors. To contrast this from the other categories provided in this subsection, we do not report on numbers related to participant characteristics or specific methods. As a response to said degree of interpretation, we instead include these considerations in our qualitative analysis.

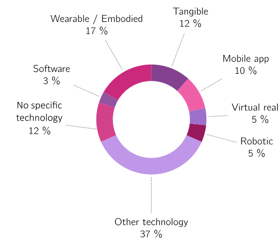
3.3.3 Types of Sport. Concerning the types of sport covered within the corpus (see Figure 3(b)), we found that most of the research in our corpus did not focus on a specific sport (45%), i.e., addressed sport and physical activity in general. This comprises, for instance, new sports which were often created in the context of exergames: For example, iGYM is a system that is inspired by (air-)hockey [39, 40], and Pet-N-Punch mimics a whack-a-mole game with physical input [96]. Additionally, we found generic artefacts that are designed to help people to be more physically active [29, 32], or requirement analyses on sport and disability in general [61, 87]. Apart from these, the most popular types of sport were *ball games* (18%), including, for instance, tennis [94, 115] or goalball [91, 146]. Further, 15% of the research addresses *endurance* sports, such as swimming



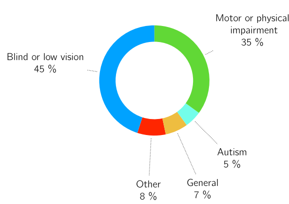
(a) Contribution types [149] in the corpus.



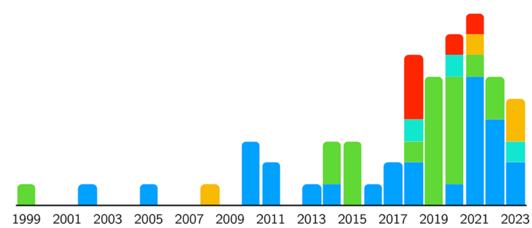
(b) Types of sport in the corpus.



(c) Technology types of focus in the corpus.



(d) Communities of focus in the corpus (cf. [75]).



(e) Communities of focus in the corpus under consideration of the publication history from Figure 2.

Fig. 3. Characterising the corpus regarding contribution types, types of sport, types of technologies and communities of focus. Percentages are rounded.

[36, 97] or walking and running [53, 116]. *Outdoor* and *adventure* sports, such as climbing [64, 118] or skiing [2, 4], represent 13% of the corpus. *Other* sports (8%), for instance, include dancing or aerobic and fitness exercises [34, 76, 77, 128].

3.3.4 Types of Technologies. We categorised the publications in our corpus in terms of technologies (see Figure 3(c)). A total of 17% focus on *wearable* or *embodied* technologies while an additional 10% discuss a *mobile app*. *Tangible* systems represent 12% of the corpus. Further technologies include *robotic* (5%), ***Virtual Reality* (VR)** (5%) and *software* (3%) contributions. The latter comprises, for instance, a taxonomy that will be implemented in automated text analysis [77]. A total of 37% of all publications describe research with *other* kinds of interactive systems not included in the above categories. Many of these systems contain motion-capturing components to measure wheelchair movements [40, 50] or ball trajectories in blind sports [91, 120]. This category also includes console and gaming-inspired technology (e.g., [94, 95]). Finally, 12% did not focus on an explicit type of technology, e.g., Khurana et al. [61] investigated general technology use for accessible sport with a focus on analytics.

3.3.5 Communities of Focus. The corpus covered a range of disabilities (see Figure 3(d) and (e)). We grouped publications regarding the categories introduced by Mack et al. [75] since we have also used their disability-related keywords in our search term. Similar to their findings, there is a large proportion of publications in our corpus that addresses people who are blind or have low vision (45%). People who have a *motor or physical impairment* are the second most researched community (35%). Interestingly, the corpus does not contain any research that specifically addresses people who are *deaf or hard of hearing*, which represents the third largest group of publications in the review by Mack et al. [75]. The *autism* community was addressed in 5% of the corpus and *other* communities, including *cognitive* disabilities and *intellectual or developmental disabilities*, comprised 8%. Additionally, 7% of research in the corpus did not address specific communities and rather considered *general disability or accessibility* issues.

4 Results

In the following, we present themes and sub-themes that were crafted through Template Analysis. We group our results with respect to the RQs. Sections 4.1 and 4.2 present results related to RQ1, i.e., *What is the perspective of HCI research on disability and sport, and what kinds of contributions are made by existing work?* Section 4.3 relates to RQ2, i.e., *How does existing work relate to Mueller and Young [101]'s 10 Lenses to Design Sports-HCI, and how would the lenses need to be expanded to facilitate the design of equitable and enriching sports experiences for disabled people?*

4.1 Perspectives on Disability and Sport Expressed through Research Focus and Technological Artefacts

Here, we discuss how HCI research approaches sport in the context of disability. Main themes address shifts in the purpose of sport, the creation of new and game-based sports as a means of addressing real-world barriers and the role of in(ter)dependence and participation when creating SportsHCI systems for disabled people.

4.1.1 Theme: Disability Shifts the Intended or Perceived Purpose of Sport. The design of sports technologies is approached differently for disabled people as distinct requirements are established or assumed. Research in our corpus suggests that sport often functions as a tool for therapy and as a means of social inclusion, which displaces other central meanings [126]. We illustrate this shift by describing two sub-themes that we crafted in our analysis. First, as a response to an impairment-centric view on disability that relates to the medical model, researchers present sport as part of therapy to treat or prevent disability-related health issues. Second, researchers adapt perspectives within social models of disability. They focus on barriers that prevent participation in sport. Therefore, technology is viewed as a means to improve social inclusion. Throughout the corpus, however, authors rarely make explicit reference to any models of disability that were adopted. An exception is the research by Alsaleem et al. [6] and Ando et al. [7] who take a position within the ICF model of disability[3], highlighting the multifaceted dimensions of disability, e.g., biological, psychological and social (cf. also [27]).

Sub-Theme: Sport as Therapy. The work included in our corpus suggests that sport is often leveraged as therapy to improve the health of disabled people, or to prevent further deterioration of disability-related health issues. Such deficit-based perspectives of disability can promote the medical but also the psychological model of disability, and primarily situate sport among treatments of the underlying disability, e.g., to '*[change] the behavioural characteristics of autism*' [72]. However, through this perspective, different purposes and experiences of sport can be neglected. *It associates sport for disabled people with therapy and rehabilitation instead of granting them access to the many other benefits of it.* Despite the criticism of medical perspectives from critical disability studies [43, 79], leveraging sport as therapy appears to be a main objective in the corpus, with a slight downward trend from 2020 (see Figure 4).

The medical model may manifest in the motivation, choice of language or technology design. Motivating research with the prevention of diseases (e.g., [95, 140]) can introduce a medical focus

[3] https://www.who.int/standards/classifications/international-classification-of-functioning-disability-and-health

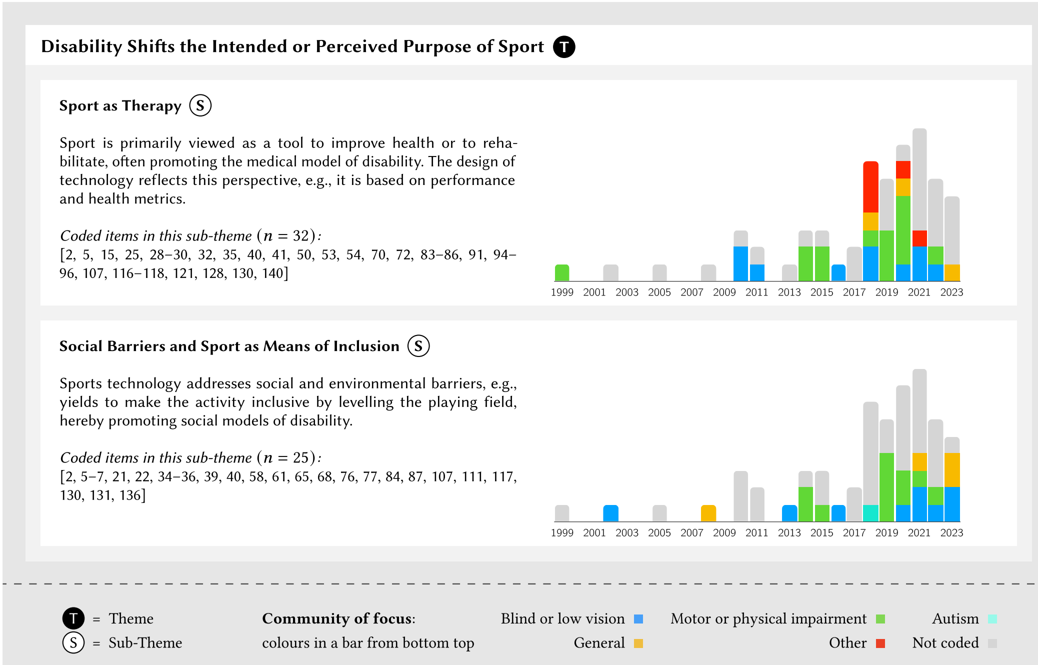


Fig. 4. Thematic overview of the theme *Disability Shifts the Intended or Perceived Purpose of Sport*. Included are all the items coded within the sub-themes along with bar plots showing their publication history.

on sport. Likewise, medical and deficit-based language, such as a comparison between disabled and '*healthy*' people [29, 70] further contributes to this. Finally, these perspectives can be reflected in technology design. For instance, prototypes are evaluated or refined based on physiological parameters such as heart rate [32], potentially neglecting non health-related benefits of the activity that would have focused on improving the user experience instead.

Sub-Theme: Social Barriers and Sport as Means of Inclusion. Leveraging social models of disability (see Section 2.2), sports technology can support inclusive group activities, create more accessible virtual worlds and provide a friendly competition between athletes and players regardless of disability. Several publications in the corpus implicitly adopt this perspective on disability by *presenting barriers as social constructs and enhancing inclusion through interactive sports technology* as objective of their research. Malik et al. [76, 77] investigate student-teacher communication to develop inclusive virtual aerobic classes for visually impaired people. Likewise, Doro Peres and dos Reis [22] implement a universally accessible mobile exergame. These contributions address aspects of the social model by attempting to remove the social barriers to group exercise. Similarly, exergaming often facilitates virtual worlds in which such barriers do not exist (also see Section 4.1.2). Here, the barrier regarding the lack of fair competition in sport with non-disabled peers was also addressed. Exergames can be customised to a high degree, and therefore, adapt to (non-)disabled players. For instance, unlike a real-world sport, a (virtual) puck can behave differently depending on who is interacting with it [39, 40].

Mason et al. [87] found that people using wheelchairs view '*social relationships [as] contributors and barriers to participation*'. Exergame players mentioned the difference in exercising or playing at the same location with people they already knew and strangers on the Internet. Especially, the latter

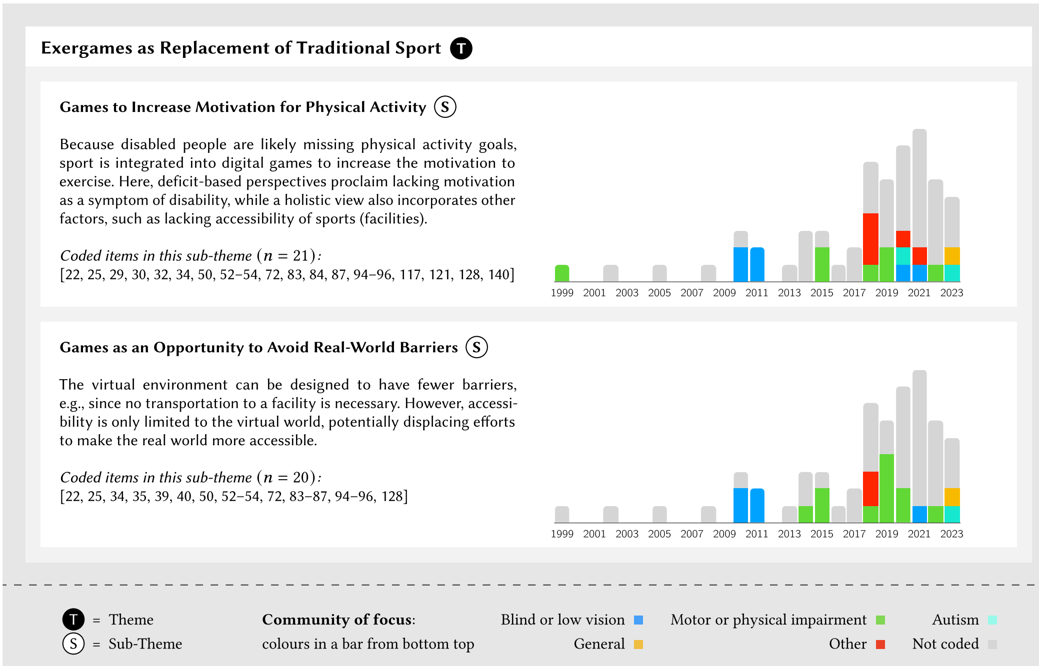


Fig. 5. Thematic overview of the theme *Exergames as Replacement of Traditional Sport*. Included are all the items coded within the sub-themes along with bar plots showing their publication history.

requires careful consideration of how to provide inclusion since communicating disabilities online is a controversial discussion (e.g., in social VR [152]). This may highlight one facet of shortcomings of the social model of disability in the context of sport.

4.1.2 Theme: Exergames as Replacement of Traditional Sport. Surprisingly, without an explicit focus in our search, a larger part of the corpus introduced or evaluated exergames or movement-based games, although the share of this research seems to have decreased recently (see Figure 5). For example, Mason et al. [84–87] and Gerling et al. [34, 35] research wheelchair-based exergames, and Morelli et al. [94–96] repurposed traditional exergames to make them accessible for people who are blind or have low vision. Two purposes were central to the authors' motivations: First, games were seen as a means of increasing motivation, and authors viewed them as a tool to help disabled people change potentially sedentary lifestyles. Second, games were seen as an accessibility opportunity as they are separate from the real world, thus introducing a controllable, virtual setting, in which real-world barriers can potentially be avoided.

Sub-Theme: Games to Increase Motivation for Physical Activity. Many researchers motivate their work by stating that disabled people in particular face unique barriers that hinder participation in exercise. Therefore, opportunities for physical activity are lacking, which leads to '*sedentary lifestyles*' (cf. [29, 50, 140]). They argue that this ought to be avoided in order to prevent negative health outcomes, and to achieve this, they propose exergames or movement-based games that aim to increase the motivation for individuals among various target groups. This includes people with learning disabilities or research that interpreted mental health conditions as disability [29, 30, 128, 140] and neurodivergent people [32]. Despite their prevalence in the corpus, the share of people who are blind or have low vision [117] and people with limited mobility [54, 84] is smaller in this sub-theme.

Francillette et al. [29, 30] and Senette et al. [128] adopt individual, *deficit-based perspectives* and *argue that a lack of motivation is a symptom of disability-inducing conditions*, especially among people who they describe in their own words as '*people with severe mental disorders [that] may have functional and cognitive impairment that can also affect their decision to start a more active lifestyle*' [29]. Adopting a more holistic perspective, Mason et al. [84] conducted interviews with the target group to broadly investigate into the design of playful technology for wheelchair users. Similarly, by organising participatory design workshops in which adolescents who are blind or have low vision *create and modify their own games*, Regal et al. [117] want to empower them as they believe that '*increase[s] long term motivation*' to exercise. The researchers also acknowledge that disabled people face societal and individual barriers that render exercise inaccessible (e.g., '*limited time or financial cost[s]*' [84]). To enable disabled people to exercise despite these barriers, therefore, these publications introduce playful technology and games to offer additional motivation. However, they did not study long-term effects. For instance, Regal et al. [117] state that '*a long-term effect [on physical activity] cannot be drawn*'.

Sub-Theme: Games as an Opportunity to Avoid Real-World Barriers. Exergames can provide adapted versions of sports in limited environments that can be designed to remove accessibility barriers, primarily those affecting people with motor or physical impairments (see Figure 5). Additionally, they facilitate exercising at home, which can reduce other barriers to sport experienced by disabled people. Barriers can be *primary and exist in the activity itself*, e.g., in tennis, which can be difficult to play for people who are blind or have low vision [94]. Additionally, there can be *secondary barriers such as transportation to sporting facilities, safety or high cost of adaptive equipment* (cf. [61, 87, 95]).

To remove primary barriers, physical effort that is required in the real-world activity can be adapted or removed in exergames. For instance, Ioannou et al. [54] designed '*a VR exergame that would be otherwise too difficult*' for people who the authors describe as '*players with reduced physical capabilities*'. They translate light exertion into enhanced avatar movement, facilitating adjustment to the individual player. Additionally, games can balance between players, reducing the barrier that people with different skills may find it difficult to exercise together or compete against each other. For example, Gerling et al. [35] discuss general considerations of balancing physical activities in exergames, and Graf et al. [39, 40] provide a specific exergame that requires ability-specific input for disabled and non-disabled players.

Secondary barriers can disappear in virtual environments as exergames have different meta-level requirements than real-world sports: If they are played at home, disabled people do not need to organise transportation which often represents a barrier to physical activity [87]. Safe exercising is primarily discussed in the context of people who are blind or have low vision. Morelli et al. [94–96] designed exergames for this group which '*may be safer to play and can be played without the help of others*' [95]. Compared to real-world bowling and tennis, their games can be only played at home and walking around is not necessary.

4.1.3 Theme: The Role of In(ter)dependence and Participation in Sport with(out) Others. Sport can be an individual or social activity. Accordingly, this social dimension can also be observed in accessible sports. We identified two main objectives in the corpus: First, sport is seen as an opportunity to foster community among disabled people, and among disabled and non-disabled people. Second, research explores the potential of technology to provide assistance in the context of sport, and strongly emphasises opportunities for independent participation in sport. This is reflected in our three sub-themes (also see Figure 6).

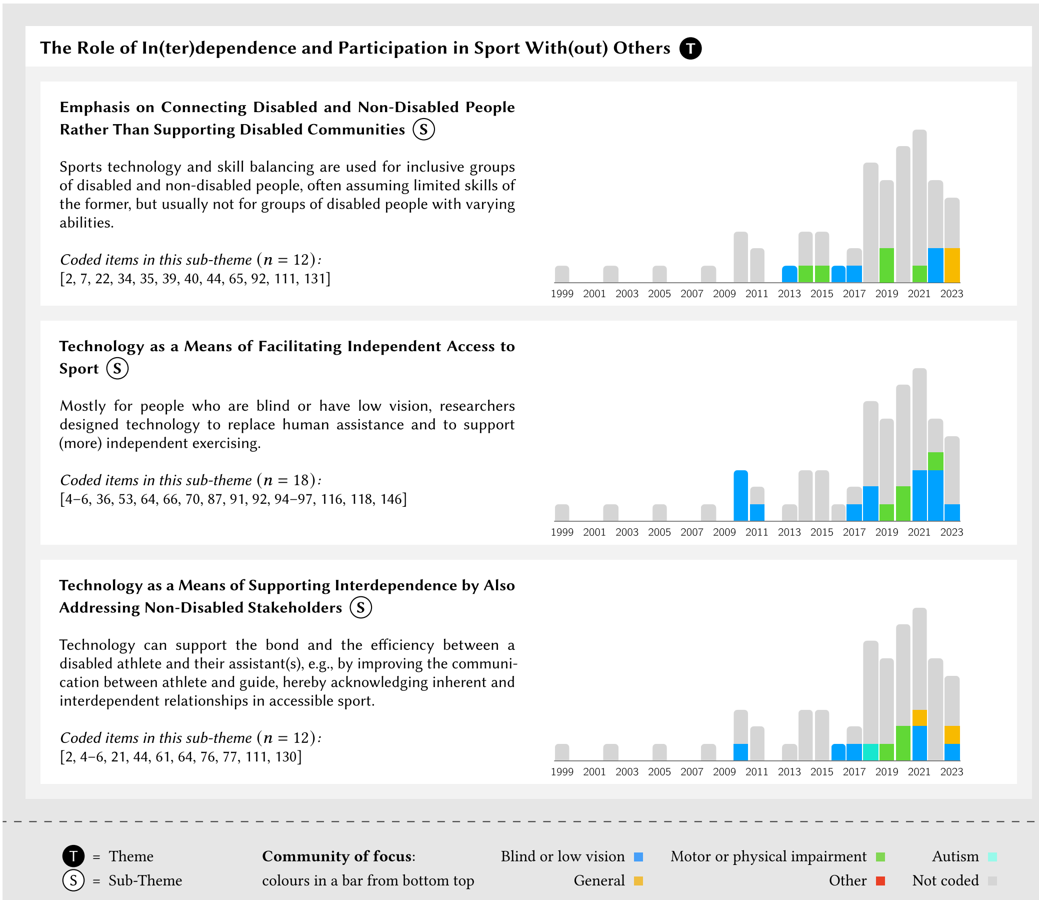


Fig. 6. Thematic overview of the theme *The Role of In(ter)dependence and Participation in Sport with(out) Others*. Included are all the items coded within the sub-themes along with bar plots showing their publication history.

Sub-Theme: Emphasis on Connecting Disabled and Non-Disabled People Rather Than Supporting Disabled Communities. A number of publications discuss enabling people with different disabilities to be active together, while some works focus on specific disabled communities only, e.g., people taking part in wheelchair basketball and rugby, or blind tennis [61, 115]. *Most of the work around sport in communities focuses on the inclusion of disabled people* in these activities. Such participation raises questions about inclusive competition, which often requires a way of *balancing abilities*. Here, digital technology was seen as an opportunity to level the playing field. For example, Gerling et al. [34] introduce a toolkit for movement-based games which can also be played together with non-disabled peers '*to empower persons with mobility disabilities and foster inclusion through shared experiences*'. Likewise, Gerling et al. [35] discuss effects of three '*balancing approaches*' (input, time, score) on (non-)disabled competitive player experience in exergames. Similarly, in their air-hockey-inspired game, Graf et al. [39, 40] vary goal size and ball shooting method for non-disabled players and players using an electric wheelchair. In contrast to that approach, Ando et al. [7] introduce a sport with specialised wheelchairs, which were used by all participants regardless of their abilities.

Interestingly, there was no publication in the corpus with a focus on competition with a diverse group of disabled people having different abilities who were members of the same team. The rules of blind football,[4] for instance, require goalkeepers to be (partially) sighted while other players are blindfolded. Kobayashi and Tatsumi [66] evaluated a training system for floor volleyball, which also has such different roles. However, their research only focuses on front-court players that have a visual impairment, not addressing rear-court players that may not be disabled [66].

Sub-Theme: Technology as a Means of Facilitating Independent Access to Sport. Throughout the corpus, there was a strong focus on technology that provides an opportunity to enable disabled people to access sport independently, i.e., without the assistance of non-disabled people. Research primarily focused on people who are blind or have low vision, but also spanned people with limited mobility (see Figure 6). For example, through interactive technology in adapted sports equipment, Alsaleem et al. [4, 5] implemented a '*shared-control scheme*' that lets tetraplegic people actively participate in skiing and sailing. The scheme to steer a sailing boat or skis reduces reliance on guides to situations where it is necessary or requested by the user.

Regarding people who are blind or have low vision, a typical research goal was to *improve non-visual feedback for orientation and navigation to reduce reliance on human guidance*. For instance, Miura et al. [91] and Watanabe et al. [146] developed a system that gives goalball players feedback on their motions, enabling them to train specific aspects of the game independently. Gibelli et al. [36] and Muehlbradt et al. [97] introduced wearable systems in swimming for blind people, yielding to replace the "tapper"[5]. Swimmers can receive feedback on their orientation in the pool and do not have to rely on assistance, for instance from tappers. Inspired by findings from their user study, in which Gibelli et al. [36] found that blind swimmers want to train '*autonomously*' while '*feeling safe*," they developed a tactile feedback-enhanced bathing cap that provides navigation cues to the swimmers, such as direction and distance to the wall. India et al. [53] and Rector et al. [116] explored walking and running. Rector et al. [116] discuss different feedback modalities to provide orientation and navigation cues for people running or walking on a track. However, in addition to that, both leverage environments that introduce fewer hazards to people who are blind or have low vision. Walking at home immersed in a virtual world [53] and exercising on a running track [116] are two options for avoiding real-world barriers in these activities, providing access to this sport without human guidance. They show that not only improving feedback orientation and navigation feedback could facilitate more accessible sports, but that simplifying its environment may also be helpful, however, at the cost of removing the facet of exploring and experiencing the outside world.

Sub-Theme: Technology as a Means of Supporting Interdependence by Also Addressing Non-Disabled Stakeholders. A significant share of publications, particularly from the last decade, also addresses non-disabled stakeholders in disabled sport, acknowledging that there are instances in which disabled people leverage the assistance of others for participation in sport (e.g., [2, 4, 61]). For example, we encountered systems that address coaches (cf. [61]), teachers (cf. [21]) or guides (cf. [2, 4]).

Within these projects, *supporting communication* was discussed as a key objective in the context of professional stakeholders giving instructions in non-visual channels for people who are blind or have low vision. For instance, Haladjian et al. [44] and Aggravi et al. [2] discuss haptic feedback communication during athlete-guide exercise. De Silva et al. [21] investigate how teacher-student communication can be improved with technology, and Khurana et al. [61] mention difficulty in remote coaching for disabled weightlifters.

[4] https://www.paralympic.org/blind-football/about
[5] A person standing at the end of the lane tapping swimmers when approaching it.

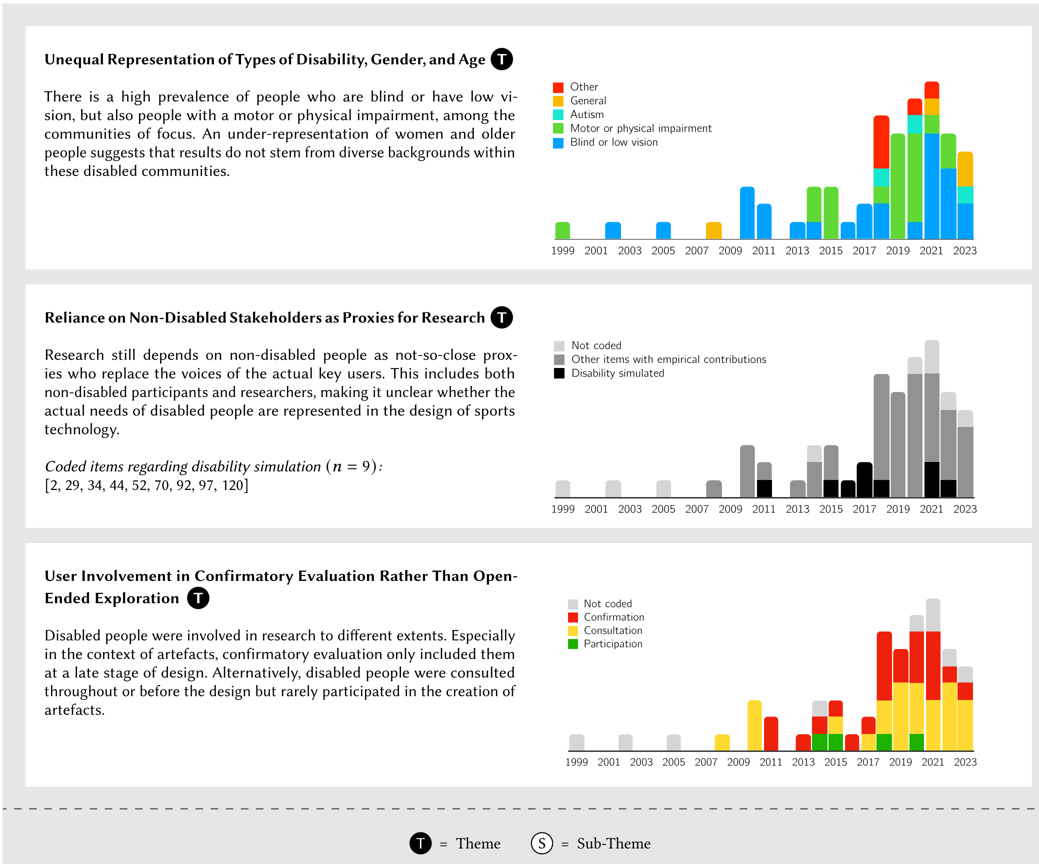


Fig. 7. Thematic overview of the results on themes concerning the *Involvement of Disabled People in Technology Design and Evaluation*, including select codings of the corpus.

Addressing non-professional settings, Alsaleem et al. [4–6] reflect on communication design in a shared-control situation where a full transfer-of-control to a disabled user is not possible. Along the same lines, they developed a shared-control adapted ski as well as a sailing boat where tetraplegic people and their assistants can share control over the steering mechanism, highlighting the potential for technology to support participation in those sports that can be difficult to access independently.

4.2 Involvement of Disabled People in Technology Design and Evaluation

Our research also examined how disabled people were involved in research in an effort to further explore how our research community views disability in the context of sport. Overall, we observed that not all types of disability were addressed evenly (cf. also [75]), that those user studies that did involve disabled people favored involvement of younger men, and that there are instances in which research on disability and sport continues to rely on non-disabled proxies while only involving disabled people in consultation (see Figure 7 for an overview).

4.2.1 Theme: Unequal Representation of Types of Disability, Gender, and Age. In our corpus, we observed an imbalance in the types of disability and groups of disabled people who were identified as audiences of interest: A large part of the corpus discusses sport and technology for people who are blind or have low vision, which is in line with the findings from Mack et al. [75] who report a high prevalence of accessibility research for that community. Here, researchers primarily present and discuss sensory substitution technologies, where vision is either substituted with auditory or haptic feedback. For instance, in swimming technology for blind people, Muehlbradt et al. [97] introduced a computer vision system that recognises "T"-shaped lines in a swimming pool. On their headphones, blind swimmers then receive information on location and direction. Gibelli et al. [36], on the other hand, implemented tactile feedback into a swimming cap to convey this information.

Likewise, the majority of studies in our corpus were conducted with an unbalanced sample of participants with respect to gender. In these cases, *women were usually under-represented, and participation of non-binary people was rarely reported*: Studies usually had more male participants or a balanced sample. Rarely, more women took part. For instance, De Silva et al. [21] reported that in their interview study, 14 women and 7 men participated. Furthermore, among a few publications, two non-binary participants were reported (e.g., [21, 86]). However, there is also a large set of publications that did not specify the demographic data of the participants.

Regarding age, children frequently appeared in studies and as target groups, but older adults rarely participated. But apart from specific research on sports technology for children (e.g., [94, 117, 130]), the majority of studies were conducted with adult users. Here, most studies did not include older adults, i.e., people aged 70 or older. Only Eisapour et al. [25] discuss physical technology specifically for older users. Possibly, research on this topic often has a focus on rehabilitation and therapy, i.e., topics we excluded from the keyword searches, or does not specifically identify as accessibility research.

4.2.2 Theme: Reliance on Non-Disabled Stakeholders as Proxies for Research. A large part of the research body included in our review relied on non-disabled people to conduct research. Apart from the researchers themselves, among which none positioned themselves as disabled in the publications, frequently only non-disabled stakeholders were in roles that allowed them to significantly contribute to the outcome of a project. Specifically, *a number of artefacts for disabled target groups were pilot-tested without disabled people* [29, 44, 92], *disability was simulated* in user studies [44, 70, 120], and some research consulted *stakeholders that were not the key users of resulting systems* [6, 22, 35, 130]. Generally, simulating disability, including the replacement of disabled people in pilot studies, continues to be applied in research, but with a slowing trend (see Figure 7).

In the case of pilot tests of protocols or artefacts, only few authors explained their choices or reflected upon the limitations of their chosen research approach. For example, Mason et al. [84] tested a questionnaire with non-disabled people due to '*population size*'. Sadasue et al. [120] reflect on limitations and how the '*higher spatial recognition abilities*' of '*visually impaired people*' affects the results, however, miss a discussion on how congenital blindness affects spatial recognition [123]. In certain cases where disability was simulated (e.g., via blindfolding people who were not blind or had low vision), researchers did not argue why they did not conduct their studies with disabled users [44, 70, 92]. Overall, this implies that disabled voices are not sufficiently included in many projects, limiting the insights that can be gained into the alignment of technological artefacts with the needs and preferences of disabled user groups.

However, it is also important to acknowledge that not all systems solely address disabled people, and the involvement of diverse groups of stakeholders should therefore be expected. For example, Gerling et al. [35] tested their design considerations with disabled people and their non-disabled peers who were supposed to compete against each other in their exergame. Alsaleem et al. [6] iteratively designed their artefacts and involved tetraplegic people as the main users but also medical staff and guides who collaborate with them on the sailing boat. Likewise, Sharma et al.

[130] talked to parents of autistic children as proxies who observed technology usage of their children. However, the use of proxies in research needs to be carefully appraised as it may introduce biases and shift focus away from the main users of a technology [119].

4.2.3 Theme: User Involvement in Confirmatory Evaluation Rather Than Open-Ended Exploration. Within the corpus, the extent to which disabled people were involved in research differed, particularly with respect to the influence that disabled people could exert over research focus and outcomes. Here, *the large majority of works with an artefact contribution involved disabled people in confirmatory user studies that were carried out once a specific system was designed.* In many of these cases, researchers designed and implemented prototypes of their artefacts and then invited disabled people to take part in lab [54, 96] or field evaluations [29, 130]. While some studies were carried out using qualitative methods, a substantial part focuses on quantitative measures or mixed-method approaches, measuring athlete or player performance [35, 91, 120] or assessing other aspects such as player experience [85] or intrinsic motivation [54].

In contrast, *work that involves disabled people at the design stages often does so through interviews, focus groups, or design workshops*, and the share of such work has recently become more prominent. For instance, De Silva et al. [21] and Carrington et al. [15] investigate state-of-the-art accessible sports technologies and derived design considerations for future improvements. Likewise, Gibelli et al. [36] leverage interviews in a more narrow context of swimming guidance for blind people and developed a prototype based on the results. Further, Mason et al. [84] conducted in-depth interviews to inform a broader survey addressing disabled people to gain insights into their perspectives on playful technology for physical activity. Additionally, some researchers involved users in *participatory design efforts*: Regal et al. [117] and Ratto et al. [115] leverage this method and let users design their interfaces for sport. Ratto et al. [115] analysed the design process itself, while Regal et al. [117] focused on prototypes that participants developed.

In some cases, disabled people were involved in the early stages of development. For example, Graf et al. [39] iteratively designed an air hockey-inspired exergame for disabled and non-disabled players, and started with an initial prototype in a pilot study. Results then motivated how their game was further adjusted, and the refined prototype was again tested with users. Similarly, Alsaleem et al. [4–6] iteratively designed their prototypes and frequently consulted their users. Since their shared-control system affected tetraplegic sailors and skiers as well as guides and medical staff, these stakeholders were all involved in the design process.

Finally, there are publications in our corpus that at no point involve disabled people, e.g., are fabrication-only [41], contribute systems [48, 58, 121] or algorithms [76]. Here, whereas Malik et al. [76] consulted the target group in their other research [77], Greenspan and Danielescu [41] did not mention preceding user involvement.

4.3 Virtues of Sport

In this section, we discuss the applicability of Mueller and Young [101]'s framework on the virtues of sport to the papers included in our review, i.e., appraise the 10 lenses *reverie*, *pleasure*, *humility*, *sublime*, *oneness*, *sacrifice*, *beauty*, *pain*, *consistency* and *perseverance*. First, we give an overview of how the virtues are (not) addressed within the corpus; then, we present themes that address alternative aspirational values as communicated by the research.

4.3.1 Exploring the Representation of Virtues of Sport in Sports Technology for Disabled Users. In this theme, we examine each of the 10 lenses (also see Section 2.3.2 and [101] for the sub-lenses), and whether, how and to which extent they play a role in the papers included in our corpus. Overall, we show that certain lenses, such as *reverie*, *pleasure*, *humility* or *oneness*, appeared in various publications while we found only a few works that address other lenses, such as *beauty* or *pain*.

Reverie. The virtue of reverie relates to experiences during lone exercising, which may include the absence of stimuli and intellectually challenging tasks. In the corpus, independent exercising was a dominating topic, particularly for people who are blind or have low vision. In contrast to other approaches that yield to make walking without human guidance accessible to this target group (e.g., [70, 116]), the system developed by India et al. [53] only requires little intellectual investment to navigate, and thus, allows for stimulation of the mind in the new (virtual) environment. Thus, in this context, the absence of stimuli as well as barriers (cf. [87]) may contribute to the facilitation of reverie, however, limits its implementation to predominantly virtual environments. Furthermore, a substantial share of work included in our corpus specifically addresses stakeholders beyond the disabled person (e.g., [5] and [61], see Section 4.1.3), highlighting that disabled people often engage in sport in the presence of others (e.g., their assistants). Here, it should be discussed whether the narrow definition of the virtue needs to be expanded beyond lone exercising, instead also comprising exercising in the presence of others where people are well-attuned to each other, and the company of the other person is not foregrounded, e.g., athlete-guide dyads [45].

Pleasure. We found pleasure, fun or enjoyment mostly only mentioned superficially in publications (e.g., [39, 54, 140]). Most of the publications included in the corpus did not explore this virtue in depth, which would allow connecting it to pleasure as described in the framework. Instead, publications, for example, describe physical activity as '*source of pleasure*' [86]. Thus, engaging with pleasure, despite only shallowly, still expands on the common health-based focus, contributing to improved sports experiences. Publications that address pleasure and valued positive experiences commonly presented research on exergames (e.g., [34, 86]), where player experience and engagement play a central role. However, in the context of Mueller and Young [101]'s work, this needs to be appraised with care: While exergames can facilitate pleasure, there is anecdotal evidence that they shift attention from the player's body [84]. This implies that the source of pleasure would not stem from exertion, but from the game, which may—in the context of disability—be desirable for players. e.g., to '*distract from exertion and pain*' [87]. Adding to this consideration, Ioannou et al. [54] developed a system that supports the sub-lens *pleasure of a firmer 'I'* as it facilitates an illusion of improved physical capabilities that can be leveraged for competing with '*more capable peers*'. This might add to findings from Gerling et al. [35] who identify multiple factors that influence player experience in game-balanced exergames. However, their results also suggest negative effects if people are aware of game-balancing and the discrepancy between actual and expected experience is too high. This raises a question about whether a firmer "I" should be anticipated.

Humility. According to Mueller and Young [101], humility, i.e., the '*awareness of one's own bodily limitations*," can be introduced through design elements such as competition which is implemented in various sports technologies. For instance, Fu et al. [32] present young autists who exercise in parallel with their heart rates. This competitive environment can facilitate humility and '*stimulate extended durations of a physical activity*'. Adding to that, Richardson et al. [118] state that in adventure sports, '*an individual tends to compete against the environment itself, or themselves, rather than another person or team*," stressing the individual aspect of humility. This may relate to the sub-lens of *environment features as lie detectors*, i.e., the environment can facilitate '*a sense of meekness*' [101]. However, humility also needs to be critically examined in the context of disability. For example, Gerling et al. [35] discuss how to design fair competition in exergames for dyads of disabled and non-disabled players, applying balancing mechanisms to provide a level playing field regardless of physical abilities. This contrasting perspective underlines that, in the context of disability and sport, designing technology that facilitates humility should be designed with care, under consideration of individual abilities and with an understanding of the context in which making people aware of their limitations may or may not be appropriate.

Sublime. Sublime describes the feeling of joyful fear which can be facilitated, for instance, through open water swimming or climbing [101] and was rarely picked up on in the corpus. Regarding climbing, Richardson et al. [118] pick up on the impracticality of facilitating a sublime-like experience as the competition against gravity can be difficult or impossible to emulate virtually (see also [101]). Similarly, Kobayashi [64] explore indoor climbing for this target group as well and highlight the safety of the sport. Consequently, facilitating sublime may be a relevant discussion for people who are blind or have low vision. This may especially be relevant since findings can be different for senses other than the visual one. However, and most prominently, research in the corpus rather views fear as something negative, e.g., when fear of injury is addressed [53]. This highlights sublime as a privilege that may be displaced by efforts to make sport safe and accessible, underlining the potential for further development in the field of HCI, disability and sport.

Oneness. '*Intimate familiarity with one's own body*' or oneness [101] can be an important issue for disabled people and appeared frequently in publications. Gibelli et al. [36] engage deeper with this lens. They argue that swimming '*improv[es] individuals' perception of the self and, therefore, their control over their own body*' and further point out that sport can help blind people to increase independence. To reinforce that, they leverage wearable technology to increase independence from tappers by providing proprioceptive feedback on their body position in the water. This can be linked to the sub-lens *heightened awareness of one's own bodily practices* of oneness. Thus, for this community, such feedback can contribute to a better understanding and perception of the self, serving as a basis for experiencing oneness. On the other hand, oneness, especially *making ourselves home in our bodies*, is relevant to using assistive devices. Integrating these into sport with technology could further promote this lens. For instance, Graf et al. [39] and Mason et al. [85] integrate wheelchairs as components of their exergames. This may improve familiarity with wheelchairs, promote acceptance of them as part of the sport, and thus, could ultimately affect oneness.

Sacrifice. Mueller and Young [101] argue that sacrifice to sport requires '*toil and agony,*' this theme rarely appeared in the corpus. Like sublime, sacrifice can be considered a privilege that may currently be of secondary importance for research. In our corpus, Alsaleem et al. [4] motivate the relevance of sport for disabled people with its ability to facilitate a sense of coherence or purpose in life, which could be connected to the sub-lens *sacrifice to be someone*. This inspires a discussion on sports technology that facilitates this sense of coherence, e.g., within a community or the whole world. However, imposing upon disabled people that they lack coherence or a purpose can promote the psychological model of disability [79], thus, requiring extensive involvement and consultation of the target group when designing for such virtues.

Beauty. Beauty in sport, e.g., through rhythm, order or spectacle [101] was no focus of technology in our corpus. However, Mueller and Young [101] argue that in rhythm-based sports technology, beauty can be facilitated. Thus, providing rhythm-based exergames to people who are blind or have low vision [76, 77], wheelchair users [34] or intellectually disabled people [128] increases access to this experiential side of sport for various target groups and opens up room for further discussion about this virtue.

Pain. Unsurprisingly, in our corpus, pain is usually viewed as something that must be avoided, e.g., with sensory-substitution technology for blind swimmers that yields to reduce injury [36, 97] or through exergames [87]. Mueller and Young [101], however, argue that pain is '*something elementary*' and can be a '*reflection on user's freedom*'. Thus, increasing access to, for instance, extreme sport where people can '*push their limits*' [92] could be a worthwhile consideration. Still, viewing the ability to perceive pain as a virtue can be a privilege and disabled people's perspective towards it should be taken into account for technology design that facilitates pain.

Consistency. Consistency, e.g., in endurance sport, can be connected to some research in our corpus on motivating disabled people to exercise. Researchers focus on motivation from two perspectives: They address the lack of motivation for sport with technological interventions and they view sport as a means to increase personal motivation. Especially the latter can be viewed as virtuous. Consistency requires a certain amount of motivation to establish regularity in training [142]. One sub-lens states that sport can be a useful tool to be able to '*strive*' within other aspects of life (*consistency as training for work and life*) [101]. Regarding that, Regal et al. [117] outline that '*shap[ing] habits through regular exercise*' as a purpose of sport, which relates to this sub-lens, needs to be established for their target group. However, as low motivation is linked to access barriers (e.g., [29, 83]), there may be two relevant perspectives: First, the design of engaging sports technology can address some of these barriers [30, 140]. Second, through the lens of the social model of disability, it should not be the individual's responsibility to remove barriers [78], and thus, technology should complement rather than replace efforts of the community to address these barriers.

Perseverance. The considerations for perseverance, i.e., '*engagement in exertion activities despite difficulty or delay in success*' [101] can be, like consistency, tied back to research approaches in our corpus that address motivation. Especially a delay in success, would however, require long-term research or in-depth consultation of participants instead of confirmatory studies that rely on non-participatory design prototypes (e.g., [28]). Generally, this reveals a challenge for HCI research which is often carried out with a focus on short-term results, and it may inspire a discussion on the relation between virtuous technology design and sustainable research [63].

4.3.2 A Reflection on the Lenses from the Perspective of Research on Disability, Technology and Sport. Not all of Mueller and Young [101]'s lenses were relevant in the context of the research included in our corpus, and we found *community* and *being well* as two additional core themes that should be considered when discussing virtues of sport in the context of disability, i.e., themes that were not included in Mueller and Young [101]'s framework, but need to be addressed when starting a discussion on virtuous sports technologies for disabled people. Thus, in the following, we present two inductive themes that describe how technology was designed to address these aspects, and we link our findings back to the philosophy of sport.

Forming Connections with Others. In our corpus, community aspects of sport were strongly represented (see Section 4.1.3). To some extent, this contrasts Mueller and Young [101]'s framework, where reverie is described as the absence of '*the social aspect of exertion*,' and where humility is linked to comparison with better-performing athletes (rather than togetherness). Adopting a more constructive perspective, the authors suggest that oneness relates to the '*self as part of a bigger whole*'. Thus, the social dimension is reflected within the framework, but not to the extent to which social aspects of sport are represented in research on sports technology and disability.

Here, we want to note that experiencing sport with peers, e.g., in parallel or interdependently [105], has gained relevance in SportsHCI [42, 89, 99]. It was also central to various publications in our corpus: Disabled and non-disabled people *develop relationships through sport* (e.g., [118]), and technology can serve as a way of facilitating this. For example, people can maintain *friendship* through balanced competition in exergames [35, 39], and technology has the potential to make sport a more inclusive form of leisure more widely [65]. This can foster a *sense of belonging*, and may especially be relevant in the context of inclusive group activities: Designing sport for groups of like-minded people with a range of abilities can increase relatedness, further promoting a sense of belonging [22, 117]. Here, Khurana et al. [61] also reiterate on the '*sense of belonging*' and state that sport provides the opportunity to '*learn from peers*,'' which contributes to personal growth.

The concept of interdependence [10] was also present in the works, e.g., with collaborative control of sports equipment, such as sailing boats or skis, Alsaleem et al. [4, 5] provide disabled sailors and skiers an opportunity to collaboratively engage in an extreme sport. Furthermore, athlete-guide relationships (cf. [4, 5, 44]) may facilitate *trust* in partners as well as technology. Here, technology provides a channel for communication (e.g., a haptic bracelet [44]) which eases the interaction with a partner and creates a sensation of safety. Especially for this interdependence, social factors in sport (cf. [126]) seem to have high relevance. Consequently, designing for the "relating body" [103] can be an important aspect of SportsHCI in the context of disability.

Being Well and Caring for Oneself. Caring for oneself was a central motive in the papers included in our corpus. This contrasts Mueller and Young [101]'s aspiration to move beyond physical health, focusing on additional benefits of sport, and striving to achieve personal growth.

In our analysis, we identified two key dimensions of being well. First, sport was regarded as *an opportunity to physically and cognitively rehabilitate* in order to be well. This perspective, of course, requires physical or cognitive characteristics of disabled people's bodies that can be improved. For example, Morelli et al. [95] argue that obesity is a common issue for people who are blind or have low vision, and that higher levels of well-being can be achieved through sport. Lu et al. [72] motivate their research with a positive effect on '*physiological functions of autism*'. Likewise, Greenspan and Danielescu [41] mention improved psychological health of amputees that return to playing (team) sport. We want to note that these approaches strongly reflect the medical model of disability (also see Section 2.2), suggesting that to be well, disabled people need to engage in rehabilitation. Second, work included in our corpus views sport as a means of *increasing the capacity of the body to stay well.* In particular, researchers stress the exceptional importance of prevention for disabled people due to a higher risk of developing secondary health conditions. In that context, for instance, Graf et al. [40] mention pain, fatigue, depression and obesity as a consequence of physical inactivity. Further, Carrington et al. [15] underline the '*physical and mental health improvements as well as quality of life gains*' of physical activity.

Overall, we note that the relationship between disability, being well and sport is complex, and we further address this issue in the discussion of our work (see Section 5.3.1).

5 Discussion

In this literature review, we explored research on technology and sport in the context of disability. Here, we first revisit the main RQs. Then, we reflect on challenges and opportunities when viewing sports technology for disabled users through the lens of virtues. Additionally, we discuss points for reflection for the HCI research community and how we currently conceptualise sport in the context of disability. Along with these, we also outline opportunities for future research for the accessibility research community.

5.1 Revisiting the RQs

RQ1: What is the perspective of HCI research on disability and sport, and what kinds of contributions are made by existing work? Our analysis shows that research in HCI, disability and sport strongly focuses on the removal of barriers to and within sport, evidenced by the large number of technologies that are perceived as more accessible (e.g., exergames, see Section 4.1.2) or that address access barriers through assistance (see Section 4.1.3). With respect to the purpose of sport, we conclude that much of the work focuses on the health benefits of sport (see Section 4.1.1) rather than viewing it as an inherently valuable, enriching activity. In this context, technology is predominantly discussed as a way of motivating disabled people to engage in sport and lead healthier lives (see Sections 4.1.1 and 4.3.2). Considering the types of sport currently addressed by research, we observe that a range of publications does not address one specific sport, and that other dominant streams are ball games, endurance sports and outdoor activity. Further, there is a narrow focus on specific audiences, with technology addressing people who are blind or have low vision, and people with limited mobility being over-represented in current research. Moreover, these target groups are only partially consulted. Overall, we conclude that there is an opportunity for future research to address sport from a more holistic perspective that moves beyond a sole focus on health benefits, and to extend to disabled audiences currently not broadly addressed by our community.

RQ2: How does existing work relate to Mueller and Young [101]'s 10 Lenses to Design Sports-HCI, and how would the lenses need to be expanded to facilitate the design of equitable and enriching sports experiences for disabled people? Considering that the functionalist perspective on sport dominates in the corpus, engagement with virtues of sport that extend beyond health benefits is superficial, which is in line with Mueller and Young [101]'s reasoning behind their framework and the desire to explore additional facets of sport. In terms of virtues that were represented in our corpus, we want to highlight the facilitation of pleasure and humility in (competitive) exergames as well as the complex interplay of the disabled body and social connections that affects reverie and oneness (see Section 4.3.1). Adding to their framework, we found that community, i.e., *forming connections with others* (see Section 4.3.2), is a strong underlying value when designing sports technology for disabled people. Likewise, we observed the theme of *being well* (see Section 4.3.2), which needs to be critically appraised in the light that research is typically led by non-disabled people, only consulting the disabled community (see Section 4.2.3). This raises the question of whose values are in fact represented in system design (which we discuss further in the following section). Overall, this highlights the need for further reflection on two key challenges, (1) how to design sports technology in the context of disability that values a purpose of sport beyond health benefits, more strongly reflecting Mueller and Young [101]'s lenses, and (2) a critical appraisal of virtue-based design approaches in the context of disability and sport.

5.2 A Critical Appraisal of Virtues (of Sport) in the Context of Disability

Virtue-based approaches to the design of sports technology warrant further reflection in the context of disability, particularly because the original considerations of Mueller and Young [101] were articulated in the context of non-disabled people.

First, we note that much of the work included in our corpus does not explicitly relate to the 10 lenses formulated by Mueller and Young [101]. However, we want to highlight that *caring for oneself* and *forming connections with others* directly connects with the overarching goals for humans to aspire to through virtuous behaviours: For example, Plato considers eudaimonia (i.e., happiness or well-being) the highest aim [31], which, to some extent relates to the theme of caring for oneself, and James views love as the singular foundation principle of all ethics [147], suggesting that human relationships are of fundamental importance for a virtuous life.

However, what needs to be critically appraised here is that virtues provide a normative orientation. It is thus worthwhile asking who defines these norms. Philosophy has struggled with disability, e.g., Edwards [23] views it as a harmed condition, subscribing to a deficit model. Similar perspectives are also reflected by Goodley [37], who discusses how to lead a good life '*despite disability*'. In the context of technology design, Alper et al. [3] positioned technology as a step towards the good life *with* disability; however, the authors still implicitly position technology to address potential deficits.

Thus, by adopting such frameworks as a lens on sport, there is a risk that this overemphasises curative and rehabilitative perspectives, neglecting the potential of sport to provide enriching and empowering leisure (also see Phoenix and Orr [112] for a similar discussion in the context of sport in late life). Here, it may be worthwhile to discuss the need for new normative frameworks rooted in progressive views of disability, e.g., Barnes [8] value-neutral model of the minority body that incorporates elements of the social model of disability [129], and that does not automatically assume disability is negative.

Overall, there needs to be a space for disabled communities to shape what a good life and being well means to them, opening up space for sport to be more than a tool to improve health, in fact aligning with the overarching vision behind Mueller and Young [101]'s 10 lenses. This is also relevant in the context of other themes prominent in our corpus, such as the focus on technology as a means of promoting independence (see Section 4.1.3), which to some extent contradicts work in disability studies that emphasises the relevance of *interdependence* [10], human relationships and *forming connections with others* (see Section 4.3.2). Here, researchers, designers and the disabled community should reflect upon the virtues proposed by Mueller and Young [101] in the context of disability. For example, the lens reverie in principle affords solitude, and, by extension, independence. However, in the context of disability, concepts such as Goodwin [38]'s *self-regulated dependency*, i.e., disabled people choosing when they prefer to work with assistance, need to be accounted for. Similarly, we want to encourage our research community to critically appraise other lenses, e.g., sublime and pain (see Section 4.3.1). Overall, this highlights the importance of carefully examining frameworks for the design of SportsHCI technology through the lens of disability, ensuring that the perspectives of disabled people and progressive views on disability are adequately represented.

5.3 Moving Forward: Points for Reflection for Future Work Developing Sports Technology for Disabled People

In this section, we summarise key points for reflection for researchers and designers wishing to develop sports technology for disabled users, drawing together conclusions from our review of existing literature along with considerations regarding virtues in the context of sport.

5.3.1 Point for Reflection 1: Can We Reconcile a Focus on Health with Other Purposes of Sport?

Much of the work included in our review highlights the health benefits that sport offers to disabled people (see Sections 4.1.1 and 4.3.2). In contrast, Mueller and Young [101] highlight the need to examine sport beyond health outcomes, recommending that SportsHCI research focuses on its inherent experiential value and role as leisure. While this aligns with other HCI research calling for technology for disabled people to move beyond therapy and rehabilitation [134], future research should carefully examine whether health and leisure do in fact need to be treated as a dichotomy. For example, Seippel [126] discusses seven meanings of sport that include to *keep fit*, and shows that meanings are not disjoint, i.e., exercising for health can also enable other experiences, e.g., that of fun or community.

However, this is a conversation that requires care, the right balance and meaningful involvement of disabled people. Here, we want to highlight the many assumptions made by work included in our corpus with respect to disability where requirements are established solely around the field of health, e.g., '*for preventing chronic disease*' [117] or '*to improve the physiological functions [...]*' [72]. This assumption to address disabled people's health first may displace other aspects of sport and is particularly concerning given the low level of involvement of disabled people in the work included in our corpus (see Section 4.2). To improve the process of gathering requirements, disabled people should be included throughout all stages of design, empowering disabled people to arrange their own priorities of sports technology. In that context, Williams et al. [148] also argue that there needs to be a shift in perspective regarding the establishment of requirements. They suggest that technological interventions predominantly transmit normative assumptions about our bodies, calling for community perspectives and critical scholarship to *unsettle* these.

Given that HCI seeks to contribute not just medical applications but wants to engage humans through technology more widely, virtuous interaction is relevant. Being able to appreciate and live the plurality of reasons to engage in sport is a privilege, and it should be respected that doing sport solely for one or multiple reasons, including health, is a personal decision. Here, future work should move beyond physical health as the dominant meaning of sport, and address a plurality of virtues in the early stages of design. Most importantly, disabled people need to be given an opportunity to participate in research in a position of power, e.g., be actively involved in the design of prototypes. Additionally, technology should not be viewed as a means of only making sport itself, but also making the experiential side of it accessible.

5.3.2 Point for Reflection 2: Should Immersive Systems Be Used as a Way to Sidestep Real-World Access Barriers? We observed a large amount of research in which exergames were introduced as a means of creating an accessible space within which disabled people were invited to exercise: On the one hand, such systems can often be played at home, avoiding inaccessible sports facilities or social stigma [83]. On the other hand, exergames offer an opportunity to make adaptations that remove access barriers directly related to the sport at hand (also see Section 4.1.2).

While we do not want to discount the motivational value of exergames and the general appeal of immersive systems in the context of sport, the HCI community should reflect upon potential risks that come with an overemphasis on such technology in the context of sport for disabled people. First, exergames can only be regarded as exercise to a certain extent in the sense that prior research has shown their limitations in invoking significant energy expenditure (e.g., see [81]). Second, exergames may fail to facilitate access to the social benefits of sport (see Section 4.1.2): While exergames can be a tool to increase access to physical activity in general, solitary exercise at home cannot compensate for the lack of inclusion in sport in the community. Thus, primarily designing sports technology for home use risks further segregation of disabled people, and should not be a pathway societies choose to avoid effectively addressing real-world barriers to sport.

Future work in this space needs to reflect on the purpose of sport and gather requirements to design for the amount of energy expenditure and community involvement. Also, researchers should scrutinise why we exercise and why we play, and carefully consider whether exergaming can address the requirements disabled people have.

5.3.3 Point for Reflection 3: Independence, Interdependence and Inclusion—What Is the Role of Community? Our results show that much of the existing sports technology aspires to empower disabled people by facilitating independent exercise (see Section 4.1.3). At the same time, another share of publications included in our corpus views sport as an opportunity to foster inclusion and engage disabled people in sport together with non-disabled people (see Section 4.1.1).

Here, we want to take the opportunity to unpack those two perspectives. Concerning *independence*, there is a contradiction with more recent considerations rooted in disability studies that call for researchers and designers to apply the lens of *interdependence*, i.e., acknowledging the inherent relationship between people, other people, assistive technology and the environment [10]. In this context, further involvement of disabled people in technology design (see Section 4.2) could be a pathway to explore when to design for *independence*, and when the *interdependence* framework may be more suitable. This could also be examined through Mueller and Young [101]'s lenses and the associated purpose of sport, i.e., whether the intention is to facilitate a solitary experience such as when striving for reverie (see Section 4.3.1), or one that leaves room for the involvement of other people to facilitate forming connections with others (see Section 4.3.2).

Overall, we want to note that neither solitary nor community-based participation in sport is more valuable than the other, and it is not our place to decide how an individual should engage in physical activity. Instead, we hope that the HCI research community will make informed decisions with respect to the consequences of supporting independent participation in sport or developing technology for community settings, thereby producing a range of systems that support different modes of participation in sport so that there is plurality in sports technology for disabled people.

5.3.4 Point for Reflection 4: Centring Broad Groups of Disabled People and Their Values in the Design and Development of Sports Technology. We want to close with a reflection on who is currently involved in and addressed by research that seeks to facilitate sport among disabled people. In our analysis, we observed two challenges for our research community when moving forward: (1) the superficial involvement of disabled people in system design, development and evaluation that has also been noted by previous work (e.g., [75]); and (2) the strong emphasis on certain communities of disabled people, leaving others unaddressed, and offering room for future work.

Including disabled people throughout the research process, e.g., through participatory methods [117], transfers power to the disabled community [124]. This ensures that artefacts are not only developed by non-disabled people or evaluated at the end of the design cycle (see Section 4.2). Further, it can add to more diverse perspectives on sport, preventing the dominance of medical ones represented in sports technology. Additionally, since communities are heterogeneous, involving broad target groups may help with basic access, however, equitable experiences of sport may require a more fine-grained, intersectional approach to fully explore disabled people's lived experiences [51], e.g., by involving mixed-ability teams (cf. [151]).

Future work in the field of HCI, disability and sport should comprehensively involve disabled people, ensuring that sports technology aligns with their values, preferences and interests. Here, researchers need to work closely with the community of focus, e.g., by applying participatory methods, and by leveraging frameworks that centre the requirements of the disabled community (see Section 5.2).

Overall, our work shows that there are several opportunities for the HCI research community to develop sports technology for disabled people that centres their needs and preferences, that broadens the perspective on disability and sport and that ultimately contributes to more varied systems that address sport in its entire breadth. In this context, we would like to encourage the research community to also address the experiential side of sport [26], e.g., by implementing relevant virtues with technology [101] and our contextualisation (see Section 4.3), but to do so in conversation with disabled communities to ensure that value systems do not just represent non-disabled views.

6 Limitations

Our work needs to be interpreted in the light of a number of limitations. Given that we were interested in work produced by the HCI research community, we focused our search on the ACM Guide to Computing Literature only. Therefore, our corpus does not include possibly relevant work not indexed in this database. Additionally, we decided to not include keywords for specific sports in the query, which may have brought up additional publications but would have done so in a fragmented way. Likewise, we chose to exclude exclusively medical research as per our IC and EC, not accounting for work on therapy and rehabilitation due to our interest in sport as leisure. Here, future work could explore rehabilitative sports technology to complement our review. Beyond these technicalities associated with the systematic review, there is room for additional research regarding theoretical frameworks to analyse sports technology in HCI. In our work, we opted for the framework by Mueller and Young [101] which is geared towards technology design and emphasises the experiential aspect of sport relevant to our review, but which is not validated through empirical work. Here, there is potential to explore alternative frameworks, for example, from the field of sports science. Finally, we want to highlight that the individual backgrounds of the authors of this work may have resulted in biases that may have impacted the research, and we would like to point readers to our positionality statement (see Section 3.2.2).

7 Conclusion

Sport is a common and engaging type of leisure and has a range of benefits. However, equitable access for disabled people remains a challenge. In the HCI research community, there have been various efforts to improve access to sport through the provision of technology and the creation of alternative pathways to physical activity. Our review of 60 publications in this area shows that there remains a strong focus on sport to obtain health benefits, and that both independent exercise and sport to foster inclusion are relevant streams of research. In particular, this applies to people who are blind or have low vision or persons with limited mobility. In this context, the experiential dimension and role of sport as engaging leisure remains under-explored. Our work supports previous findings in the HCI and accessibility research community that called for more meaningful involvement of disabled people in the design of technology that addresses them [75], and illustrates how virtue frameworks can be leveraged to reflect upon the experiences that sports technology facilitates for disabled people. Overall, we hope that our account of HCI, disability and sport inspires discussion and research efforts that seek to develop technical systems that facilitate equitable access to all facets of sport for all of us.

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Appendices

A Query

Search query for abstract, title, keywords:

```
(sport 'physical activity' 'physical activities' athlete)
AND
(accessibility accessible disability disabled impairment impaired
'assistive technology' 'assistive technologies')
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B Full Corpus

Table 4. Full Corpus That Was Analysed in the Literature Review

	Authors	Year	Title
■	Aggravi et al. [2]	2016	Haptic Assistive Bracelets for Blind Skier Guidance
■	Alsaleem et al. [4]	2019	Leveraging Shared Control to Empower People with Tetraplegia to Participate in Extreme Sports
■	Alsaleem et al. [5]	2020	Experience Is not Required: Designing a Sailing Experience for Individuals with Tetraplegia
■	Alsaleem et al. [6]	2020	Applying Ability-Based Design Principles to Adaptive Outdoor Activities
■	Ando et al. [7]	2021	Research on the Transcendence of Bodily Differences, Using Sport and Human Augmentation Medium
■	Carrington et al. [15]	2015	"But, I Don't Take Steps": Examining the Inaccessibility of Fitness Trackers for Wheelchair Athletes
■	De Silva et al. [21]	2023	Understanding Challenges and Opportunities in Body Movement Education of People Who Are Blind or Have Low Vision
■	Doro Peres and dos Reis [22]	2023	VeeMo: An Universal Exergame for Kindergarten
■	Eisapour et al. [25]	2018	Participatory Design of a Virtual Reality Exercise for People with Mild Cognitive Impairment
■	Ferrari et al. [28]	2022	Training with a Mobile FES-Cycling System: A Case Study with a Spinal Cord Injured Pilot to Investigate Performances Optimization
■	Francillette et al. [29]	2018	Development of an Exergame on Mobile Phones to Increase Physical Activity for Adults with Severe Mental Illness
■	Francillette et al. [30]	2021	Development of a Mobile Exergame to Implement Brief Interventions to Increase Physical Activity for Adults with Schizophrenia
■	Fu et al. [32]	2020	Improving Fitness Levels of Individuals with Autism Spectrum Disorder: A Preliminary Evaluation of Real-Time Interactive Heart Rate Visualization to Motivate Engagement in Physical Activity
■	Gerling et al. [34]	2015	Designing Wheelchair-Based Movement Games
■	Gerling et al. [35]	2014	Effects of Balancing for Physical Abilities on Player Performance, Experience, and Self-Esteem in Exergames
■	Gibelli et al. [36]	2023	Improving Swim Accessibility through Vibro-Tactile Sensory Substitution: A Preliminary Study
■	Graf et al. [39]	2019	IGYM: An Interactive Floor Projection System for Inclusive Exergame Environments
■	Graf et al. [40]	2019	IGYM: A Wheelchair-Accessible Interactive Floor Projection System for Co-Located Physical Play

(continued)

Table B1. Continued

	Authors	Year	Title
■	Greenspan and Danielescu [41]	2020	Designing Low-Cost Sports Prosthetics with Advanced 3D Printing Techniques
■	Haladjian et al. [44]	2017	VIHapp: A Wearable System to Support Blind Skiing
■	Hermann et al. [48]	2005	AcouMotion—An Interactive Sonification System for Acoustic Motion Control
■	Hicks and Gerling [50]	2015	Exploring Casual Exergames with Kids Using Wheelchairs
■	Ikegami et al. [52]	2011	Development of a Tracking Sound Game for Exercise Support of Visually Impaired
■	India et al. [53]	2021	VStroll: An Audio-Based Virtual Exploration to Encourage Walking among People with Vision Impairments
■	Ioannou et al. [54]	2019	Virtual Performance Augmentation in an Immersive Jump & Run Exergame
■	Kawai and Tomita [58]	2002	A Support System for Visually Impaired Persons to Understand Three-Dimensional Visual Information Using Acoustic Interface
■	Khurana et al. [61]	2021	Beyond Adaptive Sports: Challenges & Opportunities to Improve Accessibility and Analytics
■	Kobayashi [64]	2010	A Basic Inspection of Wall-Climbing Support System for the Visually Challenged
■	Kobayashi and Suzuki [65]	2022	Accessibility Improvement of Leisure Sports "Mölkky" for Visually Impaired Players Using AI Vision
■	Kobayashi and Tatsumi [66]	2021	Floor-Volleyball Motion Feedback System for Visually Impaired Players
■	Lassnig et al. [68]	2008	(E-)Accessibility Research from the Perspective of the Tourism, Sport and Leisure Industries—Selected Project Results and Future Focus of the e-Motion Competence Centre
■	Liao et al. [70]	2021	Robotic Guidance System for Visually Impaired Users Running Outdoors Using Haptic Feedback
■	Lu et al. [72]	2023	A Flow Study on Virtual Reality Games to Help Autistic Youngsters with Healthy Activities
■	Malik et al. [76]	2021	Increasing Access to Trainer-Led Aerobic Exercise for People with Visual Impairments through a Sensor Mat System
■	Malik et al. [77]	2021	Determining a Taxonomy of Accessible Phrases During Exercise Instruction for People with Visual Impairments for Text Analysis

(continued)

Table B1. Continued

	Authors	Year	Title
■	Mason [83]	2018	Playful Interactive Systems to Support Physical Activity among Wheelchair Users
■	Mason et al. [84]	2019	Design Goals for Playful Technology to Support Physical Activity Among Wheelchair Users
■	Mason et al. [85]	2020	Dash Lane: An Adaptive Exergame for People Using Manual Wheelchairs
■	Mason et al. [86]	2020	Dash Lane Mobile: Exploring Hypercasual Play to Provide Accessible Physically Active Breaks
■	Mason et al. [87]	2022	Including the Experiences of Physically Disabled Players in Mainstream Guidelines for Movement-Based Games
■	Miura et al. [91]	2018	GoalBaural: A Training Application for Goalball-Related Aural Sense
■	Miura et al. [92]	2022	A Study on Sonification Method of Simulator-Based Ski Training for People with Visual Impairment
■	Morelli et al. [94]	2010	VI-Tennis: A Vibrotactile/Audio Exergame for Players Who Are Visually Impaired
■	Morelli et al. [95]	2010	Vi-Bowling: A Tactile Spatial Exergame for Individuals with Visual Impairments
■	Morelli et al. [96]	2011	Pet-N-Punch: Upper Body Tactile/Audio Exergame to Engage Children with Visual Impairments into Physical Activity
■	Muehlbradt et al. [97]	2017	Goby: A Wearable Swimming Aid for Blind Athletes
■	Nitta et al. [107]	2014	HoverBall: Augmented Sports with a Flying Ball
■	Perla et al. [111]	2023	Technologies, Sports and Motor Activities for an Inclusive School
■	Ratto et al. [115]	2014	Blind Tennis: Extreme Users and Participatory Design
■	Rector et al. [116]	2018	Exploring Aural and Haptic Feedback for Visually Impaired People on a Track: A Wizard of Oz Study
■	Regal et al. [117]	2020	Be Active! Participatory Design of Accessible Movement-Based Games
■	Richardson et al. [118]	2022	Climb-o-Vision: A Computer Vision Driven Sensory Substitution Device for Rock Climbing
■	Sadasue et al. [120]	2021	Blind-Badminton: A Working Prototype to Recognize Position of Flying Object for Visually Impaired Users
■	Saxe [121]	1999	Virtual Interaction Using Robust Color Skin Detection
■	Senette et al. [128]	2018	An Interactive Cognitive-Motor Training System for Children with Intellectual Disability

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Table B1. Continued

	Authors	Year	Title
■	Sharma et al. [130]	2018	"Wow! You're Wearing a Fitbit, You're a Young Boy Now!": Socio-Technical Aspirations for Children with Autism in India
■	Singh et al. [131]	2013	I-Ball: A Programmable Sporting Aid for Children with a Visual Impairment to Play Soccer
■	Suzuki et al. [136]	2019	Development of Boccia Robot and Its Throwing Support Interface
■	Torrado et al. [140]	2020	Developing Software for Motivating Individuals with Intellectual Disabilities to Do Outdoor Physical Activity
■	Watanabe et al. [146]	2022	GoalBaural-II: An Acoustic Virtual Reality Training Application for Goalball Players to Recognize Various Game Conditions

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