# Exploring the Opportunities and Challenges with Exercise Technologies for People who are Blind or Low-Vision

Kyle Rector[1], Lauren Milne[1], Richard E. Ladner[1], Batya Friedman[2], Julie A. Kientz[3]
[1]Computer Science & Engineering, [2]The Information School & [3]Human-Centered Design & Engineering, DUB Group | University of Washington
Seattle, WA, USA 98195
{rectorky, milnel2, ladner}@cs.washington.edu, {batya, jkientz}@uw.edu

## ABSTRACT

People who are blind or low-vision may have a harder time participating in exercise due to inaccessibility or lack of experience. We employed Value Sensitive Design (VSD) to explore the potential of technology to enhance exercise for people who are blind or low-vision. We conducted 20 semi-structured interviews about exercise and technology with 10 people who are blind or low-vision and 10 people who facilitate fitness for people who are blind or low-vision. We also conducted a survey with 76 people to learn about outsider perceptions of hypothetical exercise with people who are blind or low-vision. Based on our interviews and survey, we found opportunities for technology development in four areas: 1) mainstream exercise classes, 2) exercise with sighted guides, 3) rigorous outdoors activity, and 4) navigation of exercise spaces. Design considerations should include when and how to deliver auditory or haptic information based on exercise and context, and whether it is acceptable to develop less mainstream technologies if they enhance mainstream exercise. The findings of this work seek to inform the design of accessible exercise technologies.

**Author Keywords**

Accessibility; exercise; exergames; visual impairments; eyes-free; audio feedback; health; value sensitive design

**ACM Classification Keywords**

K.4.2 [Computers and Security]: Social Issues – Assistive technologies for persons with disabilities; H.5.2 [Information Interfaces and Presentation]: User Interfaces.

## INTRODUCTION

People who are blind or low-vision can have a harder time participating in exercise than people who are sighted. They are also more likely to be obese [9, 42] and to maintain inadequate fitness levels starting in their youth [9]. People with more severe visual impairments are less likely to believe that exercise is important and are more likely to have parents who do not encourage them to exercise [42], and thus they exercise less [36]. They may also miss out on the social aspects of exercise, such as exercise classes that are taught by instructors who do not know how to adapt to people who are blind or low-vision [35].

Exercise technologies, such as exergames and fitness trackers, encourage physical activity for many users. These technologies may provide motivation, workouts, and act as a gateway to more advanced exercises [37]. However, most exergames [27] and health tracking technologies [25] have accessibility issues for people who are blind or low-vision because many of the necessary cues are visual (see Figure 1). While research efforts for exergames for people who are blind or low-vision are on-going [27, 28, 29, 34], typically these are limited to exergames that involve only upper body exercise and do not provide as much energy expenditure as full body exercise [4]. Opportunities exist to research and develop other types of exercise technologies outside of a game setting, specifically for different contexts (e.g. gym, outdoors) and with different groups of people (e.g. alone, with a sighted guide, with friends). Better access to exercise technologies has the potential to provide more independent exercise opportunities for people who are blind or low-vision. That said, blind of low-vision users could put themselves at an increased safety risk because they lack of awareness of situational factors. Because accessible exercise technologies are related to health and may provide benefits *or harms*, it is important to consider the tradeoffs.

To understand the opportunities and challenges of technology playing a role in accessible exercise, we turn to Value Sensitive Design (VSD) [5, 16], an approach that requires designers to interact with both direct and indirect stake-

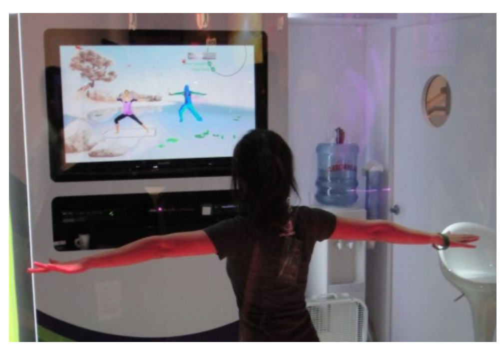

**Figure 1. An exergame player is required to see the avatars on screen and text rules in the upper right hand corner to play. Image: CC BY 2.0 popculturegeek on Flickr.**


*ASSETS '15,* October 26-28, 2015, Lisbon, Portugal
© 2015 ACM. ISBN 978-1-4503-3400-6/15/10$15.00
DOI: http://dx.doi.org/10.1145/2700648.2809846

holders as well as to elicit values and value tensions:

1. We interviewed 10 people who are blind or low-vision, as direct stakeholders, to learn about their current exercise habits, benefits and challenges of exercise, and how they use or do not use technology with exercise.
2. We interviewed 10 people who coach, instruct, direct, or volunteer for exercise activities with people who are blind or low-vision, as indirect stakeholders. We inquired about their experience with people who are blind or low-vision, along with how they or direct stakeholders that they work with use or do not use technology with exercise.
3. We conducted a survey with 76 people from the general population, another group of indirect stakeholders. We asked about their sentiments toward hypothetical scenarios where people who are blind or low-vision join public or semi-public exercise activities while using technology.
4. Two researchers coded the interviews and employed cross-case analysis [18] to determine the values participants felt an exercise technology should embody. We present a list of existing technologies that the participants use and discuss how those technologies do or do not address the reported values and features. We also present innovative technology mock-ups mentioned by our participants.

We have three main contributions: (1) the identification of the patterns, challenges, and technology use in exercise with people who are blind or low-vision, (2) an understanding of outsider perceptions of hypothetical exercise scenarios where people who are blind or low-vision use technology, and (3) a set of design opportunities and considerations that we hope will inform future accessible exercise technologies.

## BACKGROUND AND RELATED WORK

Below, we discuss VSD in more detail and how it informs our methodology. We also present current Eyes-Free Exercise Technology in both research and practice.

### Value Sensitive Design

In our study, we used value sensitive design's [5, 16] tripartite methodology to account for values from various stakeholders. VSD may start from a value, technology, or context of use [16]. Because we wanted to determine technology opportunities and considerations organically, we chose to start from a context of use: exercise for people who are blind or low-vision. Yetim provides a nice summary of the evolution of VSD [46]. The three parts consist of a Conceptual, Empirical, and Technical Investigation:

*Conceptual Investigation* – This first investigation involves the consideration of the stakeholders (direct and indirect) affected by a context of use. *Direct Stakeholders* are those who are directly immersed in the context of use and engage directly with the technology. In our case, our direct stakeholders are people who are blind or low-vision with varying ranges in sight and physical fitness. *Indirect Stakeholders* are people who are affected by the context, but do not directly interact with the technology. Those people include coaches, instructors, sighted guides, volunteers, or others who help facilitate fitness for people who are blind or low-vision. This may include friends, family, or bystanders who observe exercisers who are blind or low-vision.

After a preliminary identification of stakeholders, conceptual investigations typically follow by brainstorming possible benefits and harms for each stakeholder group, and a set of corresponding values and value tensions. For example, in our research direct stakeholders may experience a value tension between *independence* and *safety,* while indirect stakeholders may experience a value tension between *service* and *respect*. Indirect stakeholders could have a hard time deciding whether or not to provide *service* by helping someone who is blind or low-vision while in an exercise setting, because they might be unsure if the blind or low-vision persons might that offer to help as *disrespectful*.

*Empirical Investigation* – With an initial set of stakeholders and values, the empirical investigation strives to learn more about stakeholder values centered on a context of use. We conducted semi-structured interviews with both direct and indirect stakeholders about exercise habits, currently used technologies, and possible new technologies. With the corresponding data and analysis, the empirical investigation may confirm values from the conceptual investigation as well as uncover new values that were previously missed.

*Technical Investigation* – The technical investigation focuses on how existing technologies either support or hinder important values, in addition to having stakeholders brainstorm new and innovative technologies. Here, we assessed the reported and proposed technologies from the empirical investigation and discuss how those technologies do or do not address these important stakeholder values.

### Eyes-Free Exercise Opportunities

Although there is a need for more accessible exercise opportunities, there are several organizations and sports that support accessible exercise. For example, national organizations such as the United States Association of Blind Athletes (USABA) [43] and the Canadian Blind Sports Association (CBSA) [8] facilitate sports for athletes who are blind or low-vision. Sports specifically invented for this population include Goalball and Beep Baseball, as well as adapted mainstream sports such as ice hockey (Courage Canada Hockey for the Blind [12]), skiing (Ski for Light [38]), and cricket (Cricket Association for the Blind in India [7]). These types of accessible sports are important because they provide the opportunity to participate in open sports (with changing variables such as a moving ball or players [45]), which people who are blind prefer [23] over predictable closed sports (e.g. running on a treadmill) [45]. However, they may only reach a subset of people based on location, athletic ability, or interest. Therefore, ubiquitous technology solutions have the potential to complement these organizations to reach a wider audience.

### Eyes-Free Exercise Technology

With the recent popularity of exercise tracking technologies, such as Fitbit [15] and the Nike fuel band [31], there have been several research efforts investigating how to leverage these technologies and the data they collect to increase fitness. For instance, to encourage useful exercise habits for adults (e.g. [10, 15]) and for older adults who may face significant barriers to exercise [1, 14]. Although useful, these health tracking applications are often not accessible to people who are blind or low vision [25].

Accessible exergaming has been recognized as a research problem across many disciplines [26]. One option is to make an existing exergame accessible to people who are blind or low-vision. For example, with VI-Bowling [28] and VI-Tennis [27] Morelli et al. analyzed the visual cues used in Wii Sports Bowling and Tennis and converted them to audio feedback from the speakers or tactile feedback from the Wii Remote; for a track running game on the Kinect, Morelli et al. [30] developed a solution using video capture to find visual cues and communicated the information using audio and tactile feedback with a Wii Remote.

Researchers have also developed original exergames that are accessible to people who are blind or low-vision. For example, in Pet-N-Punch the player has to hit rodents and pet cats at a farm using a Wii Remote and nunchuck; participants were able to achieve light to moderate upper body exercise [29]. Eyes-Free Yoga is an original exergame that coaches yoga to people who are blind or low-vision by giving personalized feedback on yoga postures [34].

Beyond exergames, there are opportunities for innovative technologies to be developed for different contexts (e.g. gym, outdoors) and with different groups of people (e.g. alone, with a sighted guide, with friends). The design and development of accessible exercise technologies may provide an impact in both research and practice. Therefore, we hope our work will uncover important values behind accessible exercise and the opportunities for technology design.

## RESEARCHER STANCE

The research team is comprised of people with backgrounds in Computer Science, Human-Computer Interaction, and Accessibility. We were able to recruit participants for our study because of prior volunteer experience at a school for the blind, prior volunteer experience at an organization that facilitates recreation for people of all abilities, and previous research experience. All of the authors are sighted, so it is possible that the interview and survey materials may have a bias toward a sighted perspective.

## CONCEPTUAL INVESTIGATION

*Stakeholders.* We began our conceptual investigation by brainstorming direct and indirect stakeholders. Because we are studying eyes-free exercise opportunities, the direct stakeholders are people who are blind or low-vision. Indirect stakeholders include those who are involved in fitness for people who are blind or low-vision (e.g., coaches, directors, instructors, and volunteers who enable exercise) and the general public who also participate in exercise because they may impact the decision of a person who is blind or low-vision on (e.g., in fitness classes or bystanders). We did not include some indirect stakeholders in our research. In particular, we did not work with friends or family of people who are blind or low-vision. While this group is more directly involved on a personal level, they may have less expertise in an exercise setting. It is possible that a family member or friend may also be teacher, coach, volunteer, or a survey respondent so we did not let that affect our recruitment.

*Harms and Benefits.* Our research team also brainstormed the potential benefits and harms of different types of exercise and exercise technology and the underlying values that stakeholders attach to the space. We determined that two explicitly supported project values [5] for eyes-free exercise should be *accessibility* (people of any visual ability should be able to use the technology) and *fitness* (supports any exercise activity).

*Values.* The goal of this research is to uncover values related to eyes-free exercise. To identify preliminary values to help focus our interviews, we read related work about values and eyes-free technologies. The authors uncovered possible stakeholder values that include but are not limited to *independence* [2, 16, 22, 39], *safety* [22, 40], *being mainstream* [39, 40], and *confidence* [2, 16] (see Table 3 for a complete list). People should have the ability to exercise independently, whether that is with or without a friend, chaperone, or technology. In addition, they should be able to maintain a sense of safety throughout the exercise, whether that involves multiple sources of information, a viable back up plan, or exercising caution when planning a workout. When they are exercising, they should not feel like they stand out in the crowd in a negative manner, and they should feel confident during exercise. The authors hypothesized that they would uncover additional values, and the list of values would change throughout the empirical and technical investigations.

## EMPIRICAL INVESTIGATION METHODS

We conducted semi-structured interviews and a survey to elicit values from direct and indirect stakeholders:

1. Group 1 (Direct Stakeholders): We conducted semi-structured interviews with people who are blind or low-vision (Table 1).
2. Group 2 (Indirect Stakeholders): We conducted semi-structured interviews with people who facilitate exercise for people who are blind or low-vision (Table 2).
3. Group 3 (Indirect Stakeholders): We conducted a survey of the general population.

| Attribute | Counts |
|---|---|
| **Gender** | Female (6), Male (4) |
| **Age** | Range: 21-68, Median: 36 |
| **Vision** | Totally blind (2), Legally blind (2), Degenerative condition (3), Light perception only (2), Peripheral vision in one eye (1) |
| **Duration** | Since birth (6), Later in life (4) |
| **Physical Activity** | Sedentary (4), Active walker (3), Active (1), Very active and travel to compete (2). |

**Table 1. Demographic information about Group 1 participants (Direct stakeholders – blind or low-vision).**

| Attribute | Counts |
|---|---|
| **Gender** | Female (5), Male (5) |
| **Age** | Range: 25-67, Median: 45 |
| **Vision** | Sighted (4), Visually impaired (1), Degenerative condition (2), Totally blind (1) Not reported (2) |
| **Role** | Coach (2), Program manager (2), Director (1), Sighted guide (2), Pilot (2), Yoga instructor (1), Spin instructor (1) |
| **Sports Facilitated** | Swimming (1), Biking (7), Running (4), Triathlon (3), Skiing/Snowboarding (3), Kayaking (3), Rock climbing (2), Goalball (1), Beep Baseball (1), Yoga (2) |
| **Role Duration** | Range: 1.5-15 years, Median: 4 years |

**Table 2. Demographic information about Group 2 participants (Indirect Stakeholders – facilitate fitness)**

In the interviews for Group 1, we inquired about the benefits and challenges of exercise as well as participants' exercise technology background in different contexts. First, we asked about exercise history and about whether they exercise alone, with others, or in a gym setting. We asked about technologies or accessibility solutions used during exercise. We provided hypothetical exercise scenarios with technology, offered two balanced reasons for why a certain technology may or may not be preferred, and asked for their feedback. For example:

*Joe takes a mainstream yoga class. He uses a special mat (which looks like a regular yoga mat) that detects his weight distribution and gives some feedback about how to adjust his pose via one headphone so Joe can still listen to the instructor.*

*Idea 1: Some people say it's OK to wear headphones in a class because you will receive extra information.*

*Idea 2: Some people find it concerning to wear headphones because they will appear different and could possibly fall behind in the class or not hear the instructor.*

*Do you tend to agree with Idea 1 or Idea 2? Why?*

We finished by asking about previous stories while exercising where they experienced some form of difficulty (e.g., felt unsafe, felt not confident, etc.) and about possible innovative technologies that could help in these situations.

In the Group 2 indirect stakeholder interviews, we inquired about experiences facilitating exercise with people who are blind or low-vision and, if applicable, how it differed from people who are sighted. We asked for supporting stories to obtain additional contexts and details about their experiences. We asked about technology use and asked the same use case scenarios as Group 1.

Finally, the survey for Group 3 presented three scenarios in which a person who is blind or low-vision is using an accessible technology to facilitate exercise and inquired about the thoughts of survey respondents. For example: *You are currently attending an exercise class at the gym, and a participant who is blind joins the class. Please check off the feelings that apply most to you.* Answers include: *excited, neutral, stressed, unsure of how much space to give them, and unsure of whether or not to help them*.

For all three groups, we were careful to order the questions so as not to intentionally prime the interview toward a specific value (e.g., How do you feel about safety?).

For interviews, we recruited 10 direct stakeholders who were blind or low-vision (Group 1: D1-D10, Table 1) and 10 indirect stakeholders (Group 2: I1-I10, Table 2). For the survey, 76 members of the general population were respondents to our Group 3 survey (S1-S76, 51 female, 25 male; ages 18-76; median age 34.5). We recruited survey respondents via email. We were conducting a qualitative analysis, and thus recruited until we reached data saturation, which was after 10 interviews for Group 1 and Group 2 (which is consistent with findings that that data saturation usually occurs before reaching 12 interviews in a given population [19]). All of the interviews were conducted over the phone and lasted from 30 minutes to two hours.

We audio-recorded and transcribed the interviews. For the interview transcripts and survey text responses, we employed cross-case analysis [18] where two researchers independently read the transcripts and identified themes and values. Then the two researchers met and synthesized a master set of themes and values. Next the two researchers used these themes and values to re-code the entire set of interviews. After semi-randomly selecting and coding the same five interviews, the researchers reviewed each other's work and made revisions as necessary. The researchers then independently coded the rest of the interviews. Throughout this process, the researchers met regularly to iterate on the code set.

## RESULTS

First, we discuss the emergent themes, values and value tensions mentioned by all three groups followed by survey results from Group 3. These are summarized in Table 3.

### Stakeholder Themes, Values, and Value Tensions

*Opportunity: Knowledge transfer while exercising in a class*

*Knowledge* is an important value for technology design in general, but there are unique opportunities in the domain of accessible exercise. **Mainstream exercise classes** are one opportunity where technology may enhance the experience for someone who is blind or low-vision, because most classes are not accessible [35]. In our interviews, no direct stakeholders reported having a positive experience in a *mainstream* exercise class. D9 reported that she took a class on martial arts, and there was a lack of *respect*: "*I did that for about a few weeks and they came and told me they would like me to have special lessons by myself. ... I was so offended and I never went back.*" Direct stakeholders reported positive experiences when the class was made accessible: "*She was very, very descriptive and really used language that was very not visual per se, but in terms of positions 'to the door' 'to the window'*" (D3). Descriptive verbal instructions may provide benefit when learning an exercise, like with Eyes-Free Yoga [34]. Because of positive social benefits from attending an exercise class (e.g., *community*), technology that communicates *knowledge* in this setting may provide multiple benefits.

When blind and low-vision participants were posed with the idea of using one headphone to hear extra feedback while in a *mainstream* yoga class, they responded positively because the technology could provide them with *knowledge* when the instructor was not available: "*the instructor cannot take time to come around to each person*" (D2) and still allow them the benefit of *community*: "*it is more preferable ... because clearly you get to work out with other people*" (D10). Survey respondents also felt that the system may provide utility to them; they "*wonder what the feedback sounds like*" (S63) and also "*want feedback about how I am doing*" (S7).

That said, some of the exercise instructors and survey respondents expressed concerns about integrating this type of technology in a class: "*Hopefully they [instructors] would be encouraging and on board with him using that adaptive piece of equipment and help him calm him a little bit if he does fall behind*" (I2). In addition, "*if the person wasn't familiar with the moves being called out by the instructor, and people got distracted trying to help, it could be embarrassing for the participant*" (S30). There is a value tension that with extra *knowledge*, the instructor, class, or participant may become distracted and no longer experience *mindfulness.* Not all instructors may be on board with such a design, especially those who specialize in instructing people who are blind or low-vision. I9, an eyes-free yoga class instructor, thought that the technology would only be useful if a teacher was not present: "*I don't think it's so good. I think if he was on his own [and] if the teacher wasn't there, it's great*" (I9).

| Opportunity or Consideration | Values (V) or Value Tensions (T) |
|---|---|
| Knowledge transfer while exercising in a class | **V:** knowledge, mainstream, respect, community<br>**T:** knowledge vs. mindfulness |
| Knowledge transfer while exercising with a sighted guide | **V:** accessibility, knowledge<br>**T:** communication vs. knowledge |
| Rigorous outdoor exercise | **V:** mindfulness, outdoors/green exercise, safety<br>**T:** independence vs. safety |
| Navigating exercise spaces | **V:** accessibility, safety<br>**T:** accessibility vs. fitness |
| Audio channel design | **V:** knowledge, awareness, safety, mindfulness<br>**T:** knowledge vs. awareness, knowledge vs. safety, knowledge vs. mindfulness |
| Less mainstream solutions | **V:** mainstream, community, knowledge, safety, confidence<br>**T:** mainstream vs. knowledge, mainstream vs. community, mainstream vs. confidence |

**Table 3. Opportunities and considerations for design, and the corresponding values and value tensions (order mentioned).**

*Opportunity: Knowledge transfer while exercising with a sighted guide*

Another opportunity to integrate *knowledge* in technology design is when **exercising with a sighted guide**. Sighted guides are not very *accessible* to recruit and exercise with regularly "*So my partner only being 30 miles away - I don't think there is anyone else who has a pilot who lives that close in tandem racing*" (D10), and perhaps: "*why they don't guide is because there is that pressure. You can't let them down. You can't be the slowest ever during the day*" (I5). According to the United States Association for Blind Athletes (USABA): "*Often runners are hesitant to serve as guide runners fearing they will do something or not do something that could result in injury or a poor performance for the blind athlete*" [41].

Because the purpose of a sighted guide is "*to be their eyes*" (I3) and "*our time keepers*" (I3), innovative lightweight technologies may offset the amount of *communication* needed while exercising. For example, technology could provide *knowledge* "*about the environment*" (D3) or something that would use a *"transponder to give an audible sort of – Let's say there's five racers numbered 1 2 3 4 5. It maybe could give the splits '… And number 2 is in the lead number 3 is 2 minutes behind her' … There are the verbal cues that I do give throughout the race, all the better that it could be technology because here again that's one of the pressures on the guide is to not only run as fast as the athlete but also talk at the higher level"* (I5). Presenting *knowledge* while running in groups is feasible; Mauriello et al. developed a system that displays runner information on the back of shirts [24], which could be made accessible.

#### *Opportunity: Rigorous outdoor exercise*

Previous work has found that exercising outdoors in a rural or urban setting (termed "green exercise") lends itself to improving physical and health outcomes [33]. This was reflected as a value for many participants in our study. Participants identified *mindfulness* as a benefit to exercising *outdoors* including being "*more connected to earth"* (I7), "*out in the fresh air"* (D2), and "*away from the noise of the city"* (D4). Brisk walking with a cane, sighted guide, or guide dog is feasible, but when the pace of exercise is increased, "*trying to find somebody who is amenable who is willing to run as a guide"* (D6) is a barrier as mentioned previously. Stationary rigorous activity, considered closed exercises in adapted exercise physiology [45], may become monotonous and feel less productive: "*I know it's kind of ridiculous to expend all of that effort and not even move an inch"* (D6). While there are possible *safety* concerns, participants have a desire to engage in more open exercises [45], including **rigorous physical activity outdoors**: "*If I had more of a chance to get outdoors on a tandem outside, so that would be more exciting"* (D10).

When we presented the following hypothetical technology to both direct and indirect stakeholders: *James decides to walk around the track. With a mounted camera and headphones, he is able to hear whether or not he is staying in his lane and about nearby obstacles*, we noticed a value tension between the values of *independence* and *safety*. Several participants (D1-D4, D6-D7, I1, I3-I6, and I8-I9) were interested in using the technology and felt that "*we can't be afraid of goofing up"* (D4) and "*wouldn't be too terribly concerned if the technology failed because somehow the person got themselves to the track"* (I1). In addition, "*you can't wrap yourself up as they say in cotton wool. Just get out there and try it"* (I5) and they "*would favor it even if there is some risk involved"* (I8). Survey respondents were also positive: "*It's really cool that technology was helping the blind person in this way"* (S23).

However, two participants (D10, I10) and some survey respondents were concerned about the technology due to *safety*: "*Find someone to do it with or switch to an indoor equivalent where a sighted person isn't necessary. And if the treadmill fails you, so what? You don't hurt anybody else"* (I10). In addition, bystanders would be "*concerned that the gear will [not] work correctly and navigate around barriers"* (S68) and "*be afraid of going too close and causing the system to alert the person unnecessarily"* (S18). In addition to system errors, the technology and situation may make a person more "*susceptible to attack"* (S53) as it may call attention to one's disability [40]. Also, the technology may not warn a person in time about unexpected obstacles: "*Someone's football might fly right in their path before the camera can pick it up and warn them"* (S47).

Participants also identified strategies to mitigate these issues, for example, by becoming acquainted with the technology first (D5, D8, and I7): "*I would want to make sure that the feedback is detailed enough"* (D8). D9 and I2 were willing to try out the system as long as they had a backup plan: "*He needs to develop other skills to so that if the technology fails he would not be totally lost"* (D9). While *safety* is a valid concern, nonetheless, there is an opportunity to enable **rigorous outdoor exercise** with technology. If *safety* is accounted for in the design – with piloting, training, and proper fail cases – this line of research has the potential to generate impact.

#### *Opportunity: Navigating exercise spaces*

While *accessible* solutions such as a cane or guide dog work well in most contexts, there is a value tension with *fitness*. For instance, D1 was unable to go on a hike with their guide dog: "*I started out trying to use my guide dog but quickly disc3overed that it was very narrow and very rocky, and it was just not something that my dog was really accustomed to trying to navigate and guide me*." While it is possible to use a guide dog for running [13], D4 reported that their guide dog can get in the way of a brisk exercise walk: "*…one of those mediums being a thinking brain, and when that thinking brain which is attached to a nose tends to get a little bit too curious for its own good, which of course gets me in trouble."*

Another example of a beneficial *accessible* tool hindering a workout is using a cane at the gym. D10 resorts to only having a sighted guide instead: "*I don't carry my cane with me because I have to keep putting it down, picking it up, putting it down, picking it up … I don't want to run into anybody"* (D10). Further exacerbating the problem is that "*gyms are not laid out in a real structured format"* (D10).

An opportunity for technology development may involve developing tools that allow people to **navigate spaces catered to exercise**. One suggestion by D9 is having "*a 3D printout of the gym"* that may help people navigate between machines. A high tech option with real time feedback may involve using a haptic laser [20] that has a smaller form factor. While hiking, D1 and D3 suggested mapping out the trail with GPS and satellite, having your phone inform you if you are walking off of the trail, and give you directions if you are led astray. This is similar to Navi'Rando, a recent accessible technology that warns hikers of bends and turns [32]. These technologies will not replace a guide dog or a cane, but may help remove some of the barriers.

Another option may be to augment current accessibility tools, as opposed to developing separate systems. Such augmentations may have both performance and safety benefits. For example, research has explored how to augment service dogs to increase the amount and type of tasks they can complete [6, 21]. The Facilitating Interactions for Dogs with Occupations (FIDO) project produced a wearable technology for service dogs so they could increase communication with their owners [21] by providing interfaces the dogs could activate with their nose, by biting, or by tugging. In addition, Bozkurt et al. introduced Cyber-Enhanced Working Dogs (CEWDs), search and rescue dogs that wear sensors and actuators to enable real time monitoring [6]. These projects demonstrate the potential to augment a guide dog and reduce the need for a harness in certain situations, which could be a *safety* risk: "*There are a number of people specifically have retired use of a guide dog because of various physical ailments they develop … The scapula and the thorax that can really be pulled out of whack"* (D4).

*Consideration: Audio channel design*

As mentioned above, there are opportunities for auditory technologies to provide *knowledge* during exercise in different contexts (e.g. exercise class, exercise with a sighted guide). However, **caution must be exercised** when determining how to present audio information; it is important for someone to have an *awareness* of his or her environment even with headphones [3]. If someone was hearing constant auditory feedback while wearing two headphones outside, this could pose a serious *safety* risk: "*It's a big world outside, and it can be everything from being accosted by somebody to traffic … You still need your hearing whenever you're in the public"* (D9). In addition, survey respondents noted that headphones "*may impair their hearing"* (S67) and they "*may miss obstacles that come up from the side or behind"* (S46).

In a more controlled setting, such as an exercise class, wearing headphones may reduce *mindfulness*: *I would not wear headphones if it would distract me from hearing the instructor. I would only want to hear the instructor"* (D4). In addition, a distracting audio interface may cancel out a working strategy, for example: "*Like the treadmills, you can pretty easily tell if the people are on them, because they thump, thump, thump really loud"* (D7).

As noted above, the audio channel can be an attractive opportunity to distribute *knowledge*, but there are value tensions with *awareness*, *safety,* and *mindfulness*. For instance, referring to the scenario where James was walking on the track with a mounted camera and headphones, participants were interested in refining *when* and *how* audio feedback was delivered: *"I would not want something that speaks when you are out of your lane, but does not give enough information for how to get back into the lane"* (D8). In other words, if the system only provided *knowledge* that there was a mistake, and not how to fix the mistake, the person may lose their orientation or become discouraged, impinging on *mindfulness* or *safety*.

This value tension between *knowledge* and that of *awareness, mindfulness, and safety* demonstrates that an important design consideration is **how to deliver audio information** (e.g. speakers, headphones, one ear bud, and bone conduction headphones). On the one hand, in a public or exercise class setting where others are present, using headphones may be advantageous: "*It is not like the feedback is bothering me because they hear it via their own headphones"* (S29). Using one ear bud may be advantageous, because "*if they just have one headphone in they can still hear the instructor"* (I4). Bone conduction headphones may also be suitable: "*It doesn't go in your ear so you can hear what's going on around you"* (I8). On the other hand, in surroundings where hearing is already difficult, technology occupying both ears may be advantageous (e.g. skiing): "*There are two way radio sets which I [would] love to get … If they are going fast enough, the wind, the sound of the snow becomes really hard to hear your instructor just down the hill from you"* (I2).

To explore this tension and develop appropriate technologies, designers will have to consider how to **design the audio channel** by assessing the exercise and context to determine the appropriate type (e.g. auditory, tactile, verbal) and the frequency (e.g. constant, only when a correction is necessary, time based) of feedback. In addition, if the person who is blind or low-vision will need to wear headphones to receive information, appropriate headphones should be selected: "*It may be beneficial to use wireless headphones to preserve the integrity of the movements involved in the exercise"* (S13).

*Consideration: Less mainstream solutions*

Developing *mainstream* technology solutions may be important for an aesthetic appearance [40]. However, participants suggested that they do not mind appearing different by using a less familiar technology (e.g., mounted camera) or in a less familiar context (e.g., exercise class) to appear *less* different while exercising. While the technology might make them look "different," the outcome is that they may be able to perform the exercise and workout in a *community*: "*It's good for everyone to get to participate and if some extra equipment is necessary that's fine"* (S46). In other words, **it is okay to develop a less mainstream technology, because it will help a person who is blind or low-vision exercise in more mainstream settings.**

There are a few reasons why during exercise less *mainstream* solutions may have utility: 1) "*You're getting that extra feedback that you need to make sure you are doing it right so you don't have to rely on someone else or the instructor to give you that feedback, but you are still participating in the class"* (D5, *knowledge*), 2) "*Anything that integrates a visually impaired [person] into the normal activities of daily life that the rest of us don't even think about"* (I6, *community*), and 3) "*I think just me as a blind *person I adapt pretty quickly and then my other thing is that I am different <laughs>"* (D6, *confidence*). Developing exercise technologies that may make a person appear slightly different will give them the *knowledge* to help them join in activities and have a positive experience with others.

Participants suggested that it is okay to appear different, especially when *safety* is on the line: "*One of my times skiing ... The reason of wearing the bib that says blind on it is so other people are aware so you do stick out ... and they can be conscientious of you staying out of your way."* That being said, it is likely still a good design goal to create assistive technologies that are minimally noticeable and give people the opportunity to identify themselves as blind if they choose.

It is worth noting that we only interviewed adults, who might have gained *confidence*: "*It's always you don't feel independent. I feel that as an adult ... I don't care"* (D3). However, this is not necessarily the case when growing up: "*I was growing up as a child, I felt very, very apart and not part of this group, because if you are different you are very self-conscious"* (D3). Mainstream sports can be discouraging: "*You only get three strikes in baseball, yea well I got 5, 7 <laughs> until I hit the ball, and when you hear the PE coach calling the catcher talking to the pitcher 'Just underhand it to him'"* (D4). In addition, people may not be understanding of an assistive technology and may: "*talk about the device this blind person is using making them feel alienated"* (S21). Thus, another important and underexplored research direction may include developing technologies to make exercise accessible and enjoyable for children who are blind or low-vision, along with technologies that facilitate play between children of all visual acuities.

**General Population Response to Exercise Scenarios**

76 survey respondents from the general population about their feelings and rationale toward three scenarios as follows:

1. You are currently jogging around a running track. A person who is blind walks on the track. With a mounted camera and headphones, they are able to hear whether or not they are staying in their lane and about the obstacles in front of them.
2. You are currently attending an aerobics class at the gym, and a participant who is blind joins the class. With a special mat, which looks like a regular yoga mat, it can detect their weight distribution, and they can hear feedback about how they are doing via one headphone.
3. You are currently at home using a camera and audio-based yoga program using a video game system with a friend who is blind. You are exercising next to each other simultaneously.

| Scenario (1: track, 2: class, 3: home) | 1 | 2 | 3 |
|---|---|---|---|
| I am excited for them to participate. | 84.2 | 89.5 | 86.8 |
| I am neutral. | 15.8 | 15.8 | 7.9 |
| I am stressed out. | 2.6 | 0.0 | 5.3 |
| I would feel uneasy about the camera. | 5.3 | n/a | 5.3 |
| I am unsure how much space I should give them. | 50.0 | 15.8 | 22.4 |
| I am unsure of when I should try to help them. | 34.2 | 10.5 | 25.0 |

**Table 4. Percentage of participants from Group 3 who held that sentiment. Note that people could choose more than one answer. Scenario 2 did not contain a camera (N=76).**

Scenario 1 occurred in an outdoor, unstructured, public space (running track). Scenario 2 occurred in an indoor, structured, public space (exercise class). Scenario 3 occurred in an indoor, structured, private space (home). Table 4 shows the sentiments of survey participants for the different scenarios. One caveat regarding Scenario 3: Participants may not have a friend who is blind or low-vision, making this scenario even more hypothetical; however, we thought the scenario would be more realistic than if it were a stranger who is blind or low-vision. This decision may have affected participants' responses for this scenario.

While participants had similar views across all three scenarios with regard to feeling excited, neutral, stressed, or uneasy about the camera, there are interesting differences that emerge with respect to space and help. With Scenario 1 (walking around the track), 50% of participants "*wouldn't necessarily know how much space to give them"* (S38). This is in stark contrast to the exercise class setting (15.8%) and home setting (22.4%), where differences were found to be statistically significant (Wilcoxon rank sum test - Scenario 1 vs. Scenario 2: W=3876, $p < 0.0001$, Scenario 1 vs. Scenario 3: W=3686, $p = 0.001$). This may reflect that when the exercise space is unstructured, more people do not understand how to give enough space while exercising near someone who is blind or low-vision.

In addition, there were differences among the three scenarios in the percentage of participants who felt unsure as to whether or not they should help. While in a class setting, only 10.5% of participants were not sure about whether or not to help: "*They already have instructions"* (S12). This may be the case because the other class members are reliant on the instructor to provide assistance. The other two settings have a larger number of participants who report being unsure about whether or not to help: at home (25%) and on the running track (34.2%), and these differences are statistically significant (Wilcoxon rank sum test – Scenario 1 vs. Scenario 2: W=3572, $p < 0.001$, Scenario 2 vs. Scenario 3: W=2470, $p = 0.02$). It is possible that with proper education about etiquette while in the home or with signs in a public space, people will know how to act appropriately when exercising around someone who is blind or low-vision.

## TECHNICAL INVESTIGATION

With the emerging opportunities for eyes-free exercise technologies, we followed our empirical investigation with an investigation of current technologies and technologies brainstormed by the participants. One purpose of technical investigations in VSD is to examine how current technologies fit or omit the emergent values or issues which surfaced during the empirical investigation, and to offer stakeholders an opportunity to brainstorm new technologies that address their concerns [16]. This is important to VSD because it allows researchers to primarily reflect on the state of technology, as opposed to the stakeholders like in the Empirical Investigation. It also allows for researchers and stakeholders to brainstorm concrete ideas for this design space. Group 1 participants (D1-D10) reported technologies they currently use, and Group 2 participants (I1-I10) reported technologies that are used by people they work with or that they use themselves (because for some participants, they were also a direct stakeholder). The complete set of reported technologies is shown in Table 5. Below, we also report novel technology ideas presented by the researchers in the interviews and survey and brainstormed by participants for each emerging opportunity.

While there is an opportunity for technology to communicate **knowledge in an exercise class**, the only two reported technologies were an inaccessible heart rate monitor for PE fitness testing and a partially accessible spin bike. The heart rate monitor output was read aloud by a sighted person and does not provide any instructions as to how to complete an exercise. The spin bikes were for a spin class in which the instructor is blind (I10). Instead of relying on the inaccessible output of the spin bikes, the instructor uses "*music to indicate what you should try to be doing"* and feeling to drive the class: "*We are all working 90%. Perhaps my feet are going faster or slower. Perhaps I have more or less resistance. It is still 90% no matter what*." In addition to the researchers proposed technology of using a special mat and headphone in an exercise class for yoga, D2 suggested using a similar technology idea for jazzercise.

Currently reported technologies also do not fill in the knowledge gap when **exercising with a sighted guide**. Despite several technologies being reported while exercising with a sighted guide or bicycle pilot: bike computer, talking heart rate monitor, heart rate monitor, RunKeeper, and Strava, only one is accessible and was used during the workout. The inaccessible bike computer was read aloud by the pilot (I5), which places more work on the guide. In contrast, I3 is a coach to athletes who use a talking heart rate monitor, reducing the load on the sighted guide. The inaccessible heart rate monitor (I6), RunKeeper (I3), and Strava (I2, I6, I8) allowed for participants to record information about their workouts and analyze it at a later time. Ideally, more technologies would be developed to allow athletes to receive real-time information about their workouts, thereby reducing the load on a sighted guide or bicycle pilot. Participants brainstormed technologies to help fill this gap:

| Technology | Participant | Place | Accessible? |
|---|---|---|---|
| **Stationary Machines** | | | |
| Stationary Bike | D9, I3 | Indoors | Yes |
| Bike trainer | D6, D10, I5 | Indoors | Yes |
| Nordic ski machine | D6 | Indoors | Partially |
| Treadmill (Running) | D8, I3, I5 | Indoors | Partially |
| Treadmill (Walking) | D1, D2, D7 | Gym | Partially |
| Elliptical | D7 | Gym | Yes |
| Spin bike | I10 | Class | Partially |
| **Health Tracking** | | | |
| Talking bike computer | D6, D10 | Indoors | Partially |
| Bike computer | I1 | Indoors | Yes |
| Bike computer (bike pilot) | I5 | Outdoors | No |
| Talking heart rate monitor (biking) | D6, D10 | Indoors | Yes |
| Talking heart rate monitor (running with guide) | I3 | Outdoors | Yes |
| Hear rate monitor (biking) | D10 | Indoors | Partially |
| Heart rate monitor (PE fitness testing) | D7 | Class | No |
| Heart rate monitor (bike pilot) | I6 | Outdoors | Partially |
| Pedometer (walking) | D1 | Outdoors | Partially |
| **Phone Health Tracking** | | | |
| Talking stopwatch (walking on treadmill) | D9 | Indoors | Yes |
| Wahoo fitness (biking) | D6, D10 | Indoors | Partially |
| Pedometer apps (walking) | D6 | Outdoors | Partially |
| RunKeeper (running with guide) | I3 | Outdoors | Yes |
| Strava (bike pilot) | I2, I6, I8 | Outdoors | Partially |
| **Accessibility features** | | | |
| Magnification on iPhone or iPad (treadmill) | D1, D4, I8 | Indoors | Yes |
| iPhone Camera w/ digital zoom and flash (walking) | D4 | Outdoors | Yes |
| **Navigation** | | | |
| Sendero look around (walking) | D9 | Outdoors | Yes |
| GPS on BrailleNote (walking) | D9 | Outdoors | Yes |
| **Adaptive Sports Tools** | | | |
| Beeper baseball | I4 | Outdoors | Yes |
| Radios in helmet (skiing) | I1, I4, I7 | Outdoors | Yes |

**Table 5. Technology use reported by Groups 1&2.**

whether it would be an alarm to go off if the athlete is approaching the wall or another player (I4) or the transponder technology to notify of other competitors (I5) mentioned in the empirical investigation.

With respect to **independent rigorous exercise outdoors,** only one of the reported technologies fills the void: Beep baseball, which is an already open exercise [45] specifically designed for people who are blind or low-vision. In terms of the eleven other technologies, six are used while running, biking, or skiing with a sighted guide, and five are used while walking outdoors. There are interesting potential research efforts that try to close the gap between *independent exercise* while walking (e.g. more closed exercise [45]) and guided exercise while completing *rigorous activity* (e.g. more open exercise [45]). In addition to the researchers suggesting a head mounted camera and headphones to guide someone around the track, D4 also suggested developing a controlled setting for tennis, where a machine would serve audible tennis balls with both a consistent location and time frame (D4).

**Navigation of exercise spaces** is also not well represented by the reported technologies. D4 reported using the iPhone camera with zoom and flash to help navigate while walking, however this technology is not designed for this purpose and requires time and overhead. Secondly, D9 reported using two technologies related to navigation (Sendero look around and GPS), but they were only related to walking outdoors. There is an opportunity for technology to be developed to help people navigate new exercise spaces, such as a gym, running track, or hiking trail. D1 and D3 proposed a technology to help navigate hiking trails as mentioned in the empirical investigation. Additionally, D3 proposed giving auditory feedback to properly navigate a swimming lane, and D7 suggested wearing a camera so they could be notified as to whether or not a person is using exercise equipment.

## LIMITATIONS AND FUTURE WORK

While we carefully chose our study design, there were limitations to our approach. Our recruitment entailed contacting email lists and snowball recruitment. As a result, it is possible that we may have received less of a representative sample. In addition, the authors were not able to recruit people who are blind or low-vision and are also part of a sports team such as Goalball or Beep Baseball. Finally, we were unable to have participants work with physical prototypes as described in the interviews; they were not within a close geographic distance and some of the technologies may not yet exist. For these reasons, our study and analysis of the interviews is qualitative. In addition, there were hypothetical technologies posed in the survey and in some of the interviews. The responses may be different than if the technology existed and was regularly used.

For future work, we hope to design and develop technologies that fit the four opportunities identified by this work. Ideally, designers would involve both direct and indirect stakeholders while designing, prototyping, and testing technology.

## CONCLUSION

We presented opportunities and design considerations for eyes-free exercise technologies by employing value sensitive design. Specifically, we conducted interviews with 10 people who are blind or low-vision and with 10 people who facilitate fitness for people who are blind or low-vision, as well as a survey with 76 people from the general population who acted as outsiders to blind exercisers. We found four opportunities for design (Table 3): knowledge transfer while in an exercise class, knowledge transfer while exercising with a sighted guide, rigorous outdoor exercise, and navigating exercise spaces. In addition, we identified two further considerations (Table 3): how to properly design the audio channel and how to allow for less mainstream technologies to be viable options when enhancing exercise in a mainstream setting. We hope that researchers and designers can build from this work and inform future technologies that help make exercise more accessible for people who are blind or low-vision.

## ACKNOWLEDGEMENTS

We thank Alan Borning for his guidance and assistance to make our project a success. Our research was funded with the National Science Foundation Graduate Research Fellowship Program for two of the authors. The University of Washington Human Subjects ethics board approved this research.

## REFERENCES

1. Iñaki M. Albaina, Thomas Visser, Charles A.P.G. van der Mast, Martijn H. Vastenburg. 2009. Flowie: A persuasive virtual coach to motivate elderly individuals to walk. In *Pervasive Computing Technologies for Healthcare. 3rd International Conference on PervasiveHealth* (PervasiveHealth '09), 1-7. http://dx.doi.org/10.4108/icst.pervasivehealth2009.5949
2. Shiri Azenkot, Sanjana Prasain, Alan Borning, Emily Fortuna, Richard E. Ladner, and Jacob O. Wobbrock. 2011. Enhancing independence and safety for blind and deaf-blind public transit riders. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 3247-3256. DOI= http://doi.acm.org/10.1145/1978942.1979424
3. Shiri Azenkot, Kyle Rector, Richard Ladner, and Jacob Wobbrock. 2012. PassChords: secure multi-touch authentication for blind people. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility* (ASSETS '12). ACM, New York, NY, USA, 159-166. DOI= http://doi.acm.org/10.1145/2384916.2384945
4. Elaine Biddiss and Jennifer Irwin. 2010. Active video games to promote physical activity in children and youth: a systematic review. *Archives of pediatrics & adolescent medicine* 164, 7: 664-672. DOI= http://dx.doi.org/10.1001/archpediatrics.2010.104
5. Alan Borning, Batya Friedman, Janet Davis, and Peyina Lin. 2005. Informing public deliberation: Value sensi-

tive design of indicators for a large-scale urban simulation. In *Proceedings of the 2005 Ninth European Conference on Computer-Supported Cooperative Work* (ECSCW '05), 449-468. DOI= http://dx.doi.org/10.1007/1-4020-4023-7_23

6. Alper Bozkurt, David L. Roberts, Barbara L. Sherman, Rita Brugarolas, Sean Mealin, John Majikes, Pu Yang, and Robert Loftin. 2014. Toward Cyber-Enhanced Working Dogs for Search and Rescue. *IEEE Intelligent Systems* 29, 6: 32-37. DOI= http://dx.doi.org/10.1109/mis.2014.77
7. CABI. 2012. Welcome to the Cricket Association for the Blind in India (CABI) | Cricket Association for the Blind in India. Retrieved May 4, 2015 from http://www.blindcricket.in/
8. Canadian Blind Sports Association. 2012. Canadian Blind Sports. Retrieved May 4, 2015 from http://canadianblindsports.ca/
9. Michele Capella-McDonnall. 2007. The need for health promotion for adults who are visually impaired. *Journal of Visual Impairment and Blindness* 101, 3: 133-145.
10. Robert Cercos and Florian 'Floyd' Mueller. 2013. Watch your steps: designing a semi-public display to promote physical activity. In *Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death* (IE '13), Article 2, 6 pages. DOI= http://doi.acm.org/10.1145/2513002.2513016
11. Sunny Consolvo, David W. McDonald, and James A. Landay. 2009. Theory-driven design strategies for technologies that support behavior change in everyday life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '09), 405-414. DOI= http://doi.acm.org/10.1145/1518701.1518766
12. Courage Canada. 2015. Courage Canada Hockey for the Blind. Retrieved May 4, 2015 from http://www.couragecanada.ca/
13. Brad Crawford. 2015. A Blind Runner and His Amazing Guide Dog. Retrieved July 7, 2015 from http://thebark.com/content/blind-runner-and-his-amazing-guide-dog
14. Chloe Fan, Jodi Forlizzi, and Anind Dey. 2012. Considerations for technology that support physical activity by older adults. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility* (ASSETS '12), 33-40. DOI= http://doi.acm.org/10.1145/2384916.2384923
15. Fitbit. 2015. Fitbit Official Site for Activity Trackers & More. Retrieved May 4, 2015 from http://www.fitbit.com/
16. Batya Friedman, Peter H. Kahn Jr., and Alan Borning. 2013. Value Sensitive Design and information systems. In Ping Zhang and Dennis Galletta (eds.), Human-computer interaction in management information systems: Foundations, Springer Netherlands, 55-95. DOI= http://dx.doi.org/10.1007/978-94-007-7844-3_4
17. Nicholas A. Giudice and Gordon E. Legge. 2008. Blind Navigation and the Role of Technology. In A. Helal, M. Mokhtari & B. Abdulrazak (eds.), Engineering handbook of smart technology for aging, disability, and independence, John Wiley & Sons, 479-500. DOI= http://dx.doi.org/10.1002/9780470379424.ch25
18. Barney G. Glaser, and Anselm L. Strauss. 1967. *The discovery of grounded theory: Strategies for qualitative research.* New York: Aldine Transaction.
19. Greg Guest, Arwen Bunce, and Laura Johnson. 2006. How many interviews are enough? An experiment with data saturation and variability. *Field methods* 18, 1: 59-82. DOI= http://dx.doi.org/10.1177/1525822x05279903
20. Francis Iannacci, Erik Turnquist, Daniel Avrahami, and Shwetak N. Patel. 2011. The haptic laser: multi-sensation tactile feedback for at-a-distance physical space perception and interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 2047-2050. DOI= http://doi.acm.org/10.1145/1978942.1979239
21. Melody Moore Jackson, Clint Zeagler, Giancarlo Valentin, Alex Martin, Vincent Martin, Adil Delawalla, Wendy Blount, Sarah Eiring, Ryan Hollis, Yash Kshirsagar, and Thad Starner. 2013. FIDO - facilitating interactions for dogs with occupations: wearable dog-activated interfaces. In *Proceedings of the 2013 International Symposium on Wearable Computers* (ISWC '13), 81-88. DOI= http://doi.acm.org/10.1145/2493988.2494334
22. Shaun K. Kane, Chandrika Jayant, Jacob O. Wobbrock, and Richard E. Ladner. 2009. Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities. In *Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility* (Assets '09), 115-122. DOI= http://doi.acm.org/10.1145/1639642.163966
23. Lauren J. Lieberman, Barbara L. Robinson, and Heidi Rollheiser. 2006. Youth with visual impairments: Experiences in general physical education. *Re: view* 38, 1: 35-48. DOI= http://dx.doi.org/10.3200/revu.38.1.35-48
24. Matthew Mauriello, Michael Gubbels, and Jon E. Froehlich. 2014. Social fabric fitness: the design and evaluation of wearable E-textile displays to support group running. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14), 2833-2842. DOI= http://doi.acm.org/10.1145/2556288.2557299
25. Lauren R. Milne, Cynthia L. Bennett, and Richard E. Ladner. 2014. The Accessibility of Mobile Health Sensors for Blind Users. In *29th Annual International & Persons with Disabilities Conference* (CSUN '14).

26. Anthony Morelli. 2010. Haptic/audio based exergaming for visually impaired individuals. SIGACCESS Access. Comput. 96 (January 2010), 50-53. DOI= http://doi.acm.org/10.1145/1731849.1731859

27. Tony Morelli, John Foley, Luis Columna, Lauren Lieberman, and Eelke Folmer. 2010. VI-Tennis: a vibrotactile/audio exergame for players who are visually impaired. In *Proceedings of the Fifth International Conference on the Foundations of Digital Games* (FDG '10), 147-154. DOI= http://doi.acm.org/10.1145/1822348.1822368

28. Tony Morelli, John Foley, and Eelke Folmer. 2010. Vi-bowling: a tactile spatial exergame for individuals with visual impairments. In *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility* (ASSETS '10), 179-186. DOI= http://doi.acm.org/10.1145/1878803.1878836

29. Tony Morelli, John Foley, Lauren Lieberman, and Eelke Folmer. 2011. Pet-N-Punch: upper body tactile/audio exergame to engage children with visual impairments into physical activity. In *Proceedings of Graphics Interface 2011* (GI '11), 223-230.

30. Tony Morelli, and Eelke Folmer. 2014. Real-time sensory substitution to enable players who are blind to play video games using whole body gestures. *Entertainment Computing* 5, 1: 83-90. DOI= http://dx.doi.org/10.1016/j.entcom.2013.08.003

31. Nike, Inc. 2015. Choose Your Nike+ App. Nike.com. Retrieved May 4, 2015 from http://www.nike.com/us/en_us/c/nikeplus-fuel

32. Phys.org. 2015. Blind French hikers cross mountains with special GPS. Retrieved July 8, 2015 from http://phys.org/news/2015-07-french-hikers-mountains-special-gps.html

33. Jules Pretty, Jo Peacock, Martin Sellens, and Murray Griffin. 2005. The mental and physical health outcomes of green exercise. *International Journal of Environmental Health Research,* 15, 5: 319-337. DOI= http://dx.doi.org/10.1080/09603120500155963

34. Kyle Rector, Cynthia L. Bennett, and Julie A. Kientz. 2013. Eyes-free yoga: an exergame using depth cameras for blind & low vision exercise. In *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility* (ASSETS '13), Article 12, 8 pages. DOI= http://doi.acm.org/10.1145/2513383.2513392

35. James H. Rimmer. 2006. Building Inclusive Activity Communities for People with Vision Loss. *Journal of Visual Impairment & Blindness*, 100, suppl, 863-865.

36. Barbara L. Robinson, and Lauren J. Lieberman. 2004. Effects of visual impairment, gender, and age on self-determination. *Journal of Visual Impairment & Blindness*, 98, 6: 351-366.

37. Victoria Schwanda, Steven Ibara, Lindsay Reynolds, and Dan Cosley. 2011. Side effects and "gateway" tools: advocating a broader look at evaluating persuasive systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11), 345-348. DOI= http://doi.acm.org/10.1145/1978942.1978991

38. Ski for Light. 2015. Ski for Light, Inc.® Retrieved May 4, 2015 from http://sfl.org/

39. Kristen Shinohara and Josh Tenenberg. 2007. Observing Sara: a case study of a blind person's interactions with technology. In *Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility* (Assets '07), 171-178. DOI= http://doi.acm.org/10.1145/1296843.1296873

40. Kristen Shinohara and Jacob O. Wobbrock. 2011. In the shadow of misperception: assistive technology use and social interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '11). ACM, New York, NY, USA, 705-714. DOI= http://doi.acm.org/10.1145/1978942.1979044

41. The United States Association of Blind Athletes. 2015. Sports Adaptations. Retrieved May 4, 2015 from http://usaba.org/index.php/sports/sports-adaptations/

42. Moira E. Stuart, Lauren Lieberman, and Karen E. Hand. 2006. Beliefs about physical activity among children who are visually impaired and their parents. *Journal of Visual Impairment & Blindness*, 100, 4: 223-234.

43. The United States Association of Blind Athletes. 2015. The United States Association of Blind Athletes. Retrieved May 4, 2015 from http://usaba.org/

44. Evette Weil, Melissa Wachterman, Ellen P. McCarthy, Roger B. Davis, Bonnie O'Day, Lisa I. Iezzoni, and Christina C. Wee. 2002. Obesity among adults with disabling conditions. *Journal of the American Medical Association*, 288, 10: 1265-1268. DOI= http://dx.doi.org/10.1001/jama.288.10.1265

45. Joseph P. Winnick. 2011. *Adapted physical education and sport.* Human Kinectics.

46. Fahri Yetim. 2011. Bringing discourse ethics to value sensitive design: pathways toward a deliberative future. *AIS Transactions on Human-Computer Interaction*, 3, 2: 133-155.