Design and Real-World Evaluation of Eyes-Free Yoga: An Exergame for Blind and Low-Vision Exercise

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People who are blind or low vision may have a harder time participating in exercise due to inaccessibility or lack of encouragement. To address this, we developed Eyes-Free Yoga using the Microsoft Kinect that acts as a yoga instructor and has personalized auditory feedback based on skeletal tracking. We conducted two different studies on two different versions of Eyes-Free Yoga: (1) a controlled study with 16 people who are blind or low vision to evaluate the feasibility of a proof-of-concept and (2) an 8-week in-home deployment study with 4 people who are blind or low vision, with a fully functioning exergame containing four full workouts and motivational techniques. We found that participants preferred the personalized feedback for yoga postures during the laboratory study. Therefore, the personalized feedback was used as a means to build the core components of the system used in the deployment study and was included in both study conditions. From the deployment study, we found that the participants practiced Yoga consistently throughout the 8-week period (Average hours = 17; Average days of practice = 24), almost reaching the American Heart Association recommended exercise guidelines. On average, motivational techniques increased participant's user experience and their frequency and exercise time. The findings of this work have implications for eyes-free exergame design, including engaging domain experts, piloting with inexperienced users, using musical metaphors, and designing for in-home use cases.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility**; **Accessibility technologies**

Additional Key Words and Phrases: Accessibility, video games, exergames, visual impairments, Kinect, motivation, deployment, eyes-free, audio feedback, yoga, health

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This article is an extended version of a conference paper that was presented at the 15th ACM SIGACCESS International Conference on Computers and Accessibility (ASSETS '13) [Rector et al. 2013] that includes new data on the design of Eyes-Free Yoga from a proof-of concept system to a fully functional game and new results from a real-world deployment study assessing its promise motivating exercise.
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1. INTRODUCTION

A number of barriers can prevent people who are blind or low vision from exercising, including inaccessibility, travel difficulties, or lack of encouragement [Ponchilla 1995; Rector et al. 2013; Sherrill et al. 1984]. There is a need for more access to recreational and athletic programs [Ponchilla 1995] and for more encouragement from both parents [Stuart et al. 2006] and the general public [Sherrill et al. 1984] to engage in physical recreation. Although exercise classes may be an option, class instructors often do not know how to adapt their classes for people who are blind or low vision [Rimmer 2006]. These barriers can have a negative impact on physical activity for people who are blind or low vision, and thus they are more likely to be obese than their sighted counterparts [Capella-McDonnall 2007; Weil et al. 2002]. Having the ability to exercise independently can mitigate the barriers above to allow broader access to exercise. Exergames, or exercise games, can provide fitness activities and act as a gateway to more advanced exercises [Schwanda et al. 2011]. However, many people cannot play mainstream exergames due to having a disability [Weil et al. 2002]. Better access to exergames may provide more exercise opportunities for people who are blind and low vision. In addition, exergames have the benefit of not relying on a sighted guide.

Several exergames have been developed for people who are blind or low vision: VI-Tennis [Morelli et al. 2010a], VI-Bowling [Morelli et al. 2010b], and Pet-N-Punch [Morelli et al. 2011]. These systems have demonstrated a potential for eyes-free exergames and provide benefits including physical exertion, enjoyment, and knowledge of performance. One common denominator, however, is that the evaluation of these systems occurs in lab settings with one to two sessions, and there is a high rate of discontinuing assistive technology use [Dawe 2006; Johnston and Evans 2005; Riemer-Reiss and Wacker 2000]. Studying the feasibility and motivating factors of an accessible exergame system used over a longer term in a real-world settings can further demonstrate their potential.

In response, we developed and conducted a long-term evaluation of 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]. Eyes-Free Yoga began as a research proof-of-concept prototype with an initial feasibility study in a lab setting, where we found that most participants preferred personalized verbal feedback on their postures [Rector et al. 2013]. We integrated the personalized feedback into a now a fully functional exergame with motivational techniques for which we were able to conduct an 8-week deployment study in the homes of four participants who are blind or low vision. Our system provides four full yoga workouts with descriptive audio instructions. All of the descriptive instructions, not real-time personalized feedback, are located at http://eyesfreeyogamanual.kyle-rector.com. The close collaboration with yoga instructors has made Eyes-Free Yoga a system that can introduce yoga in an accessible and independent setting for people who are blind or low vision. The results from our two studies suggest that participants are able to understand pose corrections and were motivated to use the system throughout the study period as measured by frequency of engagement and time spent practicing yoga per day.

There are several contributions to this work. First, we have developed two versions of an exergame accessible to people who are blind or low vision, including a version that is a fully developed game suitable for an in-home exercise regimen over an extended period. Second, through our studies, we learned how understandable auditory feedback and motivational techniques can enhance exergame play for individuals who are blind or low vision. Finally, our work provides insights for future game developers of accessible exergames for people who are blind or low vision.

2. BACKGROUND AND RELATED WORK

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 Compact Disc (CD) sets have been developed to practice yoga while at home [Klein 2013; Yoga Center of Marin 2014]. 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 is expensive [So Sound Solutions]. A less-expensive solution, Visually Impaired Yoga Mat [Rousettus 2015], provides tactile cues for foot and hand placement. Some yoga instructors have spent time working with 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.

2.2. Persuasive Technologies for Physical Fitness

One aspect of exercise technologies well studied in the Human-Computer Interaction (HCI) community is how to persuade people to continue toward their exercise goals. According to Fogg [2003], there are three different functional roles that a persuasive technology can take: (1) a *tool* to increase capability, (2) a *medium* that provides an experience, or (3) a *social actor* that creates a relationship. Existing *tools* to promote exercise include Fitbit [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 using 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 (Laura) [Bickmore et al. 2005], and a mobile lifestyle coach [Gasser et al. 2006]. Each of these systems provides coaching support and rewards for positive feedback, such as a happy face for completing activities.

Finally, Fritz et al. [2014] studied users who used wearable fitness trackers for an extended period (3 to 54 months) and found benefits as a tool for reporting numbers and as a social actor to provide rewards and social networking capabilities. We designed Eyes-Free Yoga as a persuasive technology that uses nonvisual techniques to serve as a *tool* to lower the barrier to practice yoga through sound-based posture guidance. In addition, we designed the system to be a *social actor* that provides positive feedback through words of encouragement and musical awards. The intention is for Eyes-Free Yoga to achieve longer-term engagement and opportunities for exercise.

2.3. Exergames

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, that 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. We 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 how close they were to earning badges or advancing to the next level).

2.4. Accessible Exergames

There are several efforts from the research community, including accessible alternatives to mainstream exergames and an original exergame called Pet-N-Punch. VI-Bowling [Morelli et al. 2010b] and VI-Tennis [Morelli et al. 2010a] are adapted from Wii Sports games, where the necessary visual cues were converted to audio feedback from the speakers or tactile feedback from the Wii Remote. VI-Tennis was evaluated with children who had better scores and enjoyment with the accessible version. VI-Bowling, evaluated with adults, was found to be enjoyable and a sufficient challenge. In addition, Morelli et al. [2011] developed a solution using video capture and a Kinect track running game to provide audio and tactile feedback in lieu of captured visual cues. However, there are limitations; players did not always learn from their mistakes, and it may be difficult to generalize to all types of games. Pet-N-Punch, an original exergame, uses the Wii remote and nun chuck for upper body exercise with auditory and tactile feedback [Morelli et al. 2011]. The player has to hit rodents and pet cats at a farm. They found participants were able to achieve light to moderate exercise.

Eyes-Free Yoga is also an original game, as opposed to an existing game modification. While energy expenditure is useful for assessing the effectiveness, our measures of success are over the long term with measuring 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.

3. EYES FREE YOGA: PROOF-OF-CONCEPT PROTOTYPE AND FEASIBILITY STUDY

For our first version of the system, as first described in Rector et al. [2013], we used six design principles used to inform a proof-of-concept prototype design. We determined these principles based on the goal of Eyes-Free Yoga: 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 initial proof-of-concept prototype.

3.1. Prototype Description

Eyes-Free Yoga uses the Kinect 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:

1. *Accessible for Eyes-Free Interaction:* Eyes-Free Yoga was designed to be accessible for people who are blind and low vision, along with 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]. We consulted an audio yoga workout CD specifically created for people with visual impairments to capitalize on descriptive techniques and understandable words and phrases [Klein 2013]. Participants used their voice to give commands and thus did not have to acquaint themselves with a controller or novel equipment.
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

Fig. 1. The six poses used for evaluation, listed in the order in which they were performed. Credits: first image, stand by Claire Jones from the Noun Project [Jones 2016]; last five images, yoga by Claire Jones from the Noun Project [Jones 2016a, 2016b, 2016c, 2016d, 2016e].

audio/visual guide. We determined the yoga positions by collaborating with three yoga instructors and one yoga instructor in training, one of which had experience working with people who are visually impaired. We used Kinect Skeletal Tracking to avoid the need for worn sensors. As a result, we were constrained to standing postures (Figure 1). To determine the verbal feedback, the lead researcher took five courses on the fundamentals of yoga from one of the yoga instructors, and 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 rather than using computer-generated speech. Additionally, participants used their voice to control Eyes-Free Yoga to avoid the need of a controller while exercising. We 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. *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.
4. *Caters to a Novice Target Audience:* The target audience of our exergame was people who are new to yoga. We chose introductory postures; those poses gradually became more difficult as participants progressed through the study. 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,"* then the exergame would give modifications and the verbal feedback would account for those modification. We chose phrases that were not specific to yoga so people who had never attended a yoga class could follow the directions.
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 gameplay. Participants could ease into the pose while hearing comprehensive instructions. While holding a pose, the exergame offered verbal adjustments and auditory confirmation. 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.
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*

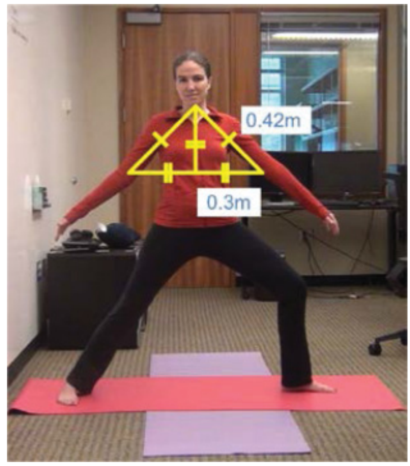

Fig. 2. In Warrior II, her arms are at 45° and need to be raised to ≥80°. Eyes-Free Yoga responds with a verbal correction of *"Bring your arms closer to your head."*

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].

3.1.1. 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. To provide custom verbal corrections, we used Kinect Skeletal Tracking, which contains 20 body joints in three dimensions. We were able to calculate relative positions between two joints and 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° (Figure 2). The game responds with the appropriate verbal correction. To reduce errors with occlusion and rotation of the body [Dutta 2012], we gave instructions such that the user would face the Kinect regardless of pose. We also used "Joint Filtering" provided by the Kinect. As a result, we did not encounter issues with occlusion during the development or studies. Each posture has an average of 10.5 rules and a mode of 11 rules. The least constrained pose, Tree, has 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, has 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 corrections to make based on the Kinect Skeletal Tracking data. The suggested verbal correction is prioritized by location of the issue (Figure 3, below). 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 verbal corrections are strategies for systems that direct human action [Heer et al. 2004]. It is worth noting that if an instruction has to be repeated 4 times in a row, the game moves 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°. 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

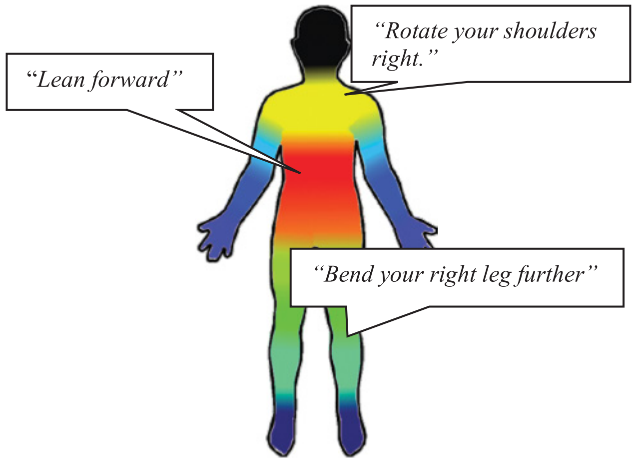

Fig. 3. Priority of adjustments shown on the human body. The highest priority is the core, which is red (hot), and lowest priority is the feet, which are purple (cold). The head orientation is not measured.

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], which we may use for a future version of Eyes-Free Yoga.

3.2. Study Description

To assess the initial prototype of Eyes-Free Yoga, we conducted a mixed method, quasi-experimental evaluation with 16 participants who were blind or low vision. Participants 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.

We counter-balanced the study so participants were randomly placed into Group A (*baseline* first, *experimental* second) or Group B (*experimental* first, *baseline* second). We did not account for yoga experience when randomizing the participants. The game presented poses in the order shown in Figure 1 for both groups with three poses per condition. While Figure 1 displays Warrior I and Tree Pose from the side for illustration, the participants were facing the Kinect camera for all six postures.

All participants practiced the same postures in the same order that is more consistent with a yoga class, but where the risk of learning effects was low. Participants in Group A received verbal feedback for Mountain Pose, Warrior I, and Warrior II. Mountain Pose does not help for either Warrior I or Warrior II, because the Warrior postures require a lunge and positioning of the arms. Warrior I and Warrior II both involve a person lunging, but the torso and arms are held in different positions. The participants in Group B received feedback for Reverse Warrior, Tree, and Chair postures. These postures do not have much in common in terms of their requirements: Tree is focused on balance, Chair is focused on core and leg strength, while Reverse Warrior has a different requirement for each limb. While it is possible that participants experienced learning effects, the postures are distinct from one another.

3.2.1. 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. Yoga mats were arranged in a plus formation, so participants learned about "front, back, right, left, and base" location. The mats were arranged such that if the person's toes were aligned with the front of the mat, they were facing the Kinect sensor. These locations were referenced in the instructions so the participants knew where to move. For example, Warrior II 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*."

During Warrior I, Warrior II, Reverse Warrior, and Chair postures, Eyes-Free Yoga asked the participants if they were experiencing back or knee pain. If a participant answered "yes," via voice, then the exergame would give accommodating modifications so the participant could complete a modified pose. 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 3 times each for 15s or, in the case of the experimental prototype, until they completed the verbal corrections.

After performing the postures, we conducted a follow-up interview with participants where we asked about their thoughts on the game and to provide open responses about the usefulness of the customized feedback. Interviews and sessions were audio and video recorded and then transcribed and analyzed. We extracted still photos from video recordings of each pose while removing any identifying information. We asked 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 blind to which photos depicted a pose with custom feedback versus one without custom feedback.

3.2.2. Participants. We recruited 16 participants (8 females, average age 23.8, age range 13 to 60), where 12 were blind and 4 were low vision, to participate in our study. We recruited participants through email lists and the Washington State School for the Blind. The study was conducted at the school and at the University of Washington. The study lasted between 45 and 90min, and we compensated participants with $20 cash. Participants' previous yoga experiences were evenly divided: 5 had never practiced, 5 had little experience, and 6 had taken 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 participant), not being able to follow an exercise class (2 participants), difficulty finding the right class (1 participant), and it not being a priority (2 participants). Six participants mentioned the importance of extra audio instructions in a proposed class setting.

3.3. Study Results

Study results below include the frequency of custom verbal corrections in the *experimental* prototype, pose quality using both the *baseline* and *experimental* prototypes, and participants' engagement.

3.3.1. 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 (Figure 4). For Warrior II, we included a strict rule labeled: "Left knee behind ankle" (Appendix of Rector et al. 2013). In this rule, 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*

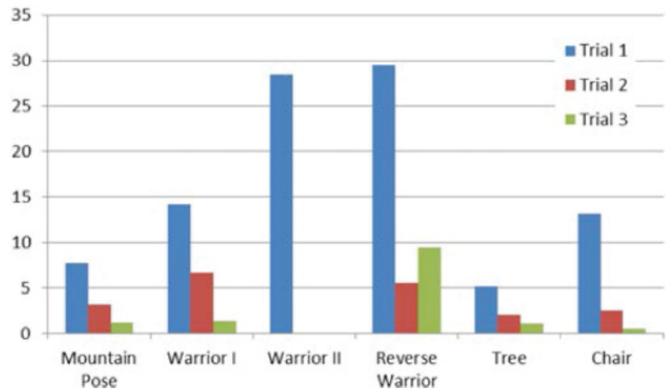

Fig. 4. Average suggestions given for each pose and trial. (The first three poses reflect Group B, while the second three reflect Group A.)

facing forward] but I turn my whole body [forward] and as soon as I turn [...] then my [leg] turns." While Warrior II was not the most difficult posture, this difficulty reflected a limitation in our system. As a result, we removed this rule altogether in the final version of the system. This issue did not arise during the pilot testing.

For the other five positions, people needed fewer verbal corrections if they attempted the position multiple times (Figure 4). Overall, Group B needed fewer suggestions (244) than Group A (336), but the two groups received feedback for different postures. 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). The decrease of verbal corrections in each trial of Mountain Pose, Warrior I, Tree Pose, and Chair Pose may suggest that participants were learning the poses over each trial.

3.3.2. Yoga Instructor Ratings. 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 did not know if the participant had used the *baseline* or *experimental* version of Eyes-Free Yoga. The meetings lasted between 30 and 90min, and they were compensated with a $25 Target gift card. The yoga instructors had practiced yoga from 11 to 20 years with an average of 14.5 years. They taught classes from 3 to 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. For the participants who requested to stop early, they would do so after completing the posture one time. This was due to fatigue after holding the posture along with the verbal corrections. There were also participants who were unable to complete a posture due to fatigue (Warrior I: 1/16 participants, Warrior II: 2/16 participants, Tree: 2/16 participants, Reverse Warrior: 4/16 participants, and Chair: 4/16 participants), and we recognize this as a limitation of our study. 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 ($W = 0.89$, $P < .001$) 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) ($Z = 14025.5$, $P = 0.57$)

Table I. Number of Participants Who Gave Positive Answers 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

conditions. If we remove the five *experimental* poses that resulted in people finishing early before addressing all of the verbal corrections, then the quality of *experimental* poses (avg. = 3.31, std. dev. = 0.91) shows more promise ($Z = 12605.5$, $P = 0.29$).

3.3.3. Participant Feedback. 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, because they were experienced with Qigong where the instructor did not give as many corrections as Eyes-Free Yoga. A one-sample Pearson Chi-Square test of proportions shows that preference for the *experimental* prototype differed significantly from chance ($\chi 2\ (1, N = 16) = 6.25, P = .01$). One participant from Group A spent the most time of any participant learning Reverse Warrior but enjoyed his session because of 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."*

Most participants (13) said they would play again, and all 16 said they would recommend the game. The three participants who would not play again were the person who disliked the verbal corrections and the two that had no preference between the corrections and *baseline* prototype. Of the 13 who would play again, 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 also asked questions based on the goals of GameFlow [Sweetser and Wyeth 2005] (Table I). 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 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, ability to pause the game, better voice recognition for stating if they have pain or not, and relaxed knee placement parameters; we have integrated the latter three suggestions into the current system. Although we attempted to use universal language, some

Table II. 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 Corpse Pose	11. Reverse Warrior Pose
			12. Bridge Pose
			13. Happy Baby
			14. Bound Angle Pose
			15. Reclined Twist
			16. Corpse Pose

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, which we have also created (http://eyesfreeyogamanual.kyle-rector.com).

4. EYES-FREE YOGA: FULLY FUNCTIONAL PROTOTYPE AND REAL-WORLD DEPLOYMENT STUDY

Based on the results of the feasibility study and to explore new research questions, we have expanded on the original prototype design significantly to move it from a lab setting to the real world as 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. The original prototype was a proof-of-concept and nonindependently operated and had no motivational techniques. This section describes the new version and its additional features.

4.1. Eyes-Free Yoga Design

Eyes-Free Yoga 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) screen reader, 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 Workouts 1–4 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 the 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 lengths (Table II). 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 on a 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. Because participants felt fatigue when adjusting their postures during the lab study, we kept the length of verbal feedback to 15s. As a result, we did not measure whether the amount of verbal feedback changed throughout the deployment study.

Table III. 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

4.2. 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, similarly 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, similarly to creating a habit as in Stawarz et al. [2014].
2. **Musical levels:** As a person advances to the next level, he or she hears water sounds with increasing power in addition to the background music (Table III). This conveys a sense of progress. Users spend 1.5× as long as they do in the previous level.
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, then they still needed to complete the workout.
Endurance Badge: For each workout, the person needs to exercise for a minimum required amount of time.[1]

[1]Workout 1: 20 minutes; Workout 2: 30 minutes; Workout 3: 45 minutes; Workout 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 fewer than 5min to receive an endurance or consistency badge. While it is possible that these motivational techniques may not be compatible with yoga's philosophy, 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.

4.3. 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 *Standard Eyes-Free Yoga (EFY)* or 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, also called *Enhanced EFY*.

While we had a small number of participants, we used a single-case experimental design with randomization tests. These research designs can provide results with high internal validity, even for a small number of participants [Dugard 2014], and are common in education and behavioral research [Dallery et al. 2013]. Randomization tests for small samples are common in genomics [Mootha et al. 2013] and single-case methods are suggested as an emerging experimental design at ACM Computer Human Interaction Conference on Human Factors in Computing Systems (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] and is ideal to pilot test novel technologies in the field.

To increase statistical power, we conducted an ABAB study design, where A is *Standard Eyes-Free Yoga* and B is *Enhanced EFY*. 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 varied length of each phase controlled for historical effects. The number of measurements for each single-case experiment was 56, which allowed a total of 4,495 random arrangements and hence a minimum P value of $2.22 \times 10\text{e-}4$. 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; the participants had access to all four workouts and the yoga postures in every phase of the study. Thus, all participants were 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. 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

Table IV. Demographic and Background Information for Each Participant. For P2, L = Left eye and R = Right eye

P#	Age	Gender	Occupation	Vision	Yoga Experience	Exergame Experience
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

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. On leaving, we told the participant that he or she was free to use (or not) use the system and pick any of Workouts 1–4 whenever they would like.

Participants first used the system in phase A, or *Standard EFY*. 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 *Standard EFY* or 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.

Participants then used the system in phase B, or *Enhanced EFY*, 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 1 and also added questions about their experiences with the three motivational techniques. 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 and added a question on how participants felt when the *Intervention* condition was removed and added back in again.

4.2.1. Participants. We initially recruited six participants through blind and low-vision mailing lists, but, due to vacations and an injury, two dropped from the study early, which resulted in four total participants completing the full deployment study (Table IV). We conducted two study sessions at the participants' residence (1 to 2h for the initial visit and 30 to 60min for the final) plus two 15- to 30min 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.

4.4. Study Results

We gathered quantitative data throughout the study via system usage logs as well as participant feedback through qualitative interviews. For the qualitative interviews, we conducted a thematic analysis of representative quotes from participants, with the themes being influenced by the quantitative data. We did not conduct inter-rater reliability on our semi-structured interviews, because people can apply the same code to multiple parts of the conversation [Armstrong et al. 1997].

4.4.1. Exercise Frequency and Minutes Exercised per Day. The four participants practiced yoga in both the *Standard EFY* and *Enhanced EFY* conditions consistently throughout the study (Figures 5 and 6). It is possible that two of our participants (P3 and P4)

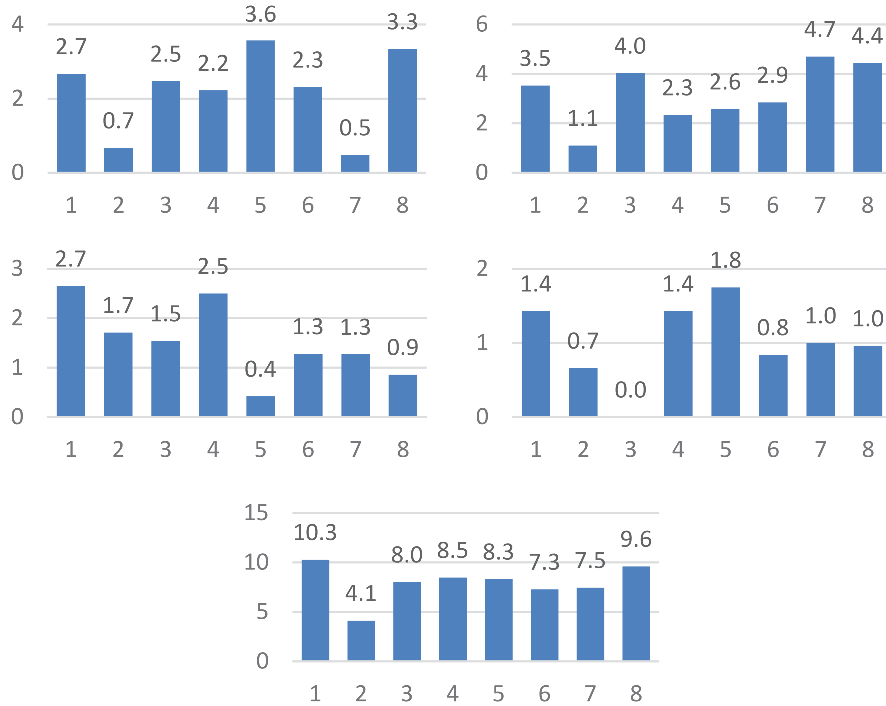

Fig. 5. Hours of yoga practice per week for P1–P4 and aggregated across all participants. The x-axis is week number, and the y-axis is hours exercised.

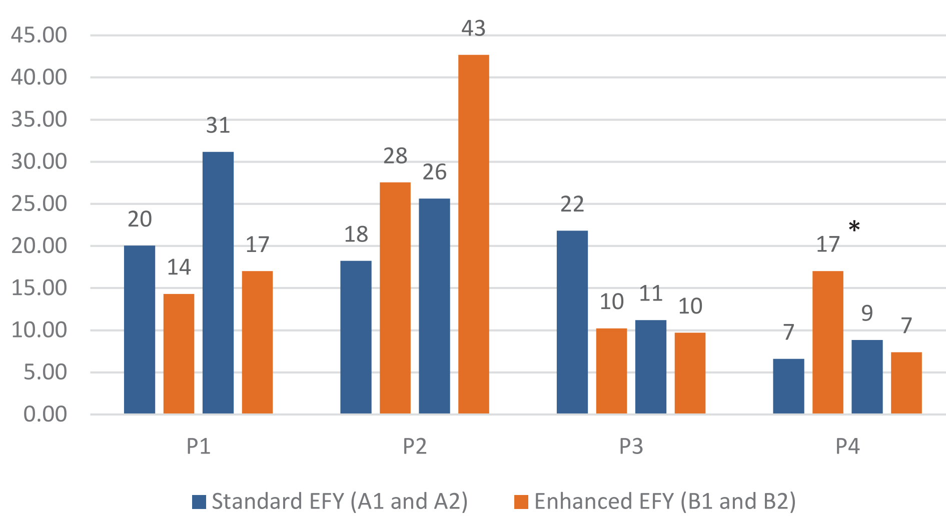

Fig. 6. Average minutes of yoga practice per phase and across participants. $^*P = .05$.

Table V. Objective Performance Metrics across Conditions and Participants. Phase Differences Consistentwith the Hypothesized Direction Are Highlighted in Blue. Inconsistent Differences Are Highlighted in Red

	P1	P2	P3	P4	Ave.
Time					
Total Hours of Yoga Practice	17.7	25.5	12.2	8.8	16
Phase Mean Difference (in minutes)	-19.8	26.4	-13.1	8.9	0.59
% Phase Change	-39%	60%	-40%	58%	2%
p-value	0.97	0.16	0.79	**0.05**	0.49
Days Practiced					
Total Days of Yoga Practice	22	35	23	17	24
% Phase Change	-39%	61%	5%	5%	8%
p-value	0.91	0.16	0.56	**0.05**	0.30

experienced a novelty effect and that P1 and P2 did not experience the novelty effect (Figure 5). Overall, the hours used per week across the study does not show a novelty effect (Figure 5). The total average time of Yoga practice across participants amounted to 16h (range = 9 to 26), with an average of 24 days of Yoga practice throughout the 8-week period. Because we used a single-case experimental design, we chose Phase Mean Differences as the test statistic to evaluate the effect of the *Enhanced EFY* [Heyvaert and Onghena 2014], which is the equivalent metric to mean differences in group designs. For *Standard and Enhanced* conditions, participants had equal access to the four workouts with different lengths. Throughout the study, the participants made the choice of whether to exercise and the length in which to exercise. Because we did not want the participants' choice of workout to be a confounding factor with the motivational techniques, we generated a randomized ABAB sequence for each participant.

Raw phase mean differences indicated a reduction in minutes of exercise per day with the *Enhanced EFY* condition in P1 and P3, whereas P2 and P4 experienced an increased in minutes per day with the *Enhanced EFY* condition. Percentage of phase changes indicated increases in minutes per day with the *Enhanced EFY* condition for P2 and P4 and reductions for P1 and P3, with higher proportional increases for P2 and P4 (close to 60%) and an overall pooled increase of 2%. On average, the proportional increase of days of yoga practice in the *Enhanced EFY* condition was higher than in the *Standard EFY* condition (8%), with P2 having the largest increase (61%; see Figure 6).

Finally, using a one-tailed distribution and assuming an effect in the direction of the *Enhanced EFY* condition, we found statistically significant effects in P4 and effects approaching a trend in P2 ($P = .16$) for both the number of minutes and the number of days practiced per phase. In contrast, the effects of the *Intervention* in P1 and P3 did not approach statistical significance (see Table V).

4.4.2. 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 *Enhanced EFY* did not change the behavior of most participant's exercise habits (Table V), 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 confirms the persuasive element of antecedent feedback mentioned in Glynn [1982] and Adams et al. [2009] 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, she 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 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 qualitative data of our ABAB design provided strong evidence for an experimental manipulation: Adding motivational techniques enhanced gameplay, and removal of motivational techniques minimized 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 and P4), similarly to how Schwanda et al. determined that Wii Fit could be a gateway to more rigorous exercise [2011]. 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 one 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 his or her 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 he felt that he did not deserve a badge: "*Not sure I deserved a Performance badge today; I was shaking, wobbling, and grimacing all over the place*."

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*."

Eyes-Free Yoga was successful over a longer trial, because the participants had a "relative advantage" [Riemer-Reiss and Wacker 2000] of learning yoga in a safe setting as opposed to attending classes that may not be accessible [Rimmer 2006] or using audio workouts from home without personalized feedback. Participants also may have kept using the system due to the fact that our system was efficient in providing feedback on the yoga postures, where quality and efficiency of responses is a factor as to whether people discontinue use of an assistive technology [Johnston and Evans 2005].

Another benefit to Eyes-Free Yoga is 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 *Standard EFY* and *Enhanced EFY* conditions to learn yoga in an accessible way in the privacy of their own homes, 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 a 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, and P4 has added new exercises: "*The system got me to stretch more, and squats*."

5. 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. The frequency and average time spent doing yoga exercise by participants in our deployment study—16 hours over 24 days of practice within a 2-month period—is only 30min below the 150min benchmark of weekly exercise recommended by the American Heart Association. Furthermore, our experimental design and qualitative data supported the positive role of an enhanced version of Eye-Free Yoga with motivational features and suggested, at a descriptive level, to increase frequency and minutes of exercise.

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 gameplay 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 gameplay. 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.

Eyes-Free Yoga has limitations, namely that it cannot (1) track whether the bones are held in their joints, (2) track if the person is feeling pain, (3) measure whether the correct muscles are tensed or relaxed, or (4) measure the person's breathing. Because injury prevention was important in our design, the game had to compensate with reminders throughout the game about doing things that the Kinect could not detect. We realize that our work is not meant to replace, but to enhance, yoga exercise with a trained instructor.

Across both 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.

During our observations with the lab study, there were only a few points of confusion relating to the use of metaphors that did not resonate with everyone. We made improvements on those confusing phrases in time for the deployment study. For instance, in Warrior I, the prototype told people to *"Stand with your feet below your hips as if you are tracking on parallel skis."* Participants who had not skied before were initially confused. In our full system, we provided extra guidance in addition to the metaphor to assist the person. For example, we had participants hold Mountain Pose and progress immediately into Warrior I. As a user is guided to Mountain Pose, they hear: *"Stand tall with your toes at the front edge of the yoga mat. Check that your feet are parallel to each other, directly under your hips and shoulders."* When Warrior I is introduced, the user hears: *"With your feet still planted under your hips, imagine that you are standing on two cross country skis, with a space between those two skis."* In this way, the user may or may not have expertise with skiing but is still able to understand how to position the feet in Warrior I.

Across both studies, we found advantages to using the Microsoft Kinect and body tracking. The Microsoft Kinect is a low-cost ubiquitous technology compatible with Windows machines (~$150), so it is easier for researchers and designers to replicate this work and improve the source code (online at https://github.com/krrun16/eyesfreeyoga). In addition, difficulty of device procurement is a factor in whether people abandon an assistive technology [Phillips and Zhao 2010]. By implementing assistive technology solutions using mainstream devices, they can provide logistical advantages for people with disabilities, along with not calling out their disability [Shinohara and Wobbrock 2011] and making configuration and maintenance easier [Dawe 2006].

However, the limitations of the using the Microsoft Kinect for enforcing body positions is when the positions no longer resemble someone who is standing. The version of Kinect body tracking used in the lab and in-home study was created 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]. However, the data were mainly standing positions.

Second, from the deployment study, we recommend *verbally and aurally communicating game status throughout gameplay.* 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 fewer than 5min 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 gameplay. 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 both the feasibility and deployment studies, but we identify limitations in our approaches. For the feasibility study, we realized that maintaining pose order across all participants might 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. Having each participant complete the poses in a random order or asking about their thoughts in between each pose could remedy this. 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.

From our deployment study, we compared *Enhanced EFY* intervention with a *Standard EFY* intervention. *Enhanced EFY* lead to statistically significant increases in frequency and minutes of exercise in at least one participant, but three of four participants had no statistically significant results. Interpretation of our statistical analysis requires caution, since detecting statistical effects is more challenging when two interventions are powerful to begin with, in this case introducing yoga in an accessible format. In addition, any statistical test can lead to Type II error, that is, concluding there was no effect when in fact there was one. Therefore, even though at a descriptive level the overall trend was consistent with our hypothesis (i.e., *Enhanced EFY* is more motivating), we might need a larger sample of ABAB trials to demonstrate a clear pattern of performance effects.

Conversely, across all participants, our ABAB design demonstrated that *Enhanced EFY* improved their user experience and that transitioning to *Standard EFY* worsened it. The study also showed consistent use of the system throughout the study and acceptable American Heart Association benchmarks of recommended minutes of exercise per week. The study confirms 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 conducting single-case experimental designs with a small number of participants and the appropriate design features can be used to reach sufficient statistical power to conduct statistical tests [Dugard 2014]. This is helpful when researchers have limited access to participants, such as in the accessibility community. This is especially true when conducting long-term in-home deployment studies. We increased the statistical power of our study by using an ABAB design 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 it will be more pervasive at CHI [Hekler et al. 2013] and in other HCI and accessibility research.

6. CONCLUSION

We have developed an accessible yoga exergame, Eyes-Free Yoga, where the players interact with a “yoga instructor,” receive personalized instructions for six standing yoga poses, and have four yoga workouts and motivational techniques. 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. In addition, our 8-week real-world deployment study demonstrated that our system enabled independent access to yoga while at home and motivated use throughout the study and that the motivational techniques may enhance exercise frequency and total exercise time. We believe that games that use skeletal tracking and provide comprehensive feedback will enhance the exercise experience and be accessible to more players. Based on the results of our studies, we have made Eyes-Free Yoga available for download at http://homes.cs.washington.edu/∼rectorky/efy.php.

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