Computing Technologies to Increase Access to Physical Activity for People with Visual Impairments

Understanding how to develop technologies that make exercise more accessible to people with visual impairments, particularly in the form of body-based movement and public spaces.

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People who are visually impaired are 1.5 times more likely to be obese than people who are sighted [1]. One way to prevent or address obesity is physical activity. My research has focused on designing, developing, and evaluating novel technologies to increase access to physical activity. While conducting research, I follow a user-centered design process, where I collaborate with different stakeholders throughout the process. Usually, I work with people with visual impairments as well as domain experts in physical activity. In this article, I detail two of my research avenues: eyes-free exergames (or exercise games), and my ongoing efforts in making 400-meter jogging tracks accessible. I close by describing related work carried out at the intersection of building accessible technology and improving access to physical activity for people with disabilities.

EYES-FREE YOGA

When people with visual impairments attend yoga classes, it is possible they cannot see their peers or the instructor. Exercise class instructors give a lot of visual instructions, or verbal instructions that assume vision (e.g., "move here"), so people with visual impairments may not be able to follow along. To provide extra insights into yoga postures, we designed and developed an exergame called "Eyes-Free Yoga," which delivers detailed verbal instructions and provides custom verbal feedback when a person holds standing yoga postures.

Design phase. To develop a system that pertains to yoga, I attended several introductory yoga classes to get familiar with the instructions given by the instructors. After the class, we brainstormed which yoga postures were best for beginners. I also worked with a yoga instructor in training, who provided me with important cues (or rules) for holding yoga postures. Final-

ly, we worked with a yoga instructor who had experience with people with visual impairments to compose the yoga instructions and verbal feedback. One of our visually challenged team members with prior research experience was able to provide early insights into the accessibility of the instructions and feedback in addition to conducting the research.

Develop phase. We developed our software using the Microsoft Kinect for Windows Version 1 and C#. We used Microsoft's Kinect Skeletal Tracking to determine the 3-D location of each joint. When a person held a yoga posture, we used the rules generated from the design phase to determine if they could adjust their posture. We checked these rules from the most to the least central part of the body: 1) core, 2) hips and legs, and 3) shoulders and arms (see Figure 1).

Evaluation phase. First, we conducted a lab study [2] with 16 people having visual impairments to determine the effectiveness and acceptability of custom verbal feedback for standing yoga postures. We had participants hold six standing yoga postures and listen to custom verbal feedback for half of the postures. To mitigate ordering effects due to learning and fatigue, we counterbalanced whether participants heard feedback first or second. We had four new yoga instructors rate the anonymized photos of yoga postures in terms of quality, not knowing about the study conditions. While we did not find a significant difference in quality based on whether they heard the feedback, one potential reason could be not all participants were able to follow the verbal feedback posed to them. However, 13 of the 16 participants preferred the custom verbal feedback (significantly higher than chance) because they better understood how they were doing.

Second, in collaboration with the yoga instructor who had experience teaching yoga to people who are visually impaired, we transformed the "Eyes-Free Yoga" prototype to a fully functioning game. We integrated the six standing yoga postures into four different workouts. While we provided other postures, we were not able to develop custom verbal feedback due to the limitations of the Microsoft Kinect. We

Image by Red Shine Studio

conducted an eight-week deployment study with four participants [3]. We found consistent usage over the duration of the study, with one reason that it was a safe place to learn yoga.

VIRTUAL SHOWDOWN

While virtual reality is increasing in popularity, the majority of the experiences involve visuals, requiring that users are sighted. To address this problem, we developed an accessible virtual reality game, called "Virtual Showdown" [4]. This is based on a lesser-known real-world game, "Showdown," which is similar to air hockey, except people wear blinders and use a flat wooden bat to hit a rolling ball. Players use their hearing to find the ball, which makes a sound like a maraca.

Design phase. In June 2017, I attended a sports and recreation camp for youth who are visually impaired. While attending, I noted the popularity of "Showdown" amongst the campers; there were tournament brackets and conversations throughout my stay. "Showdown" is not a mainstream game, so I wanted to determine how to make this game available outside of the camp. We realized "Showdown" would make a good virtual reality game because people use the position of their body (most notably, their head) to determine the location of the ball in 3-D space. However, there are only a few efforts in making virtual reality accessible to people with visual impairments, so we realized that this would mark the beginning of several research projects.

We watched videos of "Showdown" and read materials on the rules. We also did informal playtesting with peers and people with visual impairments to iteratively improve the game. We realized even though we designed the game with 3-D sound as per Unity and Microsoft recommendations, most people were not able to find and hit the ball. As a result, we developed virtual-reality scaffolds (or hints) to help players unfamiliar with 3-D sounds, virtual reality, or "Showdown." We designed scaffolds that provide spatial verbal hints or a combination of spatial verbal hints and vibrations to help people learn how to find and hit the ball.

Our game had seven levels, where levels 1–3 had scaffolds that slowly "degraded" (see Figure 2), and levels 4–7 increased the speed of the ball. For example, in level 1, you would hear a verbal preview of the ball with 3-D sound (e.g., "[quiet left ear] The ball is coming from the left, [medium both ears] and is going to, [loud right ear] the right."). In level 2, you would hear an abbreviated sentence with spatial sound (e.g., "[quiet left ear] Left [medium both ears] to [loud right ear] right."). Level 3 uses the same phrase as level 2, but without spatial sound (e.g., "Left to right."). Levels 4-plus had no hints. Levels 1–3 also had the following parameters:

1. Midpoint hints; as the ball crossed the halfway point of the table, the game would inform you if you needed to move your hand further to the right or left.

2. Constructive verbal feedback; if you missed the ball, the game would inform you how much you had to move your hand to hit the ball.

The vibration hints, delivered through Nintendo Switch Joy-cons, work like a metal detector. As your hand moves closer to the best destination to hit the ball, the vibration would increase in frequency.

Develop phase. We developed "Virtual Showdown" using the C# programming language in Unity, a game development software. We used the Kinect for Windows Version 2 to track the player's body. We fed the audio output into

While conducting research, I follow a user-centered design process.

Figure 1. In this picture, a person is holding Warrior II pose, but does not have their arms pointing straight out to the side. Eyes-Free Yoga determines the angle of the arms from the torso is 45 degrees, when it should be closer to 90 degrees. Eyes-Free Yoga responds with a verbal correction.

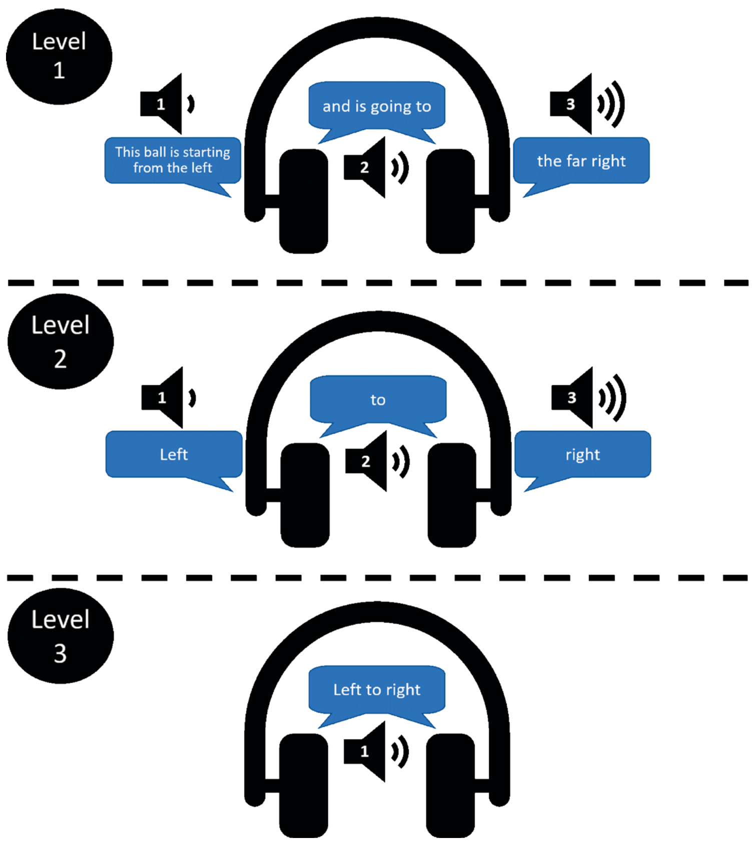
over-the-ear headphones for the best sound experience. To convey the location of the ball, we used a "swooping" sound that changed in pitch to make the ball easier to find. When the ball was on the opponent's side of the table, we included reflections and reverberations so the ball sounded further away. To help players determine whether the ball was on their right or left side or in the center, we exaggerated the lateral sound by treating the person as if their head was 25 cm (or approximately 10 inches) above the table.

Evaluation phase. We conducted a user study with 34 youth with visual impairments. The study was within subjects; each participant played "Virtual Showdown" with a) verbal scaffolds and b) verbal and vibration scaffolds. We found those who had played "Virtual Showdown" earned higher scores with only verbal scaffolds, but for those with no experience there was no difference in score. There was also no difference in preference between the two scaffolds, regardless of whether one had experience with "Showdown." Finally, 33 of the 34 participants wanted to play "Virtual Showdown" again or with friends. The opportunities for future work include determining how to teach users to use their body as an input for gameplay and how to use this type of game to encourage physical activity.

ACCESSIBLE JOGGING TRACKS

To make exercise more accessible to people with visual impairments, it is important to make existing exercise venues accessible, such as gyms and exercise classes. As a first step, we are designing and developing a mobile application that delivers verbal navigation feedback on outdoor 400-meter jogging tracks. We first detail a Wizard-of-Oz study to inform the design of our feedback and then discuss our current progress on our application.

Figure 2. A diagram showing how verbal previews change from Levels 1-3. First, the preview is spatial and in a complete sentence. Second, the preview is spatial but brief. Finally, the preview is not spatial and brief. Levels 4-7 do not have hints, but we increase the speed of the ball.



Design phase. For the navigation smartphone application to be effective, the feedback the person receives must be perceptible and understandable. We explored diverse types of feedback in a Wizard-of-Oz study [5], where a researcher acts as the "system" and the participant experiences the feedback as if the system is fully functioning. We explored verbal feedback (e.g., "correct right"), "head beat" feedback (heartbeats played into bone-conduction headphones), and wrist vibrations (pulses on smartwatches on both wrists).

In the eventual system, participants will wear a smartphone on their torso so the camera points toward the track. We chose this location of the body because it has the least rotation while walking or jogging. In our Wizard-of-Oz study, the "Wizard" controlled the feedback given from the participant's phone. Because the participant was walking, the Wizard had to control the phone's output remotely. We visited diverse 400-meter jogging tracks and could not rely on a Wi-Fi connection. As a result, we used Wi-Fi peer-to-peer to communicate between the Wizard's phone and the researcher-supplied participant phone. We sent auditory feedback to the bone-conduction headphones and vibration feedback to the smartwatches via Bluetooth.

For our study, we recruited 14 participants (9 blind and 5 low vision) who walked around the track with the three technology conditions, as well as with a human guide as a baseline. Participants walked in 100-meter segments on the straightaways for the first half of the study and curves for the second half of the study. They completed two segments for each condition (human guide, verbal, head beat, and wrist vibration). We ordered the conditions according to a 4x4 Latin Square to reduce the risk of fatigue or learning effects affecting the results. In addition to measuring their performance, we conducted semi-structured interviews after each condition to assess the participants' experiences.

We found the technology conditions had no effect on a person's performance in terms of time elapsed or time spent walking in their lane (e.g., not veer-

Figure 3. An example photo pointing toward a track straightaway from our Wizard-of-Oz study. We are using these photos to create our Custom Vision classifier.

ing). Upon interviewing participants, we found limitations with some of the feedback mechanisms. For instance, head-beat feedback was difficult to hear while on the 400-meter jogging track, especially with nearby traffic and wind. Wrist vibrations were also difficult to perceive; some cane users were unsure if their wrist was vibrating due to their cane on the bumpy track surface or because the watch was vibrating. A strength of the verbal feedback was that it was direct and familiar. Participants did not report difficulty hearing the verbal feedback. As a result, we decided to move forward with our application delivering verbal feedback.

Ongoing development phase. We are developing a smartphone application that supplies verbal navigational feedback. We are using Microsoft Azure Service's Custom Vision Service to train a custom computer vision classifier with labeled images. So far, we have labeled images of the track straightaways that we collected during the Wizard-of-Oz study (see Figure 3). Initially, two researchers independently labeled 200 photos and achieved a Cohen's Kappa of 89 percent. We have trained two classifiers, one to determine if the person is on the straightaway or curve and one to determine if a person is in their lane or veering on the straightaways. Using five-fold cross-validation, our precision and recall is 96.6 percent for the straight versus curve classifier, and precision and recall of 97.4 percent for the straightaway classifier. Thus far, we have implemented an Android application that processes one to three images per second. We plan to label images for track curves, create the classifier, and conduct live testing at both indoor and outdoor jogging tracks. We also plan to conduct user studies with the application this summer.

RELATED INSPIRING PHYSICAL ACTIVITY RESEARCH FOR PEOPLE WITH DISABILITIES

As we know, every researcher's work is built upon someone else's work, trying to address the gaps or improving the former's. Similarly, my research was inspired by several works of Morelli et al., who developed several accessible games for children and youth who are blind.[1] For example, they developed "VI-Tennis," which is an accessible version of "Wii Tennis." They provided audio and tactile cues to convey while serving, when the ball must be returned and when the ball is bouncing. They provided secondary audio cues including cheering and scoring. This research detailed how they converted the primary visual cues needed to play into other cues that are accessible, which helped me frame my own research moving forward.

Hernandez et al. had a design team with different stakeholders including children with cerebral palsy, a physiotherapist, and a mechanical engineer. They developed an action-based exercise bike game for children with cerebral palsy.[2] There are also research efforts to develop technologies that enhance wheelchair activity tracking and wheelchair exercise games. For instance, Carrington et al. collaborated with wheelchair athletes and physical and occupational therapists to explore fitness activity tracking and sharing.[3] Gerling et al. collaborated with various stakeholders, including young wheelchair users and game design-experts, to create wheelchair-controlled, motion-based video games.[4]

1 http://people.cst.cmich.edu/morel1a/index.html
2 http://equis.cs.queensu.ca/projects/cp/
3 http://www.patrickcarrington.com/
4 https://iiw.kuleuven.be/onderzoek/emedia/people/gerlingkathrin

There are opportunities for people in computing to innovate in the space of accessible exercise. Through careful design and collaboration with direct stakeholders (target users) and indirect stakeholders (domain experts in fitness and/or people with disabilities), we can conduct research, develop systems, and provide technical design guidelines that will increase access to physical activity for people with disabilities.

SUMMARY

When designing for and with people with visual impairments, engage in a user-centered design process, which includes engaging with multiple stakeholders such as 1) direct users of the technology, 2) indirect stakeholders who may interact with the direct user as well as the technology, and 3) if possible, third-party stakeholders present around the user of the technology

If developing a specialized technology (e.g., physical exercise, education), it is important to collaborate with domain experts to ensure the technology is appropriate.

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Biography

Kyle Rector is an assistant professor at the University of Iowa in the Department of Computer Science. Her research expertise is 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 have low vision.