Enhancing Quality of Life for People who are Blind or Low Vision Using Computing Technology

Kyle Rector

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Reading Committee:

Julie A. Kientz, Chair

Richard E. Ladner, Chair

Jennifer Mankoff

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Abstract

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Kyle K. Rector

Chairs of the Supervisory Committee:
Professor Richard E. Ladner, Associate Professor Julie A. Kientz
Computer Science and Engineering, Human Centered Design & Engineering

People who are blind or low vision may have a harder time participating in activities that enhance quality of life due to inaccessibility, travel difficulties, or lack of experience. Enhancing quality of life allows people to complete and enjoy activities that they view as important such as exercise, education, or engaging in culture. The goal of this dissertation is to present the artifacts and studies that give insights to help people who are blind or low vision engage in these activities.

First, I present an empirical investigation where I employed Value Sensitive Design. My Value Sensitive Design work involved 20 semi-structured interviews and a 76-person survey to learn about the opportunities and challenges for exercise technologies. I present four new themes I

discovered through this work. Then, I present Eyes-Free Yoga, an accessible yoga coach that provides personalized real-time feedback on yoga postures and auditory motivations including levels, achievements, and reminders. Using 3D camera technology, I captured a person's posture and used the expertise of yoga instructors to determine personalized feedback. I developed the motivations based on the persuasive technology literature. I conducted a 16-person laboratory study and found that 13 preferred the personalized feedback to no feedback. I also conducted a 4-person 8-week in-home deployment study and found that all four participants used Eyes-Free Yoga consistently and felt that motivations enhanced their workouts.

Then, I present Eyes-Free Art, a proxemic audio interface that helps people who are blind or low vision interactively explore 2D paintings. Using 3D camera technology, I captured a user's distance from the painting and physical gestures to present different audio representations: background music, interactive sonification of colors, interactive sound effects, and detailed verbal description. I conducted a 13-person laboratory study and found that 11 of the 13 participants preferred Eyes-Free Art to only a verbal description.

In this dissertation, I provide supporting evidence for my thesis statement: *"When applied to quality of life for people who are blind or low vision, interactive technologies support an increase in enjoyment, an increase in the amount of time engaged in the activity, people to learn more about the activity, independent access to the activity, and multiple stakeholders."*

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ACKNOWLEDGEMENTS

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For Eyes-Free Art, I give photo credits: Self-Portrait with Thorn Necklace and Hummingbird (Image: CC BY 2.0 cea + on Flickr); The Sleep of Reason Produces Monsters (public domain); The Blue Rider (public domain); The Red Studio (public domain in the US); The Stone Breakers (public domain).

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DEDICATION

To my fiancé Brandon Myers and who has provided me strength.

To my family Jennifer & Kenneth Rector, Lauren & Aaron Jones, and Bryan Rector for their endless support.

Chapter 1. INTRODUCTION

My motivation for conducting this research stems from the fact that aspects of quality of life may not be accessible for people with disabilities, including people who are blind or low vision[1]. In fact, the World Health Organization reports that people with disabilities have poorer health outcomes, lower educational achievements, and higher rates of poverty. Further, they suggest that research is conducted on how to positively impact quality of life for people with disabilities (The World Health Organization 2011). According the University of Toronto Centre for Health Promotion (Quality of Life Research Unit 2016), Quality of Life is defined as: *"The degree to which a person enjoys the important possibilities of his or her life."* With the development of technologies to enhance quality of life for people with disabilities, researchers have the potential to make an impact in these important possibilities including participation in the workplace (e.g. Branham and Kane 2015) or autonomous navigation (e.g. Azenkot et al. 2011).

1.1 MOTIVATION

Research studies indicate that people who are blind or low vision are generally not as healthy as people without disabilities. They are more likely to be obese (Capella-McDonnall 2007, Weil et al. 2002) and to report poor, fair, or worsening health. Youth and adolescents with visual impairments do not engage in enough physical activity to maintain an adequate fitness level (Capella-McDonnall 2007). Additionally, people with disabilities are less likely to be employed and are more likely to live in poverty than people who do not have a disability (Brault 2012). There are also aspects of culture that are not accessible including museums; for example, a blind patron

[1] *"Globally the number of people of all ages visually impaired is estimated to be 285 million, of whom 39 million are blind."* – Quote directly taken from Pascolini and Mariotti (2011).

may have an accessible tour available to them only once per month (e.g. Museum of Modern Art 2016, Seattle Art Museum 2016).

The HCI and Accessibility communities have pursued research in enhancing the quality of life for people with disabilities including participation in the workplace (Branham and Kane 2015, Feng et al. 2008, Maciuszek et al. 2005) autonomous navigation (Azenkot et al. 2011, Meurer et al. 2014, Sánchez and Torre 2010, Sucu and Folmer 2014), or increased social awareness (Shinohara and Wobbrock 2011). There is also existing work in the space of exergames for people who are blind or low vision (Morelli et al. 2010a, Morelli et al. 2010b, Morelli et al. 2011, Rector et al. 2013), but the space of technology to support exercise for people who are blind or low vision remains a young field and has thus far been mostly limited to in-home exercises. I believe there may be gaps in the research to pursue more open ended goals including participation in culture and society. There is a motivation to make more public activities accessible, such as outdoor exercises or museum access.

In my thesis, I motivated, developed, and studied exercise and art technologies using the Microsoft Kinect, a 3D camera with accompanying application programming interfaces, for people who are blind or low vision. I chose to address these two domains because of the inaccessibility of these activities. When I develop prototypes and systems, I connect with people who are blind or low vision throughout the process to help accessibility issues that are encountered (Mankoff et al. 2010). My goal for this work was to enable or enhance activities that enhance quality of life for people who are blind or low vision and provide takeaways for other researchers to continue work in this space.

1.2 Thesis Statement

My thesis claims are summarized in the below statement. Table 1.1 summarizes whether or not I studied each claim in each project.

When applied to quality of life for people who are blind or low vision, interactive technologies support:

1. An increase in enjoyment
2. An increase in the amount of time engaged in the activity
3. People to learn more about the activity
4. Independent access to the activity
5. Multiple stakeholders

Table 1.1. A list of the claims in my thesis statement and whether or not I studied these claims in my research projects.

Goal for activities that fit under Quality of Life	**Value Sensitive Design**	**Eyes-Free Yoga Lab**	**Eyes-Free Yoga Deployment**	**Eyes-Free Art**
Increase enjoyment	Not studied	Yes	Yes	Yes
Increase amount of time	Not studied	Not studied	Yes	Not studied
Help with Knowledge	Yes	Yes	Yes	Yes
Allow for independent access	Yes	Not studied	Yes	Yes
Work with multiple stakeholders	Yes	Yes	Not studied	Not studied

1.3 Research Questions and Approaches

To support my thesis statement, I pursued the following research questions:

RQ1: How should we design audio based exercise systems that enhance exercise in real world scenarios with multiple stakeholders?

RQ2: How should we design audio based systems to coach a person who is blind or low vision to perform an exercise that may rely on vision?

RQ3: How should we design audio based exercise systems to encourage a person to exercise over a longer period of time?

RQ4: How should we design audio based systems to help a person explore visual items, such as art, independent of a sighted guide?

To address **RQ1**, I conducted a qualitative study by employing value sensitive design and engaging with several different stakeholders involved in exercise for people who are blind. I conducted semi-structured interviews and surveys to understand the broader opportunities and challenges for exercise technology design. To answer **RQ2** and **RQ3**, I designed a developed Eyes-Free Yoga as a prototype to explore coaching a person using personalized real time feedback and as a full system to study how to encourage people to exercise over a longer period of time. Finally, I designed and built Eyes-Free Art to explore **RQ4**; I explored the use of a proxemic audio interface to explore items that are inherently visual, where the level of information detail increases as a person approaches the item.

1.3.1 *Value Sensitive Design of Exercise for People who are Blind or Low Vision*

The goal of this qualitative research was to understand the opportunities and challenges with exercise technologies developed for people who are blind or low vision. I conducted this research in three phases: conceptual investigation, empirical investigation, and technical investigation. For the conceptual investigation, I utilized related work to determine values that have emerged from other research efforts (e.g. safety and independence (Azenkot et al. 2011)). The empirical investigation consisted of semi-structured interviews with 10 people who are blind or low vision and 10 people who play a role in exercise for people who are blind or low vision. The goal was to learn about their experiences with exercise and technology. Additionally, I conducted a survey with 76 people in the public to learn about their reactions to exercise scenarios that involve a person who is blind using a hypothetical exercise technology. From this qualitative work, I derived four new opportunities for technology design and two design considerations. The technical investigation evaluated whether existing technologies used for eyes-free exercise could be used for the four opportunities. This work provides both ideas and guidelines for future work.

1.3.2 *Eyes-Free Yoga*

Exercise classes can be encouraging but are often taught by instructors who do not know how to adapt for students who are blind or low vision (Rimmer 2006). I designed, developed, and evaluated Eyes-Free Yoga to explore whether or not a person who is blind or low vision may receive an accessible form of yoga instruction. Eyes-Free Yoga provides detailed verbal instructions, and upon holding the posture, they hear feedback so they can make adjustments. I conducted a lab study with 16 people who are blind or low vision to explore the use of real-time personalized verbal feedback to see how it may help someone practice an alignment based exercise such as yoga. We explored whether or the not the participants needed to hear fewer adjustments as they repeated postures, and we recruited yoga instructors to rate the quality of the postures. We found that the real-time personalized feedback was preferred and enjoyed by participants and may have helped them learn the postures.

To explore the potential of Eyes-Free Yoga over a longer period of time, I improved the Eyes-Free Yoga prototype into a fully functioning system. I consulted BJ Fogg's Behavior Grid (The Behavior Wizard 2016) to inform the design of Eyes-Free Yoga, because I wanted it to be a persuasive technology that encourages people to exercise over a longer period of time. I developed eyes-free motivational techniques including audio levels, badges, and workout reminders and I conducted a single case subject design to see how these techniques affected the minutes of exercise per day. I conducted an in-home deployment study with four people who are blind or low vision over 8 weeks. I found that while the audio motivational techniques did not affect the minutes of exercise per day for each person, that the techniques enhanced their workout experience. The participants used Eyes-Free Yoga throughout the study, so I made Eyes-Free Yoga available for the public to download.

1.3.3 *Eyes-Free Art*

I designed, developed, and evaluated Eyes-Free Art to explore whether a proxemic audio interface may help a person who is blind or low vision explore objects that are inherently visual, such as paintings. The concept of proxemic interfaces was introduced by Edward T. Hall (Hall 1966) where the interaction with a system may change depending on the user's proximity. The HCI literature focuses on visual proxemic interfaces, so I expanded on the literature by exploring audio. Eyes-Free Art contains four zones ranging from 12+' away from the painting to <6' from the painting. As a person approaches the painting, the audio information increases in the level of detail presented: background music, sonification of colors, sound effects of objects contained in the painting, and detailed verbal description. I evaluated Eyes-Free Art with 13 people who are blind or low vision to show the potential of the proxemic audio interface for blind and low vision art exploration. Table 1.2 summarizes my research questions and my approach to each question.

Table 1.2. A summary of research questions and the approaches to answer these questions.

	Question	**My Approach**
RQ1	How should we design audio based exercise systems that enhance exercise in real world scenarios with multiple stakeholders?	Value Sensitive Design with 20 semi-structured interviews and survey with 76 people (Chapter 3)
RQ2	How should we design audio based systems to coach a person who is blind or low vision to perform an exercise that may rely on vision?	Design, development, and evaluation of Eyes-Free Yoga as a prototype (Chapter 4)
RQ3	How should we design audio based exercise systems to encourage a person to exercise over a longer period of time?	Design, development, deployment, and evaluation of Eyes-Free Yoga as a system (Chapter 5)
RQ4	How should we design audio based systems to help a person explore visual items, such as art, independent of a sighted guide?	Design, development, and evaluation of Eyes-Free Art (Chapter 6)

1.4 CONTRIBUTIONS

In this dissertation, I present both artifact and empirical contributions. My research resulted in the following outputs:

1. Design opportunities and considerations for exercise technologies catered to people who are blind or low vision. Through semi-structured interviews with 20 stakeholders, and a survey with 76 people in the public, I found that there are opportunities to build technology that: 1) provides extra guidance during public exercise classes, 2) provides extra guidance while with a sighted guide, 3) enables or enhances outdoor rigorous exercise activity, and 4) helps people navigate exercise spaces such as a running track or swimming lane. In addition, we found two design considerations: 1) design the audio channel based on the type of exercise and context including the location and existing sound in the environment, and 2) it may be acceptable to develop a less mainstream technology if it allows for someone to exercise in a more mainstream context.
2. Design, development, and evaluation of Eyes-Free Yoga as a prototype. I showed that by providing real-time personalized verbal feedback during yoga, participants increased their understanding of the yoga postures and showed promise of improving the quality of their yoga postures.
3. Design, development, and evaluation of Eyes-Free Yoga as a system. I showed that audio motivational techniques including levels, badges, and reminders enhanced their experience while exercising. In addition, participants consistently used Eyes-Free Yoga over the 8-week deployment study. Eyes-Free Yoga is available for public download and has 259 downloads to date.

4. Design, implementation, and evaluation of Eyes-Free Art. I showed that the 13 participants could explore and understand 2D paintings by interacting with a proxemic audio interface. Participants were able to explore the painting in different levels of detail including background music, sonification of colors, sound effects of objects contained in the painting, and verbal description. The participants appreciated that they could interact with the painting as opposed to engaging in a passive experience such as an audio guide.

1.5 Dissertation Overview

This dissertation is divided into 8 chapters.

- In Chapter 2, Background and Related Work, I summarize related work in Quality of Life for people who are blind or low vision, in particular focusing on work relating to exercise and art. With these topics, I summarize both existing HCI and Accessibility research along with solutions in practice. I also summarize related research with respect to Computer Vision and Body Tracking systems.
- In Chapter 3, Value Sensitive Design, I illustrate the method I used to explore the space of exercise and technology for people who are blind or low vision. I aimed to understand the current opportunities and challenges of current and hypothetical technologies in the space of exercise. I report on quantitative and qualitative findings based on 10 people who are blind or low vision, 10 who play a role in exercise for people who are blind or low vision, and 76 people from the general population to represent a third party.
- In Chapter 4, Eyes-Free Yoga Prototype and Lab Study, I describe the design and lab study evaluation of the Eyes-Free Yoga prototype to explore how real-time personalized feedback pertaining to yoga helped with GameFlow (Sweetser and Wyeth 2005) and yoga

comprehension. I report on quantitative and qualitative results that show how Eyes-Free Yoga helped people familiarize themselves with the yoga postures and enjoy using the system.

- In Chapter 5, Eyes-Free Yoga and Deployment Study, I describe the design and in-home deployment study evaluation of the full Eyes-Free Yoga system to explore how audio motivational techniques enhanced exercise. In addition, I wanted to see if the benefits from the Eyes-Free Yoga Lab Study had the potential to sustain over a longer period of time. I report on quantitative and qualitative results that show how Eyes-Free Yoga was used throughout the 8-week study duration and how the audio motivational techniques enhanced gameplay.
- In Chapter 6, Eyes-Free Art, I describe the design and lab study evaluation of the Eyes-Free Art prototype to explore how a proxemic audio interface for blind or low vision may help with art exploration. I report on quantitative and qualitative results that show how Eyes-Free Art allowed participants to explore the painting using different audio interactions based on their proximity and how they were able to get a better sense of the painting versus only a verbal description.
- In Chapter 7, Discussion and Future Work, I discuss the limitations of my research, the themes that emerged, and opportunities for future work.
- In Chapter 8, Summary and Concluding Remarks, I summarize the contributions of my thesis.

Chapter 2. BACKGROUND AND RELATED WORK

In this chapter, I discuss the background and related work for technologies that utilize computer vision, and technologies that enhance quality of life for people who are blind or low vision. Further, I focus on exercise and art because they are the two domains I explore in my research. For exercise and art, I describe both background and related research for people who are blind or low vision.

2.1 COMPUTER VISION TECHNOLOGIES

2.1.1 *3D Camera Platform Technologies*

There have been several 3D camera systems developed, from off-the-shelf products to more sophisticated systems which involve setting up a more permanent dedicated space. Range scanning captures body surface information from four different locations, and models around 200,000 points (Anguelov et al. 2005). This type of system, while accurate, is prohibitive in terms of cost[2]. Motion capture systems, such as Vicon (2016), record the motion of a person wearing sensors on a bodysuit or attached to their body. The recordings are taken at a high frame rate (e.g. 150 frames per second) and the readings are turned into motion sequences. This system may be useful to acquire ground truth readings of a person, but also requires a dedicated space and funding. Because my goal is to enable independent exercise, I chose to work with technologies that are affordable and easy to set up in any space.

Technologies such as using two cameras for stereo vision or triangulation, and the Microsoft Kinect (Kinect 2016) are more affordable options. Time-of-flight (tof) cameras provide an affordable way to provide 3D imaging using a technique called sub-nano gating. When a light reflects off of 3D objects, the photons return at different times. For example, if position A is 1mm

[2] Cyberware’s pricing (http://cyberware.com/pricing/domesticPriceList.html): $200,000

further away than position B, the photon for A will return 7 picoseconds after the photon for position B (Yahav et al. 2007). Ganapathi et al. (2010) developed a real time motion capture system using a tof camera, which is the camera used in the second generation Microsoft Kinect. For the Eyes-Free Yoga prototype and system, I chose to work with the first generation Kinect, which uses an infrared (IR) laser in combination with a CMOS sensor, due to widespread deployment of Kinect for Windows. For my final project (Eyes-Free Art), I used the second generation Kinect.

2.1.2 *Computer Vision Based Activity Recognition Algorithms for 3D Platforms*

Ganapathi et al. (2010) provided a novel algorithm for tracking a 3D human pose without the use of markers being placed, and it was a seminal paper in human pose tracking. They modeled a human pose using a generative model of 15 rigid body parts via hill climbing, and combined this with a discriminative model that has previous evidence of the body part locations in the event of fast movement or occlusion. They have provided further work in 3D tracking of unusual human poses (Ganapathi et al. 2012). Multiple projects have rendered 3D pose estimates or gait parameters from depth images (Girshick et al. 2011, Plagemann et al. 2010, Shotton et al. 2013, Stone and Skubic 2011). SCAPE is a 3D surface model developed for animation of people. Their data driven model is based off of articulated pose estimation (accounting for both location and orientation of parts), and pose deformation (Anguelov et al. 2005). Kinect Skeletal Tracking (KST) was developed with a large training set of human poses labeled with 20 different colors for each portion, which are used in a randomized decision forest classifier. They ensured their dataset had variety of sizes and clothing to account for potential users (Shotton et al. 2013). KST is part of the Kinect for Windows Software Development Kit (SDK) version 1 and is well adopted with written documentation (Skeletal Tracking 2016). More recently, I use Microsoft Body Tracking (Microsoft 2016). I use KST and Body Tracking in my research to track postures and movements using the Kinect. KST is restricted to standing postures, so I work with only standing yoga postures with Eyes-Free Yoga.

2.2 QUALITY OF LIFE FOR PEOPLE WHO ARE BLIND OR LOW VISION

It is important to define Quality of Life as a foundation for my dissertation. According to the University of Toronto Centre for Health Promotion, Quality of Life is *"The degree to which a person enjoys the important possibilities of his or her life"* (Quality of Life Research Unit 2016). HCI and Accessibility researchers recognize that quality of life is an important goal, and there are research efforts in spaces such as participation in the workplace (Branham and Kane 2015, Feng et al. 2008, Maciuszek et al. 2005) or autonomous navigation (Azenkot et al. 2011, Meurer et al. 2014, Sánchez and Torre 2010, Sucu and Folmer 2014). I believe there may be gaps in the research to pursue more open ended goals including participation in culture and society. The goal of my dissertation is to not only provide access to various activities, but also sense of enjoyment, mindfulness, and knowledge. Quality of Life is further defined as three overlapping areas:

1. **Being:** This facet relates to a person's physical, mental, and spiritual wellbeing. There is a priority for people with disabilities to promote their own health; this one of the priorities of the 2005 U.S. Surgeon General's Call to Action (USSG CTA) (United States Surgeon General 2005) My Eyes-Free Yoga (Rector et al. 2013) and Value Sensitive Design (Rector et al. 2015) research may provide both physical (Ross and Thomas 2010) and mental health benefits (Khalsa et al. 2012).
2. **Becoming:** This facet relates to a person achieving goals and becoming a better person with practical (e.g. employment), leisure (e.g. relaxation), and growth (e.g. education) life goals. My research in Eyes-Free Art and Eyes-Free Yoga (Rector et al. 2013) fit here; both yoga and

art are both leisure activities that may help a person continue to learn new things and be challenged.

3. **Belonging:** This facet relates to a person's physical, social, and community belonging. The goal of research in this space is to allow people who are blind or low vision to participate in more public spaces with others. While the ultimate goal of my dissertation research is to enable people who are blind to explore exercise and art in more public settings, I have evaluated my research in the lab and home setting. My discussion chapter will explore the opportunities for future work that involves interacting with other people and in more public spaces. It is important to pursue this line of research; another goal of the USSG CTA is that the public *"understands that people with disabilities can lead healthy lives"* (United States Surgeon General 2005); one way to address this goal is to have people who are blind or low vision engage in activities alongside everyone else like at a gym or museum.

2.3 Quality of Life in the HCI Literature

There have been research efforts in the HCI community to enhance quality of life for the general population, which I survey through the lens of being, belonging, and becoming. With respect to being, there have been research efforts to improve physical, psychological, and spiritual well-being. Some examples are improvement in sleep quality (Bauer et al. 2012, Choe et al. 2011), hygiene (Bonanni et al. 2005, Chang et al. 2008), and nutrition management (Mamykina et al. 2011, Parker et al. 2013). Additionally, there has been a focus on mental health and well-being, including fashionable clothing to facilitate light therapy (Profita et al. 2015), the ability to predict postpartum depression via social media use (Choudhury et al. 2013), and technology mediated communication (Isaacs et al. 2013) or depression interventions (Doherty et al. 2012). Spiritually, there have been projects exploring people's values and how they affect online participation

(Sukumaran et al. 2014) or online reading (Hsieh et al. 2014), as well as tools to help with prayer (Gaver et al. 2010, Wyche et al. 2008, Wyche and Grinter 2009).

The second area of quality of life, belonging, may relate to feeling welcome in a certain physical space, a social circle, or a community space. HCI researchers have explored the design of physical spaces to create better environments for people with dementia or in care homes (Müller et al. 2012, Wallace et al. 2012) and for those living abroad (Wyche and Chetty 2013). With regards to social belonging, there have been research efforts studying the use of social networks (Burke et al. 2010, Chen et al. 2009, Jung et al. 2013) and how to enhance family communication (Mynatt et al. 2001, Rowan and Mynatt 2005), intimacy (Neustaedter and Greenberg 2012, Raffle et al. 2010, Vetere et al. 2005), and neighborhood communication (Masden et al. 2014). There is work on improving people's sense of belonging with a community by improved health care (DeRenzi et al. 2008, Farnham et al. 2012, Wärnestål et al. 2014), health promotion (Guana et al. 2014, Parker et al. 2012), and mentorship (Kuznetsov et al. 2011).

In the third area of quality of life, HCI researchers have developed projects that help people improve themselves in practice, leisure, and growth. There have been research efforts investigating practical matters like cleaning (Forlizzi and DiSalvo 2006), cooking (Clear et al. 2013, Uriu et al. 2012), volunteering (Jianqiang et al. 2011, Starbird and Palen 2011), and increasing one's independence (Leonardi et al. 2009). Another aspect of becoming is to improve activities of leisure. For example, researchers have investigated improving physical activity for people who have chronic pain (Singh et al. 2014) and improving mindfulness in everyday activities (Bellotti et al. 2008, Shastri et al. 2010, Thieme et al. 2013). There is also existing research on helping people grow in skills, including interview skills (Johnsen et al. 2007), social skills (Escobedo et al. 2012), and text literacy (Findlater et al. 2009). Finally, researchers have investigated how technology can help people adapt to change, including breakups (Sas and Whittaker 2013) and moving (Shklovski et al. 2008).

2.4 Eyes-Free Exercise

Within Quality of Life, one of the two domains in which I focus is exercise. In this subsection, I present background and related work on HCI, Exergame, and Exercise Technologies. Following, I summarize background and related work on Eyes-Free Exercise Opportunities, and Eyes-Free Exergame and Exercise Technologies. Because two of my chapters focus on the exercise of yoga, I also present related work pertaining to yoga.

2.4.1 *HCI, Exergame, and Exercise Technologies*

Exergame design addresses two important goals: attractiveness and effectiveness. Each of these two goals has a dual flow model: 1) Attractiveness: The person's skill should match the challenge of the game, and 2) Effectiveness: The person's fitness level should match the intensity of the game (Sinclair et al. 2007). The game should be enjoyable and have a sense of "GameFlow" while achieving the desired exercise. There are important factors addressed in GameFlow that I included in the design of the Eyes-Free Yoga prototype as well as evaluated for in my lab study using interviews: ability, concentration, challenge, skills, control, goals, and external factors (Sweetser and Wyeth 2005). I attempt to cater the Eyes-Free Yoga prototype to novices, having only standard yoga postures to help with these factors.

Researchers have evaluated the use of exergames in deployment studies to assess exergame potential and health outcomes. For example, Uzor and Baillie (2014) found after a 12-week study with older adults, there was better adherence to the exergame than standard care, which demonstrated potential for real world use. In addition, Kosse et al. (2011) conducted a 6-week evaluation with older adults with the goal of improving their balance, which was successful using the Berg Balance Scale. As I transformed Eyes-Free Yoga from a prototype to a fully functioning exergame system, I employed persuasive techniques from related research such as providing a selection of workouts (Doyle et al. 2011), virtual rewards for physical activity (Berkovsky et al. 2010) and antecedent stimuli (Adams et al. 2009, Glynn 1982) (known to enhance game technologies (Adams et al. 2009)) by informing participants as to how close they were to earning badges or advancing to the next level.

Beyond exergames, the HCI community has studied how to persuade people to continue toward their exercise goals using technology. According to Fogg's book, Persuasive Technology, there are three different functional roles that a persuasive technology can take: 1) being a **tool** and increasing capability, 2) being a **medium** that provides an experience, and 3) being a **social actor** that creates a relationship (Fogg 2003).

- Existing **tools** to promote exercise include Fitbit (2015), Jawbone's UP (Jawbone 2015), and Houston (Consolvo et al. 2006). Fitness tools can make a user's target behavior easier to achieve by presenting relevant measurements by numbers or other visual stimuli. Choe et al. (2013) found that positive framing of numerical information can impact one's self-efficacy to complete their goal.
- Some examples that provide a **medium** are UbiFit (Consolvo et al. 2008), Fish'n'Steps (Lin et al. 2006), or GoalPost/GoalLine (Munson and Consolvo 2012). These provide an experience of growing a garden, fish, or trophy case, with the growth reflecting their fitness level.
- Persuasive technologies that are **social actors** include UbiFit (Consolvo et al. 2008), a relational agent interface named Laura (Bickmore et al. 2005), and a mobile lifestyle coach (Gasser et al. 2006). Fritz et al. (2014) studied users who used wearable fitness trackers for an

extended period (3-54 months) and fund benefits as a **tool** for reporting numbers and as a **social actor** to provide rewards and social networking capabilities. Each of these systems provide coaching support and rewards for positive feedback, such as a happy face for completing activities.

I designed the Eyes-Free Yoga system as a persuasive technology that uses non-visual techniques to lower the barrier of practicing yoga through sound-based posture guidance. The Eyes-Free Yoga system is a **tool** because it leads a user through each posture and a **social actor** by providing positive feedback such as words of encouragement or badges (Munson and Consolvo 2012). The intention is for Eyes-Free Yoga to achieve longer-term engagement and opportunities for exercise.

2.4.2 *Eyes-Free 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 (2015) and the Canadian Blind Sports Association (2012) 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 2015), skiing (Ski for Light 2015), and cricket (Cricket Association for the Blind in India 2012). 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 (Winnick 2011)), which people who are blind prefer (Lieberman et al. 2006) over predictable closed sports (e.g. running on a treadmill) (Winnick 2011). 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.

2.4.3 *Eyes-Free Exergame and Exercise Technologies*

Accessible exergaming has been recognized as a research problem across many disciplines (Morelli 2010). There are three possible phases during gameplay in which a disability be negative: 1) receiving stimuli, 2) determining a response, and 3) providing input to the game (Yuan et al. 2011). For people with visual impairments, the problem occurs with phase 1, because most stimuli in video games are visual (Morelli et al. 2010a). Two strong efforts from the research community are the creation of accessible alternatives to Wii Sports games, VI-Bowling (Morelli et al. 2010b) and VI-Tennis (Morelli et al. 2010a). Morelli et al. (2010a, 2010b) completed a careful analysis of primary (or necessary) 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 and Folmer (2011) developed a solution using video capture to find visual cues and communicated the information using audio and tactile feedback with a Wii Remote. VI-Tennis was evaluated with children. The researchers measured the difference in energy expenditure, scores, and enjoyment from the original Wii Sports game. They found that people scored better and enjoyed the game more with the accessible version and produced health benefits due to physical activity. VI-Bowling, evaluated with adults, was found to be enjoyable and a sufficient challenge.

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. In addition, they found participants comparing scores to one another after the completion of the study. (Morelli et al. 2011).

While my work with Eyes-Free Yoga involves the development of an exergame, I did not evaluate my work similar to related research. Eyes-Free Yoga was evaluated in two different studies: lab study of a prototype (Rector et al. 2013), and deployment of a completed system. For the lab study, my measures of success were yoga quality and GameFlow (Sweetser and Wyeth 2005), namely because yoga is not an aerobic exercise and calorie expenditure is not a goal. I followed the same considerations that are important for therapeutic exergaming (Doyle et al. 2011) by including feedback to assist in player competence and enjoyment. For the deployment study, my measure of success was minutes of exercise per day. To our knowledge, our research represents the first in-home deployment study of an exergame for people who are blind or low vision that looked at long-term engagement, rather than short-term use in a lab setting.

Beyond exergames, there are opportunities for other kinds of innovative technologies to be developed to help with exercise for people who are blind or low vision. With the recent popularity of exercise tracking technologies, such as Fitbit (2015) and the Nike fuel band (Nike, Inc. 2015), there have been several research efforts investigating how to leverage these technologies and the data they collect to increase fitness. The goal of this research is to encourage useful exercise habits for adults (e.g. Cercos and Mueller 2013, Fitbit 2015) and for older adults who may face significant barriers to exercise (Albaina et al. 2009, Fan et al. 2012). Although useful, these health tracking applications are often not accessible to people who are blind or low vision (Milne et al. 2014). There are opportunities to design new technologies 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. From interviewing relevant stakeholders including people who are blind or low vision and people involved in their fitness along with surveying people in the public about technology and exercise, I uncovered important values behind accessible exercise and the opportunities for technology design.

2.4.4 *Eyes-Free Yoga Opportunities and Yoga Technologies*

While yoga for people who are blind or low vision is not yet mainstream, there have been efforts to make the practice more accessible. Multiple CD sets have been developed to practice yoga while at home (Klein 2013, Yoga Center of Marin 2014). Another in-home solution, So Sound Yoga Board, communicates through body sensations when the person is out of alignment and indicates which parts of the body are under stress, but it is expensive (So Sound Solutions 2015). A less expensive solution, Visually Impaired Yoga Mat (Rousettus 2015), provides tactile cues for foot and hand placement. Some yoga instructors have spent a long period of time working with the people who are blind or low vision to gain a better understanding of yoga, such as being aware of the words used to instruct the class (Meyer 2006). One yoga instructor had sighted people use blindfolds to gain empathy (McPherson 2006). Another group of instructors held poses and let the students feel them. Overall, most of the opportunities for people who are blind or low vision to engage in yoga have needed contact with a yoga instructor with the knowledge and experience to accommodate.

Yoga exergames have been developed on the Wii Fit and the Kinect. In general, they are not accessible for eyes-free interactions. For example, the Wii Fit requires the television be at eye level for a player to view their progress. A recent Kinect-based exergame, Your Shape Fitness Evolved (Ubisoft Entertainment 2012), has yoga workouts that provide visual feedback to enable a player to correct their alignment. However, players are required to compare their body to an instructor avatar on the screen (see Figure 2.1, below).

Figure 2.1. 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.

Players need to keep their play space green or "in sync" with the instructor. The required tasks for their body are displayed in text in the upper right corner of the screen and turn green when done correctly. The only audio cue is a bell sound informing that an adjustment was completed, but the particular adjustment suggestion is visual. There are verbal cues reliant on sight (e.g. *"watch her feet"*) while others are accessible (e.g. *"keep the lunge low"*). Chopra's Leela is a yoga exergame that primarily uses visual feedback to enhance the experience (Microsoft 2015). Eyes-Free Yoga uses positive aspects of each game, such as suggesting body adjustments and verbal and audio feedback to confirm that the player has finished a movement.

2.5 Eyes-Free Art

2.5.1 *Current Eyes-Free Museum Opportunities*

Both organizations and researchers have addressed the important problem of the inaccessibility of museums. For instance, the Smithsonian Institution Accessibility Program has published recommendations for accessibility for people who are blind or low vision in museums including how to effectively communicate (Ziebarth 2010), create tactile exhibits (Fernandes 2012, Fuller and Watkins 2010), and use current media technology (Goldberg 2010). There have been one-off exhibits containing accessible tactile art pieces, including “Please touch the art” (Hein 2015), “Systematic Landscapes” (Stice 2006), LEGO Blind Art Project (2016), and quilted versions of artwork (Shortley 2014). Museums have also created audio tours including the MoMA (2016), Metropolitan Museum of Art (2016), SAM (2016), and Currier Museum of Art (2016). Two apps have been created that allow for haptic and verbal interaction: Tooteko (2015) allows patrons to explore a tactile piece and hear cued audio information, while STQRY (2015) is an interpretive guide that provides content based on a user’s location within the museum. We distinguish ourselves from STQRY because we allow users to explore a painting from different distances to form their own experience. Finally, there are online resources to access audio descriptions including from Art Beyond Sight (2005b).

There have also been research efforts in using haptics and/or sound to either assist with navigation in the museum or communicate information about exhibits. For example, the Accessible Aquarium Project (2016) has been an ongoing project since 2006, which strives to provide informative sonifications based on the static objects or current movements of fish in the exhibit. The Haptic Lotus (van der Linden et al. 2011) increases and shrinks in size as users get closer or further to a point of interest in a museum. In contrast, the Accessible Mobile Guide (Ghiani et al. 2008) places actuators on fingers to the left and right of the device to communicate in which direction the museum visitor should walk. Our work complements efforts such as these by allowing patrons to explore deeper into particular paintings, as opposed to supporting higher-level museum navigation and exhibit exploration. Further, we contribute the ability to explore the painting in different dimensions with an auditory-only interface.

2.5.2 *Sensory Substitution*

There is an opportunity to use sensory substitution to convey information about visual aspects of images, paintings, or charts (Bach-y-Rita and Kercel 2003) using haptics and/or sound. There have been research efforts to convey information about 2D images or graphics, with the majority of research focusing on color to sound and haptic representations of charts and graphs (Doush et al. 2010, Braier et al. 2014, Giudice et al. 2012, Goncu et al. 2014, Vogel and Balakrishnan 2004). In the space of haptics, tools such as the Phantom Haptic Joystick, Novint Falcon Device, VTPlayer Tactile Mouse, and mobile device vibrations have been used to present colors (Kahol et al. 2006), relative object sizes (Braier et al. 2014, Douglas and Willson 2007, Giudice et al. 2012, Vogel and Balakrishnan 2004), textures (Li et al. 2010), depth (Morris and Joshi 2003), and boundaries (Doush et al. 2010, Giudice et al. 2012, Goncu et al. 2014, Morris and Joshi 2003). Computer Vision also has been used to create printed tactile renderings of images (Hernandez and Barner 2000, Reichinger et al. 2011, Wang et al. 2008). For our work, we chose not to use haptics because we felt that current haptics technology limited the richness of the experience we wanted to create in addition to the technology being difficult to scale and costly to deploy.

Sound has been used for conveying edges (Banf and Blanz 2013, Yoshida et al. 2011) and spatial locations of items (Goncu et al. 2015, O'Neill and Ng 2008), but has been mostly used to convey colors using sonifications. Sonifications are interactive and translate colors to sound based on hue (Banf and Blanz 2013, Cavaco et al. 2013, McGee 2013, Payling et al. 2007, Pun et al. 2010, Quinn et al. 2012, Sonified 2011), saturation (Cavaco et al. 2013), brightness (Cavaco et al. 2013, Meijer 1992, Quinn et al. 2012), height (Meijer 1992), or depth (Pun et al. 2010). In addition, a sonification can synthesize new sounds (McGee 2013, Sonified 2011) or vary different aspects of sound including instruments (Banf and Blanz 2013, Pun et al. 2010, Quinn et al. 2012), timbre

(Cavaco et al. 2013, Payling et al. 2007), pitch (Cavaco et al. 2013, Meijer 1992, Quinn et al. 2012), or volume (Cavaco et al. 2013, Meijer 1992). Users can interact with sonifications by walking (Quinn et al. 2012), using images (Cavaco et al. 2013, Meijer 1992, Payling et al. 2007, Pun et al. 2010, Sonified 2011), or single or multi-touch interaction (Banf and Blanz 2013, McGee 2013). One commonality among these projects is that sounds are presented as a literal translation of the color, which may produce less aesthetically pleasing sounds. Our sonification approach addresses this by altering composed music by changing the volume of instruments to convey changes in color. We chose to only alter the instruments used and their volume to keep the audio presentation simple and easy to learn, as well as aesthetically pleasing (a priority, given the target domain of art appreciation).

A creative and aesthetically pleasing way to convey information with sound involves the use of soundscapes, or a mixture of sounds. Kabisch et al. (2005) presented spatialized recorded audio while exploring a landscape panorama; this interaction involved both sight and sound. Eyes-Free Art can be considered a type of soundscape, wherein the user can interactively control the types of sounds received by changing their proximity relative to the target artwork.

2.5.3 *HCI and Interactive Art*

The HCI community has embraced interactive art and made contributions on how to make this interest suitable for a research audience, including how to evaluate art installations (Gonçalves et al. 2012), evaluate enjoyment (Gonzalez et al. 2009), and determine vocabulary terms to increase our understanding of interaction and play (Morrison et al. 2011). Morrison et al. (2011) determined terms from participant observation with interactive art, including: situation social play, interactive play, speculative play, and comprehension. Because our Eyes-Free Art prototype is currently built for one user at a time, we hope that users will engage in the latter three terms; we want the participants to engage with the system, explore the audio and learn more about the painting.

In addition to comprehension, another strength to interactive play is that it increases enjoyment in artistic spaces (Gonzalez et al. 2009); it is important to bring a sense of liveliness to art displays (Wakkary and Hatala 2006). In order to make Eyes-Free Art interactive, we implemented four different zones that users can walk between and provided a sonification and sound effect zone that allow users to receive additional interactive audio information based on the position of their hand. Eyes-Free Art is an interactive prototype exploring the design of proxemic audio interfaces. In the corresponding lab study, we studied whether or not the proxemic audio interface has a good interaction, not if it is good art (Höök et al. 2003). We leave the challenges of artistic quality (Höök et al. 2003) and how it will be placed in the physical context of a museum (Raptis et al. 2005) for future work.

We build upon prior work in the areas of proxemic interfaces, eyes-free museum opportunities, and sensory substitution. Further, Eyes-Free Art is novel in implementing a scalable, aesthetically interesting interactive audio experience for conveying paintings to people who are blind or low vision. This is also the first work to explore adapting proxemic interfaces to the audio domain.

2.6 Chapter 2 Summary

In this chapter, I presented a background in technologies that utilize Computer Vision and describe why I use the mainstream Kinect technology. I summarize the background and related work on quality of life for people who are blind or low vision with an additional focus in exercise and art. I identified gaps in and distinguished myself from current research in exercise activity and art engagement with people who are blind or low vision. The goal of my dissertation work is to address the uncovered gaps in the space of eyes-free quality of life.

Chapter 3. VALUE SENSITIVE DESIGN

In this Chapter, I wanted to pursue other opportunities for technologies to make an impact in exercise for people who are blind. This chapter addresses RQ1: *"How should we design audio based exercise systems that enhance exercise in real world scenarios with multiple stakeholders?"* The goal of this work was to determine more generalizable opportunities outside of yoga as an exercise. I employed value sensitive design (VSD) to explore the potential of technology to enhance exercise for people who are blind or low vision. I 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. I 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 my interviews and survey, I 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 future accessible exercise technologies.

3.1 INTRODUCTION

As mentioned in Chapter 3, people who are blind or low vision can have a harder time participating in exercise than people who are sighted. 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 (Rimmer 2006).

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 (Schwanda et al. 2011). However, most exergames (Morelli et al. 2010a) and health tracking technologies (Milne et al. 2014) have accessibility issues for people who are blind or low vision because many of the necessary cues are visual.

While research efforts for exergames for people who are blind or low vision are on-going (Morelli et al. 2010a, Morelli et al. 2010b, Morelli et al. 2011, Rector et al. 2013), typically these are limited to exergames that involve only upper body exercise and do not provide as much energy expenditure as full body exercise (Biddiss and Irwin 2010). 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 or 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) (Borning et al. 2005, Friedman et al. 2013), an approach that requires designers to interact with both direct and indirect stakeholders 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 (Glaser and Strauss 1967) 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.

3.2 Background of Value Sensitive Design

In our study, we used value sensitive design's (Borning et al. 2005, Friedman et al. 2013) tri-partite methodology to account for values from various stakeholders. VSD may start from a value, technology, or context of use (Friedman et al. 2013). 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 (Yetim 2011). The three parts consist of a Conceptual, Empirical, and Technical Investigation.

3.2.1 *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 view that offer to help as disrespectful.

3.2.2 *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.

3.2.3 *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.

3.3 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.

3.4 CONCEPTUAL INVESTIGATION

3.4.1 *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.

3.4.2 *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 (Borning et al. 2005) 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).

3.4.3 *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* (Azenkot et al. 2011, Friedman et al. 2013, Kane et al. 2009, Shinohara and Tenenberg 2007), *safety* (Kane et al. 2009, Shinohara and Wobbrock 2011), *being mainstream* (Shinohara and Tenenberg 2007, Shinohara and Wobbrock 2011), and *confidence* (Azenkot et al. 2011, Friedman et al. 2013) (see Table 3.3 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.

3.5 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 3.1).
2. Group 2 (Indirect Stakeholders): We conducted semi-structured interviews with people who facilitate exercise for people who are blind or low vision (Table 3.2, below).
3. Group 3 (Indirect Stakeholders): We conducted a survey of the general population.

Table 3.1. Demographic information about Group 1 participants (Direct stakeholders – blind or low vision).

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

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), Tandem bicycle 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

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. 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. See Appendix F for the direct stakeholder interview questions.

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. See Appendix G for the indirect stakeholder interview questions.

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. The scenarios used in the survey were similar to those in Group 1, except that the person who is blind or low vision was referred to as a different person. 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."* See Appendix H for the indirect stakeholder survey.

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 3.1) and 10 indirect stakeholders (Group 2: I1-I10, Table 3.2). For the survey, 76 members of the general population were respondents to our Group 3 survey (S1-S76, 51 females, 25 males; 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 (Guest et al. 2006)). 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 (Glaser and Strauss 1967) 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.

3.6 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 3.3.

Table 3.3. Opportunities and considerations for design, and the corresponding values and value tensions (listed in the order mentioned).

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

3.6.1 *Stakeholder Themes, Values, and Value Tensions*

3.6.1.1 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 (Rimmer 2006). 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 (Rector et al. 2013). 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).

3.6.1.2 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 (2015): *"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."*

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. (2014) developed a system that displays runner information on the back of shirts, which could be made accessible.

3.6.1.3 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 (Pretty et al. 2005). 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 (Winnick 2011), 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 (Winnick 2011), 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 (Shinohara and Wobbrock 2011). 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.

3.6.1.4 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 discovered 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 (Crawford 2015), 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 (Iannacci et al. 2011) 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 (Phys.org 2015). 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 (Bozkurt et al. 2014, Jackson et al. 2013). The Facilitating Interactions for Dogs with Occupations (FIDO) project produced a wearable technology for service dogs so they could increase communication with their owners (Jackson et al. 2013) 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 (Bozkurt et al. 2014). 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).

3.6.1.5 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 (Azenkot et al. 2012). 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).

3.6.1.6 Consideration: Less mainstream solutions

Developing *mainstream* technology solutions may be important for an aesthetic appearance (Shinohara and Wobbrock 2011). 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 may be acceptable 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 under-explored 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.

3.6.2 *General Population Response to Exercise Scenarios*

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

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.

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.

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 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 3.4 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.

Table 3.4. 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: 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

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.

3.7 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 (Friedman et al. 2013). 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 3.5 (next page). While the technology listed is accessible, they may not address the emerging themes that we learned about during the interviews and surveys. 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.

Table 3.5. Technology use reported by Groups 1&2.

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

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: 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 (Winnick 2011) 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 (Winnick 2011)) and guided exercise while completing rigorous activity (e.g. more open exercise (Winnick 2011)). 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.

3.8 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: knowledge in an exercise class, knowledge while with a sighted guide, rigorous outdoor exercise, and navigating exercise spaces. Ideally, designers would involve both direct and indirect stakeholders while designing, prototyping, and testing technology.

3.9 Chapter 3 Summary

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 3.3): 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: 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 (see Table 3.3). I derived four new opportunities for technology design and two design considerations. The technical investigation evaluated whether existing technologies used for eyes-free exercise could be used for the four opportunities. This work provides both ideas and guidelines for future work. 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.

Chapter 4. EYES-FREE YOGA PROTOTYPE AND LAB STUDY

This chapter presents the prototype version of the first system I built called Eyes-Free Yoga, and the first empirical investigation of the prototype in a lab setting. I address RQ2: *"How should we design audio based systems to coach a person who is blind or low vision to perform an exercise that may rely on vision?"* The reason I addressed this research question is that people who are blind or low vision may have a harder time participating in exercise classes due to inaccessibility, travel difficulties, or lack of experience. Exergames can encourage exercise at home and help lower the barrier to trying new activities, but there are often accessibility issues since they rely on visual feedback to help align body positions. To address this, I first developed the prototype version of Eyes-Free Yoga using the Microsoft Kinect that acts as a yoga instructor, teaches six yoga poses, and has customized auditory-only feedback based on skeletal tracking. I ran a controlled lab study with 16 people who are blind or low vision to evaluate the feasibility and feedback of Eyes-Free Yoga. I found that participants enjoyed the prototype, and that the extra auditory feedback helped their understanding of each pose. I discuss the implications of this work for improving auditory-only feedback and on the design of exergames using 3D cameras.

4.1 INTRODUCTION

Research studies indicate that people who are blind or low vision are generally not as healthy as people without disabilities. They are more likely to be obese (Capella-McDonnall 2007, Weil et al. 2012) and to report poor, fair, or worsening health. Youth and adolescents with visual impairments do not complete enough physical activity to maintain an adequate fitness level (Capella-McDonnall 2007). As a child's visual impairment increases, both their view that physical activity is important and their parents' expectations decrease, because they had lower expectations to succeed (Stuart et al. 2006). As a result, the amount of physical activity decreases (Robinson and Lieberman 2004). Exercise classes can be encouraging but are often taught by instructors who do not know how to adapt for those who are blind or low vision (Rimmer 2006).

One recent trend to increase exercise activity is the use of exergames, or exercise games, which are video games used for exercise. Exergames can provide fitness activities and act as a gateway to more advanced exercises (Schwanda et al. 2011). However, many people cannot play these games due to having a disability (Weil 2002). In particular, exergames have accessibility issues for people who are blind or low vision because many of the cues necessary to play a game, such as aligning one's body to an on-screen figure, are visual (Morelli et al. 2010a). There is existing work in the space of exergames for people who are blind or low vision (Morelli et al. 2010a, Morelli et al. 2010b), but it remains a young field and has thus far been mostly limited to controller-based interaction. Better access to exergames while at home would provide more exercise opportunities for people who are blind and low vision or for those who do not want to interact with a screen. In addition, exergames have the benefit of not relying on a sighted guide.

In response to this need, we developed Eyes-Free Yoga, a game that provides solely auditory output using Microsoft Kinect for Windows. Yoga was chosen for its physical (Ross and Thomas 2010) and mental health benefits (Khalsa et al. 2012). Our exergame provides instructions for yoga poses and custom feedback to help players improve their poses. To create a yogic game that provides a similar experience to studio yoga and includes proper techniques, we included yoga instructors throughout the design iterations. Our goal is to enable people who are blind or low vision to practice yoga effectively and independently. We also aim to encourage users to practice yoga in a class setting if they find it beneficial.

There are several contributions from our work. First, we developed an accessible exergame prototype for people who are blind or low vision. The prototype can hear, speak, see, and act as a yoga instructor. Second, we determined that understandable auditory feedback may improve a player's body position in an exergame. Finally, our work can provide general insights for future developers of exergames that use skeletal tracking.

4.2 Eyes-Free Yoga Prototype Design

We discuss in detail the six design principles used to inform Eyes-Free Yoga. These were identified from our project: allow people who are blind or low vision and new to yoga to learn the practice and encourage in-person class attendance. We follow with a technical description of how we developed our prototype.

4.2.1 *Design Principles*

Eyes-Free Yoga uses the Kinect platform to guide players through six different yoga poses, recognize whether the player is in the correct position, and provide feedback on how to correct their position if they are not. We identified these six principles based off of the goal of our project: accessible, yogic, encourages confidence, targeted to novices, accessibility features do not compromise learning, and encourages a challenging workout.

4.2.1.1 Accessible for Eyes-Free Interaction

Eyes-Free Yoga was designed to be accessible for people who are blind and low vision. Consequently, this principle applies to anyone who could benefit from performing yoga without having to look at a screen, which could be a form of situational impairment (Sears et al. 2003). To reduce the risk of improperly described inadvertent visual cues, we completely removed the screen component. We consulted yoga materials specifically created for people with visual impairments to capitalize on descriptive techniques and understandable words and phrases (Klein 2013). The exergame aspired to have clear audio instructions and ease of interacting with a player. Participants used their voice to give commands and thus did not have to acquaint themselves with a controller or novel equipment.

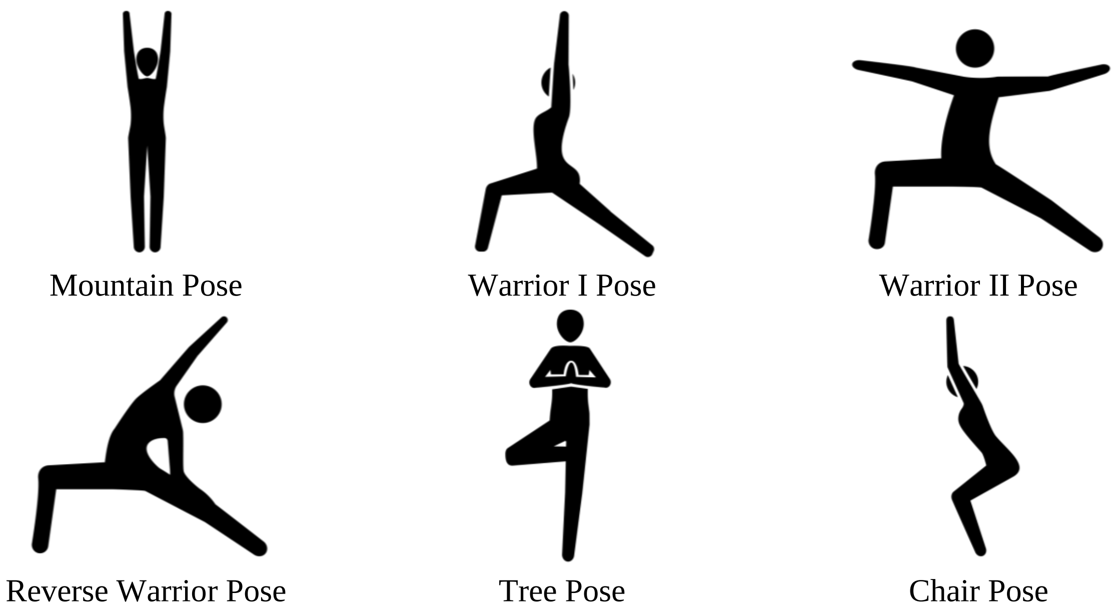


Figure 4.1. The six poses used for evaluation, listed in the order in which they were performed. Credits: 1st image - stand by Claire Jones from the Noun Project; Last five images - yoga by Claire Jones from the Noun Project.

4.2.1.2 Game Provides a Yogic Experience

Our goal with Eyes-Free Yoga was to create an experience comparable to attending a yoga class or performing yoga along with an audio/visual guide. To determine the six appropriate yoga positions and respective verbal feedback, we collaborated with three yoga instructors and one yoga instructor in training, one of which had experience working with people who are blind or low vision. As an additional constraint, our poses needed to be compatible with Kinect's Skeletal Tracking, which requires users to be in a standing position. Based on the yoga instructors' feedback, we determined a set of six standing yoga poses for our study (Figure 4.1). To gain a deeper understanding of the poses, the lead researcher took five courses on the fundamentals of yoga from one of the yoga instructors. In addition, the training yoga instructor gave us a teacher-training manual authored by her school (Hot Yoga for Life 2016). After developing the script and demonstrating our exergame, one instructor gave us specific feedback about the most common mistakes made by people for each pose. They helped edit the script and commands used to correct each mistake.

We incorporated relaxing, meditative music in the background to enhance the experience. Another collaborating yoga instructor provided the voice for the scripts to add more reality, rather than using computer-generated speech. Interacting with the game using only their voice allowed participants to maintain the yogic experience by performing pose after pose without interruption to manipulate a controller. We did not require any body-worn sensors to increase comfort and used two standard yoga mats to replicate a yoga class. They were arranged one on top of the other in a plus-shape to give participants bearings of the game space.

4.2.1.3 Game Instills Confidence

We wanted to encourage confidence, future gameplay, and possible attendance at future yoga classes. We gave positive verbal cues for adjustments and by playing a wooden xylophone tone when the player achieved the correct adjustment. Participants were told *"Good job!"* by the yoga instructor when they were holding the pose correctly. This method affirmed to participants they were performing the pose correctly. Ideally, if they fixed the adjustments while at home and performed the corrected pose at an in-person class, the yoga instructor would have a positive review.

4.2.1.4 Caters to a Novice Target Audience

The target audience of our exergame was people who are new to yoga. We chose poses that serve as basis for learning more complex poses, and the poses gradually became more difficult as participants progressed through the game. We offered a modification for Tree Pose, a balance posture, for those whose balance was poor. The participants had the option to perform the poses between 1 and 3 times depending on if they were tired. Our exergame asked the participants if they were experiencing back or knee pain. If a participant answered *"yes,"* the exergame would give accommodating modifications so the participant could complete a modified pose. Along with utilizing nonvisual descriptions, we chose phrases that were not specific to yoga so people who had never attended a yoga class could follow the directions.

4.2.1.5 Accessibility Does Not Hinder Learning

We wanted to design a game that offered comprehensive instructions and verbal corrections without interfering with the flow of game play. Participants could ease into the pose while hearing comprehensive instructions. While holding a pose, the exergame offered verbal adjustments and auditory confirmation to assist in pose improvement. Participants could master poses they might encounter in yoga classes; we did not adapt any of the poses. This method differs from class situations in which a pose description is given and the instructor has to then assist the person who is blind or low vision in achieving the pose while everyone else is already holding their pose and possibly moving on.

4.2.1.6 Encourages a Challenging Workout

We determined rules for each pose using skeletal tracking and custom verbal corrections so the participants were only told *"Good job!"* when they performed the pose correctly. We did not offer shortcuts, except to avoid injury, so participants were required to learn and achieve the pose to receive positive feedback. This would also provide the challenge element of GameFlow (Sweetser and Wyeth 2005).

4.2.2 *Technical Development*

We built our game using the Microsoft Kinect for Windows Software Development Kit (SDK) version 1.6 and C#, which includes speech recognition. We used information from yoga instructors to program a set of rules for each pose. The rules utilized Kinect Skeletal Tracking, which contains 20 body joints, to provide custom verbal corrections. The 20 joints recognized by the Kinect SDK provide information about their X, Y, and Z position. Because we were able to calculate the distance between any two skeletal points, we could calculate the different body angles using the Law of Cosines.

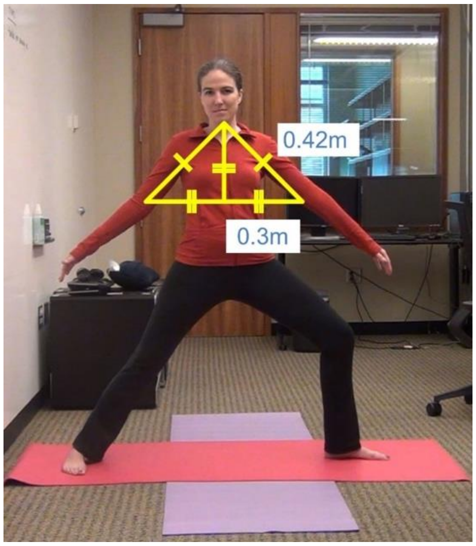


Figure 4.2. In Warrior II, her arms are at 45° and need to be raised to ≥ 80°. The Kinect responds with a verbal correction of *"Bring your arms closer to your head."*

For example, the game can calculate that the "armpit" angle is currently 45° and the proper angle should be at least 80° (see Figure 4.2). The game responds with the appropriate verbal correction. To reduce errors with occlusion and rotation of the body (Dutta 2012), we determined how the participant should face the Kinect based on the pose. We also used built-in "Joint Filtering" provided by the Kinect. As a result, we did not encounter any issues with occlusion during the development or the studies.

The rules were determined after reading yoga resources and asking yoga instructors for common errors. The lead researcher interviewed one yoga instructor at a yoga studio about important and unimportant aspects of each pose. The researcher would act out the poses and possible errors to gain clarification. Each pose had an average of 10.5 rules and a mode of 11 rules. The least constrained pose, Tree, had 7 rules due to the main focus on balance. People performing this posture could use their arms however they wanted. The most constrained pose, Reverse Warrior, had 12 rules, because each limb was contributing something unique.

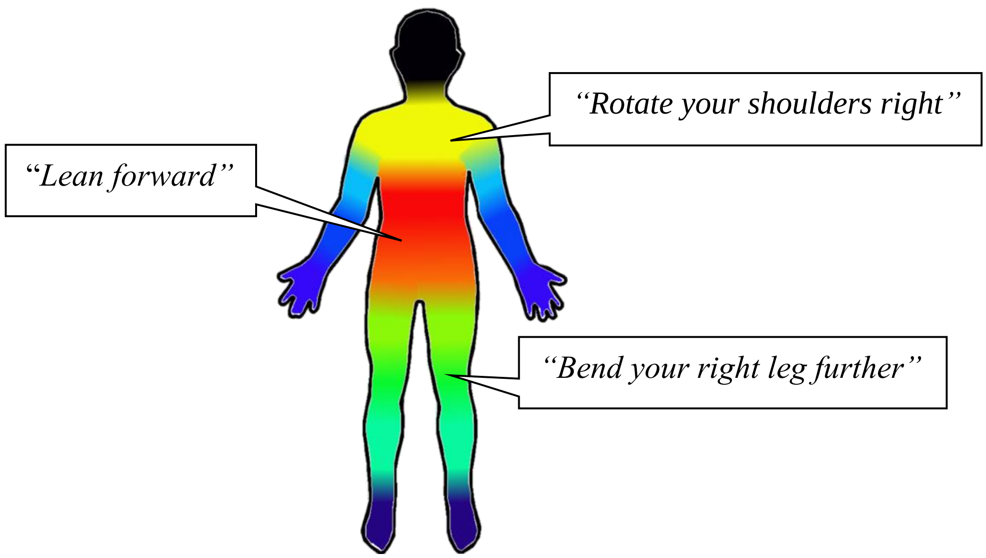


Figure 4.3. Priority of adjustments shown on the human body. The highest priority is the core, which is red (hot), and lowest priority is the feet, which are purple (cold). The head orientation is not measured.

Each violated rule provides the appropriate verbal correction to fix the issue. The rules have from 1 to 4 choices of verbal corrections to make based on the Kinect Skeletal Tracking data. The suggested verbal correction was prioritized by location of the issue. We designed the verbal feedback to first adjust the center of the body followed by the legs and arms to lessen the amount of verbal corrections. The priority of corrections given is shown in Figure 4.3. Appendix A provides detailed pseudocode examples of the rules and verbal corrections given for Warrior II. It is worth noting that if an instruction had to be repeated four times in a row, the game would move forward to avoid frustrating a player.

Kinect Skeletal Tracking does not adapt to bent knees, which is why the newest SDK removes the legs from Skeletal Tracking for seated users. The measured angles for the knees were higher than expected; a knee bent at a 90° angle would return a value closer to 145°. As a result, the rules catering to the knees were less constrained; I could only detect whether or not the leg was bent, but not necessarily how bent. The lead researcher stood in front of the Kinect and then bent down to reach their toes. According to the Kinect, the lower legs shrunk by 3" and the upper legs shrunk by 7". Recent Computer Vision research shows the potential to expand to more advanced poses and improve the issue encountered with bent knees (Ganapathi et al. 2012).

4.3 Validation of Accuracy

To assess the ability of Eyes-Free Yoga to help novices learn new yoga poses and provide an enjoyable exercise experience, we conducted an evaluation with 16 participants who were blind or low vision. Our study design used mixed methods and a quasi-experimental component where every participant practiced yoga using a *baseline* and *experimental* prototype version of the game:

- The *baseline* prototype provides step-by-step instructions to perform a pose with no feedback about how the participant is doing.
- The *experimental* prototype is the same as the *baseline* prototype but provides custom verbal and auditory feedback to correct a player's position.

The study was counter-balanced in that participants were randomly placed into Group A (*baseline* first, *experimental* second) or Group B (*experimental* first, *baseline* second). The game presented poses in the order shown in Figure 4.1 for both groups with 3 poses per condition.

4.3.1 *Study Methodology and Data Analysis*

We interviewed participants to assess their experience practicing yoga and current exercise habits as seen in Appendix B. Following the interview, the participants listened to a tutorial presented by the game to gain bearings of the game space. The yoga mats were arranged one on top of the other in a plus-formation, so the participants learned about "front, back, right, left, and base" location. These locations were referenced in the instructions so the participants knew where to move. For example, Warrior Two began with spreading the legs apart while facing the Kinect: *"Stand in base. Stretch your arms out to the sides, and step your feet apart until your heels are under your wrists. Relax your arms."* They also listened to a tutorial about custom feedback: Group A listened after three poses and Group B listened at the beginning. It stated they would hear more instructions followed by a tone when they completed the instruction correctly. The participants performed the six yoga poses up to three times each for 15 seconds, or in the case of the experimental prototype, until they completed the verbal corrections.

Upon game completion, we conducted a follow-up interview (see Appendix C) with participants to assess their perceived quality of the experience. We asked participants about their thoughts of the game and asked them to provide open responses about the usefulness of the customized feedback. The interviews were audio recorded and the game session was video recorded, which we then transcribed and analyzed. We extracted still photos from video recordings of the participants performing each pose while removing any identifying information. We worked with four yoga instructors from the community to rate the quality of each pose on a Likert Scale (1 – very bad to 5 – very good). The instructors were unaware of which photos depicted a participant performing a pose with custom feedback versus one performing without custom feedback.

4.3.2 *Participants*

We recruited 16 participants who were blind or low vision to participate in our study. There were 8 females and 8 males, and 12 were completely blind while 4 were low vision. Their average age was 23.8 years with a range between 13 and 60 years. We recruited participants through email lists and by partnering with the Washington State School for the Blind. The study was conducted at the school and at the University of Washington. The participants spent between 45 and 90 minutes completing the study and were compensated with $20 cash. Participants were evenly divided with regard to previous yoga experience: 5 had never practiced yoga, 6 had little experience, and 6 had taken yoga classes. Ten participants had attended exercise classes besides yoga, many of them through their school. Reasons participants gave for not attending classes included lack of time (1), not being able to follow an exercise class (2), difficulty finding the right class (1), and it not being a priority (2). Six participants mentioned the importance of extra audio instructions in a proposed class setting, which may not be fulfilled in current yoga classes.

4.4 RESULTS

Below we describe the results of Eyes-Free Yoga's custom feedback on the users' performance and how the yoga instructors rated the poses. We then discuss participants' engagement with the game overall and their experience with the customized feedback.

4.4.1 *Quantitative Results*

We discuss the frequency of custom verbal corrections in the experimental prototype and suggest when it may or may not be beneficial. We then describe yoga instructor feedback on the pose quality using both the baseline and experimental prototypes.

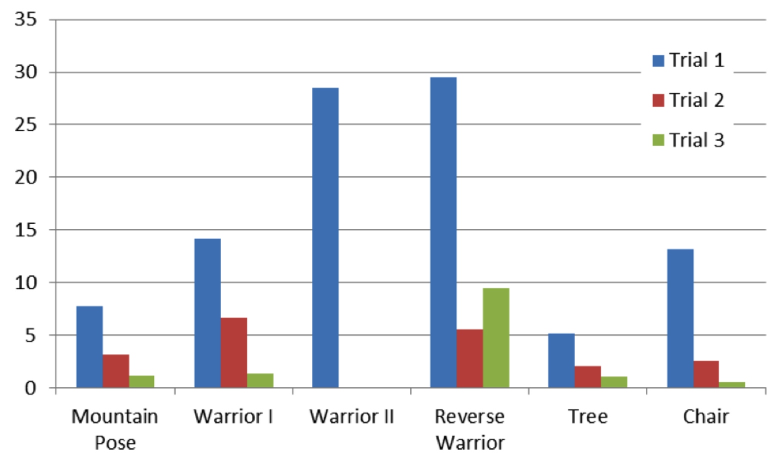


Figure 4.4. Average suggestions given for each pose and trial. (First 3 poses reflect Group B, while second 3 reflect Group A).

4.4.1.1 Behavior of Customized Verbal Corrections

The amount of customized verbal corrections differed between the poses. The implications may indicate pose difficulty or current limitations of our system. For example, Warrior II was only attempted once by all of our participants (see Figure 4.4). Eyes-Free Yoga included strict rules on the relation between the knee and ankle on both the y and z-axis to avoid injury. The knee should never move past the ankle (y-axis) or roll inside of the ankle (z-axis). This concept could be grasped because participants were able to complete Warrior II, but learning knee placement along with the other rules of Warrior II made it difficult: *"I turn my leg, and then I turn my body. Even though I know I need to stay like this [with my body facing forward] but I turn my whole body [forward] and as soon as I turn […] then my [leg] turns."* We fixed this issue in the latest version of Eyes-Free Yoga by relaxing the knee rules but without risk of injury.

The other five poses demonstrated expected results: people need to receive more verbal corrections at first, but need less in future trials (see Figure 4.4). Group B needed fewer suggestions (244) than Group A (336). It is difficult to compare by this metric because Group A and B received feedback for different poses, which were of varying difficulty. Mountain Pose, Warrior I, Tree

Pose, and Chair Pose each required fewer suggestions with each subsequent trial, which may suggest that participants were learning the poses over each trial. In addition, as would be expected, Tree Pose, which had the fewest rules, gave the least amount of corrections (3.67 per participant). Reverse Warrior had the most rules and gave the most corrections (20.7 per participant). In the future, the game difficulty may be increased or decreased by adding or removing rules that would not result in injury.

4.4.1.2 Yoga Instructor Ratings

To determine the impact of Eyes-Free Yoga's verbal corrections, we recruited four experienced yoga instructors to rate every pose using a 5-point scale (1 = very bad and 5 = very good). The yoga instructors saw anonymous photos in random order and were blind to whether the participant had used the *baseline* or *experimental* version of Eyes-Free Yoga. The meetings lasted between 30 and 90 minutes, and they were compensated with a $25 Target gift card. The yoga instructors had practiced yoga from 11 – 20 years with an average of 14.5 years. They taught classes from 3 – 15 years with an average of 9.25 years. Their yoga styles included Samarya, Hatha Vinyasa, Vini, and Iyengar. Two of them were more forgiving, while two focused more on alignment.

There was not a significant difference between the quality ratings of the *baseline* (avg. = 3.16, std. dev. = 0.28) and *experimental* (avg. = 3.25, std. dev. = 0.26) ($Z = 14025.5$, $p = 0.57$) conditions. If we remove the five *experimental* poses that resulted in people finishing early before addressing all of the verbal corrections, the quality of *experimental* poses (avg. = 3.31, std. dev. = 0.91) shows more promise ($Z=12605.5$, $p = 0.29$). Using the Shapiro-Wilk W Test, the ratings for both baseline ($W=0.90$, $P < .001$) and experimental ($W=.89$, $P < .001$) were not normally distributed. The system would relax the rules, and sometimes the participants would request to stop early. One reason this may be the case is because the participants were not always able to address all of the provided verbal corrections because of differences in flexibility and strength. As a result, the quality of the final pose with the experimental prototype was not as high as if they had been able to follow the verbal corrections correctly.

4.4.2 *Qualitative Results*

At the end of the study, we interviewed the participants. We asked about their experience while using the *experimental* prototype. Thirteen participants favored the extra verbal corrections over the *baseline* prototype, two had no preference, and one disliked the extra verbal corrections. A one-sample Pearson Chi-Square test of proportions shows that preference for the *experimental* prototype was significantly different than chance ($\chi 2$ (1, N=16) = 6.25, p = .01). One participant from Group A spent the most time out of any participant learning Reverse Warrior, but enjoyed his session because he enjoyed the feedback: *"This is kind of fun! I'm glad to know that it actually tells you how you are doing because I wasn't sure on the first few [poses] if I was doing it right."*

Participants' overall thoughts on the game were positive. We asked participants if they would play again or recommend it to a friend. Most participants (13) said they would play again, and all 16 said they would recommend Eyes-Free Yoga. One participant noted why, *"I think a lot of people do not exercise because they don't know how to and something like this could explain it."* Prior work shows that exergames can be a gateway to exercising more in the future (Schwanda et al. 2011), and 11 participants felt that games like this would encourage exercise class attendance. *"If you have a little understanding of what the pose is like, you may not be afraid to attend the classes."* One profound comment spoke to the novelty of accessible video games: *"It was the first real experience of a video game where honestly, after I opened the file I'd be able to play and I've never really had that experience."*

We asked questions based on the goals of GameFlow (Sweetser and Wyeth 2005) to see if participants enjoyed the game (see Table 4.1). Some aspects were stronger than others; yoga is a calming exercise, so our strengths included concentration and lack of distraction. Many were new to yoga so they found it challenging, but not too challenging. This may explain why fewer participants found they were able to perform the poses, felt skilled, or felt control over their bodies. Balance was a challenge, especially while performing Tree Pose, which could have had a negative effect on body control.

Table 4.1. Number of participants (n=16) who gave free response answers with a positive sentiment based on GameFlow (Sweetser and Wyeth 2005).

Question	**Positive**
How did you feel about your ability to complete the tasks?	11
How did you feel when trying to concentrate on the game?	15
How challenging did you find the game?	13
How skilled did you feel while playing the game?	9
How much control did you have while playing?	10
How did the goals of the game affect you?	10
How concerned were you with external factors not relating to the game?	15

We received suggestions for improvement including more accurate skeletal tracking, better voice recognition, and relaxed knee placement parameters. One common theme was the desire to have options. Several wanted levels of difficulty, the ability to pause the game, and varying feedback levels. Although we attempted to use universal language, some participants still had difficulty easing into the poses based on our verbal descriptions. This sparked the desire for a manual to come with the game so participants could read descriptions of the poses before beginning the game. This could come in the form of a yoga term glossary. While holding the poses, some participants reported a desire for reminders to breathe and variety of positive feedback.

4.5 DISCUSSION AND FUTURE WORK

We have shown through our design and evaluation of Eyes-Free Yoga that we adhered to our design principles. It is eyes-free, incorporates the work of many yoga instructors, and motivates people who were new to yoga to either play again or attend a yoga class. Our participants felt the benefit of a workout: *"I felt a little of burning near the end you know [in] the chair position."*

We gained valuable insights while running the studies. Examples given in a yoga class may have a different meaning while working with someone who is blind or low vision. For example, saying *"move two steps forward"* would mean about two feet for a sighted person, but was observed as small steps for most of the participants due to careful walking habits. In addition, despite having yoga instructors involved in the script development and adjustments, an exergame cannot replace a yoga instructor. The customized verbal corrections may not provide enough information, especially for more complicated poses, and human intervention may be needed to reach all potential game players. As a result, we hope this prototype may be a gateway to provide enough confidence for people who are blind or low vision to become comfortable enough with the concept and vocabulary attend regular yoga classes.

While designing Eyes-Free Yoga, the yoga instructors raised questions about how much information the Kinect could detect. We realized that our prototype would have limitations, namely that it 1) cannot track whether the bones are held in their joints, 2) cannot track if the person is feeling pain except for the few explicit questions, 3) cannot measure whether or not the correct muscles are tensed or relaxed, and 4) cannot measure how well the person is breathing. Because injury prevention was important in our design and study, the prototype had to compensate with reminders about doing things that the Kinect could not detect. There is room for improvement based on suggested feedback about reminders to breathe. We realize that our work is not meant to replace, but to enhance, yoga exercise with a trained instructor.

We carefully picked our study design, but we have also identified limitations with our approach. For example, maintaining pose order across all participants may negatively affect their performance in later poses due to fatigue. The participants might have been skeptical about their abilities, skills, and control of their body because they completed the most difficult poses last. This could be remedied by having each participant complete the poses in a random order or asking about their thoughts in between each pose. On the other hand, participants who received extra feedback during the first three poses may have increased their understanding of yoga. It is possible that their second half performance was inflated. Our study was a single session in a controlled setting. A longitudinal study would provide stronger evidence about whether or not participants preferred the customized feedback and if they would want to integrate the game in their exercise routine.

Our game may help inform technologies for people who are blind or low vision. This population relies on auditory cues for applications including navigation through the physical world, navigation on the computer, and for specific movements such as taking a photo or doing handiwork. Our project may help developers of navigation technologies by giving both verbal and auditory cues to guide a user. Determining proper auditory feedback for larger and smaller movements is an important research problem.

This project also has implications for the larger academic community. Accessible design may help inform universal design for future games. Having effective auditory feedback strategies for blind and low vision games may generalize to other research projects. For example, by providing refined feedback for ergonomics or other exercises involving careful body position, game developers could use this information to integrate verbal and auditory feedback during game play. Designing, implementing, and evaluating an exergame that provides solely auditory feedback and still meets the needs of exergame players is a challenging research problem.

We also feel there are improvements that can be made to our exergame to increase the potential benefits, including:

1. Option to ask: Am I doing this right (possibly by sending photo to an expert)?
2. Ability to pause the game
3. Integrate more yoga poses
4. Have easy, medium, and hard levels
5. Calibration of the body to enable ability based exergaming
6. Provide balance modifications earlier in the instructions
7. Provide instructions when a person is facing the wrong way or in a range not compatible with the Kinect
8. Provide additional rewards such as badges

While designing our research study, we opted to not teach the poses before playing the game to avoid learning effects. Based on feedback from two participants, we would add a synopsis of each pose before they try the pose for the first time. A social element could allow friends to compare their progress and provide motivation to continue playing the game. The latest version of Eyes-Free Yoga can be used independently; after initially guiding the person programmatically to the start point, the game play does not need a sighted guide.

4.6 Chapter 4 Summary

I developed an accessible yoga exercise system, Eyes-Free Yoga, where the players interact with a "yoga instructor" and receive audio-based instructions for six standing yoga poses. This new accessible exercise prototype can enable people who are blind or low vision to access yoga while at home, which could improve both their physical and mental health. I showed through an evaluation with 16 people who are blind or low vision that the game was enjoyable and provided useful customized feedback. This project may positively impact more than just people who are blind or low vision. For example, if a sighted person is performing a yoga position where their head cannot face the screen, he or she may receive the feedback they need with auditory cues. Exergames with more comprehensive feedback may provide an enhanced experience and be accessible to more players. I found that the real-time personalized feedback was preferred and enjoyed by participants and may have helped them learn the postures. I hope to provide general insights for exergames that use skeletal tracking.

Chapter 5. EYES-FREE YOGA AND DEPLOYMENT STUDY

Based on the results of the lab study, I expanded on the original prototype design significantly. I transformed Eyes-Free Yoga from a prototype to a fully functional system designed for long-term engagement with new postures, four full workouts, and motivational techniques that can be used without assistance from researchers. Additionally, my evaluation changed from a lab setting to a real world in-home deployment. The original prototype was a proof-of-concept, non-independently operated, and had no motivational techniques. I describe the new version and its additional features. This chapter addresses RQ3: *"How should we design audio based exercise systems to encourage a person to exercise over a longer period of time?"*

5.1 SYSTEM DESCRIPTION

The Eyes-Free Yoga fully functional prototype consists of a suite of hardware: Windows laptop, Microsoft Kinect for Windows, and external speakers. In addition to default programs, the laptops had Windows 8.1, Kinect for Windows Toolkit, Python, NonVisual Desktop Access (NVDA), and the Eyes-Free Yoga custom software installed. We saved five Rich Text Format (rtf) files to the Desktop containing transcripts of the audio instructions for the four workouts and computer instructions to use NVDA and Eyes-Free Yoga. Eyes-Free Yoga appears as a shortcut on the desktop so users can quickly access the program. Users interact with the system using NVDA screen reader. Laptops were configured to automatically login and start NVDA so users are able to work without assistance. To simplify use, they only have to navigate the desktop and within open RTF files.

Eyes-Free Yoga contains four workouts of varying length (Table 5.1, below). The four sequences and the verbal scripts describing each pose were developed in consultation with one yoga instructor to ensure a properly designed workout that provided variety (Sinclair et al. 2007). All standing poses have custom corrections, based my technique described in (Rector et al. 2013) that uses the Kinect to detect body posture and provide verbal corrections and audio-based feedback when the pose is correct.

Table 5.1. Pose sequence of the four different workouts in the fully functional exergame.

Workout 1 (26 min)	**Workout 2 (40 min)**	**Workout 3 (67 min)**	**Workout 4 (80 min)**
1. Cat/Cow Pose	1. Lower Back Release	1. Mountain Pose	1. Cat/Cow Pose
2. Child's Pose	2. Thread the Needle Pose	2. Warrior I Pose	2. Child's Pose
3. Downward Dog Pose	3. Bridge Pose	3. Warrior II Pose	3. Downward Dog Pose
4. Downward Dog Flow	4. Bridge Flow	4. Reverse Warrior Pose	4. Downward Dog Flow
5. Standing Forward Fold	5. Happy Baby	5. Tree Pose	5. Plank Pose
6. Standing Forward Flow	6. Bound Angle Pose	6. Chair Pose	6. Chair Pose
7. Mountain Pose	7. Reclined Twist	7. Standing Forward Fold	7. Standing Forward Fold
	8. Corpse Pose	8. Downward Dog Pose	8. Tree Pose
		9. Plank Pose	9. Warrior I Pose
		10. Cobra Pose	10. Warrior II Pose
		11. Reclined Twist	11. Reverse Warrior Pose
		Corpse Pose	12. Bridge Pose
			13. Happy Baby
			14. Bound Angle Pose
			15. Reclined Twist
			16. Corpse Pose

5.2 Eyes-Free Motivational Techniques

In addition to providing an accessible alternative to yoga that is suitable for the home, we were interested in motivating users to begin practicing yoga and sustain their practice over a longer period of time. This corresponds to Fogg's Behavior Grid as a "Green Path" behavior, which is doing a new behavior from now on (The Behavior Wizard 2016). This path suggests to: 1) couple the trigger with an existing habit, 2) increase one's self-efficacy by making the behavior easier to do, and 3) reduce demotivation by making the behavior more familiar. However, standard motivational techniques in persuasive technologies are at many times visual, and thus we had to design motivational techniques to be accessible. We developed auditory reminders (fulfills #1) and musical levels and audio badges (fulfills #2 and #3) specifically designed to be suitable for people who were blind or low vision. We developed eyes-free motivational techniques by developing a non-visual metaphor for those in visual games. Auditory reminders may help establish a new habit, similar to visual reminders in (Stawarz et al. 2014). Communicating game status is an important gaming heuristic (Pinelle et al. 2008). We developed an informative background track, water, to communicate game status. Finally, we chose musical badges to provide positive encouragement as a **social actor** (Fogg 2003). While badges in gameplay may be viewed as competitive, Mekler et al. found that badges can be useful as an indicator of progress (2013).

1. Musical reminders: Ten minutes before a person prefers to exercise, the computer plays the first background music track as a reminder to exercise. The system asks the user to choose a time they would prefer to exercise, similar to creating a habit as in (Stawarz et al. 2014).
2. Musical levels: As a person advances to the next level, they hear water sounds with increasing power in addition to the background music (see Table 5.2). This conveys a sense of progress. Users spend 1.5x as long as they do in the previous level.

Table 5.2. Level progression of Eyes-Free Yoga. Participants spent 1.5x longer in each level.

Level	# Minutes spent in level	Background Water
1	30	None
2	45	Water drops
3	67.5	Creek
4	101.25	Stream
5	151.875	Lake
6	227.8125	Rapids
7	341.71875	Sea
8	Until end of study	Ocean

3. Musical achievements: We developed three different types of musical achievements, or badges (Munson and Consolvo 2012), that one could receive while exercising:
    - Performance Badge: A person needs to achieve the posture specified by the system for at least 50% of the standing postures and complete the full workout. If the workout had no standing postures, they still needed to complete the workout.
    - Endurance Badge: For each workout, the person needs to exercise for a minimum required amount of time (Workout: 1: 20 minutes; 2: 30 minutes; 3: 45 minutes; 4: 60 minutes).
    - Consistency Badge: A person needs to earn three endurance badges within one calendar week.

These three badges all have a distinct musical sound. Players can visit their badges by visiting the "Trophy Case." The trophy case announces the number of badges earned and plays the respective sounds. To keep people motivated and knowledgeable during the workout, the system announces when they have less than five minutes to receive an endurance or consistency badge. While it is possible that these motivational techniques may not be compatible with yoga, we hoped that the accessible techniques would provide more information and encouragement during exercise.

We developed the musical levels and achievements in conjunction with Eyes-Free Yoga in Microsoft Visual Studio with C#. They were implemented behind a flag so users would only hear them if the motivational techniques option was enabled. We implemented musical reminders with Microsoft's Task Scheduler by running Windows Media Player with background music at specified dates and times.

5.3 STUDY DESCRIPTION

We conducted an 8-week in-home deployment study of Eyes-Free Yoga with four people with visual impairments. We designed the deployment study to be 8 weeks in duration where participants used it under two conditions:

1. *Baseline* – Participants used the system as described in Section 4.1
2. *Intervention* – Participants used the *Baseline* system and also had the motivational techniques described in Section 4.2 enabled.

While we had a small number of participants, we used a single case experimental design with randomization tests, which provided a large number of permutations and statistical power. Single case experimental designs provide internal validity even for a small number of participants (Dugard 2014), and are used in other fields such as behavioral health (Dallery et al. 2013), whereas some types of randomization tests are common in genomics (Mootha et al. 2013). Single case methods are suggested as an emerging experimental design at CHI (Hekler et al. 2013). It is also an agile method that has been recommended to evaluate technologies for behavior change (Vilardaga et al. 2014).

To increase statistical power, we conducted an ABAB study design, where A is *Baseline* and B is *Intervention*. Given the requirements of randomization tests, the length of each A and B phase were determined at random prior to the beginning of each single case experiment (Heyvaert and Onghena 2014), with a constraint that each A and B phase was at least 7 days so participants could experience each condition. The number of measurements for each single case experiment was 56, which allowed a total of 4495 random arrangements and hence a minimum p value of $2.22\times10e-4$. In this study, our primary outcome measure was the number of minutes per day of exercise. We chose to not counterbalance participants because we were not assessing learning effects during the study, with all participants in the ABAB study design.

The study began with researchers conducting an in-person, audio-recorded interview consisting of questions about demographics and their background with exercise, yoga, and exercise technology (shown in Appendix D). We installed the equipment in their home and allowed the participant to familiarize him or herself with the system. The researchers set up the participants' preferred NVDA settings including voice, volume, and speed. The participant listened to the instructions, started Eyes-Free Yoga, and used it until they had just begun Workout 1 and exited the system. We scheduled two future phone interviews and one in-person meeting, depending on each individual's ABAB randomized sequence. Upon leaving, we told the participant they were free to use or not use the system and pick any of the four workouts whenever they would like.

Participants first used the system in phase A, or *Baseline*. After every workout, the system sent an email survey with a space to give feedback and report any issues. Within the last 1-3 days of phase A, we conducted the first phone interview and asked questions about their experience using the system, whether they would recommend it to others, and their exercise habits (shown in Appendix E).

Participants then used the system in phase B, or *Intervention* and completed the same surveys as in phase A. Within the last 1-3 days of phase B, we repeated the phone interview from phase A, but also added questions about their experiences with the three motivational techniques (shown in Appendix E). The participants then completed another phase A and B before completing the study. At the end of the study, we collected the equipment and conducted a final interview with the same questions as before, but also added a question on how participants felt when the *Intervention* condition was removed and added back in again (shown in Appendix E).

5.3.1 *Participants*

We initially recruited 6 participants through blind and low vision mailing lists, but due to vacations and an injury, 2 dropped from the study early, which resulted in 4 total participants completing the full deployment study (Table 5.3). We conducted two study sessions at the participants' residence (1-2 hours for the initial visit and 30-60 minutes for the final), plus two 15-30-minute phone interviews. We compensated participants $50 for each 1/3 of the study and another $50 upon completion of the study for a total of $200. We paid consistently across conditions and our Institutional Review Board required prorated payments due to the long duration. The same compensation was given to participants regardless of how much they used the system to ensure that it had no impact on the study results in terms of our outcome measures.

Table 5.3. Demographic and Background information for each participant. For P2, L = left eye and R = right eye.

P#	Age	Gender	Occupation	Vision	Yoga	Exergame
P1	29	F	Postdoctoral fellow	Blind	Several classes	None
P2	52	M	Unemployed	L: Blind R: Low vision	Few classes	None
P3	38	F	Collections Representative	Blind	None	Wii Sports
P4	54	F	Retired	Blind	1 class	None

Table 5.4. Percentage of change for each outcome between phases, pooled % changes and results of meta-analysis of RTs.

	P1	P2	P3	P4	Pooled	Meta-analysis of RTS
Minutes (%)	-38.3	50.2	-31	57.3	9.55	p=.024*

5.1 Study Results

We gathered quantitative data throughout the study via system usage logs. A meta-analysis of all four single case experiments indicated an increase in number of minutes exercised per day while in the Intervention condition (Table 5.4).

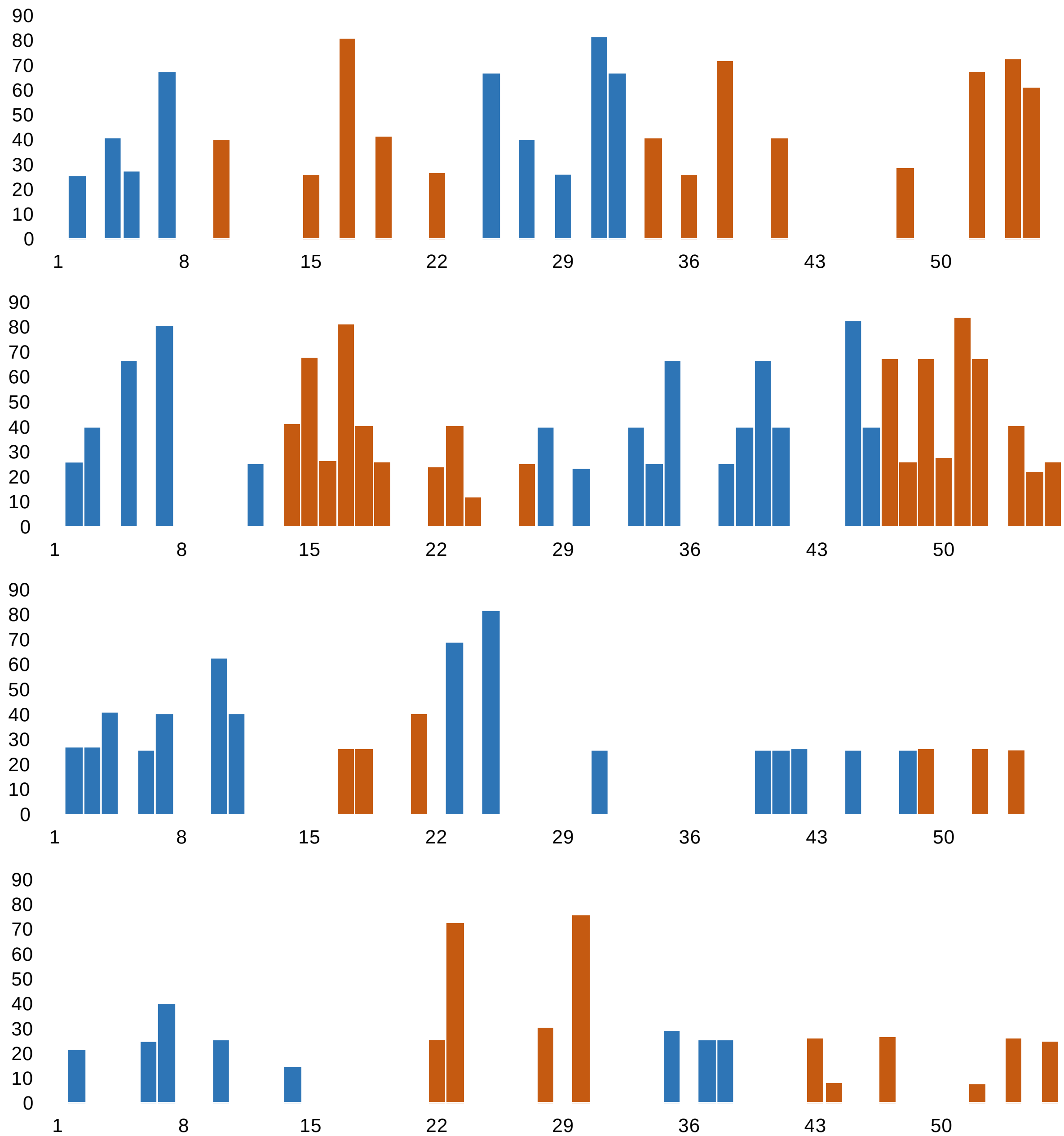


Figure 5.1. P1-P4 usage over the 8-week deployment. Day # is on the x-axis and # minutes exercised is on the y-axis. Baseline have blue bars, while Intervention have orange bars.

In addition, the motivational techniques enhanced Eyes-Free Yoga by making the game more interesting with auditory badges and music. Because we conducted a single case experimental design, we chose Standardized Mean Difference as an appropriate test statistic for single case experiments (Heyvaert and Onghena 2014), which is the equivalent metric to mean differences in-group designs.

5.1.1 *Minutes Exercised Per Day*

The four participants practiced yoga between the *Baseline* and *Intervention* conditions consistently throughout the study (Figure 5.1, previous page). For each participant individually, Standardized Mean Differences between phases (SMD) were not statistically significant (Table 5.5). However, the pooled % of change between phases (Table 5.4) suggests an overall percentage increase in number of minutes practiced per day (9.55%) and a meta-analysis of these SCDs (Onghena and Edgington 2005) suggests that this difference was statistically significant (p = 0.024).

Table 5.5. Standardized Mean Difference and p-values for each outcome between phases.

		P1	P2	P3	P4
Minutes	SMD	-0.379	0.433	-0.231	0.248
	p-value	0.174	0.162	0.236	0.302

5.1.2 *Participant Feedback*

During the interviews, participants gave explicit reasons for why they enjoyed the system and why the system helped them. While we did not evaluate each motivational technique separately, we received qualitative feedback to delineate the impact of each technique.

While the motivational techniques did not necessarily change the behavior of each participant's exercise habits (Table 5.4), they did enhance Eyes-Free Yoga from the perspective of the participants.

The auditory badges were the most noticed and well-received feature from when they were introduced: *"I noticed the earning badges is something new so that's really cool"* (P3). In particular, people enjoyed the anticipation of getting the badges during the workouts: *"I'm curious* *when I'm going to get the next badge"* (P2). Providing more information about when a participant would receive a badge provided enjoyment during the game: *"I liked hearing that I was about to get an endurance badge"* (P1), and: *"That was cool. I liked that. It tells you 'You have five minutes before you earn a certain badge'"* (P3). This provides evidence of the persuasive element of antecedent feedback mentioned in (Glynn 1982) and that it enhances game technologies (Adams et al. 2009).

The musical levels were added as extra background noise and were not as noticeable by the majority of participants. P3, however, favored the levels during gameplay: *"I noticed another sound was added to the music. So I thought it was a good addition."* As P3 progressed through the levels, they continued to report positive feedback about the background water: *"I thought that was cool, it sounded like a mini lake or something."* Finally, P3 was interested in integrating different sounds into the game: *"Possibly drums, Native American type of music."* Overall, this feature may be of benefit to some players and so it should be an option for gameplay.

The auditory reminders did not serve their intended purpose because the participants chose to mute or turn down the volume of their computer while not playing. However, P1 and P3 still found this feature helpful. For instance: *"Establishing certain times of day was more helpful"* (P1). P3 would have the computer quiet until playing, and so the musical reminder *"creates the mood for playing."* Overall, participants found that they did not need the musical reminders, because they *"either made the decision that I'd done the routine for the day or I wouldn't for the day"* (P2).

Overall, the motivational techniques enhanced gameplay. When participants were asked how they felt when these features were removed, they took notice: *"It was a little disappointing to not have the musical achievements"* (P1), and *"Kind of bland. It was just more mechanical. Once they were added it added so much more to it and it seemed empty"* (P3). In addition, P2: *"definitely* *noticed that they were gone. Once you get used to them being there, they're part of your internal clock."*

As the motivational techniques were added back to the system, P2 emphasized their impact: *"They made the whole experience better. It just reminded me that I was in the process of the whole game. It also kind of reminded me to trigger in my head of what to do tomorrow and what I did today."* P3 added: *"It was just a better experience."*

Two of the four participants used Eyes-Free Yoga as a gateway to exercise on a regular basis (P1, P4), similar to how Schwanda et al. (2011) determined that Wii Fit could be a gateway to more rigorous exercise. Participants were asked before and during the study about their current exercise level using the exercise stages of change (Marcus et al. 1992). Two participants had been exercising regularly for more than 6 months ("maintenance phase" (Marcus et al. 1992)), while one participant had intentions within the next 6 months ("contemplation phase" (Marcus et al. 1992)), and within the next 30 days ("preparation phase" (Marcus et al. 1992)). By the end of the study, the latter two participants had been maintaining a regular exercise regimen and were in the "action phase" (Marcus et al. 1992). P1 had moved from the preparation phase to the action phase and said this at the end of the study: *"I feel like I've gotten stronger."*

Because participants had the ability to use Eyes-Free Yoga over the 8-week study, they could gain a better understanding of and appreciation for yoga. Yoga can provide a balance between relaxation and physical challenge. For instance: *"I like the meditation times and quiet my brain and concentrate on breathing"* (P2), while on the other hand: *"Its good practice for balancing and a form of exercise and it's good that it's challenging"* (P4). P1 expressed that they learned more about yoga as the study progressed: *"By the last times I was getting better because I was getting different feedback. I felt like I must've learned something."* P3 found a benefit from using Eyes-

Free Yoga throughout the study: *"Now the more I do it, it's more natural. I would say more at ease, or more relaxed."*

We found that regardless of motivational techniques, participants chose to use the system throughout the 8-week period. There were several reasons for using Eyes-Free Yoga, including enjoying the four different routines: *"I've been able to learn the routine and anticipate what's coming next and refine the poses a little bit"* (P1). P2 also favored the use of routines: *"I enjoyed the fact that there were four different routines. Some at night when I wanted to relax or stretch and the other ones for more of a strenuous workout. I incorporated into my other workouts."*

Another reason for adhering to the system was the accessible feedback: *"I like the feedback. … It's definitely something that I can participate in and use easily and feel like I can learn it and it's easy to comprehend"* (P3) and: *"It does have good instruction about the poses. As a blind person it was very accessible in that way"* (P4).

While participants were enthusiastic to use the system, there were also factors that made using the system a challenge. For example, P1 started a new job and had to figure out their new schedule: *"A little harder for me to stay motivated because I'm working full time. I have to really convince myself to do it."* Another reason was a warmer summer: *"I feel fatigued so I try not to play when it's really hot"* (P1), and: *"It was also pretty hot"* (P4).

Another factor pertained to the conundrum of yoga being a game, as identified by P1 and P2. Despite this, they enjoyed the experience: *"I don't usually think of yoga as being a video game. A different way of thinking about it, but I realized it can be kind of fun"* (P1), and: *"Don't get caught up, doing it just to acquire virtual accomplishment. Nonetheless, I liked when I got the accomplishments"* (P2). In addition, P2 had an experience where they felt they did not deserve a badge: *"Not sure I deserved a Performance badge today; I was shaking, wobbling, and grimacing all over the place"* (P2).

Eyes-Free Yoga as a system may have provided motivation due to the benefits particular to people who are blind or low vision. P2 found that Eyes-Free Yoga provided a safe environment to learn yoga: *"It's interesting and a good way for someone to demystify it in privacy with as little or as much as they want. Especially for someone like me that's blind. When you're in a room with other people you wonder if you're the sore thumb. So there's a little sense of being awkward especially when you're doing something like this."*

Another benefit to Eyes-Free Yoga are the detailed descriptions that are accessible to blind players, which addresses the fact that exercise instructors do not know how to communicate with people who are blind or low vision (Rimmer 2006): *"I've always wondered what yoga was like and how to do the actual positions but I just never had the opportunity to me or learn the movements or have them described. So if someone was interested in doing yoga on their own, I would recommend it"* (P3).

Because participants had the opportunity in both the *Baseline* and *Intervention* conditions to learn yoga in an accessible way in the privacy of their own home, this may have affected use in both conditions. In other words, the effect of the motivational techniques may have been mitigated due to the system itself being an intrinsic motivator.

While Eyes-Free Yoga may motivate more in-home exercise for people who are blind or low vision, this may not translate to yoga classes. For instance, P1 felt that Eyes-Free Yoga made exercise more convenient: *"I don't have that much free time. I haven't found a place to go yet to exercise since we moved here."* P2 expressed similar concern: *"I feel like I know more of the poses, and that's less intimidating. But how willing am I to get to a place? The game is not solving other* *issues."* P4 mentioned money as a factor to use Eyes-Free Yoga over a yoga class: *"For me the taking public classes are usually about having the money."* While attending yoga classes can be beneficial, we found that developing a system for in-home exercise can be a viable solution, similar to developing exergames for older adults (Liu et al. 2014).

The participants of this study have expressed interest in using the system again: *"It is definitely something I would want to invest in when it became available"* (P1), *"I made it a part of my day to day routine"* (P2) and *"If I had the opportunity again I would probably try it"* (P4). One participant plans to purchase a yoga cd set, P4 has added new exercises: *"The system got me to stretch more, and squats."*

5.2 Discussion

Eyes-Free Yoga's design is eyes-free, incorporates the work of many yoga instructors, and motivates people who were new to yoga to continue playing and practicing yoga, which our studies show led to positive experiences at both the learning phase and for long term engagement.

We made several improvements suggested by participants in the feasibility study for our fully functioning prototype including the ability to pause the game, integration of more yoga poses, instructions at the beginning of game play to ensure a player is standing far enough away and is facing the Kinect, and motivating rewards such as badges. We removed the necessity for someone sighted to assist with game play. Since conducting the study, we have posted the code online and have received reports from people who have been able to successfully use it without assistance.

Across the lab and deployment studies, we found that instructions with metaphors were more understandable than others. When viewing others or images is not an option with unfamiliar exercises, listening to instructions becomes paramount. For example, *"Reach your arms out to your sides"* is less descriptive than *"Stretch your arms out to your sides, like a tightrope walker's* *pole."* From the fully functioning prototype, in Thread the Needle Hip Stretch, while lying on the floor, being told to *"press your left knee open"* may be subject to interpretation, but when told to move *"like a single butterfly's wing,"* this movement is relatable. The use of metaphors could extend to other types of exercises beyond just yoga, and designers should check with target users to ensure that their metaphors are understandable. In the lab study, some people were able to interpret *"Stand with your feet below your hips as if you are tracking on parallel skis,"* while others had difficulty because they had never skied before. Determining the right text to inform body poses and movements may be an interesting natural language processing research problem.

We recommend verbally and aurally communicating game status throughout game play. With video games, a progress bar is persistent throughout gameplay, and players can view their status at any time. However, with eyes-free games, designers have to explicitly communicate the game status with verbal or audio feedback. Two participants expressed positive feedback during *Intervention* toward hearing when they had less than five minutes to earn a badge or advance to the next level. In addition, at the beginning of each *Intervention* session, they would hear the requirements to earn each badge and how long in hours and minutes they had until advancing to the next level. When earning a badge or advancing a level, the musical achievement played in the background. Because the verbal channel is serial, designers can pick strategic times in which to communicate such as in between exercises.

The findings from both studies have implications for the larger academic community. Accessible design, including effective audio feedback strategies, may help inform universal design for future games. For example, by providing refined feedback for ergonomics or other exercises involving careful body position, game developers could use this information to integrate verbal and auditory feedback during game play. Designing, implementing, and evaluating an exergame that provides solely auditory feedback and still meets the needs of exergame players is a challenging research problem.

We carefully chose our study designs for the deployment study, but we identify limitations the approach. From our deployment study, we compared a *Baseline* and *Intervention,* with a *Baseline* condition that was powerful to begin with: introducing yoga in an accessible format. With consistent use of the system throughout the study and positive qualitative feedback, we provide concrete evidence that our system has potential for long-term use and that the motivational techniques can be a positive, though not required, option for players. Other factors may have influenced system usage, such as that each participant had different time windows and time durations in each phase. However, these different time windows were required by our study design to provide interval validity and increase statistical power.

From our deployment study, we found that there is an opportunity to increase statistical power with a smaller number of participants when conducting single case experimental designs (Dugard 2014). This is helpful when researchers have less access to participants, such as in the accessibility community. This is especially true when conducting long term in-home deployment studies. We ensured that our study design had high statistical power by conducting an ABAB study with each phase being determined at random (Heyvaert and Onghena 2014) with the constraint that each phase was at least 7 days. This type of study design is conducted in related fields such as behavioral health (Dallery et al. 2013) and behavioral change (Vilardaga et al. 2014), and we hope will be more pervasive at CHI (Hekler et al. 2013) and in other HCI research.

5.3 Chapter 5 Summary

I developed an accessible yoga exergame, Eyes-Free Yoga, where the players interact with a “yoga instructor”, receive personalized instructions for six standing yoga poses, have four yoga workouts, and motivational techniques. My 8-week real world deployment study demonstrated that our system enabled independent access to yoga while at home, motivated use throughout the study, and that the motivational techniques can be a good option to enhance the exercise. I believe that games that use skeletal tracking and provide comprehensive feedback will enhance the exercise experience and be accessible to more players. I found that while the audio motivational techniques did not affect the minutes of exercise per day for each person, that the techniques enhanced their workout experience. Based on the results of my studies, I have made Eyes-Free Yoga available for download at http://eyesfreeyoga.kyle-rector.com.

Chapter 6. EYES-FREE ART

The goal of this chapter is to expand from Chapters 3-5 and explore another aspect of quality of life outside of exercise. This chapter addresses my research question: *"How should we design audio based systems to help a person explore visual items, such as art, independent of a sighted guide?"* Engagement in the arts is an important component of participation in cultural activities, but remain a largely unaddressed challenge for people with sensory disabilities. 2D artwork, including paintings, are inaccessible to people who are blind or low vision due to their inherently visual nature. There are existing customized solutions for presenting paintings via haptics and/or audio, but these are costly both economically and in curatorial time. To address this, I present Eyes-Free Art, a proxemic auditory system that provides an engaging and interactive auditory experience for 2D art work. The proxemic audio interface allows a user to move closer and further away from a painting to experience background music, a novel sonification technique, sound effects, and a detailed verbal description. I conducted a controlled study with 13 people with visual impairments and found that participants enjoyed Eyes-Free Art because they could interact with and explore the painting as they moved between the zones. My work provides implications for designing audio interpretations of paintings and proxemic audio interfaces.

6.1 INTRODUCTION

The arts are an important component of full participation in cultural and educational activities, where children and adults alike take an ownership in their learning (Hernandez and Barner 2000). Unfortunately, the majority of art still remains inaccessible for people with sensory disabilities. People who are blind or low vision have a hard time experiencing visual arts, such as paintings, due to the inherently visual nature of the medium.

There are existing options to make art accessible, including guidelines for verbal descriptions and accessible art tours or guides. Art Beyond Sight (2005a), for example, creates accessible art programs and educational materials to help museums generate more accessible programs. In addition, larger museums such as the Metropolitan Museum of Art (2016) or the Museum of Modern Art (MoMA) (2016) provide recorded audio guides specifically for patrons who are blind or low vision. There are also in-person accessible art tours that provide detailed verbal descriptions or tactile art exhibits (e.g., Seattle Art Museum (SAM) (2016)). However, these solutions are not yet pervasive and are costly both economically and in terms of curatorial time. Typical accessible tours are offered infrequently (e.g. SAM and MoMA offer such tours once per month); these tours are also limited to only covering a handful of items out of the museums' large collections due to the curatorial effort involved in creating detailed, accessible descriptions.

Many museums provide audio descriptions, but the descriptions are based on the premise that the user is sighted. The descriptions focus more on interpretation and historical context rather than on literal visual descriptions of the work. In addition, the audio guides themselves can be difficult for a person who is blind to operate without being able to see the buttons and read the instructions because they are not designed for that use case. With these limitations, it is challenging to create a fully engaging experience that is low-cost and pervasive.

To address this, we present Eyes-Free Art, an auditory system that provides an engaging, interactive, "on demand" auditory experience and an interpretation in complement to a visual art piece. The experience uses a proxemic interface built using a Microsoft Kinect to provide four accessible audio interpretations of existing paintings. We use the Microsoft Kinect to determine where the user is in relation to the painting, and play an audio interpretation aloud based on the zone (Figure 6.1, below). The zones include background music, sonification, sound effects, and a verbal description. We created an alternative sensory experience, which, while not equivalent to the original visual artwork, aims to be aesthetically interesting and appealing. We employed a user-centered approach, first conducting interviews with stakeholders (curators, artists, and blind art patrons) that shaped our approach to the system development. Then, after implementing Eyes-Free Art, we conducted a user study with 13 people with visual impairments.

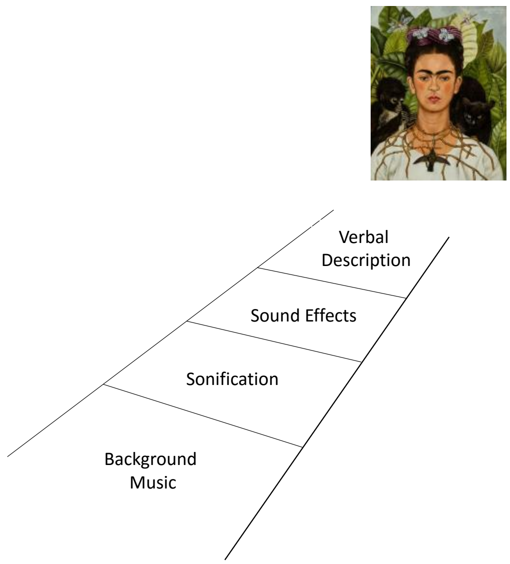


Figure 6.1. Eyes-Free Art is a proxemic audio interface that changes the audio interpretation based on a user's distance from a painting. From furthest to closest the user hears: 1) background music, 2) a novel sonification technique, 3) sound effects, and 4) detailed verbal description. Image: Self-Portrait with Thorn Necklace and Hummingbird (Frida Kahlo, 1940).

This research offers several contributions. First, we developed an accessible system to help people who are blind or low vision explore existing paintings. We present findings and considerations relevant to advancing this class of interaction. We also expand on prior work on proxemic interfaces to consider how this interaction style might apply in the realm of audio, rather than visual media, and contribute guidelines for proxemic audio design. Finally, our work can provide general insights to artists or accessibility curators for providing audio interpretations of 2D artwork.

6.2 BACKGROUND OF PROXEMIC INTERFACES

Anthropologist Edward T. Hall (1966) introduced the idea of proxemics, where people are able to assess how much distance to place between themselves and others based on their relationship type: intimate, personal, social, or public. Vogel and Balakrishnan (2004) incorporated the idea of proxemic distances into technology by developing an interactive framework for large interactive displays for multiple users, specifically how to transfer from implicit to explicit interactions with both personal and public information. Morris et al. (2006) also introduced the concept of proxemics with multi-user surface computing gestures, using proxemic distance as one of several design dimensions for cooperative gestures. Marquardt and Greenberg (2012) used proxemic theory to inform the design of ubicomp technologies, and created the zones from furthest to closest: ambient display, implicit interaction, subtle interaction, and personal interaction (Greenberg et al. 2011). Dingler et al. (2015) created a similar framework for using four zones in front of larger screens, while Harrison and Dey (2008) employed a similar technique using a computer screen and web camera. Hello.Wall (Prante et al. 2003) employed a proxemic technique with a light display where the user progresses from an “ambient zone” shown to all users to a “cell interaction zone” where users can interact with the wall itself. Eyes-Free Art also has four zones, but we made each zone of equal length to avoid making one more important than the other. Our work expands upon previous work, which is visual, by exploring how to design proxemic audio interfaces.

Unlike proxemic visual interfaces, the space of proxemic audio interfaces is young. There is prior work on location-based audio interfaces, for example, Sørensen et al. (2013) developed a system where music follows a user from room to room based on their location. The type and volume of songs changes based on the context. In Fosh et al.’s (2013) Sculpture Garden, audio is foregrounded when users engage and backgrounded when they reflect; our system also supports user control over audio levels in support of interpretation and reflection. To the best of our knowledge, Eyes-Free Art is the first to specifically consider the design of a proxemic audio interface (Greenberg et al. 2011), where the detail of audio information increases across several zones as a person moves closer to the target object.

6.3 Initial Interviews and Design Goals

Before determining our project direction, we interviewed people who are blind or low vision and museum/art domain experts about their experiences with accessible or inaccessible art and how technology may be involved while consuming art. We interviewed seven people who are blind or low vision (VI1-VI7: 6 females, 28-65, median age = 53), five artists (A1-A5: 1 female, 29-68, median age = 48, two tactile artists), one museum curator (C: female, 58), and one museum accessibility coordinator (ACC: female, 37).

In the discussions with the people who are blind or low vision, we inquired about the benefits and challenges while consuming art, accessibility at art museums, ideal art experiences, and whether or not they use technology while consuming art. From the artists and curator, we wanted to learn about what patrons are intended to learn or experience while engaging with a piece of art and whether they have had experience developing or curating art that was accessible. From the accessibility coordinator, we wanted to learn about how the museum experience differs for people who are blind or low vision as opposed to people who are sighted. In addition, we wanted to learn about the benefits and challenges of creating accessible experiences in the museum.

From these interviews, we determined the following set of design goals for 2D visual art. First, we wanted to develop a low cost solution that can scale. Providing access to mainstream technology in a public setting can increase the user's independence: *"It makes it easier to schedule things, time things, [and] do things on my own schedule"* (VI6). Further, VI2 found that not having access to an accessible technology in the museum hindered their independence: *"They were like if you want a guided tour you have to prearrange 30 days in advance."* Second, we wanted to make the experience subjectively satisfying and aesthetically pleasing. The experience should be moving; C noted that *"the point of art in museums is to have a direct personal experience ... in your body."* More concretely, the design of audio should sound appealing: *"When the sound is good, you don't notice it that much. When the sound is bad, it annoys you"* (A2). Third, it is important to include a detailed verbal description including a *"sense of scale, the colors involved"* (ACC). Our fourth goal was to also convey emotion and mood; VI2 enjoyed hearing the background music on an audio guide because *"the music gives certain moods."*

Goals 3 and 4 are distinct, and yet both are important: *"There are two kinds of descriptions; one is informative and one is aesthetic ... you have things like the color, maybe the shapes that are being used ... but art tends to also convey a certain aesthetic ... in that respect it is very important to convey visually all of that information for the mood or the sentiment from the painting"* (VI1). In order to convey emotion, mood, and provide detailed descriptions, we decided to implement different dimensions of audio in a proxemic audio interface.

6.4 Eyes-Free Art System Description

We built our system using the Microsoft Kinect for Windows V2 Software Development Kit version 2.0 and C#. The Kinect is placed approximately 4 feet above the ground and below the painting (Figure 6.2, next page). We used Body Tracking (Microsoft 2016), which contains 25 joints, to track the person's distance from the painting. We developed the experience for five paintings that contained different objects and colors (Figure 6.3, next page).

Figure 6.2. Eyes-Free Art presented in a room. The painting is projected on the wall to simulate a gallery, with the Kinect sensor below. On the floor is a white tape and cardboard "ladder" used as a tactile cue to navigate between the 4 zones.

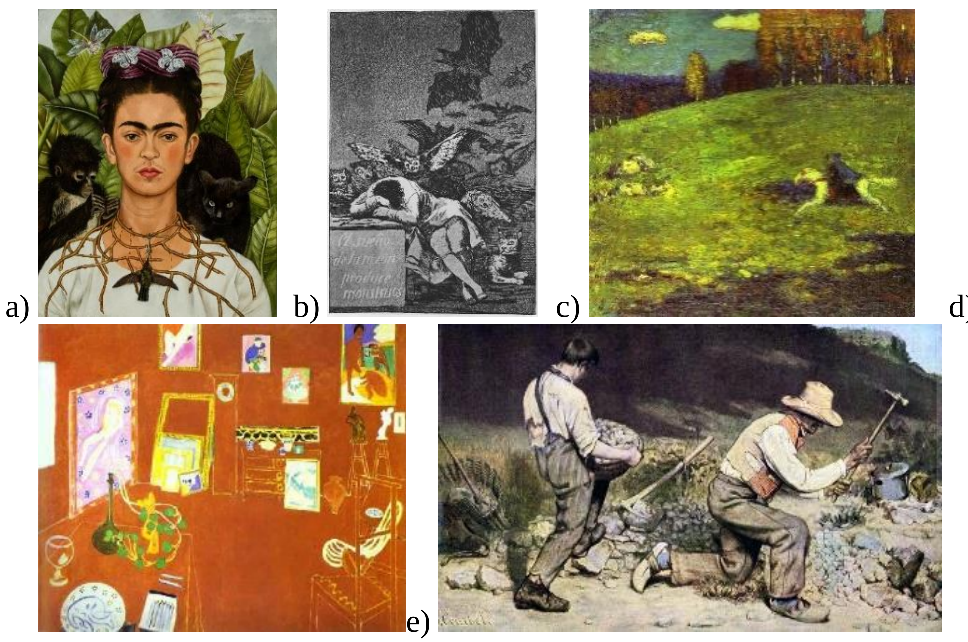


Figure 6.3. Five paintings explored in Eyes-Free Art: a) Self-Portrait with Thorn Necklace and Hummingbird (Frida Kahlo, 1940), b) The Sleep of Reason Produces Monsters (Francisco Goya, 1797-1799), c) The Blue Rider (Wassily Kandinsky, 1903), d) The Red Studio (Henri Matisse, 1911), and e) The Stone Breakers (Gustave Courbet, 1849).

6.4.1 *Proxemic Audio Interface*

Eyes-Free Art has four zones, similar to Hall's proximity theory (Hall 1966) and Marquardt's application to visual interfaces and ubicomp (Greenberg et al. 2011). As a user moves closer to the target in a proxemic visual interface, more details are rendered (Harrison and Dey 2008). Our system mimics this relationship between distance and detail in the visual system by providing four audio zones that range from general to specific information about the painting. First, we provide general background music to draw a person into the piece, followed by an interactive sonification of the colors in the painting. Third, the user interacts with the painting learning about specific objects through sound effects. Finally, the most detailed and specific information, a verbal description, is played aloud.

The four zones of Eyes-Free Art (Zone 1 – Zone 4) are arranged in a 6'x12'+ foot space, with audio cues to ensure the user remains in front of and facing the painting. Zone 1 is closest to the painting and Zone 4 is furthest away from the painting (Zone 1: 0'-6' from painting, Zone 2: 6'-9' from painting, Zone 3: 9'-12' from painting, Zone 4: 12'+ from painting). We used Body Tracking (Microsoft 2016) to determine the zone where the person is standing. As the user enters each zone, a verbal cue is played aloud (e.g. *"You have entered Zone 1: verbal description"*). If the user stops facing the Kinect, *"twist your body slightly left"* or *"twist your body slightly right"* is played aloud so the user can correct their position.

Body Tracking is also used to track the location of the user's right hand (left could be used as well). The user's right hand may be used to explore the painting in Zones 2 and 3. The user raises their right hand and moves it in free space within a 3'x3' square centered on their right shoulder. The region is centered on the camera in the y-axis, and ranges from ¾' to the left of the camera to 2 ¼' to the right of the camera in the x-axis. In this way, the person is able to reach all of the painting with his or her right hand. The painting is resized while maintaining the proportions to fill the 3'x3' space as much as it can. If the painting is in portrait orientation, the height is 3' and if the painting is landscape orientation, the width is 3'. We focus on one-handed rather than bimanual interaction, since many people who are blind will need their other hand to hold a white cane or a guide dog leash; adapting for left-handed use would be straightforward.

When the user first approaches the painting (just before entering Zone 4), some key metadata is read aloud (the painting title, artist, year, and country where it was painted). This "pseudozone" was added based on pilot-testing feedback that indicated it was helpful for setting the stage of interpreting what occurs in subsequent zones; in a museum setting, this metadata zone would also facilitate quick navigation by allowing users to quickly scan amongst several works and then proceed with in-depth interactions only with the items of most interest. Below we will describe the zones in order from furthest (Zone 4) to closest (Zone 1).

6.4.1.1 Zone 4: Background Music

After presenting basic facts about the painting (title, year, artist), Eyes-Free Art conveys an overall mood by playing a background music track. For each painting, we selected a genre of music based on a pairing chosen by Mechanical Turk workers. For each Turk task, we provided a picture of a painting from Figure 6.3, 13 musical genres[3] including example clips and composers/artists, and asked: *"What genre(s) of music are most appropriate for this painting?"* The responses were checkboxes so the turkers could select multiple genres. We had five turkers provide responses for each of the five paintings.

[3] Jazz, R&B/Rap/Hip-hop, Reggae, Rock, Dance/Electronica, Classical, Baroque, Renaissance, Country, Folk, Christian/Gospel, Pop and Other (text field).

We deployed the tasks on Amazon's Mechanical Turk (2016) and paid each worker $0.20 per task. The workers took a total of 24 minutes for all 25 tasks, with an average of 57.7 seconds per task (for a paygrade of $12.48 per hour). For each painting, we chose the musical genre that had the most votes (Table 6.1). In the future, we anticipate that the musical genre could also be selected by an artist or curator or based on heuristics about country, year of origin, and artistic genre. Further, a machine learning algorithm could potentially be developed based on training data provided by Mechanical Turk workers, artists, or curators for a larger set of paintings.

Table 6.1. Music pairings for each painting as determined by the highest vote of Mechanical Turk workers.

Painting	**Musical Genre**
Self-Portrait with Thorn Necklace and Hummingbird	Reggae
The Sleep of Reason Produces Monsters	Classical
The Blue Rider	Baroque
The Red Studio	Rock
The Stone Breakers	Folk

When a user enters Zone 4, Eyes-Free Art provides a description: *"People have chosen the musical genre of <genre name> to pair with this painting."* The Pandora station of that genre is chosen and the first song in the queue is played aloud. The song may or may not have lyrics. Pairing a particular song with a painting influences the interpretation, and it is possible to choose a song that is either helpful or misleading. Thus we believe it can be important to have expert curation when selecting a song; however, we consider this future work. We chose to pair a genre of music over a single track because it allows for the visitor to appreciate the style of music as opposed to particular components of the song.

6.4.1.2 Zone 3: Sonification

The goal of the sonification is to allow a user to have an aesthetically pleasing auditory experience while gaining a sense of the quantity and variety of colors in the painting. We chose these priorities over learning about all colors or the ability to create a full mental picture of the painting because that may require significantly more user training and degrade the casual museum visitation experience.

We use Body Tracking as described above to track the user's right hand. As the user's hand is exploring the painting, a 35-second orchestral musical loop is played aloud. Musical instruments are played at different volumes to represent different colors. Three sets of instruments correspond to the three primary colors in RGB (orchestra – red, piano – green, harp – blue). The pixel under the location of the user's right hand is played aloud. In order to make different regions of the painting sound distinct from one another, we choose the closest of nine colors to that pixel. The nine colors and instrument volumes are shown in Table 6.2 – these mappings were chosen empirically via trial and error exploration of various mappings. These mappings are the same for all paintings.

Table 6.2. Map from color to instrument volume in our 35-second orchestral track.

Color (RGB)	Orchestra volume	Piano volume	Harp volume
Red (255, 0, 0)	100	10	10
Purple (255, 0, 255)	100	10	100
Blue (0, 0, 255)	10	10	100
Teal (0, 255, 255)	10	100	100
Green (0, 255, 0)	10	100	10
Yellow (255, 255, 0)	100	100	10
White (255, 255, 255)	100	100	100
Gray (128, 128, 128)	50	50	50
Black (0, 0, 0)	10	10	10

For example, if a user's hand hovers close to the top of Self Portrait with Thorn Necklace and Hummingbird (Figure 6.4), the pixel is matched with the closest color, Blue. The orchestra and piano are played at a volume of 10, and the Harp is featured at a volume of 100.

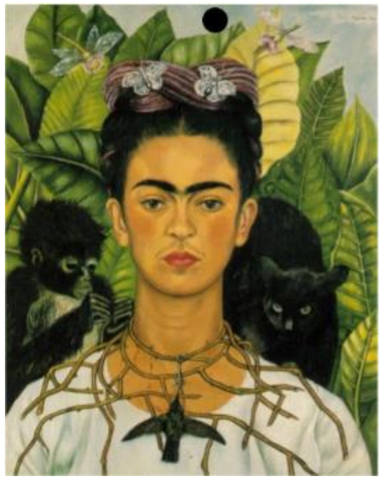


Figure 6.4. The user's hand (black dot) is hovering over a color which is matched with blue. As a result, the harp is played at volume 100 and other instruments are played at volume 10.

When the user's hand crosses an edge in the painting (Figure 6.5), a gong that is distinct, yet cooperates with the music, is played aloud. To avoid the gong's overpowering the sonification, it can only be played every 500 milliseconds.

Figure 6.5. Edges for Self-Portrait with Thorn Necklace and Hummingbird. The edges were manually drawn.

When a user enters Zone 3 they hear: *"You have entered Zone 3: Sonification."* They hear an audio tutorial explaining how the sonification works. The user hears an initial "synopsis" of the painting, which is done by averaging all of the pixel colors and choosing the closest color. Finally, the system instructs the user to reach their right hand forward to explore the painting.

6.4.1.3 Zone 2: Sound Effects

Unlike the goals of background music and sonification, which are meant to set a mood and give a general impression of the work, the goal of the sound effects is to convey the literal aspects of the paintings, specifically, the type and location of objects contained in the painting. The user has a chance to hear about the major components of the painting and understand the spatial relation between those objects.

As the user explores the painting with their hand, the position of her or his hand determines which sound is to be played aloud. A separate image (Figure 6.6) is loaded with manually annotated regions representing the different objects. A sound effect is played aloud when the user's hand is over the corresponding region. If the sound file has finished playing or the user's hand leaves the object, then the system is ready to play another sound effect. When the user's hand is not hovering over any object, a relevant background sound is played. For example, in a landscape, the user hears breeze flowing through grass. If the user's hand is not hovering over the painting, no sounds are played.

Figure 6.6. Sound effect regions (right) for Self-Portrait with Thorn Necklace and Hummingbird (left). The regions were manually colored (green = leaves, orange = monkey, pink = cat, red = butterflies, yellow = bird).

Ideally, the sound effects would be automatically detected via computer vision or mined from text descriptions. We attempted to create such a system by selecting a set of 100 paintings and used OpenCV's face detector (Open cv dev team 2016), a proprietary face detector, two human detectors (GitHub 2016b, Laptev 2016), and code for detecting objects with the 1000 most common words used in captions (GitHub 2016a) as features in a machine learning system. However, we unfortunately were not able to train an effective algorithm for this task. These computer vision techniques, while making sufficient progress on photographic images, do not generalize to paintings because painters may paint objects in an abstract manner and with different brushstrokes or colors. We also gathered text descriptions from Wikipedia and an Art History textbook (Janson and Janson 2007), and then used Stanford's CoreNLP parser (Manning et al. 2014) to gather the nouns. Finally, we filtered these nouns using the 1000 most common words used in captions (GitHub 2016a) to determine a list of nouns. Deriving a list of objects was not successful using this methodology, either, because most painting descriptions contain information about the history, interpretation, and facts of the painting, not only the objects contained.

Because there was no viable option to automatically acquire the objects contained in the painting, we chose to manually pair the sound effects. In the future, it would be interesting to develop algorithms to automatically detect objects based on computer vision or text extraction, perhaps using crowd workers to confirm or update the algorithm's object placement.

When the user enters Zone 2, they hear *"You have entered Zone 2, Sound effects."* First, Eyes-Free Art informs the user that they will hear sounds made by the objects contained in the painting. A "synopsis" of all of the sounds is then played aloud so the person can hear the objects represented in the painting. Finally, the user is able to explore with their right hand as described above.

6.4.1.4 Zone 1: Verbal description

Finally, the user can enter Zone 1 to receive the most detailed information about the painting. A verbal description, manually curated from a combination of Wikipedia articles and an Art History textbook (Janson and Janson 2007), is read aloud to the user. The description includes title, artist, year, materials used, contents of the painting, and history of the painting. We chose to manually curate the verbal description of the painting due to the lack of consistent written descriptions online; we believe with improved and consistent descriptions we could automatically scrape online text. At any point in the verbal description, the user can pause the narration by moving between the different zones to interact with the painting. The interaction on subsequent visits to each proxemic zone is faster because the instructions are not repeated unless requested by the user (instructions for each zone can be requested via the audio command *"Repeat"*).

6.5 User Study

To assess the ability of Eyes-Free Art to provide an enjoyable and informative audio experience for a painting, we conducted a user study with 13 participants who were blind or low vision. Our study design had every participant experience a *baseline* and an *experimental* condition. The *baseline* was only the detailed verbal description, similar to most museums and online resources. The *experimental* condition was the complete Eyes-Free Art system, which also contains the same verbal description as described in the baseline.

Each participant interacted with three paintings: one with the *baseline* condition and two with the *experimental* condition. We gave participants *baseline* only for one painting because the verbal description was standard and we wanted to keep the study duration to about one hour; we are also not formally comparing "performance" between the two systems – the *baseline* condition's presence was intended to remind participants of the status quo experience they would have at museums today, hence, sacrificing full counter-balancing in order to limit participants' time commitment was a reasonable tradeoff. Participants had the chance to experience two paintings in the *experimental* condition to ensure they were able to fully explore the four different zones. For each participant, we used a modified Latin Square design to choose three of the five paintings (shown in Figure 6.3), such that all five paintings were used in the *baseline* and *experimental* conditions equally. The study was counter-balanced so the participants were placed into Group 1 (*baseline* first, *experimental* second, *experimental* third) or Group 2 (*experimental* first, *experimental* second, *baseline* third).

6.5.1 *Participants*

We recruited 13 participants (12 females, ages: 19-71, median age: 52) who were blind or low vision to participate in our study. Seven participants were blind while six had low vision. Four of the participants identified as artists and for two of those four it was their occupation. The participants reported that they typically visited art museums: never (1), once a year (3), a couple of times a year (4), and once a month (5). We recruited the participants via local email lists and by connecting with a local art museum. The participants spent about an hour completing the study and were compensated with a $100 gift card.

6.5.2 *Methodology*

We interviewed participants to learn about their level of vision, artistic experience, and frequency of attending art museums. Following the interview, the participants were told to imagine that they were in an art museum standing in front of a painting. In the *experimental* condition, we explained that they would slowly approach the painting, and that the audio they hear would change. Participants were given a tutorial on the tactile "ladder" (Figure 6.2), where the center of the ladder allows them to move between zones, and when placing their feet on the rungs, they would be in a particular zone. In this way, the participants knew where to move as they were exploring the painting.

The participants used either the *baseline* verbal description or the *experimental* Eyes-Free Art condition (with the order used in Group 1 or Group 2), and we orally administered a questionnaire containing both closed-form (5-point Likert-scale from strongly disagree to strongly agree) and open-form questions, to assess their experience, learn about any benefits, and receive feedback for improvement. The *baseline* follow-up interview was about the verbal description, while the *experimental* interview was about each of the four zones and the overall system. The interview also contained a list of statements in which participants had to list how much they agreed. At the end of the study, we asked participants whether they preferred the *baseline* or *experimental* condition. The interviews were audio recorded and the entire session was video recorded. The initial, *baseline*, and *experimental* interviews are in Appendix I.

6.5.3 *Results*

Below we discuss the differences in participant experience between the *baseline* and *experimental* conditions, followed by participant feedback for each of the four zones.

6.5.3.1 Baseline vs Experimental Experience

Eleven of the thirteen participants preferred Eyes-Free Art to the *baseline* condition. A Chi-squared test for given probabilities shows that the preference for Eyes-Free Art was significantly higher than chance ($\chi 2$ (1, N=13) = 6.23, p = 0.013). One reason for this preference was that: *"It [Eyes-Free Art] gave it [the painting] more dimension"* (P7), and *"because you get a fuller appreciation of the picture"* (P1). Further, participants appreciated the proxemic audio interface moving from general to specific: *"The system sort of would mirror other people just looking,* *because if you [a sighted person] were far away from it, then you won't really know what's on it, so it's just a general idea, and as you get closer to it you would actually get more out of it"* (P4).

Participants also felt that they were able to gain more information about paintings in the *experimental* condition than in the *baseline* condition. For the statement, *"I had a much better understanding of the contents of the painting,"* participants had a higher agreement in the *experimental* condition using a Wilcoxon signed rank test (Z = 2.602, p = .009), where the medians were *baseline* = 2 and *experimental* = 4. Further, while the verbal descriptions were consistent between the *baseline* and *experimental* conditions, participants felt that the verbal description in the *experimental* condition was more informative. For the statement *"After listening to the verbal description, I had a better understanding of the contents of the painting"*: A Wilcoxon signed rank test found there was a higher agreement with this statement in the *experimental* condition (Z = 2.836, p = .005) with medians *baseline* = 3 and *experimental* = 5. This may indicate that the verbal description was more informative when the person had the opportunity to gain context about the painting using the other three zones in the *experimental* condition. Participant 13 noted that the verbal description in the proxemic audio interface *"certainly pulled it all together"* (P13).

Eyes-Free Art and the *baseline* were more comparable when conveying a sense of aesthetics or emotion; there was no significant difference (Z = 0.513, p = .608) in participants' agreement with the statement: *"After using the system, I had a good sense of the general aesthetics/emotional content of the painting."* For instance, P9 reported in the *baseline* condition that *"it [the verbal description] gave you a very good idea of the emotional expression and it gave a lot of detail of what was in the painting."* However, participants' reactions during the study sessions seemed to indicate greater emotional involvement with the art work when using Eyes-Free Art; several participants laughed aloud with pleasure while using the system, and one participant was moved to tears by the novel perspective on art that the system provided her. P4 noted, *"[Eyes-Free Art] gives you an intense feeling without spending hours [at the museum]."*

Participants appreciated that, in comparison to *baseline* verbal descriptions, Eyes-Free Art is an interactive system: *"It makes it more interactive… sometimes at museums you feel a little left out [as a blind patron]"* (P5). Participants felt that it *"felt more like total experience instead of just standing in front of something"* (P13). In addition, P4 noted that *"you can choose yourself how much time to spend on the painting."* The use of the hand was useful to scan the painting: *"I can move my hand back and forth, and in that way look at something more specifically"* (P3). Even though participants moved themselves and their hands around a space, they did not find Eyes-Free Art to be more fatiguing to use than the *baseline* condition. For the statement *"I found the system fatiguing to interact with"*: there was no significant difference in terms of participant agreement ($Z = -0.159$, $p = .874$).

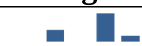
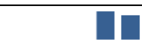
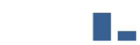
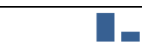
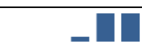
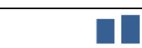
6.5.3.2 Per-Zone Feedback

Each zone in Eyes-Free Art provided a unique benefit to participants, because the zones educated participants about different aspects of the painting. Participants mentioned that the background music *"instantly sets a mood"* (P5), while the sonification provided more information about colors: *"It [the sonification] did give me a very good sense of brightness and darkness of the colors"* (P6). Finally, the verbal description *"helped give a complete picture"* (P10).

As the participants began using Eyes-Free Art, the music zone was able to set the mood for the painting: *"It [the music] set the mood of the picture, which was really important… [Goya's] art is dark and very troubled, and the classical [music], you could get a sense of the volumes from that, what his intent was"* (P3). However, the music may not be as compelling for more comprehensive painting descriptions such as genre (median = 3) or time period (median = 2) (Table

6.3, Music). In order for the music to provide a more educational experience, P9 suggests to *"research the story about the painting to help select music that complements the art work."* For future work, we anticipate that an artist or curator could choose a particular genre or song to pair with the painting.

Table 6.3. Median values and histograms of participant agreement with statements about Eyes-Free Art (*experimental* condition). Strongly Disagree = 1 to Strongly Agree = 5.

Music	**Median**	**Histogram**
"I was able to assess the mood of the painting(s)."	4	
"I was able to assess the genre of the painting(s)."	3	
"I was able to assess the time period of the painting(s)."	2	
Sonification		
"I was able to hear instruments playing at different volumes."	4	
"I was able to distinguish the instruments playing red (orchestra)."	4	
"I was able to distinguish the instrument playing green (piano)."	4	
"I was able to distinguish the instrument playing blue (harp)."	4	
"I was able to distinguish white (quieter), gray (medium), and black (louder)."	4	
"I was able to get a sense of the lightness or darkness of the painting(s)."	4	
"I was able to get a sense of the quantity and variety of colors the painting(s)."	4	
I was able to identify specific colors in the painting(s)."	4	
Sound Effects		
"I was able to locate objects of interest."	4	
Overall		
"I was able to easily navigate between the four zones."	5	
"The order of the four audio zones made sense to me."	4	

The sonification zone required the longest amount of training (a couple minutes to listen to the instructions), but provided an enjoyable experience and an idea of the colors in the painting. The participants appreciated that we used composed music and only changed the volumes: *"This has got harmony to it. It's just cool. It takes away the frustration. I felt like smiling"* (P9). In addition, participants felt that they were able to distinguish the instruments and get a sense of the colors in the painting (all medians = 4) (Table 6.3, Sonification): *"For people who can't see colors, it definitely gives an idea"* (P5). The gong effect to demarcate edges within the paintings was generally confusing to users; they seemed more interested in having an effect to note the edges of the painting itself (in order to better understand its aspect ratio) than the edges of painted objects.

Our participant responses elicited interesting directions for future sonifications. We chose to blend instruments to convey blended colors so there were fewer instruments to learn (i.e. instead of having different instruments for the nine colors in Table 6.2). We encountered an interesting tradeoff where participants wanted more instruments to convey different colors, but also realized the limitations with that approach: *"maybe include yellow… I know that if you add too many colors, it will be hard to remember"* (P5).

Because the sound effect zone played audio contained by the objects in the painting, it provided a realistic experience: *"It brought the picture, [again,] alive"* (P3). In addition, P6 mentioned that the sound effects *"created a feel you were actually in that place."* Finally, participants felt that they were able to locate objects of interest (median = 4) (Table 6.3, Sound Effects).

Overall, participants felt that they were able to navigate between the four zones (median = 5), but the order of the zones had differing responses (median = 4) (Table 6.3, Overall). In fact, six participants listed that they would want to hear a verbal description at the beginning (i.e., the most distant zone) to help decide if they want to visit that painting, suggesting that our "pseudozone" that announced metadata upon first approach was not as sufficiently detailed as may be desirable: *"Verbal description first to have specific content especially for painting"* (P6). More specifically, P11 suggested that they *"would add an extra very short verbal description at the beginning."*

6.6 Discussion and Future Work

We have shown through our design and evaluation of Eyes-Free Art that we have developed a novel proxemic audio interface, allowing people who are blind or low vision to explore paintings interactively. Our work has given us valuable insights into the design of proxemic audio interfaces and into future iterations of Eyes-Free Art.

6.6.1 *Proxemic Audio Interfaces*

We developed a proxemic audio interface where we changed the type of audio presentation (e.g. background music, changing music, sounds, and verbal) based on the person's proximity from a painting. However, it is possible to design a proxemic audio interface that utilizes only one type of audio presentation. For instance, an interface may involve a semantic zoom exclusively of verbal information, increasing the level of the verbal description as a person approaches the painting. The information presented in each zone may also change from our current approach depending on user preference. For example, a verbal semantic zoom may contain: 1) the title and synopsis of the painting, 2) the genre, style, and history behind the painting, 3) the ability to explore with the hand to hear the names of the objects, and 4) the ability to explore with the hand to hear the names of the colors contained in the painting. Generally, our design is that each zone of the proxemic audio interface would increase in detail as the user approaches an object, regardless of the type of the audio presentation.

Another consideration for proxemic audio interfaces may include whether the zones are intended for one or multiple users. The interface can be personalized, presenting a different experience based on the identity of the user, or be designed to allow multiple users to experience the interface together. If the interface is meant for individual exploration, the system may ensure the user's privacy by providing headphones, using directional audio, or allowing only one person at a time. On the other hand, people might want to experience a painting or other object together, so designers would need to consider the tension between the technology and the social activity (Damala et al. 2008). Further, designers need to determine how to present audio output based on multiple gestures from multiple users so that it is both understandable and conducive to discussion. Because proxemic audio interfaces may be public and support a "shared use" (Vogel and Balakrishnan 2004) of both private and collaborative group experiences, how one presents the audio information will need to be carefully designed so that the competing goals of private and public information are both possible while remaining decipherable.

Our work leaves open other questions of how to design proxemic audio interfaces. For example, the number of zones used in an interface may be determined based on the size of the space, the number of people visiting the space, or the pace that people need to walk through an exhibit. Another question may be how to design a proxemic interface for people with different levels of vision, including people who are totally blind, partially sighted, and totally sighted. People with different visual acuities may prefer the audio presentations to be of different lengths and detail. Whether to provide different interfaces based on the person's preference or provide a more universal interface is open to discussion and based on museum resources.

6.6.2 *Eyes-Free Art in the Museum*

The initial interviews, design, and evaluation of Eyes-Free Art revealed interesting directions for future work. Our intent with this research was to explore the concept of a proxemic audio interface, thus we built Eyes-Free Art and conducted the user evaluation in the lab for one user at a time. We realize that evaluating a potential museum installation with a lab study may not generalize to an in-the-wild experience (Hornecker and Nicol 2012). In order to adapt Eyes-Free Art to a museum experience for future evaluation, we would need to account for multiple users, as discussed above, and the fact that sound bleed and pollution is often a concern for museum curators. These constraints warrant the use of headphones and possibly using a different technology to infer depth. Because multiple people could be approaching a painting from different directions, using RFID tags, a motion capture system, or a small mounted camera on the person may be a more viable method to infer intent and distance from a painting. If Eyes-Free Art were installed in a Children's museum or interactive museum, then the sound pollution may not be as much of a concern and may help stimulate children's creativity (Zheng et al. 2007).

Another direction for future work is determining whether Eyes-Free Art should be used to interpret existing paintings or used to compose audio experiences for new paintings. Some participants mentioned the risk of assigning audio to an existing painting without the artist's permission, particularly so with the background music zone. The paintings selected in this study were in the public domain, so there is a decision to make of who is qualified to select sounds and music, whether it be a curator, art historian, anonymous crowd workers, or an automated algorithm. Answering this question is beyond the scope of this work, but could provide a good area for future study. On the other hand, if an artist creates an audio experience using Eyes-Free Art as a standalone experience or to complement a visual art piece, then Eyes-Free Art can allow an artist new mechanisms for enhancing a patron's interpretation and experience of a piece. This is an area we are actively exploring as future work. It is important to note that this requires more time and training on the part of the artist.

Because proxemic interfaces also have the goal of "immediate usability" (Vogel and Balakrishnan 2004), one future challenge is how to present a sonification without the necessity of training an individual. Currently, the user has to learn the mapping of red, green, and blue to instruments, as well as understanding changes in volume. It is possible that HSV will be a more intuitive mapping. Participants in the study suggested having more colors mapped to instruments to be more comprehensive, but this would increase the amount of time needed for training. One possible solution may include a tutorial for sonification as the user is exploring the painting by mentioning the names of the colors for the first minute of interaction. Designing sonification techniques that balance the competing demands of learnability, expressivity, and audible aesthetics remains an open research problem.

6.7 Chapter 6 Summary

We designed, developed, and evaluated Eyes-Free Art, a proxemic audio interface that helps people who are blind or low vision explore paintings. Further, we contributed the concept of a proxemic audio interface, demonstrated its feasibility, and discussed future directions for how to integrate these interfaces in public settings. By conducting a lab-based study with 13 people who are blind or low vision, we found that Eyes-Free Art gave a good sense of the painting, in particular the colors and objects contained in the painting, and provided a rich, interactive interpretation of the art work that was appreciated by users. We hope that our work will generalize to researchers and designers who want to build immersive audio experiences that are based on tracking a user.

Chapter 7. DISCUSSION

In my introduction, I state that my goal is to design, develop, and evaluate technologies that enhance quality of life for people who are blind or low vision. I explain in Chapters 3-6 the prototypes and system that I developed, the empirical user studies I conducted to address my goals, and the corresponding research questions. In this chapter, I discuss the limitations of my research and follow with opportunities for future work.

7.1 LIMITATIONS

In Chapter 3, I explored the opportunities and challenges of developing exercise technologies to help people who are blind or low vision. I engaged with different stakeholders (direct, indirect, and third party public) to learn about their values, experiences, and ideas in this space. While we were careful to iterate our interview and survey materials through peer feedback and piloting, we identify that all of the researchers are sighted, and hence the materials may have had a sighted bias. Additionally, we scoped our stakeholders to people who are blind or low vision, people who facilitate their fitness, and the general public; we did not include family members, friends, or orientation and mobility instructors who may also have an interesting perspective. Because we engaged in email list, Facebook, and snowball sampling, it is possible that we did not get a representative sample of participants. For instance, I hoped to recruit athletes from sports teams, but interacted with people who competed in more independent sports. Finally, we used hypothetical technologies and scenarios in our interviews for multiple reasons including that the technologies may not exist and the fact that participants may be far geographically.

In Chapter 4, I chose to build a prototype version of Eyes-Free Yoga to explore the concept of using real-time personalized verbal feedback for yoga postures. We conducted a within-subjects study to ensure that each participant had the ability to compare their experience with and without receiving feedback on the held postures. I identify that there were limitations to the study. For example, participants held six yoga postures up to three different times and may have experienced fatigue. In addition, the participants were counterbalanced in terms of whether or not they received feedback, but the order of the postures remained the same. However, yoga workouts may follow a certain progression (e.g. Bikram Yoga), thus why we chose this study design. There were other limitations of Eyes-Free Yoga that have been addressed in the full system: *"Pause"*, more postures, system provide instructions when the person is not facing the Kinect, rewards and badges, text instructions to read, and programmatically guiding a person to the correct spot on the floor.

In Chapter 5, I built a fully functioning workout system with four workouts ranging from 25 minutes to over 1.5 hours. The system included all of the features mentioned in the previous paragraph. Additionally, we conducted an in-home deployment study for 8 weeks with four participants who are blind or low vision. One limitation of my study is that I only had four participants. I conducted a single case subject design with semi-random ABAB study design (such that each A and B phase was at least 7 days long) to increase statistical power (Dugard 2014, Heyvaert and Onghena 2014). Another limitation of the study is that the *baseline* condition of a fully functioning workout system with personalized feedback was powerful to begin with. The audio motivational techniques including badges, levels, and reminders enhanced the participant experience, but did not influence the number of minutes exercised per day. To address this, I conducted a mixed-methods study so that I could complement the numerical data with user quotes about their experience.

In Chapter 6, I designed, built, and evaluated a prototype called Eyes-Free Art to help people who are blind or low vision to explore 2D paintings. I conducted a controlled within subjects' lab study to explore the participant experience between a verbal description and the proposed system. I conducted a controlled lab study to explore the concept of using a proxemic audio interface to explore a painting, so one limitation of my study is that it may not be applicable to use in a museum with multiple patrons (Hornecker and Nicol 2012). Additionally, Eyes-Free Art was presented as a tool to interpret existing paintings. There may be limitations in the musical, sound, and verbal choices that were made when crafting the experience. For example, background music may set the tone of the painting or it may be misleading if not chosen carefully. Currently, we have a collaboration with a blind artist to craft an original experience with the intent of a public installation.

7.2 Opportunities for Future Work

From my dissertation research, I was able to design, build, and evaluate novel experiences in the domains of exercise and art to help enhance quality of life for people who are blind or low vision. I interacted with people who are blind or low vision, domain experts such as yoga instructors, artists, curators, sighted guides, bicycle pilots, and coaches. While I have addressed my research questions posed in the introduction, I have opened opportunities for future work in the space of enhancing quality of life for people who are blind or low vision, particularly in three areas: 1) expanding the set of users who benefit from these technologies, 2) improving the capabilities of existing technologies and the content they provide, and 3) improving user study methodology for people with disabilities.

7.2.1 *Expanding the Set of Users and Contexts*

- **Designing and developing solutions that can be effective in public spaces:** I designed and developed Eyes-Free Yoga and Eyes-Free Art with the underlying motivation of helping people who are blind or low vision have access to activities that are mostly not accessible. Additionally, I wanted to help people participate in these activities in more public settings. The studies I have conducted have taken place either in the lab or home, so there is a motivation to deploy accessible technologies in more public spaces. For instance, researchers have conducted user studies of their technologies in the wild (Azenkot et al. 2011, Bigham et al. 2010, Consolvo et al. 2008), however these activities are mostly slow paced, safe, and familiar. An interesting research challenge is to deploy technologies that enable activities that may put encourage faster paced exercises where safety may be more of a concern, or novel experiences that were not previously accessible such as navigating museums independently of a sighted guide.

- **Enabling interactions that involve more than one user:** Although researchers have developed and studied technologies to help people with disabilities, there are fewer research efforts on how to integrate people with and without disabilities in healthy and entertaining activities. For example, having an exercise partner can motivate people to continue a physical activity (Wu et al. 2009), so connecting people of differing abilities may be beneficial. However, there may be challenges when building technologies that allow people of differing abilities to use in parallel (Allender et al. 2006). There are examples of exergames that include handicaps such as increased haptic feedback (e.g. Truck Pull (Stach and Graham 2011)), or allowing each player to set a personal goal (e.g. TripleBeat (De Oliveira and Oliver 2008)). However, players might able to detect the skills of their competitor. When different users may not know each other, like in remote gaming, designers should exercise caution not to disclose one's abilities to other players (Yim and Graham 2007).

- **Embracing low vision interactions:** The work in my dissertation involves eyes-free interactions, essentially removing the screen from all interactions. As a result, users give input using their body and voice, and receive output in the form of music, audio, and verbal information. However, many of the participants in which I have interacted are low vision, not totally or legally blind. As a result, there may be an advantage to designing visual feedback in concert with auditory output. This may also help people with degenerative conditions; they can familiarize themselves with the accessible audio interface while using their vision to help, so that they are prepared to use the audio interactions exclusively in the event of vision loss.
- **Working with different age groups:** The majority of my user studies have involved adults (ages 18+) with the exception of my Eyes-Free Yoga lab study where I had participants ages 13+. Working with adults is important, but there is an opportunity to interact with children who are blind or low vision to make an impact earlier in life (Rector et al. 2015). In fact, for activities such as exercise, these children are already at a disadvantage. Children may experience reduced expectations by their parents (Stuart et al. 2006) and then they decrease their physical activity (Robinson and Lieberman 2004). Many children do not complete enough physical activity to maintain an adequate fitness level (Capella-McDonnall 2007). Outside of exercise, it is important to consider children in accessibility research. Children can take an ownership in their learning when experiencing the arts (Hernandez and Barner 2000). An interesting direction for future work is to understand the needs of children with disabilities (e.g. physical education, scholastic activities, creativity) and develop technology that facilitates interaction between children of differing abilities (e.g. Sobel et al. 2016).

7.2.2 *Improving the Capabilities of Existing Technology and the Content They Provide*

- **Utilizing Computer Vision and Machine Learning:** In Chapter 3, I note the limitations of Kinect Skeletal Tracking and how I had to constrain my solution to standing postures. In Chapter 6, I mention that I did not succeed at automatically detecting the objects contained in the painting, despite using several robust Computer Vision techniques that work with images, and as a result had to manually annotate the objects in each painting. There is an opportunity for researchers who build artifacts for Human-Computer Interaction and Accessibility to contribute to other fields in Computer Science. For example, object detection in paintings is an interesting research direction for Computer Vision and Machine Learning researchers (e.g. http://arxiv.org/pdf/1505.00110v1.pdf). At the same time, the applications of this work could benefit people with or without disabilities. An example future project may involve a first round of object detection, followed by people from Mechanical Turk improving those annotations, and then training a Machine Learning classifier with attributes including artist, genre, and time period. If precision and recall are within an acceptable range, then several paintings that do not have descriptions may have the ability to be annotated.
- **Expanding to faster paced exercises:** In Chapter 5, I note that blind athletes use stationary equipment to engage in rigorous physical activity. There is an opportunity to utilize the Kinect sensor or other body worn sensors to facilitate faster paced exercises where the person can move freely with their body indoors or outdoors. Some examples include Gerling et al. (2013a, 2013b) who developed Kinect based tracking for wheelchair users so they could participate in exergames or Folmer (2015) who developed a running aid with a drone for people who are blind. This research area is still young, and as observed in my Value Sensitive Design research, there are research avenues in designing technology that can facilitate

rigorous exercise and also be aware of indirect stakeholder such as sighted guides, instructors, or the general public.

- **Exploring the tradeoff between sonified information and aesthetics:** As I mentioned in Chapter 2, there is an opportunity to use sensory substitution to convey information. Sonifications have been explored in several domains including reading charts and graphs (Doush et al. 2010, Braier et al. 2014, Giudice et al. 2012, Goncu et al. 2014, Vogel and Balakrishnan 2004), interactive exhibits (e.g. Quinn et al. 2012), and interpreting pictures (Hernandez and Barner 2000, Reichinger et al. 2011, Wang et al. 2008). However, all these techniques require lead time to understand the sonification. Additionally, the sonification may not sound aesthetically pleasing to the ears and may reduce a user's motivation to understand the sonification. An interesting direction for future work is to explore the tradeoff between producing a sound that is aesthetically pleasing and a sound that conveys information, perhaps finding an optimal point in between. I explore this concept formatively in Eyes-Free Art by providing a sonification that has a foundation in already composed music. There may be other options for sonifications including altering existing music or sounds, or composing music or sounds in real time with constraints to maintain a pleasant sound (e.g. only pentatonic scales, no tri-tones, etc.).
- **Developing better verbal descriptions:** Researchers have explored how to develop verbal descriptions for visual items, including on demand descriptions such as VizWiz (Bigham et al. 2010), automatic alternative text descriptions (García et al. 2016), or detailed curated descriptions by experts (MoMA 2016, Metropolitan Museum of Art 2016, SAM 2016, Currier Museum of Art 2016). Descriptions of visual items may include high level information (e.g. summary, trends in charts, points of interest that sighted people first notice)

or low level information (e.g. particular objects, points, or raw color or numerical values). An interesting research question may be *"How do we determine the optimal verbal description for a person who is blind or low vision based on the visual task, and what techniques may contribute to the optimal description?"* For example, if a blind person wants to visit a complex visualization briefly, then a summary containing high level details or points of interest may be best. On the other hand, if the person has more time to explore, then providing low level details may also be useful. If we are able to determine the user's goal, then there are both automatic (e.g. computer vision) and manual techniques (e.g. crowd workers, experts) to create a verbal description, where some techniques may work better than others. Another idea may also include the use of proxemics so users can zoom into a specific or detailed verbal description or zoom out to a high level description while completing a visual task.

7.2.3 *Improving Empirical User Study Methodology when Working with People who have a Disability*

- **Create a toolkit to run both portable and accessible studies to involve more users:** In my research, I encountered issues with recruitment including: 1) large geographical distances, 2) transit constraints such as avoiding unfamiliar bus routes or accessible transportation not being reliable, 3) time constraints including not able to take a portion of time off of work, and 4) monetary constraints where the cost to participate in the study outweighed the benefits of the study. These issues may also co-occur depending on each participant situation. As a result, I was able to recruit only 16 and 13 participants for my lab studies, and 4 participants for my deployment study. For one of my lab studies, I had to travel several hours in each direction to connect with participants. For my Value Sensitive Design research, I interacted with only 10 direct due to the work being qualitative, but because it was a phone interview, I had the ability to interact with several more participants. I could recruit more participants when factors such as travel and time were mitigated. An interesting direction for future work may involve expanding upon the Lab of Things (Brush et al. 2013) that also combats issues that accessibility researchers may face. How can we design a toolkit that helps researchers quickly create accessible instructions and labeled items packages to send in the mail for a deployment? Could we create a network of schools for the blind or are willing to facilitate user studies and have their students participate in user studies given consent, or assent with parental consent? What other possibilities exist such that we can recruit more participants regardless of distance or socioeconomic status while maintaining engagement in the study?

- **Including indirect stakeholders in user studies:** When developing assistive technology solutions, it may be important to understand the perspective of the indirect stakeholder. For example, Gerling et al. (2014) interviewed able bodied participants after playing an exercise game where they competed with a wheelchair user. Gaining the third party observer perspective may also be important, as they may have incorrect assumptions of or a negative impact on a person with a disability (Shinohara and Wobbrock 2011, Rector et al. 2015). Future research studies that evaluate a hypothetical or real prototype or system should consider including the reactions of indirect stakeholders. A prototype that is received well in a user study with a person who has a disability (who may provide more positive ratings than people without a disability (Trewin et al. 2015)) may be contested by chaperones, friends, family, coaches, or third party observers in the public. According to the third wave of HCI (Harrison et al. 2007), technology solutions exist within a social context, and this context may provide valuable insights to improve existing technology or create new solutions that may or may not involve technology.

Chapter 8. SUMMARY AND CONCLUDING REMARKS

In the final chapter of my dissertation, I summarize the previous chapters, summarize my research contributions, and make concluding remarks.

8.1 A SUMMARY OF PRIOR CHAPTERS

In Chapter 1, I motivated the need for more research in enhancing quality of life for people who are blind or low vision. Quality of Life is defined as: *"The degree to which a person enjoys the important possibilities of his or her life"* (Quality of Life Research Unit 2016). Within quality of life, I focused on two domains of exercise and art exploration – these activities may provide physical or mental benefits, and help people who are blind participate in culture. I explored these domains by designing and building artifacts and conducting empirical mixed methods user studies with stakeholders in the community.

In Chapter 2, I summarized background and related work to provide a foundation for: 1) 3D cameras and body tracking, 2) quality of life, 3) exercise and technology, and 4) art and technology. With items 2-4, I presented related work for people who are blind or low vision. I used the Microsoft Kinect sensor for Chapters 3, 4, and 6. Within quality of life there are three facets: *being (physical, mental, and spiritual wellbeing)*, *becoming (achieving goals and becoming a better person)*, and *belonging (physical, social, and community belonging)* (Quality of Life Research Unit 2016). My Value Sensitive Design research (Chapter 5) relates to *being*, Eyes-Free Yoga (Chapters 3-4) relates to both *being* and *becoming*, and Eyes-Free Art (Chapter 6) relates to *becoming*. In the future, I hope to focus on research relating to *belonging* by developing more public facing accessible experiences, such as a public art display with multiple modalities.

In Chapter 3, I address my first research question: *“How should we design audio based exercise systems that enhance exercise in real world scenarios with multiple stakeholders?”* To address this, I employed Value Sensitive Design to learn about the opportunities and challenges for exercise technologies for people who are blind or low vision. Chapters 3-4 were exploring one form of exercise (yoga) and in one context (in-home) so the goal of Chapter 5 was to discuss any form of exercise in more contexts (in-home, at the gym, outdoors). I conducted semi-structured interviews with 10 direct stakeholders and 10 indirect stakeholders along with a survey of 76 people in the general public. From this study, I learned four different opportunities for eyes-free exercise technologies: 1) provide more information in a public exercise class, 2) provide more information while exercising with a sighted guide, 3) enable or enhance rigorous outdoor exercise, and 4) help navigate exercise spaces. This research serves as motivation for future work beyond my dissertation.

In Chapter 4, I address my second research question: *“How should we design audio based systems to coach a person who is blind or low vision to perform an exercise that may rely on vision?”* To address this, I designed, developed, and evaluated a prototype version of Eyes-Free Yoga. Eyes-Free Yoga is an accessible yoga coach that provides personalized real-time verbal and auditory feedback to help people who are blind or low vision learn yoga. Eyes-Free Yoga had six design principles: 1) accessible for eyes-free interaction, 2) game provides a yogic experience, 3) game instills confidence, 4) caters to a novice target audience, 5) accessibility does not hinder learning, and 6) encourages a challenging workout. I conducted a mixed method within subject empirical study with 16 people who are blind or low vision and found that 13 preferred Eyes-Free Yoga to a version with no feedback. We found promise that there was an improvement with yoga posture quality when anonymized screenshots of the participants were rated by four yoga instructors.

In Chapter 5, I address my third research question: *"How should we design audio based exercise systems to encourage a person to exercise over a longer period of time?"* To address this, I designed, developed, and evaluated a fully functioning system based off of the Eyes-Free Yoga prototype. In addition to the real-time feedback, Eyes-Free Yoga has four full workouts, and auditory motivational techniques including auditory levels, auditory badges, and musical reminders. I conducted a single case subject design with ABAB study design with four people who are blind or low vision. The *baseline* version (A) was the full Eyes-Free Yoga workout system without motivational techniques, and the *experimental* version (B) included the audio techniques. We found after an 8-week in-home deployment study that the participants used Eyes-Free Yoga throughout the study duration, and felt that the motivational techniques enhanced their workouts.

In Chapter 6, I address my last research question*: "How should we design audio based systems to help a person explore visual items, such as art, independent of a sighted guide?"* To address this, I designed, developed, and evaluated a prototype version of Eyes-Free Art, a proxemic audio interface that allows people who are blind or low vision to explore 2D paintings using audio, musical, and verbal information. The goals of this project were to: 1) develop a low cost solution that can scale, 2) make the experience subjectively satisfying and aesthetically pleasing, 3) provide detailed verbal descriptions, and 4) convey emotion and mood. I conducted a mixed method within subject empirical study with 13 people who are blind or low vision to compare the experience with only a verbal description versus the Eyes-Free Art prototype. I found that 11 participants preferred Eyes-Free Art because they could interact with the painting and explore the painting with the different zones.

In Chapter 7, I state the limitations of my work from Chapter 3-6 and discuss the future opportunities for research based upon my work. I believe there are opportunities to design and develop solutions to work with a more diverse set of users and in more contexts than just in a home or lab setting, to collaborate with researchers in fields including Computer Vision and Machine Learning, to develop better automatic or curated verbal descriptions of visual objects, and to include more direct and indirect stakeholders in user studies.

8.2 A Summary of Contributions

In this dissertation, I made the following claims in my thesis statement:

When applied to quality of life for people who are blind or low vision, interactive technologies support:

1. An increase in enjoyment
2. An increase in the amount of time engaged in the activity
3. People to learn more about the activity
4. Independent access to the activity
5. Multiple stakeholders

Table 8.1 shows whether or not I studied each claim in each project, and if the claim was confirmed qualitatively or quantitatively.

Table 8.1. Table listing the claims in my thesis statement and whether or not the claims were confirmed. "Yes" means the claim was confirmed quantitatively and "Qualitative" means the claim was supported through participant quotes.

Goal for activities that fit under Quality of Life	Value Sensitive Design	Eyes-Free Yoga Lab	Eyes-Free Yoga Deployment	Eyes-Free Art
Increase enjoyment	Not studied	Yes	Qualitative	Qualitative
Increase amount of time	Not studied	Not studied	Yes	Not studied
Help with Knowledge	Qualitative	Yes	Qualitative	Yes
Allow for independent access	Qualitative	Not studied	Yes	Yes
Work with multiple stakeholders	Yes	Qualitative	Qualitative	Not studied

In my dissertation, I made contributions to the fields of HCI and Accessibility. I contributed three artifacts and empirical findings for each of these artifacts. In addition, I conducted a separate empirical study to help shape future work for eyes-free exercise technologies. Below, I summarize my research contributions.

8.2.1 *Artifact Contributions*

I designed and developed the Eyes-Free Yoga prototype (Chapter 3) that acts as a yoga coach and provides real-time verbal and auditory feedback to help a person who is blind or low vision improve their yoga postures. First, the prototype provided verbal instructions to achieve the posture. As the user holds the pose, they receive verbal feedback in order from their core to their limbs. As they fix a verbal feedback instruction, they hear a confirmation tone. Through this work, I showed that *using a 3D camera, designers can implement more detailed verbal feedback for alignment based exercises***.** HCI researchers can utilize the methodology (described in Chapter 3 and Appendix A) and collaborate with domain experts to build similar systems in other domains. Additionally, the detailed audio feedback can complement existing visual based exercise games to help people who are sighted as well.

As a follow up, I designed and developed the Eyes-Free Yoga system (Chapter 4) that is a fully functioning workout system with four workouts and auditory motivational techniques. First, the system provides instructions to lead users through four workouts ranging from 25 minutes to over 1.5 hours. Secondly, the personalized real-time feedback is available for standing postures. There are three different types of audio motivational techniques: 1) auditory reminders – plays music at a predetermined time to remind the person of the workout, 2) auditory levels – plays different bodies of water in the background during exercise as a player makes progress, and 3) auditory badges – reward a person for exercising for a certain period of time, three times per week, or holding at least half of postures while addressing the personalized feedback. I showed that it is possible to *implement audio based motivational techniques for exercise games***.** Both application and game designers could enhance existing systems by providing multiple modalities for users with different abilities.

I also designed and developed Eyes-Free Art (Chapter 6) that is a proxemic audio interface meant to provide an interactive audio experience of 2D paintings for people who are blind or low vision. The system has four zones that change as a person moves closer to the painting. Zone 4 (12+') presents background music, where the genre was paired by a set of five online crowd workers. Zone 3 (9-12') is an interactive sonification, where the user can move their hand in space and hear changes in an orchestral loop based on the colors in which their hand is hovering. Zone 2 (6-9') plays sounds of the objects contained in the painting based on the position of the user's right hand in space. Finally, Zone 1 (<6') presents a detailed verbal description of the painting. I presented *the first work designing a proxemic audio interface and discussion about how to expand upon this work*. HCI researchers could use proxemics in spaces including smart homes or public spaces that utilize the audio channel when vision is not preferred or possible.

8.2.2 *Empirical Contributions*

Motivation and future guidelines for exercise technologies catered to people who are blind or low vision: From the Value Sensitive Design study, I found four new opportunities for eyes-free exercise technology design: 1) knowledge transfer while participating in an exercise class, 2) knowledge transfer while exercising with a sighted guide, 3) enabling rigorous outdoor exercise, and 4) navigating exercise spaces. I determined these opportunities after engaging with relevant stakeholders including people who are blind or low vision of different fitness levels and those involved with their fitness (sighted guides, coaches, instructors, etc.). These findings may help HCI and Accessibility researchers motivate new artifacts to help in this space.

Preference for real-time personalized feedback for alignment based activities versus not hearing feedback: From the Eyes-Free Yoga lab study results, I found that 13 of the 16 participants preferred hearing the custom feedback over not receiving any feedback. Reasons for this preference include knowing whether or not they are performing posture correctly; this is not addressed with audio based yoga workouts or in public classes where instructors do not necessarily know how to communicate with people who are blind or low vision (Rimmer 2006).

Audio based motivational techniques enhance exercise games catered to people who are blind or low vision: From the Eyes-Free Yoga deployment study results, we found that participants used the system throughout the 8 weeks. We found that participants did not change their minutes of exercise per day based on the condition. However, we received qualitative reports that the participants enjoyed the motivational techniques, and when removed the system was reported as bland or boring. While yoga and badges may not be compatible, participants enjoyed hearing about their progress.

Preference for proxemic audio interface to explore visual items versus only a verbal description: From the Eyes-Free Art lab study, we found that 11 of the 13 participants preferred using the proxemic audio interface to explore a 2D painting over only hearing the verbal description. Reasons for this preference include the ability to interact with a painting with their distance and their hand as opposed to a passive experience when listening to a verbal description.

8.3 Concluding Remarks

As I completed my research for my dissertation, I realized that the systems I built provide new opportunities for people who are blind or low vision to engage in activities to enhance their quality of life, as opposed to only physical or mental health. I will continue this goal of developing more well-rounded technologies in future work. Another common strength with Eyes-Free Yoga and Eyes-Free Art is the ability to interact and learn while using the body as an input, whether it be a posture, distance, or the hand. In addition, the auditory detail provided verbally, musically, or with sounds provided a more comprehensive and enjoyable experience. I believe that there are more opportunities to design and develop novel solutions with an interdisciplinary team including domain experts and people with disabilities to help people enjoy aspects of quality of life that may otherwise be inaccessible.

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APPENDIX A

In this appendix, I provide the pseudocode to demonstrate how the Kinect keeps track of 11 rules for Warrior II. The rule is either evaluated in meters (m) or degrees (°). The corresponding pseudocode and verbal corrections are written for each rule. In the table, the italicized variables are from the KST. The colors on the left correspond to the priorities shown in Figure 4.3.

	Rule	Pseudocode and Verbal Corrections
	Back straight (m)	backX = Abs (*ShoulderCenterX* – *HipCenterX*) backX > .0762 *"Lean sideways toward your left"* backX < -.0762 *"Lean sideways toward your right"* backZ Abs (s (*ShoulderCenterZ* – *HipCenterZ*) backZ > .0762 *"Lean forward"* backZ < -.0762 *"Lean backward"*
	Hips forward (m)	hipZ = *HipRightZ* – *HipLeftZ* hipZ > .1 *"Rotate your hips left"* hipZ < -.1 *"Rotate your hips right"*
	Hips level (m)	hipY = *HipRightY* – *HipLeftY* hipY > .05 *"Move your right hip downward so it is level with your left hip"* hipY < -.05 *"Move your left hip downward so it is level with your right hip"*
	Shoulders forward (m)	shoulderZ = *ShoulderRightZ* – *ShoulderLeftZ* shoulderZ > .1 *"Rotate your shoulders left"* shoulderZ < -.1 *"Rotate your shoulders right"*
	Left leg bent Right leg straight (°)	quadLeft = distance (*HipLeft*, KneeLeft) calveLeft = distance (*KneeLeft*, *AnkleLeft*) ankleHipLeft = distance (*AnkleLeft*, *HipLeft*) kneeLeft = calcAngle (ankleHipLeft, quadLeft, calveLeft) kneeLeft > 170 *"Bend your left leg further"* quadRight = distance (*HipRight*, *KneeRight*) calveRight = distance (*KneeRight*, *AnkleRight*) ankleHipRt = distance (*AnkleRight*, *HipRight*) kneeRight = calcAngle (ankleHipRt, quadRight, calveRight) kneeRight < 155 *"Straighten your right leg"*
	Left knee behind ankle (m)	leftKneeToAnkleX = *KneeLeftX* – *AnkleLeftX* leftKneeToAnkleX < 0 *"Move your left knee backward behind your ankle"*
	Arms straight (°)	shouldWristL = distance (*ShoulderLeft*, WristLeft) lowArmL = distance (*ElbowLeft*, WristLeft)

		upArmL = distance (*ShoulderLeft*, ElbowLeft) elbowLeft = calcAngle (shouldWristL, lowArmL, upArmL) shouldWristR = distance (*ShoulderRight*, *WristRight*) lowArmRt = distance (*ElbowRight*, WristRight) upArmRt = distance (*ShoulderRight*, *ElbowRight*) elbowRight = calcAngle (shouldWristR, lowArmRt, upArmRt) elbowLeft < 150 && elbowRight < 150 *"Straighten your arms"* elbowLeft < 150 *"Straighten your left arm"* elbowRight < 150 *"Straighten your right arm"*
	Arms sideways (°)	shouldCenter = (*ShoulderRight* + *ShoulderLeft*)/2 upSpine = distance (shouldCenter, *Spine*) spineElbowL = distance (*Spine*, ElbowLeft) shouldElbowL = distance (shouldCenter, *ElbowLeft*) armLeft = calcAngle (spineElbowL, upSpine, shouldElbowL) spineElbowRight = distance (*Spine*, *ElbowRight*) shouldElbowR = distance (shouldCenter, *ElbowRight*) armRight = calcAngle (spineElbowR, upSpine, shouldElbowR) armLeft < 80 && armRight < 80 *"Bring your arms closer to your head"* armLeft < 80 *"Bring your left arm closer to your head"* armRight < 80 *"Bring your right arm closer to your head"* armLeft > 100 && armRight > 100 *"Lower your arms"* armLeft > 100 *"Lower your left arm"* armRight > 100 *"Lower your right arm"*
	Elbows symmetric (m)	elbowZ = *ElbowRightZ* – *ElbowLeftZ* elbowShoulderLeftZ = *ElbowLeftZ* - *ShoulderLeftZ* elbowShoulderRightZ = *ElbowRightZ* - *ShoulderRightZ* elbowZ > .1 elbowShoulderLeftZ < -.1 *"Move your left elbow backward"* elbowShoulderRightZ > .1 *"Move your right elbow forward"* elbowZ < -.1 elbowShoulderRightZ < -.1 *"Move your right elbow backward"* elbowShoulderLeftZ > .1 *"Move your left elbow forward"*
	Wrists symmetric (m)	wristZ = *WristRightZ* - *WristLeftZ* wristElbowLeftZ = *WristLeftZ* - *ElbowLeftZ* wristElbowRightZ = *WristRightZ* - *ElbowRightZ* wristZ > .1 wristElbowLeftZ < -.1 *"Move your left wrist backward"* wristElbowRightZ > .1 *"Move your right wrist forward"* wristZ < -.1 wristElbowRightZ < -.1 *"Move your right wrist backward"* wristElbowLeftZ > .1 *"Move your left wrist forward"*

APPENDIX B

Eyes-Free Yoga lab study initial interview

1. What is your age?
2. Have you ever performed yoga before? Why or why not?
3. How long have you been performing yoga?
4. What kind of exercises do you perform?
5. Have you or do you plan to attend exercise classes? What classes? How often?
    a. If not, what factors keep you from attending such a class (i.e. making mistakes, commute, or lack of understanding from the instructor)?
    b. If so, did you prepare for the classes in any way? (Learn information about the exercises ahead of time, practice them ahead of time, purposely search for an instructor willing to show you the exercises, meet the instructor ahead of time)?
6. What would you change about current fitness classes that might encourage you to attend?
7. Would you classify yourself as sighted, low vision, or totally blind?
8. How would you rate your balance?

APPENDIX C

Eyes-Free Yoga lab study exit interview

Questions 8-14 pertained to GameFlow (Sweetser and Wyeth 2005)

1. What were your thoughts on playing the game?
2. How did you feel while playing the game?
3. How did the auditory feedback (specific instructions and beeps) affect your playing of the game?
4. How likely are you to play a similar game in the future?
5. How likely would you recommend this game to others?
6. How likely would this game encourage future public exercise class attendance?
7. Do you have any suggestions for how we can make this game better?
8. How did you feel about your ability to complete the tasks?
9. How did you feel when trying to concentrate on the game?
10. How challenging did you find the game?
11. How skilled did you feel while playing the game?
12. How much control did you have while playing?
13. How did the goals of the game affect you?
14. How concerned were you with external factors not relating to the game?

APPENDIX D

Eyes-Free Yoga deployment study initial interview

Demographics

1. What is your age?
2. What is your gender?
3. What is your current occupation?
4. How would you describe your vision (low vision or totally blind)?
5. How long have you been blind/low vision?

Exercise background

1. Regular exercise can be stated as a physical activity being performed 3-5x per week for 20-60 minutes per session. Do you exercise regularly according to this?
    a. Yes, I have been for <u>MORE than 6 months</u>.
    b. Yes, I have been for <u>LESS than 6 months</u>.
    c. No, but I intend to in the <u>next 30 days</u>.
    d. No, but I intend to in the <u>next 6 months</u>.
    e. No, and I do <u>NOT</u> intend to in the <u>next 6 months</u>.
2. If answered a, b in question 6- What kind of exercises do you perform?
3. If answered c, d, e in question 6 - If not, what, if anything, have you done previously for fitness? or want to do for fitness?
4. Do you have any barriers to physical activity? If so, what are they?
5. Have you or do you plan to attend exercise classes? What classes? How often?
    a. If not, what factors keep you from attending such a class (i.e. making mistakes, commute, or lack of understanding from the instructor)?
    b. If so, did you prepare for the classes in any way? (Learn information about the exercises ahead of time, practice them ahead of time, purposely search for an instructor willing to show you the exercises, meet the instructor ahead of time)?
6. What would you change about current fitness classes that might encourage you to attend?
7. Do you have any current fitness or wellness goals? If so, what are they?

Yoga background

1. Have you ever performed yoga before? Why or why not?
2. How long have you been performing yoga?
3. How would you rate your balance?

Exercise Technology background

1. Do you have experience playing exergames (exercise games)?
    a. If yes - What systems have you used (i.e. Wii Fit, Kinect)?
    b. If yes - What games have you played? Describe the exercises used.
    c. If no - Why have you not played exercise games before?
2. Have you used any other tools for fitness? If so, what?

APPENDIX E

Eyes-Free Yoga deployment study interviews

1) End of the 1st *baseline* phase, 2) End of the 1st *experimental* phase, and 3) End of the study

All Three Interviews:

1. What were your thoughts on playing the game?
2. How did you feel while playing the game?
3. How did the auditory feedback (specific instructions and beeps) affect your playing of the game?
4. How likely are you to play a similar game in the future?
5. How likely would you recommend this game to others?
6. How likely would this game encourage future public exercise class attendance?
7. Are you completing other types of exercise? If so, what?
8. Regular exercise can be stated as a physical activity being performed 3-5x per week for 20-60 minutes per session. Do you exercise regularly according to this?
    a. Yes, I have been for MORE than 6 months.
    b. Yes, I have been for LESS than 6 months.
    c. No, but I intend to in the next 30 days.
    d. No, but I intend to in the next 6 months.
    e. No, and I do NOT intend to in the next 6 months.

Additional questions at the end of the 1st experimental phase:

1. How did the musical achievements affect your playing of the game?
2. How did the musical reminders affect your playing of the game?

Additional questions at the end of the study:

1. How did you feel when the musical achievements and reminders were removed from the system?
2. How did you feel when the musical achievements and reminders were added back to the system?

APPENDIX F

Value Sensitive Design Direct Stakeholder Interview

Exercise background

1. Does exercising matter to you? How come?
2. Regular exercise can be stated as a physical activity being performed 3-5x per week for 20-60 minutes per session. Do you exercise regularly according to this definition?
    a. Yes, I have been for MORE than 6 months.
    b. Yes, I have been for LESS than 6 months.
    c. No, but I intend to in the next 30 days.
    d. No, but I intend to in the next 6 months.
    e. No, and I do NOT intend to in the next 6 months.
3. If answered a, b in question 1 - What have you done for fitness?
    a. If ambiguous - ask about where they exercise (at home, in a gym or exercise class, anywhere else outdoors (e.g. sidewalk, running track, field, etc.)) and who they exercise with
    b. or if they don't, ask why not? (e.g. why do you not exercise at the gym)
4. If answered c, d, e in question 1 - If not, what, if anything, have you done previously for fitness? or want to do for fitness? Why?
    a. If ambiguous - ask about where they exercise (at home, in a gym or exercise class, anywhere else outdoors (e.g. sidewalk, running track, field, etc.)) and who they exercise with
    b. or if they don't, ask why not? (e.g. why do you not exercise at the gym)
5. How did you get involved with <each exercise> in general? What do you like about it?
6. Do you have any current fitness or wellness goals? If so, what are they?

Going deeper into particular exercise

1. Give me a story of your typical workout. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
2. What do you like about this exercise? dislike?
3. What benefits do you gain from this type of exercise?
4. What challenges or barriers do you encounter with this type of exercise? How do you overcome them?
5. Do you have any stories of when you improved your fitness?
6. Do you have any stories of when you had an injury or were discouraged from exercising in any way?
7. Describe an ideal exercise experience. What would it be like?

Exercise Technology background

1. Do you use any adaptive technology to enable exercise? What have you used? *Examples: guides to help you stay on track (person or rope, etc...), braille labels, adaptive skis*

   a. If not, why not?

2. Do you use any mainstream technology to enable exercise? What have you used? *Examples: Wii Fit, Kinect, fitness apps on phone, Fitbit, heart rate monitor, other wearables*
   a. If not, why not?
3. Do you have any concerns while using these technologies? If so what?
4. Do these concerns change based on context of where you are exercising (i.e. home, gym, out and about)? If so, how?

Scenarios

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.

Idea 1: Some people say it's great that the person is able to exercise on a track independently.

Idea 2: Some people say it might be a problem because the person may risk injuring themselves because they do not have a sighted guide or the technology may fail.

1. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Kelly decides to use a single person aerobic exercise game in front of a 3D camera sensor. The system is able to tell her how fast she performs jumping jacks and other exercises.

Idea 1: Some people say it's OK because the person is able to exercise in private from the convenience of their own home.

Idea 2: Some people may find it less enjoyable because they are not exercising or competing with friends or partners.

2. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Joe takes a mainstream yoga class. He uses a smart mat (which looks like a regular yoga mat) which 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.

3. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Value Scenarios

1. Please tell me about a time when you were exercising and did not feel independent. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
2. Could you imagine a situation in which using technology (low tech or high tech) may help you feel more independent while exercising?
3. Please tell me about a time when where you were exercising and felt like you stuck out in the crowd. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
4. Could you imagine a situation in which using technology may help you feel less like you stuck out in the crowd while exercising?
5. Please tell me about a time when you were exercising and felt unsafe. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
6. Could you imagine a situation in which using technology may help you feel safer while exercising?
7. Please tell me about a time when you were exercising and felt distracted. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
8. Could you imagine a situation in which using technology may help you feel mindful while exercising?
9. Please tell me about a time when you were exercising and did not feel confident. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
10. Could you imagine a situation in which using technology may help you feel more confident while exercising?

Demographics

1. What is your age?
2. What is your gender?
3. What is your current occupation?
4. How would you describe your vision (low vision or totally blind)?
5. How long have you been blind/low vision?
6. What is your general location?

APPENDIX G

Value Sensitive Design Indirect Stakeholder Interview

Demographics:

1. What is your current role in facilitating fitness for people who are blind or low vision? How long have you had this role?
2. Why are you a <role>?
3. Do you work exclusively with blind or low vision adults or do you work with sighted individuals as well?
4. How did you decide to begin this path?
5. How did you prepare for this path?

Exercise:

1. What do you value about exercise?
2. What types of exercises do you currently facilitate?
3. Do you work with a team, repeated sessions, or sessions where anyone is free to attend?

If an instructor or teacher:

1. Do you modify your teaching/companionship to work specifically with people who are blind/low vision?
   a. If so, how?
   b. How do you prepare?
2. Please tell me about a time when you worked with someone who was blind or low vision and used a strategy that worked well. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
3. Please tell me about a time when you worked with someone who was blind or low vision and used a strategy that was confusing or difficult. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
4. Does the pace or structure of your class change when working with people who are blind versus those who are sighted? If so, give us a story of what happened. If not, why not?
5. How do sighted participants react to blind participants?
6. What benefits do you hope participants will receive?
   a. sighted vs low vision/blind
7. What challenges or barriers might your participants find (what they find difficult about starting or doing)?
   a. sighted vs low vision/blind
   b. How do they overcome them?
8. Are there specific strategies you've learned to help sighted or low vision participants overcome the barriers (i.e. not being able to show a yoga pose, but explaining it instead)?
9. Please tell me about a time when you worked with someone who was blind or low vision and they (or someone) had a lot of improvement? The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.

10. Please tell me about a time when you worked with someone who was blind or low vision and they (or someone) had an injury or was discouraged in any way? The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.

If a companion:

1. Do you exercise differently with someone who is blind or low vision vs. with a sighted companion or by yourself?
    a. If so, how?
    b. If not, how come?
2. How do you prepare?
3. Please tell me about a time when you worked with someone who was blind or low vision and used a strategy that worked well. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
4. Please tell me about a time when you worked with someone who was blind or low vision and used a strategy that was confusing or difficult. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
5. What are your thoughts on safety of your blind companion? Do you think there are greater risks for them? If so, why?
6. Does the pace/structure your exercise change when working with your blind companion? If so, give us a story of what happened. If not, why not?
7. What challenges or barriers might your companion find (what they find difficult about starting or doing)?
    a. How do they overcome them?
8. Are there specific strategies you've learned to help your companion overcome the barriers (i.e. not being able to show a yoga pose, but explaining it instead)?
9. Does your companion prepare for the activity in any way?
10. Please tell me about a time when you worked with someone who was blind or low vision and they (or someone) had a lot of improvement? The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
11. Please tell me about a time when you worked with someone who was blind or low vision and they (or someone) had an injury or was discouraged in any way? The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.

Technology

1. Has adaptive technology played a role to enable exercise? What have you used? *Examples: guides to help you stay on track (person or rope, etc...), braille labels, adaptive skis*
    a. If not, why not?
2. Has mainstream technology played a role to enable exercise? What have you used? *Examples: Wii Fit, Kinect, fitness apps on phone, Fitbit, heart rate monitor, other wearables*
    a. If not, why not?
3. What benefits may occur when someone who is blind using these technologies or other aspects with exercise?
4. What challenges may occur when someone who is blind using these technologies or other aspects with exercise?

5. Do these considerations change when home alone, at the gym, out and about?

Scenarios

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.

Idea 1: Some people say it's great that the person is able to exercise on a track independently.

Idea 2: Some people say it might be a problem because the person may risk injuring themselves because they do not have a sighted guide or the technology may fail.

1. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Kelly decides to use a single person aerobic exercise game in front of a 3D camera sensor. The system is able to tell her how fast she performs jumping jacks and other exercises.

Idea 1: Some people say it's OK because the person is able to exercise in private from the convenience of their own home.

Idea 2: Some people may find it less enjoyable because they are not exercising or competing with friends or partners.

2. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Joe takes a mainstream yoga class. He uses a smart mat (which looks like a regular yoga mat) which 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.

3. Do you tend to agree with Idea 1 or Idea 2? Why? What would YOU do?

Value Scenarios

1. Please tell me about a time when you worked with someone who was blind or low vision and it felt unsafe. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.

2. Could you imagine a situation in which using technology may make the situation safer?
3. Please tell me about a time when you worked with someone who was blind or low vision and it felt constrained. (limited in what you can do) The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
4. Could you imagine a situation in which using technology may make the situation better?
5. Please tell me about a time when you worked with someone who was blind or low vision and felt that you were distracted. The story can be long or short, about something big or small. Just try to be as detailed as you can about what happened.
6. Could you imagine a situation in which using technology may make the situation better?

Demographics: Age, Gender, and general location

APPENDIX H

Value Sensitive Design Indirect Stakeholder Survey

You will read three exercise scenarios. These are hypothetical scenarios, so we ask that you imagine yourself in the situation. Please read each scenario and answer the questions below.

For reference, here are example "benefits and risks" that pertain to a scenario.
Benefits may include speed, connectedness, etc.
Risks may include privacy, distraction, etc.

Scenario 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.

1. Please check off the feelings that apply most to you (can be more than one answer):
   - I am neutral
   - I would feel uneasy about the camera they are wearing and what is recording
   - I am unsure how much space to give them
   - I am stressed out
   - I am excited for them to participate
   - I am unsure of when or if I should try to help them
   - Other:

2. What was the basis for your choices in the previous question?

3. What potential benefits and risks does this scenario expose?
   Feel free to write benefits or risks about the technology, the scenario itself, or both.

Scenario 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.

1. Please check off the feelings that apply most to you (can be more than one answer):
   - I am neutral
   - I am stressed out
   - I am unsure of when or if I should try to help them
   - I am unsure how much space to give them
   - I am excited for them to participate
   - Other:

2. What was the basis for your choices in the previous question?

3. What potential benefits and risks does this scenario expose?
   Feel free to write benefits or risks about the technology, the scenario itself, or both.

Scenario 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.*

1. Please check off the feelings that apply most to you (can be more than one answer):
   - I am unsure how much space to give them
   - I would feel uneasy about the camera and what is recording
   - I am stressed out
   - I am neutral
   - I am excited for them to participate
   - I am unsure of when or if I should try to help them
   - Other:

2. What was the basis for your choices in the previous question?

3. What potential benefits and risks does this scenario expose?
   Feel free to write benefits or risks about the technology, the scenario itself, or both.

APPENDIX I

Eyes-Free Art lab study interviews

1) Initial Interview, 2) Baseline Interview, and 3) Experimental Interview

Initial Interview

1. Level of vision? For how long?
2. How often do you visit art museums?
3. Do you identify as an artist?
    a. Is it a hobby, part of your training, part of your occupation?
4. Age?
5. Gender?

Baseline Interview

Answer from Strongly Disagree to Strongly Agree:
1. "After using the system, I had a good sense of what the painting looked like."
2. "After using the system, I had a good sense of the general aesthetics/emotional content of the painting."
3. "After using the system, I had a good sense of what the painting looked like."
4. "After using the system, I had a good sense of the general aesthetics/emotional content of the painting."
5. "I found the system fatiguing to interact with."
6. "After listening to the verbal description, I had a better understanding of the contents of the painting."
7. "Including the zone name of verbal description in this type of display is useful."

8. What were the benefits of the overall system?
9. What would you improve about this system?
10. Would you want to have a system like this installed in art museums? Why or why not?
11. Would you recommend it to others?

Experimental Interview

Answer from Strongly Disagree to Strongly Agree:
1. "After using the system, I had a good sense of what the painting looked like."
2. "After using the system, I had a good sense of the general aesthetics/emotional content of the painting."
3. "After using the system, I had a good sense of what the painting looked like."
4. "After using the system, I had a good sense of the general aesthetics/emotional content of the painting."
5. "I was able to easily navigate between the four zones."
6. "I found the system fatiguing to interact with."
7. "The order of the four audio zones made sense to me."
8. "After listening to music in the 'music' zone, I was able to assess the mood of the painting(s)."

9. “After listening to music in the ‘music’ zone, I was able to assess the genre of the painting(s).”
10. “After listening to music in the ‘music’ zone, I was able to assess the time period of the painting(s).”
11. “I was able to hear instruments playing at different volumes in the ‘sonification’ zone.”
12. “I was able to distinguish the instruments playing red (orchestra) in the ‘sonification’ zone.”
13. “I was able to distinguish the instrument playing green (piano) in the ‘sonification’ zone.”
14. “I was able to distinguish the instrument playing blue (harp) in the ‘sonification’ zone.”
15. “I was able to distinguish white (quieter), gray (medium), and black (louder) in the ‘sonification’ zone.”
16. “I was able to get a sense of the lightness or darkness of the painting(s) when in the ‘sonification’ zone.”
17. “I was able to get a sense of the quantity and variety of colors the painting(s) contained when in the ‘sonification’ zone.”
18. “I was able to identify specific colors in the painting(s) when in the ‘sonification’ zone.”
19. “I was able to locate objects of interest when in the ‘sound effects’ zone.”
20. “After listening to the verbal description, I had a better understanding of the contents of the painting.”
21. “Including the zone names of music, sound effects, sonification, and verbal description in this type of display is useful.”

22. What are the benefits of the background music?
23. What would you improve about the background music?
24. What are the benefits of the sonification?
25. What would you improve about the sonification?
26. What are the benefits of the edge sound (instrument playing as your hand crossed an edge in the painting(s))?
27. What would you improve about the edge sound?
28. What are the benefits of the sound effects?
29. What would you improve about the sound effects?
30. What are the benefits of the verbal description?
31. What would you improve about the verbal description?

32. Did the order of audio make sense as you walked closer to the painting(s)?
33. Would you remove or reorder any of the options?
34. If you were to order the four zones, what would you prefer, starting from furthest away from the painting(s) to closest?
35. What were the benefits of the overall system?
36. What would you change about the overall system?
37. Would you want to have a system like this installed in art museums? Why or why not?
38. Would you recommend it to others?

VITA

Kyle Rector is from the Department of Computer Science and Engineering at the University of Washington, co-advised by Julie Kientz and Richard Ladner. She has research interests in Human-Computer Interaction and Accessibility. More specifically, she is interested in developing Eyes-Free Technologies that enhance quality of life, including exercise and art technologies for people who are blind or low vision. She is a Google PhD Fellow (2015), an NSF Graduate Research Fellow (2012-2015), a Google Anita Borg Scholar (2010), and a Palantir Scholarship for Women in Technology Semi-Finalist (2013). Her research has been recently covered by MIT Technology Review, Microsoft, Gizmag, GeekWire, and c|net. Kyle received her MS from the University of Washington (2012) and her BS from Electrical & Computer Engineering and Computer Science from Oregon State University (2010).