An Exergame to Improve Balance in Children who are Blind

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ABSTRACT
Children with visual impairments have a greater chance to suffer from chronic health problems associated with physical inactivity, such as obesity and heart disease, than their sighted peers. In recent years, non-visual exergames have been explored as a promising health intervention method to increase existing exercise opportunities for this vulnerable population. Because vision plays a major role in postural control, individuals who are blind tend to have poor balance. To address this health issue, we developed a novel non-visual skiing exergame that is played using a pressure-sensitive input controller and haptic feedback provided using a motion-sensing controller. A user study with eleven children who were blind found a significant improvement in balancing skills after playing the game multiple times.

Keywords
Visual Impairment, Children, Exergames, Health, Balance

Categories and Subject Descriptors
H.5.2 [**HCI**]: User Interfaces—*Haptic I/O*

1. INTRODUCTION
Various studies have found that children with visual impairments often exhibit delays in motor development, such as poor balance and inefficient gait that are considered byproducts of predominantly sedentary behaviors during the developmental years [2]. Further, they have fewer opportunities to be physically active due to safety concerns, dependence on sighted exercise partners, and a general lack of accessible activities [13].

Though video games are considered a contributing factor in children's increasingly sedentary behavior [14], games that use physical activity as input, i.e., exergames, could be a powerful weapon in the fight against childhood obesity. Because existing exercise games are not accessible to players who are blind [6], a number of exercise games have been developed that can be played using nonvisual feedback, e.g., audio and haptic cues [6–8, 10].

Figure 1: A child who is blind playing the nonvisual skiing exergame. Players control their speed by using their motion-sensing controllers as ski poles. A pressure sensitive input controller is used for input, where players lean to the left or to the right to pass through a virtual gate that is indicated using haptic cues.

Beyond stimulating physical activity and general fitness, exergames may also contribute to gross motor skill development, which is important consideration for developing youth; particularly children who are blind. Because vision plays such a major role in postural control [3], individuals who are blind often have poor balance and are consequently at a much higher risk of falling [12]. Therefore we present a non-visual skiing exergame that can improve postural control in children who are blind. This paper makes the following two contributions: (1) we share design experiences of how an existing balancing exergame can be made accessible using commercially available controller technology; and (2) we report quantitative results on the effectiveness of our game to improve a blind player's balancing skills.

2. RELATED WORK AND BACKGROUND

VI Tennis [6] and VI Bowling [7] are accessible versions of the popular Wii Sports exergames (tennis/bowling), where haptic and audio cues indicate when and what upper body gesture to provide using a motion-sensing controller (Wii remote). Pet-n-punch [8] is a haptic/audio whac-a-mole like exergame that is played using two Wii remotes to stimulate larger amounts of physical activity. User studies with accessible exergames found blind subjects to engage into light-to-moderate levels of physical activity, with moderate levels being considered high enough to yield significant health benefits [1].

Beyond games that involve upper-body gestures, two approaches have explored making whole body exergames accessible. Real-time sensory substitution [9] is an technique that uses video analysis to detect important visual cues in two Kinect Sports exergames (hurdles / javelin throw) and substitutes these into haptic cues provided with a Wii remote. Eyes-Free Yoga [10] an audio exergame that teaches different yoga poses with detailed verbal feedback provided on each pose based on skeletal information acquired with a Kinect. Yoga can improve balance and strength. A user study with sixteen participants who were blind or visually impaired performed a qualitative evaluation of this game, which found that they enjoyed this game and audio feedback helped with understanding each Yoga pose.

Beyond games that rely on motion-sensing input, exergames have been developed that aim to improve whole-body motor skill development; specifically balance. Wii Fit is a popular exergame that utilizes a pressure sensitive input device, called the Balance Board that measures the user's center of balance. To date Wii Fit has sold nearly 23 million copies worldwide. Recent studies with Wii Fit demonstrate that it improves balance in children with poor motor skills due to developmental delays [5, 11]. Based on these results we believe accessible Wii Fit games could improve balance in children who are blind. Our approach is most related to Eyes-Free Yoga [10] as we also aim to improve balance. In addition to differences in input technology (Balance Board) and feedback modality (Haptic), we perform a quantitative assessment on the effectiveness of our balance game, where their approach reports qualitative results.

3. DESIGN OF THE SKIING EXERGAME

Exercise games, such as Wii Fit are inaccessible to individuals who are blind, as video games typically rely on visual cues to indicate what input to provide and when [9]. Though audio feedback may be provided, this generally doesn't contain sufficient information to be able to play the game. Wii Fit requires players to stand on a balance board, which looks like a household body scale where players provide input by shifting their center of balance. Wii Fit contains exercise games in four different categories, yoga, strength training, aerobics and balance. Because people who are blind often have poor balance [12] our interest is in balance games. Wii Fit offers nine balance games including: Soccer Heading, Ski Slalom, Ski Jump, Table Tilt, Tightrope Walk, Balance Bubble, Penguin Slide, Snowboard Slalom, and Lotus Focus. We verified that none of these games were playable without visual feedback.

Figure 2: The Wii Fit Slalom Ski game, blue flags indicate the gates the player has to ski through by shifting their balance to the left or the right. In the upper right corner of the screen the player's center of balance is rendered as a red dot on an outline of the Balance Board.

From these nine games, the Ski Slalom game was chosen to explore making it accessible. This game was preferred over other games because its gameplay is relatively easier to explain than some of the other games that relied on abstract concepts. The goal of the Ski Slalom game is to ski down a hill the fastest while going through as many gates as possible. The visual feedback of this game shows an avatar skiing downhill with sets of gates appearing to the right or to the left of the avatar (see Figure 2). Based on this visual information, players shift their weight to the left or right in order to ski through a gate. Speed is controlled by leaning forward or backward. The top right corner of the screen shows the outline of the balance board with a red dot indicating the player's current center of balance. The score is a combination of the time it takes to ski down and the number of gates that the player missed. Because this game is time-trial based, it offers a high replay value; encouraging players to try to improve their best score.

Because the access to source code of commercial games is restricted, we implemented our accessible Ski Slalom game as a standalone windows application; an approach that is shared with other accessible exergames that are currently available [6, 7]. Our game was implemented in C# using the open source WiiMoteLib library that allows for communicating with the balance board via Bluetooth. To make the gameplay of the Ski Slalom game accessible, we followed the sensory substitution strategies proposed by Morelli [6]. This requires implementing the existing audio and haptic feedback of the original game, as well as identifying essential visual cues and substituting these as haptic and/or audio cues. A problem with this approach is that the balance board used for input offers no capability for providing haptic feedback. The use of haptic feedback is desired as a related study found using supplemental haptic feedback in addition to audio, significantly improves performance of playing exergames [6]. Exergames are often played in a social/noisy environment, which makes it difficult to rely on audio feedback only. We explored solutions that involved embedding vibrotactors in the balance board itself, but we ended up with a solution that requires players to hold a Wii remote capable of providing haptic feedback in each hand and incorporating their use into the gameplay. A benefit of this approach is that hands are more receptive to haptic feedback than feet due to an abundance of tactile receptors in the fingertips. The visual cues we identified to be crucial to play the game are: (1) the direction of the gate, which indicates to the player to lean to the left or right; and (2) the speed of the player, which requires the player to lean forward or backward. To indicate the direction of the gate, vibrotactile feedback of the Wii remote in the player's left or right hand is activated. The data transmitted from the Balance Board to the game contains data from four sensors positioned in each of the four corners of the balance board. For input, we approximated the values used by the Wii Ski Slalom game, i.e., the player turns when the sensor values on one side of the board exceeds 1.5 times the value of the sensors on the other side of the board. Players control speed by leaning forward or backward. By playing a loop of the sound of skis sliding through the snow, we convey the player's speed using modulation of the pitch. Players had approximately 2 seconds, depending on the speed, to lean in the correct direction in order to pass through a gate. The direction for each gate is randomly generated and players have to pass through a total of six gates. To encourage replay, the score is the number of seconds it took a player to play the game.

We collected feedback on our game by play testing with a number of sighted subjects. Subjects did not wear a blindfold, as the game does not provide any visual feedback. Despite the audio feedback, subjects indicated that it was difficult to gauge how fast they were going, which affected their ability to pass through a gate. Based on this feedback, we decided to deviate significantly from the original gameplay of Wii Ski Slalom. Instead of leaning forward or backwards, players speed up by pumping their Wii remotes as if they were holding ski poles and were jabbing them into the ground in order to gain forward speed. In addition to offering a more realistic use for the controllers, it also provides an upper body workout. Instead of being penalized for missing a gate, we modified it so that players had to successfully pass through a gate before the next gate is generated. To ski through a gate the player needs to hold the lean in the target direction for five consecutive seconds. After passing a gate, haptic feedback stops and a sound is played. Players slow down when going through a gate and players need to speed up between gates using their virtual ski poles, as indicated using audio cues. After passing through six gates we report the player's time using speech. It takes approximately one minute to play the game similar to the original Wii Ski Slalom. Final play-testing with volunteers found our version to be playable and entertaining.

4. STUDY

A user study was conducted at a summer sports camp for children who are blind to assess the effectiveness of our skiing game to improve balancing skills.

4.1 Instrumentation

For the user study, we used the Nintendo Balance board and two Wii remote controllers. The game ran on a Windows laptop and provided audio feedback using its internal speakers. The game recorded every play session, where we recorded all values of the sensor board, and the total time it took the player to pass through all the games.

Table 1: Participants' characteristics

Characteristic	**All** $\{n = 11\}$ (σ)
Gender (M/F)	8/3
Height (m)	1.56 (0.13)
Weight (kg)	52.98 (25.56)
Percent Body Fat (%)	18.35 (7.54)

4.2 Participants

We recruited a total of 16 children who were legally blind and were between the ages of 9-16 to participate in our study. Three children ended up not participating and two children only played our game once, which excluded their data from the study. The final data analysis comprised of data from 11 participants (3 females, average age 13 years 2 months, SD= 2 years 3 months) who played the game two or more times. Children's height and weight was measured using standard anthropometric techniques. Table 1 lists the details. Body fat was measure by bio-impedance using a body fat scale. Parents and participant consented to the study prior to participation.

4.3 Procedure

User studies were held over the course of three days. Every day during the evening, there were two hours of "free time" in which children could engage in their own activities. Children that consented to participate in our user study were given the option to come play our video game during that time slot. User studies were conducted in a quiet room where we had two laptops available for children to play the game. An observer was present at each laptop. The first time children received a brief tutorial on how to play the game and we let children familiarize themselves with the balance board and controllers used to play the game. The observer provided tactile guidance to indicate to children how far to lean as to successfully ski through a gate. After the initial instruction, children played the game at least one time and we informed children that they could come back over the next two days and play the game as often as they wanted.

4.4 Results

All analyses were conducted with Stata v.12. Our analyses focused on average time to target balance, e.g., the time from when a gate was indicated using haptic feedback to the time when the player holds their weight in the target balance direction. Data were log transformed to correct for the skewness in the analyses then transformed back for clarity of interpretation. Eleven children played the game on average 5.73 times over three days (SD=3.41). A t-test was used to test if there was a change in average time to target balance (over six gates) between the first trial to the last trial. The results indicated the average time to balance significantly decreased from the first trial (X=2.135 sec, SD=.002) to the last trial (X=1.013 sec, SD=.001) ($\boldsymbol{t}_{10} = 3.25$, $p < .05$). The average balance time in the first trail is estimated to be 2.11 times greater than in the last trail (95% confidence:1.26 to 3.51 times). A linear regression was used to test the relationship between the number of trials completed and average balance time ($\boldsymbol{F}_{1,10} = 9.27$, $p < .05$). A robust cluster variance estimator was used in the regression of the 60 trials, clusters were grouped by the individual player. Results indicate that for each trial played there was a significant decrease in the average time to balance ($\boldsymbol{b}_1 = -.97, \boldsymbol{t} = -3.05$, $p < .05$).

5. DISCUSSION

For an objective measurement of an improvement in balancing skills it would have been better to use a standardized balance test, such as a unipedal stance test [11]. Because our user studies were held at a sports camp it would have been difficult to attribute any improvement in balancing skills solely to playing our game, as children were also exposed to other physical activities. Given these constraints, we believe time to balance as measured by our game is a better proxy for overall balancing skills. Though we did not perform a qualitative study like Eyes-Free Yoga [10], all children that played our game expressed really enjoying playing our game, with five children playing the game more than 8 times over three days. Controller-less input systems, such as using the Kinect have become a popular form of input for playing video games, but they may be difficult to use by players who are blind as it requires players to keep facing the Kinect sensor, which may be difficult to do without being able to see the sensor [9]. Our game uses motion-sensing controllers capable of providing haptic feedback and a pressure sensitive input controller. We believe this setup allows for a more "tangible" game experience that doesn't require players to keep track of an external sensor. Though game controllers were added to the game to allow for haptic feedback, we were able to seamlessly integrated them into the gameplay by using them as ski poles. Though we had some initial concerns about the balance board due to its height, we did not observe any children falling of the board and injuring themselves.

6. FUTURE WORK

Based on our results, we are confident other Wii Fit balance games could be made accessible by following the same strategies as used to design our skiing game. For some games (Soccer Heading) it may be difficult to incorporate the use of the motion-sensing controllers into the gameplay, but for other games (Tightrope Walk, Ski Jump) this should be easy. Future work will focus on evaluating our game with blind elderly. With an aging baby boomer generation the number of people with visual impairments is expected to double in the next decade. Individuals who are blind have poor balancing skills and a higher risk of falling, especially blind elderly. There is strong evidence that hip fractures substantially increase the risk of morbidity in the elderly. One can argue that exergames that improve balance for this vulnerable population could potentially save lives, though this may require designing different types of games that resonate better with the interests of elderly gamers [16].

7. CONCLUSION

Children who are blind are at greater risk of falling due to poor balancing skills. Exergames that use a popular commercially available pressure sensitive input controller (Wii Balance Board) have demonstrated that they can improve postural control in children with poor motor skills. Because these games typically rely on being able to see visual cues, we developed an accessible skiing exergame that can be played using audio and haptic feedback. A user study with 11 children at a sports camp for children that were blind, found a significant improvement in balancing skills when playing our game over a number of days. Our work provides general insights to game developers on how to make exergames accessible to players who are blind.

8. ACKNOWLEDGMENTS

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