Eyes-Free Yoga: An Exergame Using Depth Cameras for Blind & Low Vision Exercise

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ABSTRACT
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, we developed Eyes-Free Yoga, an exergame using the Microsoft Kinect that acts as a yoga instructor, teaches six yoga poses, and has customized auditory-only feedback based on skeletal tracking. We ran a controlled study with 16 people who are blind or low vision to evaluate the feasibility and feedback of Eyes-Free Yoga. We found participants enjoyed the game, and the extra auditory feedback helped their understanding of each pose. The findings of this work have implications for improving auditory-only feedback and on the design of exergames using depth cameras.

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

General Terms
Design, Human Factors

Keywords
Accessibility; video games; exergames; visual impairments; Kinect; eyes-free; audio feedback; yoga; health.

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 [1][21] 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 [1]. As a child's visual impairment increases, their view that physical activity is important decreases and their parents' expectations decrease, because they had lower expectations to succeed [19]. As a result, the amount of physical activity decreases [14]. 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 [13].

One recent trend to increase exercise activity is the use of *exergames*, which are video games used for exercise. Exergames can provide fitness activities and act as a gateway to more advanced exercises [17]. However, many people cannot play these games due to having a disability [21]. 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 [10]. There is existing work in the space of exergames for people who are blind or low vision [10][11], 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.

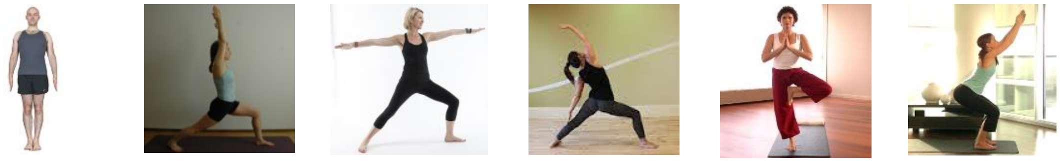
In response to this need, we developed Eyes-Free Yoga, a game that provides solely auditory output using Microsoft Kinect for Windows. Yoga was chosen for its physical [15] and mental health benefits [7]. Our exergame provides instructions for yoga poses and custom feedback to help players improve their poses. To create a yogic game that provides a similar experience to studio yoga and includes proper techniques, we included yoga instructors throughout the game 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 for people who are blind or low vision. The game 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 game developers of exergames that use skeletal tracking.

2. BACKGROUND AND RELATED WORK
Here we discuss background and related work regarding current eyes-free yoga opportunities and exergame design for people both with and without disabilities.

2.1 Eyes-Free Yoga Opportunities
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[1] [6]. Another home solution, So Sound Yoga Board, communicates through body sensations when the person is

[1] http://www.yogacenterofmarin.com/propshop.htm



Mountain Pose Warrior I Warrior II Reverse Warrior Tree Pose Chair Pose

Figure 1. The six poses used for evaluation, listed in the order in which they were performed.

out of alignment and indicates which parts of the body are under stress, but is expensive[2]. A less expensive solution, Visually Impaired Yoga Mat[3], provides tactile cues for foot and hand placement. Some yoga instructors have spent a long period of time working with the visually impaired to gain a better understanding, such as being aware of the words used to instruct the class [9]. One yoga instructor had sighted people use blindfolds to gain empathy [8]. Another group of instructors held poses and let the students feel them to gain a better understanding. 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.

2.2 Exergames

Exergame design addresses two important goals: attractiveness and effectiveness [18]. The game should be enjoyable and have a sense of "GameFlow" while still achieving the desired exercise. There are important factors addressed in GameFlow that we have included in the design of Eyes-Free Yoga as well as evaluated for in our study using interviews: ability, concentration, challenge, skills, control, goals, and external factors [20]. Exergame effectiveness can be measured in energy expended or accuracy of the exercise. Because yoga is an anaerobic exercise and calorie expenditure is not a goal, we decided to involve yoga instructors in rating the quality of the yoga poses rather than energy expended. We followed the same considerations that are important for therapeutic exergaming [2] by including feedback to assist in player competence and enjoyment, but avoided visual feedback. The game is accessible along with the added benefit of not overwhelming a player while practicing yoga.

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[4], 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. 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 (i.e., "watch her feet") while others are accessible (i.e., "keep the lunge low"). Chopra's Leela[5] is a yoga exergame that primarily uses visual feedback to enhance the experience. 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.

Two strong efforts from the research community are the creation of accessible alternatives to Wii Sports games, VI-Bowling [11] and VI-Tennis [10]. Morelli et al. 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. 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. Morelli et al. developed a solution using sensory substitution to make Kinect games accessible to for eyes-free interactions [12]. Instead of adapting a current exergame, we developed our own by involving yoga instructors. We chose yoga because the slower pace would not compromise verbal and auditory feedback.

3. EYES-FREE YOGA DESIGN

We discuss in detail the six design principles used to inform our design. These were identified from the goal of Eyes-Free Yoga: allow people who are visually impaired 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 exergame.

3.1 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 determined and followed six principles in designing Eyes-Free Yoga: accessible, yogic, encourages confidence, targeted to novices, accessibility features do not compromise learning, and encourages a challenging workout.

3.1.1 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 [16]. 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 [6]. 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.

3.1.2 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

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2 http://www.sosoundsolutions.com/yoga-board/

3 http://rousettus.com/products/yoga-equipment/visually-impaired-yoga-mat-viym/

4 http://yourshapegame.ubi.com/fitness-evolved-2012/

5 http://www.deepakchopraleela.com/

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 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 (hotyogaforlife.com). 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 to the game play, 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 in a plus-shape to give participants bearings of the game space.

3.1.3 Game Instills Confidence

We wanted to encourage confidence, future game play, 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.

3.1.4 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.

3.1.5 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.

3.1.6 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 [20].

3.2 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. For example, the game can calculate that the "armpit" angle is currently 45° and the proper angle should be at least 80° (see Figure 2). The game responds with the appropriate verbal correction. To reduce errors with occlusion and rotation of the body [3], 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.

Each violated rule provides the appropriate verbal correction to fix the issue. The rules have from 1 to 4 choices of verbal cor-

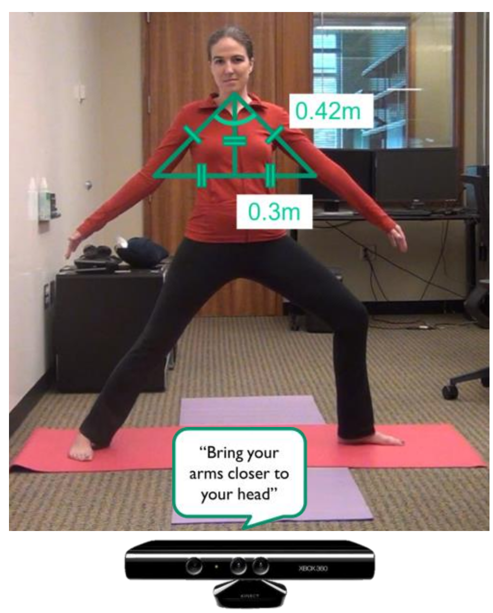

Figure 2. In Warrior II, her arms are at 45° and need to be raised to ≥ 80°. The Kinect responds with a verbal correction.

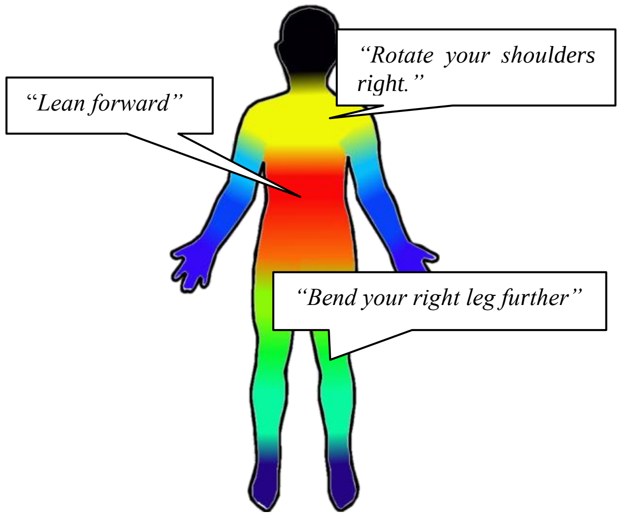

Figure 3. Priority of adjustments shown on the human body. The highest priority is the core, which is red (hot), and lowest priority are the feet, which are purple (cold). The head orientation is not measured.

rections 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 3. The appendix 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.

3.2.1 Discussion
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°. 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 [4], which we will use for a new version of Eyes-Free Yoga.

4. EVALUATION
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 1 for both groups with 3 poses per condition.

4.1 Study Methodology and Data Analysis
We interviewed participants to assess their experience practicing yoga and current exercise habits. 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 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 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 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.

4.2 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.

5. 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.

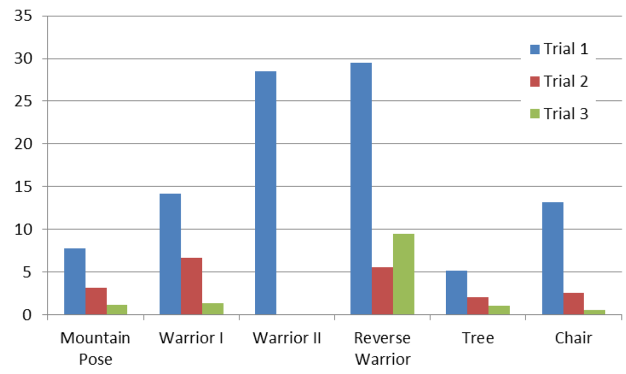

Figure 4. Average suggestions given for each pose and trial. (First 3 poses reflect Group B, while second 3 reflect Group A)

5.1 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.

5.1.1 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). 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 feel that this is a limitation of our system and that the knee rules could be relaxed 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). 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.

5.1.2 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.

The participants were not always able to address all of the provided verbal corrections because of differences in flexibility and strength. The system would relax the rules, and sometimes the participants would request to stop early. 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. 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. 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 5 *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 ($Z=12605.5$, $p = 0.29$). A longer-term study where participants have time to build strength might allow for a better evaluation of the corrections.

5.2 Qualitative Results

At the end of the study, we interviewed the participants. We asked about their experience while playing 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 ($\chi2\ (1,N=16) = 6.25$, $p = .01$). 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 the game. 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

Table 1. Number of participants who gave positive answers based on GameFlow [20].

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

shows that exergames can be a gateway to exercising more in the future [17], 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 [20] to see if participants enjoyed the game (see Table 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.

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.

6. DISCUSSION & 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 game 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 the game, 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 game had to compensate with reminders throughout the game 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.

The design of Eyes-Free Yoga and its study revealed interesting areas for future work. While running our user studies, we determined that some instructions were more understandable than others. 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."* It is beneficial to include descriptions that are tactile, use metaphors, and resonate with the player. This can be challenging, however, because everyone's background is different. 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 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?*
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. We will release the program online to be downloaded by anyone with a computer and a Kinect. The person could play anywhere with a 6'x10' space. After initially guiding a person (programmatically or with assistance) to the start point, the game play does not need a sighted guide.

7. CONCLUSION

We have developed an accessible yoga exergame, Eyes-Free Yoga, where the players interact with a "yoga instructor" and receive audio-based instructions for six standing yoga poses. This new accessible exergame can enable people who are blind or low vision to access yoga while at home, which could improve both their physical and mental health. We have shown 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. We hope to provide general insights for exergames that use skeletal tracking.

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10. APPENDIX

In this appendix, we provide the pseudocode to demonstrate how the Kinect keeps track of 11 rules for Warrior II, shown in Table 2. The rule is either evaluated in meters (m) or degrees (°). The corresponding pseudocode and verbal corrections are written for each rule. If the pseudocode is true, the corresponding verbal correction is spoken. In the table, the italicized variables are from the Kinect Skeletal Tracking.

Table 2: Pseudocode for 11 rules associated with Warrior II. The colors on the left correspond to the priorities shown in Figure 3.

Rule	Pseudocode	Verbal Corrections
Back straight (m)	backX = Abs(*ShoulderCenterX* − *HipCenterX*) backX > .0762 backX < -.0762 backZ = Abs(*ShoulderCenterZ* − *HipCenterZ*) backZ > .0762 backZ < -.0762	"Lean sideways toward your left" "Lean sideways toward your right" "Lean forward" "Lean backward"
Hips forward (m)	hipZ = *HipRightZ* − *HipLeftZ* hipZ > .1 hipZ < -.1	"Rotate your hips left" "Rotate your hips right"
Hips level (m)	hipY = *HipRightY* − *HipLeftY* hipY > .05 hipY < -.05	"Move your right hip downward so it is level with your left hip" "Move your left hip downward so it is level with your right hip"
Shoulders forward (m)	shoulderZ = *ShoulderRightZ* − *ShoulderLeftZ* shoulderZ > .1 shoulderZ < -.1	"Rotate your shoulders left" "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 quadRight = distance(*HipRight*, *KneeRight*) calveRight = distance(*KneeRight*, *AnkleRight*) ankleHipRt = distance(*AnkleRight*, *HipRight*) kneeRight = calcAngle(ankleHipRt, quadRight, calveRight) kneeRight < 155	"Bend your left leg further" "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 elbowLeft < 150 elbowRight < 150	"Straighten your arms" "Straighten your left arm" "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, shouldEl-bowL) spineElbowRight = distance(*Spine*, *ElbowRight*) shouldElbowR = distance(shouldCenter, *ElbowRight*) armRight = calcAngle(spineElbowR, upSpine, shouldEl-bowR) armLeft < 80 && armRight < 80 armLeft < 80 armRight < 80 armLeft > 100 && armRight > 100 armLeft > 100 armRight > 100	"Bring your arms closer to your head" "Bring your left arm closer to your head" "Bring your right arm closer to your head" "Lower your arms" "Lower your left arm" "Lower your right arm"
Elbows symmetric (m)	elbowZ = *ElbowRightZ* − *ElbowLeftZ* elbowShoulderLeftZ = *ElbowLeftZ* − *ShoulderLeftZ* elbowShoulderRightZ = *ElbowRightZ* − *ShoulderRightZ* elbowZ > .1 elbowShoulderLeftZ < -.1 elbowShoulderRightZ > .1 elbowZ < -.1 elbowShoulderRightZ < -.1 elbowShoulderLeftZ > .1	"Move your left elbow backward" "Move your right elbow forward" "Move your right elbow backward" "Move your left elbow forward"
Wrists symmetric (m)	wristZ = *WristRightZ* − *WristLeftZ* wristElbowLeftZ = *WristLeftZ* − *ElbowLeftZ* wristElbowRightZ = *WristRightZ* − *ElbowRightZ* wristZ > .1 wristElbowLeftZ < -.1 wristElbowRightZ > .1 wristZ < -.1 wristElbowRightZ < -.1 wristElbowLeftZ > .1	"Move your left wrist backward" "Move your right wrist forward" "Move your right wrist backward" "Move your left wrist forward"