VI-Tennis: a Vibrotactile/Audio Exergame for Players who are Visually Impaired

Tony Morelli
University of Nevada
Department of CS&E
Reno, Nevada
morelli@unr.edu

John Foley
SUNY Cortland
Department of Phys. Ed.
Cortland, NY
foleyj@cortland.edu

Luis Columna
SUNY Cortland
Department of Phys. Ed.
Cortland, NY
columnal@cortland.edu

Lauren Lieberman
SUNY Brockport
Department of Kinesiology
Brockport, NY
llieberm@brockport.edu

Eelke Folmer
University of Nevada
Department of CS&E
Reno, Nevada
efolmer@unr.edu

ABSTRACT

Lack of physical activity is a serious health concern for individuals who are visually impaired as they have fewer opportunities and incentives to engage in physical activities that provide the amounts and kinds of stimulation sufficient to maintain adequate fitness and to support a healthy standard of living. Exergames are video games that use physical activity as input and which have the potential to change sedentary lifestyles and associated health problems such as obesity. We identify that exergames have a number properties that could overcome the barriers to physical activity that individuals with visual impairments face. However, exergames rely upon being able to perceive visual cues that indicate to the player what input to provide. This paper presents VI Tennis, a modified version of a popular motion sensing exergame that explores the use of vibrotactile and audio cues. The effectiveness of providing multimodal (tactile/audio) versus unimodal (audio) cues was evaluated with a user study with 13 children who are blind. Children achieved moderate to vigorous levels of physical activity- the amount required to yield health benefits. No significant difference in active energy expenditure was found between both versions, though children scored significantly better with the tactile/audio version and also enjoyed playing this version more, which emphasizes the potential of tactile/audio feedback for engaging players for longer periods of time.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: Miscellaneous—*Haptic I/O*

Keywords

Exergames, Visually Impaired, Audio, Tactile, Health.

1. INTRODUCTION

Individuals with visual impairments are at greater risk for developing serious health problems due to lower levels of physical activity [16, 26]. Especially children with visual impairments tend to exhibit lower performance in motor skills, lower levels of physical activity and fitness, [16] and higher levels of obesity [20]. Poor self-rated health has even been linked to higher suicide rates [8] among adults with visual impairments.

Barriers to physical activity that individuals with visual impairments face include: (1) social opportunities, such as lack of exercise partners or sighted guides with whom to exercise [26]; (2) safety concerns of parents/teachers/ themselves and fear of injury while exercising [16]; and (3) self barriers, such as fear of being mocked while exercising, and a general lack of physical activities to choose from [28].

Exergames are video games that use exertion-based interfaces [2] to promote physical activity, fitness, and gross motor skill development. Although the first exergames date back to 1982 [27], only recently have they generated wide spread interest, largely due to the commercial availability of affordable hardware, advances in controller technology, increased ease of use, and the opportunity to exercise at home with family or friends.

Exergames may be powerful tools in the fight against obesity [25]. For individuals who are visually impaired, exergames may the have potential to reduce health disparities as we identify that they have some unique properties that could overcome the identified barriers to physical activity because: (1) exergames do not require an exercise partner or sighted guide to be present; (2) exergames are performed in place, which minimizes the risk of injury; (3) the ability to play the same games as their peers, with their peers or family, may increase socialization; and (4) access to exergames significantly increase their existing exercise opportunities.

The benefits of using exergames for individuals with visual impairments have not been investigated as they face barriers when trying to play exergames. Most video games rely on eye-hand coordination and provide visual cues indicating what input needs to be provided. As players with visual impairments have limited or no ability to perceive these cues, they cannot determine what input to provide.

This paper presents VI Tennis, an exergame that can be played by players who are visually impaired. The next section provides background and related work. Section 3 discusses the design and tradeoffs made for VI Tennis. Section 4 presents the results of a user study and section 5 discusses our experiences. Section 6 presents areas for future research and the paper is concluded in Section 7.

2. BACKGROUND AND RELATED WORK

Exergames are strongly related to video games, however, whereas video games typically only involve fine motor skills of the hands, exergames involve gross motor skills [2] –such as running, kicking, hitting and throwing– and that involve whole body motions. Popular commercial exergames include: (1) Konami's Dance Dance Revolution in which players match visual cues that scroll on screen to positions on a pressure sensitive dance pad; (2) Nintendo's Wii Sports in which players emulate playing tennis, bowling, boxing, golf, baseball through gesture recognition using a handheld motion sensitive controller called a Wii remote; and (3) Sony's EyeToy Kinetic which superimposes animated objects to be punched and kicked over a video image of the player which is captured with a camera. Though exergames have been criticized for yielding energy expenditures not as high as traditional forms of exercise, recent studies point out that exergames can achieve moderate-to-vigorous-physical-activity (MVPA) [25, 9], the amount of physical activity that yields health benefits. Exergames are often classified by the technology that is used to recognize motion, such as cameras, accelerometers, and custom controllers such as dance mats, exercise bikes, and heart rate monitors. In this paper, exergames are distinguished by the type of gameplay:

- **Pattern-matching** exergames such as Dance Dance Revolution and EyeToy Kinetic require the player to match lower or upper body movements, such as dance steps or punches, to visual cues [23]. Music plays an important role in these games as a round of gameplay is tied to a song and patterns in the music are used to facilitate pattern matching.
- **Sports** based exergames, such as Wii Sports, emulate playing sports using motions (swinging, punching) that resemble the way these sports are played.
- **Pervasive** exergames such as Fish'n'Steps [17] decouple the physical activity provided by the player from directly manipulating something in a game, but rather they accumulate the physical activity and allow the player to expend it in the game at a later time. Typically such games are played competitively.

Playing video games is a challenge for players who are visually impaired as video games provide predominantly visual feedback that the player must interpret to determine what input to provide [33]. Though games may provide audio or tactile cues, this generally doesn't contain sufficient information to determine *what* input to provide and *when* [33]. Because games are typically entirely visual, they lack any textual representation that can be read with assistive technology such as a screen reader or tactile display. These limitations affect players with the most severe forms of visual impairments (legally blind and totally blind) more than players who are partially sighted or who have low vision. For these players it may still be possible to play the game on a large display or make the game accessible using operating system supported accessibility features such as a magnifier or high contrast color schemes.

In the past decade there has been an active movement to create games that can be played without visual feedback [33], for example using audio feedback. An extensive overview of such games can be found on `http://audiogames.net`. No exergames exist that can be played by players who are blind, though we identified four games that have elements of gameplay that are closely related to exergames:

- Finger Dance [18] is a music game, which uses the pattern matching used in Dance Dance Revolution. Finger Dance uses four different audio cues that the player must match by pressing the corresponding keys on the keyboard in sequence with the music that is playing.
- AudiOdyssey [11] is a music game in which players receive audio instructions and provide gestures with a Wii Remote, to create and record musical beats. The player can then layer these recordings to create complex musical tracks.
- Blind Hero [32] is an accessible version of Guitar Hero; a pattern matching music game in which players emulate playing of rock music using a guitar shaped controller. Blind Hero uses vibrotactile cues provided with a haptic glove to overcome the limitation of being able to use audio due to the presence of music.
- Rock Vibe [3] is an accessible version of Rock Band, a pattern matching music game. Rock Vibe allows for playing drums using tactile cues provided to the arms.

A survey [33] of strategies used in games accessible to players who are blind, revealed that most games use a combination of audio techniques, ranging from speech and audio cues to sonification based techniques, e.g., the modulation of acoustic properties such as volume, frequency or timbre. Only recently, the use of vibrotactile feedback was successfully explored for a memory game [24] and [32, 3] for music games. Exergames and video games have significant differences and it is important to elicit these in order to understand what strategies are feasible to employ to make exergames accessible to players who are visually impaired:

- **Music** plays a dominant role in pattern matching based exergames [23], but its presence limits the use of audio based feedback, as this may interfere with the music and players may find this to be detrimental to the game experience [32].
- **Socialization** is an important aspect of exergaming [6]. Exergames are often played with friends or family. Being able to talk with other players is difficult when player must focus on interpreting audio-based forms of feedback such as audio cues.
- **Moderate** exercise has a facilitating effect on sensory and motor processes [22]. This effect could be exploited to facilitate exergaming using non-visual forms of feedback. However, studies with players performing choice response tasks while exercising show significantly higher error rates when using audio cues [4]. As an exergame is a form of a choice response task, it may indicate that the use of audio cues could be detrimental to the players' performance.

3. VI TENNIS

The active energy expenditure that a player can achieve with an exergame is directly related to the gameplay experience [7]. Consequently an exergame that is not fun to play is unlikely to engage the player in physical activity for long periods of time. Exergames differ due to different types of stimuli, rules, and behavioral requirements –factors that contribute to the game experience [2]. These properties are intrinsically determined by the nature of the exergame, such as a sport or activity, but also through reinforcement mechanisms such as rewards, points, and positive visual and audio feedback [2]. To mitigate our research on developing an accessible interface for exergames from such intricate dependencies, we modified an existing exergame rather than developing a new accessible exergame with unproven gameplay. Wii Sports is a popular exergame that emulates playing tennis, bowling, boxing, golf, and baseball through a handheld motion sensitive controller called a Wii Remote. The Wii remote is an inexpensive controller that, in addition to its pointing and motion-sensing abilities, includes a speaker, a rumble (vibrotactile) feature, and an expansion port for additional input devices. Using a handheld Wii remote, players play each Wii Sport game using motions similar to the sport it simulates is played; for example, in Wii Baseball, players swing their arms holding the Wii Remote like a baseball bat.

Studies with adolescents playing Wii Sports games [12] show that players' energy expenditure is significantly higher than when playing sedentary video games. Of the five Wii sports games, the tennis game achieves the highest energy expenditure. Though other exergames such as Dance Dance Revolution have yielded higher levels of energy expenditure in studies [9], these games typically involve whole body motions and/or pattern matching. Rather than solving three problems at the same time, we limit our research to exploring providing non-visual forms of feedback that will allow a user who is blind to engage in physical activity using upper limb motion. This type of feedback could provide the basis for developing exergames that allow their players to engage in higher levels of activity using pattern matching or whole body motions.

3.1 Wii Tennis Gameplay & Feedback

Wii Sports tennis (Wii Tennis) is played as follows. Players participate in a game of doubles, where four tennis players are visible on the screen (See figure 1). Up to four players can play this game, where each player controls a tennis player. One or two players can also team up against computer controlled players. The player simulates hitting a tennis ball by swinging their Wii remote similar to swinging a tennis racket at the appropriate time. Players either serve or return the ball depending on whose turn it is to serve (see figure 1 left and right). Wii Tennis registers forehands, backhands, volleys, lobs, slices, spin and power depending on how fast the user swings and at what angle. Though players can aim the ball in a particular direction, Wii Tennis does not offer a spatial challenge but only a temporal challenge, as Wii Tennis automatically moves players into position and players only control the swinging of the racket. Wii Tennis provides visual, audio and tactile feedback. For example, the speed and distance of the tennis ball is displayed; players hear the sound of the ball bouncing and feel vibrotactile feedback after they successfully hit the ball. Two types of feedback [33] are distinguished: (1) `primary` cues require the

Figure 1: Wii Sports Tennis: (left) Player serving the ball (right) Player returning the ball.

player to respond in a certain way as they indicate *what* to do and *when*, for example, the visualization of an approaching ball indicates what to do (prepare to return the ball) and when (when the ball is close to you); and (2) `secondary` cues such as reinforcement feedback [2] indicating whether the player's provided response was correct, such as a cheering crowd after scoring a point or a vibrotactile buzz after hitting the ball successfully.

When players learn to play a game, a cognitive model of the game is created, where in-game actions are mapped to preceding cues. To be able to play a game successfully one must: (1) have a mental model of how to play the game; and (2) be able to perceive primary cues [33]. Cues can further be `discrete`, such as the sound of the ball bouncing or `continuous` such as the visualization of the ball. Figure 2:top shows an event graph with all cues that Wii Tennis provides, and which we explain further in section 3.3.

3.2 VI Tennis Gameplay

Because Wii Sports itself cannot be modified, we created a PC game called Visually Impaired (VI) Tennis using Microsoft's XNA framework and which communicates with a Wii remote using a Bluetooth. The gameplay of VI Tennis is modeled after Wii Tennis. Players participate in a game of singles where each tennis player is positioned at the baseline. Players can use forehand or backhand strokes but no volleys, slices, spins or lobs. The tennis ball also moves with constant speed and no direction can be given to keep things simple. Players can play against another player or against a computer-controlled opponent. Similar to Wii Tennis, VI Tennis implements dynamic difficulty adjustment [10] (DDA) to keep the ability of the computer-controlled player at the same level as the player and which for accommodating varying abilities as players who are blind may have never played a video game or tennis before. DDA adjusts difficulty every 5 points and if the difference in score is greater than 3, the ability of the computer-controlled player is either increased or decreased. The level of the computer-controlled player is set between 1 and 9 (start at 6) and represents the probability out of 10 that the computer will return the ball. VI Tennis further implements a tally scoring system, which is easier to understand. Players can only score points when serving the ball and if the player does not swing, or swings too late the player loses a point. Players are not penalized for swinging too early, i.e., if players swing too early, they can still swing again as long as VI Tennis detects a swing in the allotted time frame. The sensitivity and timing of the controls of VI Tennis are based on Wii Tennis.

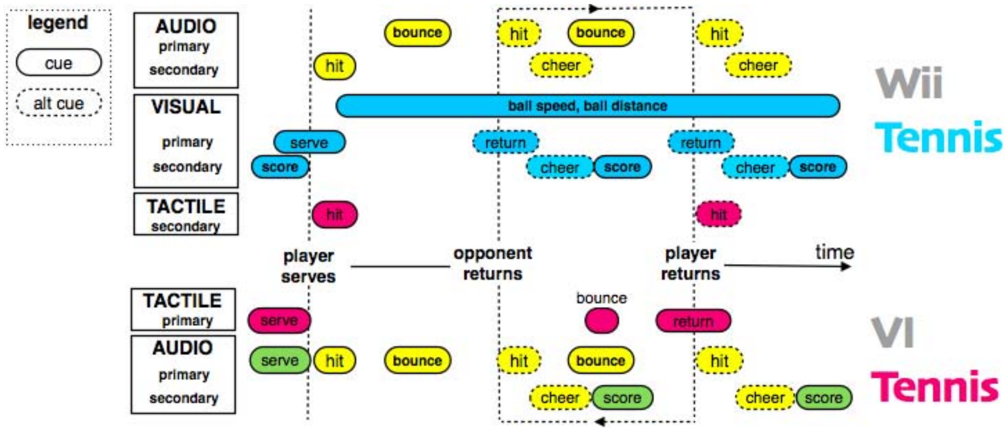

Figure 2: Primary, secondary, audio, visual and tactile cues in Wii Tennis (top) and VI Tennis (bottom).

3.3 VI Tennis Feedback

Figure 2:top shows all primary and secondary, visual, tactile and audio cues involved in the sequence of: (1) the player serving; (2) the opponent returning; and (3) the player returning the ball. The event of the opponent serving is identical to the opponent returning. Dashed events indicate alternative cues where two different events can happen, for example, the player either successfully returns the ball or the player misses it, in which case different feedback is provided. To be able to successfully play a game, players must be able to perceive primary cues [33]. We identified that all primary cues in Wii Tennis are either visual and/or audio and tactile feedback is only used as a secondary cue. An event such as the bouncing of the ball may be encoded in two modalities, e.g., a visual and audio cue. When a cue is encoded in two modalities, a cue from one modality could be left out, as it will still allow for being able to play the game -though possibly with a lower performance- because multimodal cues presented simultaneously can be detected at lower thresholds, faster and more accurately than when presented separately in each modality [19].

Primary visual cues must be substituted with non-visual cues to allow a player who is blind to play video games [32]. Sensory substitution is challenging due to the limited spatial and temporal resolutions of audio and tactile modalities [5]. Patterns for encoding information tactually generally include intensity, duration, temporal patterns, and spatial locations [29]. Encoding information with audio may include speech, audio cues or sonification. Video games further require quick responses from their players, which limits the use of complex encoding schemes as players may not be able to distinguish these fast enough. In section 2 we identified that the application of audio feedback is limited because of socialization or music constraints.

Constraints we accommodated during the design of VI Tennis were: 1) preserve the gameplay of Wii Tennis as much as possible; 2) minimize the use of additional audio and therefore prefer tactile encoding of cues; and 3) keep the number of tactile/audio cues small; or facilitate multimodal encoding of primary cues to increase their successful recognition.

The following four steps were taken and we play tested our VI Tennis prototype between each step with an adult who was blind.

1. Implement primary and secondary audio and tactile cues. We first ported Wii Tennis' primary and secondary audio and tactile cues. This prototype turned out to be somewhat playable. Though there is no cue indicating exactly when to hit the ball, after some time, our subject was able to deduce this from the timing between the audio cues that indicate the ball's speed and distance, such as the ball bouncing and opponent serving or returning the ball. Ball speed depends on how hard it is hit. A problem occurs when the player hits the ball harder, as this disrupts the timing between cues, which makes it harder to deduce when to hit the ball.

2. Substitute primary unimodal visual cues. Visual multimodal cues, such as the bouncing of the ball, are not substituted as these are encoded as audio already. We explored conveying the ball's speed and distance through modulation of the pitch of a tone. Though this worked, the subject found this to interfere too much with the ability to perceive the other audio cues. We then explored the use of vibrotactile cues, but had to remove existing secondary tactile cues to do so. A Wii Remote provides feedback with a frequency of 250Hz, whose intensity can be varied only by pulsing the motor activation. It is difficult to provide a continuous cue as perceiving changes in intensity becomes difficult as the subject's hand becomes numb from being exposed to vibrotactile feedback continuously. Instead, two discrete vibrotactile cues were used: (1) a (250ms) cue indicated the ball bouncing; and (2) a (2000ms) cue indicating the timeframe in which the ball must be returned.

3. Ensure multimodal encoding. Some cues in Wii tennis are encoded in two modalities (see Figure 2:*top*). To allow for the same rate of recognition, the speed of the ball was made constant, to allow players to deduce also when to hit the ball from the timing between the preceding audio cues. We explored providing an audio cue that tells when to hit the ball, but this simplified the gameplay too much.

4. Substitute visual secondary unimodal cues. Speech cues were added that indicate to the player whose turn it is to serve, after play testing revealed that our subject found this difficult to determine. Score is displayed visually after each point in Wii tennis and in VI Tennis this is implemented using speech cues.

Figure 2:*bottom* shows the resulting primary and secondary cues implemented in VI Tennis.

Figure 3: Children who are blind playing VI Tennis.

4. USER STUDY

VI Tennis was evaluated at Camp Abilities, a developmental sports camp for children who are visually impaired, blind, or deaf/blind, and which is held annually at the College at Brockport. The goal of this user study was to evaluate whether VI Tennis allows children to engage into MVPA. We were specifically interested in evaluating the effectiveness of providing vibrotactile cues in addition to audio cues, motivated by the observation that multimodal cues are recognized at higher rates [19]. Two versions of VI Tennis were used in the study, one providing audio/tactile cues and one with the tactile cues turned off. Both versions were play tested before the study to ensure playability. We defined the following hypotheses:

H0: Players who are blind achieve the same performance with tactile/audio cues as with audio cues.

H1: Players who are blind achieve the same levels of active energy expenditure with tactile/audio as with audio cues.

4.1 Participants

Children were recruited prior to arriving at Camp Abilities and were classified according to the sports classifications of the U.S. association of Blind Athletes. B1 athletes are totally blind with no functional vision, B2 athletes have travel vision and B3 athletes are legally blind. Four girls and nine boys from the B1 category were selected. Participants with orthopedic impairments were excluded from our study. Parents and adolescents consented to the study prior to participation. Children's height and weight was measured using standard anthropometric techniques. Three children were classified to be obese and three were overweight. Table 1 provides a summary of the participants' characteristics.

4.2 Instrumentation

Active energy expenditure was captured through an Actical omnidirectional accelerometer worn on the child's wrist. Accelerometers have been successfully used to estimate the energy expenditure of activity [31], they do not impede the user's ability to play the game, and they are more suitable to capture energy expenditures of the arm than hip positioned capturing techniques [12]. VI Tennis tracks the player's score and the computer-controlled player's level (CCPL) in a log file for each play session.

Table 1: Participants' characteristics

Characteristic	**All** $\{n = 13\}$ (σ)
Gender (M/F)	9/4
Age (*years*)	12.6 (2.5)
Height (m)	1.54 (0.1)
Weight (kg)	53.2 (17)
Body mass index (kg/m^2)	22.0 (5.4)

Table 2: Average Active Energy Expenditure

Kcal/Kg/Min	**T1** (σ)	**T2** (σ)	**Mean** (σ)
Audio	3.56 (1.1)	4.49 (2.0)	3.99 (1.6)
Audio+Tactile	4.70 (2.3)	3.47 (1.0)	4.03 (1.8)

Table 3: Total time spent in MVPA

Minutes	**T1** (σ)	**T2** (σ)	**Mean** (σ)
Audio	9.71 (0.5)	9.5 (0.8)	9.62 (0.7)
Audio+Tactile	9.83 (0.4)	9.71 (0.5)	9.77 (0.4)

4.3 Experimental Trial

User studies were held over two days. Children were randomly assigned to either group A or B. Group A (n=6) played VI Tennis on day one (T1) and the audio only version on day two (T2). Group B (n=7) played the games in reverse order. Prior to playing the game children were allowed to familiarize themselves with the controller while receiving a verbal tutorial on how to play the game. Children played the game in a quiet room. Children were allowed to play the game for 5 minutes before they were equipped with an accelerometer on their dominant arm. Children played the game for 10 minutes against a computer-controlled player, after which the accelerometer was removed for analysis.

4.4 Results

Players' performance was analyzed using the CCPL. Due to a crash, data for one participant playing the tactile/audio game during trial 2 was lost. Figure 4 shows an overview of the CCPL for both versions and trials for each minute that the game was played including the error rate. Both versions start out at level 6. For both trials, the audio version initially shows a decrease in CCPL, which only starts to increase after 6 minutes. The tactile/audio version shows an increase throughout the ten minutes that the game is played for both trials. Due to the nonparametric nature of the CCPL data, a series of Wilcoxon Signed Ranks Test was performed to analyze whether these results were significantly different. To adjust for multiple testing α was set a priori at 0.01. Data was analyzed in one-minute increments. The tests show that the first significant divergence between the tactile/audio and the audio versions of VI Tennis appeared after 3 minutes of game play ($Z_{2,12} = 2.83$ $p < 0.01$). Because of these results, H0 was rejected. Previous research has shown little difference in physical activity levels between male and females [31]. This observation, along with the limited sample sizes typical in disability research, motivated us to collapse gender into one group. Table 2 shows the average Active Energy Expenditure for participants and table 3 shows how many minutes participants were engaged in moderate to vigorous physical activity (MVPA). MVPA and minutes in MVPA were calculated by the Actical Software and is based on the estimated Metabolic Equivalent (MET) values [13]. No significant difference ($T_{2,12} = 0.179$ $p > 0.01$) was detected between both versions, which required us to accept H1.

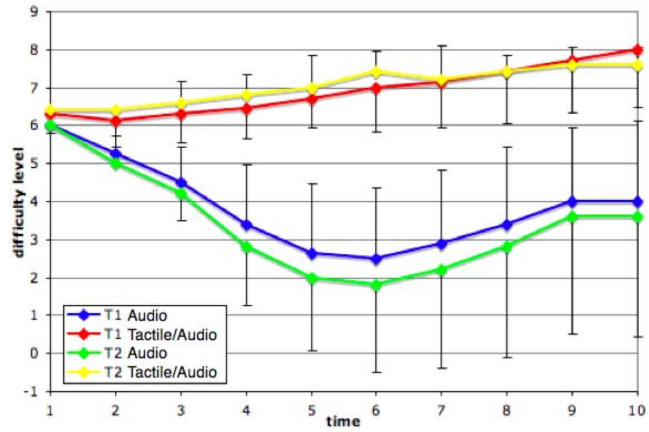

Figure 4: Computer controlled player level (CCPL) for tactile/audio and audio for both trials over time.

4.5 Qualitative Analysis

Qualitative data was collected through interviews held after the second trial. Likert scales for children are recommended to have a limited number of points on the scale or use a visual scale, neither of which is applicable in our study. Because we are performing a comparative analysis, children were asked to participate in an informal one-on-one interview after the second trial. We used non-directed interviews with open-ended questions, for example we asked children to describe the games they played, whether they liked playing each game, which version of the game they preferred and how each game could be made easier for them to play. Interviews lasted between 5 and 15 minutes and were recorded. We later transcribed these recordings and analyzed them to identify recurring themes.

All children were very excited to participate in our user study. Many children had heard about the Wii games from friends. Five children had played video games before and and one child told us she had played Wii Bowling before with help of her parent who provided her with verbal cues on how to play the game.

All (n=13) children expressed feelings of a positive experience playing both versions of VI Tennis. Children stated: *"It was really great!"* and *"I want to play tennis again!"*. After asking what they liked about the game several children mentioned health benefits such as: *"it is good as you get a lot of strength in your arms"* or *"you get to exercise"*. All children preferred the tactile/audio version as they said: *"with sounds is like we have to pay more attention, but with vibrations I just feel it and just hit or swing the remote"*, *"I liked the one that vibrates, because it would do a nice long vrrrrrr" and tell you when to hit."* and *"I like the one that buzzes because I can actually feel this one"*.

Overall children enjoyed playing VI Tennis as they told us: *"We can have fun with other people"* and *"it is really good to play with friends or whoever!"* and *"it's like having fun, and we can do things they can do, like even though we cannot see"* which emphasizes the social and normalization [21] aspects of playing games and exergames in particular. Children did not make any suggestions on how the game could be easier for them to play but two children suggested we should add the ability to play VI Tennis with two players (which had been implemented already).

5. DISCUSSION

5.1 Sensory Substitution

Children scored significantly better with the tactile/audio version of VI Tennis and expressed enjoying this version more than the audio version. A plausible explanation is that the tactile/audio version was easier to play, as the primary cues indicating when to hit the ball are encoded in multiple modalities (tactile/audio), and therefore have a higher chance of being recognized than when these are encoded in one modality [19]. Interviews with children confirmed that it was easier to recognize tactile cues. Audio cues have found to yield higher error rates [4] in studies with choice response tasks while exercising, though children only engaged in brief periods of exercise, it could be of influence. Because the tactile/audio version provides a more engaging experience, it is more likely to engage player in physical activity for longer bouts of time, which may yield larger health benefits.

We found multimodal cues to be more effective than unimodal cues, though, for more complex exergames it may not be possible to facilitate multimodal encoding of primary cues due to the limited temporal and spatial resolution of audio and tactile feedback. A Wii remote contains only one vibrotactor and adding more vibrotactors such as using a tactile suit [14], would be impractical or too costly, which precludes large scale deployment. For VI Tennis a number of tradeoffs were made, such as not being able to hit the ball in a direction or not being able to hit the ball with different speeds. Though some of these features could be added in newer versions of VI Tennis, for this study we found these tradeoffs to be acceptable as the lack of such features was not deemed significantly detrimental to the game experience during the 10 minute trials. The four steps that we used in the sensory substitution will be followed in the adaptation of other exergames as to identify their general validity. Substituting visual primary cues is an essential step to making games accessible, even if this must include removing secondary cues from audio or tactile modalities. We recommend play testing often to identify whether such tradeoffs are detrimental to the game experience. We did not evaluate VI Tennis in the exergaming contexts where the use of audio is limited, for example, when music is present or when players engage in social interaction, though it should be evident that vibrotactile feedback in these contexts is more usable.

5.2 Active Energy Expenditure

No significant difference in active energy expenditure could be detected between both versions. It is more difficult to play the game with audio cues; we observed that children playing the audio only version often started hitting the ball too early -and then not tried to swing again- or they swung too late, and therefore failed returning the ball. Though both versions start at level 6, figure 4 shows that CCPL for audio only initially goes down, and only starts to increase after 6 minutes where in comparison CCPL for tactile/audio increases throughout the 10 minute trial. Because the computer immediately starts to serve again when the players misses the ball, no significant difference in active energy expenditure between a successfully rally and consecutively missing the ball can be detected as in both cases children will still swing their arm. Like real tennis, a significant difference in energy expenditure may be detected if we introduce a brief pause before the computer player starts serving again.

6. FUTURE WORK

6.1 Whole Body Exercise

In our study with VI Tennis, children were able to engage in MVPA, but closer analysis revealed that the majority of this time was spent in moderate -rather than vigorous activity. Because children have higher metabolic rates, the daily-recommended amount of MVPA is 60 minutes for children and 30 minutes for adults [1], although it is advised children engage in vigorous activity at least 3 days per week. The amount of physical activity achieved with VI Tennis may be sufficient for adults but may not be high enough for children. Because exercising at an early age has lifelong benefits [30], future work will focus on researching tactile/audio exergames that yield higher active energy expenditure.

Studies with pattern matching exergames such as EyeToy Kinetic and Dance Dance Revolution have yielded higher levels of MVPA [9, 31]. There are two possible explanations: (1) Wii remote based exergames only involve motions of the dominant arm, whereas pattern matching exergames involve whole body movements; and (2) Sports based exergames such as Wii Tennis and Wii golf are self-paced, whereas pattern matching exergames –due to their reliance on music–are externally paced, and typically performed at a higher pace than sports based exergames.

We seek to facilitate whole body exergaming and pattern matching through whole body tactile/audio motion instructions by using multiple Wii remotes. Players will have a Wii remote strapped to each leg and hold one in each hand. As such, an EyeToy Kinetic based exergame can be developed that provides motion instructions specific to each limb that a Wii remote is strapped to. For example when a cue is provided to a leg, the player must kick their leg forward to destroy an object. Pattern matching may be facilitated if players can successfully memorize sequences of tactile/audio rhythms that are correspond to patterns in the music.

6.2 Sensorimotor Skills

A number of physical activities have been adapted for users with visual impairments [15]. Many of these activities pair a user with a visual impairment with a sighted guide. For example, in tandem cycling, a sighted guide performs the sensorimotor skill (steering) and the user with a visual impairment performs the strength skill (pedaling). Few physical activities exist where individuals with visual impairments can participate in sensorimotor skills and adapted physical education researchers have therefore called for the inclusion of users with visual impairments in sensorimotor skill activities [15]. Tennis is a sensorimotor challenge, but in Wii Tennis this is reduced to a timing based challenge as the game automatically moves the player into position. We seek to explore how a spatial challenge can be added to VI Tennis, for example by indicating with tactile/audio cues to the player whether the ball needs to be returned backhand or forehand. As a larger number of tactile/audio cues will be required to indicate spatial motion instructions, our current research focuses on determining the number of vibrotactile/audio cues that players with visual impairments can comfortably distinguish using one Wii remote. The technology developed for tactile/audio exergaming may eventually be used to make real sports accessible, for example, a tennis racket providing vibrotactile/audio cues could indicate where and when to hit the ball.

6.3 Motor Learning

Children were verbally instructed how to play VI Tennis, but we found that some children did not know or understand how to swing a tennis racket. Verbal instructions are abstract and rely upon a mental model [14] and players with visual impairments may lack such mental models. Though we assisted some children in performing the desired motions during the tutorial, during the trial, we observed them developing completely new ways to swing their racket. The sensitivity of the controls of VI Tennis were based on Wii Tennis, but this did not preclude children from using motions that had lower active energy expenditures than the motions that we taught them. Though it is debatable whether players who are blind should perform the exact same motions as sighted individuals to achieve the same amount of active energy expenditure, it may be useful to adjust the sensitivity of VI Tennis such to take into account the size of the motion made with the controller. Increasing the threshold for detecting a stroke in VI Tennis could avoid players from developing such short cuts. We are also investigating a technique for motor learning that can teach players who are visually impaired how to perform the motions in the exergame, without the aid of a sighted guide.

6.4 Barriers to Physical Activity

Section 1 discusses some of the barriers to physical activity that Individuals with visual impairments face. Once more exergames have been developed; we aim to conduct user studies where individuals with visual impairments can play exergames at their home over a longer period of time. This will allow for evaluating whether exergames can overcome these barriers and whether exergames are viable alternatives to existing physical exercise if it can be determined that they are safer while yielding amounts of active energy expenditure that are considered healthy. In our qualitative analysis of VI Tennis children were only able to play VI Tennis for a total of 30 minutes. Attitudes may be different if our exergames are played over a longer period of time.

7. CONCLUSION

This paper presents VI Tennis, an exergame for players who are visually impaired and which provides tactile and audio feedback. Four steps for sensory substitution are provided which game developers can use to adapt their exergames to the abilities of players who are visually impaired.

The effectiveness of providing multimodal versus unimodal cues was evaluated through a user study with 13 children who are blind. We found that children were able to achieve moderate to vigorous levels of physical activity with a version of VI Tennis that provides tactile/audio cues and audio only cues. No significant difference in active energy expenditure was found between both versions, though children scored significantly better with the tactile/audio version and also expressed enjoying playing this version more, which emphasizes the potential of tactile/audio feedback for engaging players in physical activity for longer periods of time.

Future work will focus on: (1) exploring whole body tactile/audio cues to achieve higher active energy expenditures; (2) adding spatial challenges to VI Tennis to investigate how sensorimotor sports can be made accessible; (3) developing a technique for motor learning; and (4) investigating whether exergames can overcome the barriers to physical activity that individuals with visual impairments face.

8. REFERENCES

[1] Center for disease control, how much activity do you need? http://www.cdc.gov/physicalactivity/everyone/guidelines/children.html.

[2] Adams, M. A., Marshall, S. J., Dillon, L., Caparosa, S., Ramirez, E., Phillips, J., and Norman, G. J. A theory-based framework for evaluating exergames as persuasive technology. In *Proc of Persuasive '09* (NY, USA, 2009), pp. 1–8.

[3] Allman, T., Dhillon, R. K., Landau, M. A., and Kurniawan, S. H. Rock vibe: Rock band®computer games for people with no or limited vision. In *Assets '09: Proc. of the 11th international ACM SIGACCESS conference on Computers and accessibility* (New York, NY, USA, 2009), ACM, pp. 51–58.

[4] Audiffren, M., Tomporowski, P. D., and Zagrodnik, J. Acute aerobic exercise and information processing: energizing motor processes during a choice reaction time task. *Acta Psychol 129*, 3 (Nov 2008), 410–9.

[5] Bach-y Rita, P., and W Kercel, S. Sensory substitution and the human-machine interface. *Trends Cogn Sci 7*, 12 (Dec 2003), 541–6.

[6] Bianchi-Berthouze, N., Kim, W. W., and Patel, D. Does body movement engage you more in digital game play? and why? In *In Proc ACII '07* (Berlin, Heidelberg, 2007), Springer-Verlag, pp. 102–113.

[7] Bogost, I. The rhetoric of exergaming. In *Digital Arts and Cultures (DAC) Conference* (December 2005), IT University Copenhagen.

[8] De Leo, D., Hickey, P. A., Meneghel, G., and Cantor, C. H. Blindness, fear of sight loss, and suicide. *Psychosomatics 40*, 4 (1999), 339–44.

[9] Epstein, L. H., Beecher, M. D., Graf, J. L., and Roemmich, J. N. Choice of interactive dance and bicycle games in overweight and nonoverweight youth. *Ann Behav Med 33*, 2 (Apr 2007), 124–31.

[10] Folmer, E. Usability patterns in games. In *Future Play '06: Proceedings of the 2006 conference* (2006).

[11] Glinert, E., and Wyse, L. Audiodyssey: an accessible video game for both sighted and non-sighted gamers. In *Proc. of Future Play '07* (New York, NY, USA, 2007), ACM, pp. 251–252.

[12] Graves, L., Stratton, G., Ridgers, N. D., and Cable, N. T. Comparison of energy expenditure in adolescents when playing new generation and sedentary computer games: cross sectional study. *BMJ 335*, 7633 (December 2007), 1282–1284.

[13] Heil, D. P. Predicting activity energy expenditure using the actical activity monitor. *Res Q Exerc Sport 77*, 1 (Mar 2006), 64–80.

[14] Lieberman, J., and Breazeal, C. Tikl: Development of a wearable vibrotactile feedback suit for improved human motor learning. *IEEE Transactions on Robotics 23*, 5 (2007), 919–926.

[15] Lieberman, L. *Adapted Physical Education and Sport.* Human Kinetics, Champaign, IL, 2005, ch. Visual Impairments.

[16] Lieberman, L., and McHugh, E. Health-related fitness of children who are visually impaired. *Journal of Visual Impairment & Blindness 95* (2001), 272–287.

[17] Lin, J. J., Mamykina, L., Lindtner, S., Delajoux, G., and Strub, H. B. Fish 'n' steps: Encouraging physical activity with an interactive computer game. In *in Proc. UbiComp 2006* (2006), pp. 261–278.

[18] Miller, D., Parecki, A., and Douglas, S. A. Finger dance: a sound game for blind people. In *Assets '07: Proc. of the 9th international ACM SIGACCESS conference on Computers and accessibility* (New York, NY, USA, 2007), ACM, pp. 253–254.

[19] Miller, J. Divided attention: evidence for coactivation with redundant signals. *Cogn Psychol 14*, 2 (Apr 1982), 247–79.

[20] Montero, P. Nutritional assessment and diet quality of visually impaired spanish children. *Ann Hum Biol 32*, 4 (2005), 498–512.

[21] Nirje, B. The basis and logic of the normalization principle. *Journal of Intellectual & Developmental Disability 11*, 2 (1985), 65–68.

[22] Paas, F. G., and Adam, J. J. Human information processing during physical exercise. *Ergonomics 34*, 11 (Nov 1991), 1385–97.

[23] Parker, J. R., and Heerema, J. Musical interaction in computer games. In *In Proc Future Play '07* (New York, NY, USA, 2007), ACM, pp. 217–220.

[24] Raisamo, R., Patomäki, S., Hasu, M., and Pasto, V. Design and evaluation of a tactile memory game for visually impaired children. *Interact. Comput. 19*, 2 (2007), 196–205.

[25] Sell, K., Lillie, T., and Taylor, J. Energy expenditure during physically interactive video game playing in male college students with different playing experience. *J Am Coll Health 56*, 5 (2008), 505–11.

[26] Shapiro, D. R., Moffett, A., Lieberman, L., and Dummer, G. M. Perceived competence of children with visual impairments. *Journal of Visual Impairment & Blindness 99*, 1 (2005), 15–25.

[27] Sinclair, J., Hingston, P., and Masek, M. Considerations for the design of exergames. In *In Proc. GRAPHITE '07* (New York, NY, USA, 2007), ACM, pp. 289–295.

[28] Stuart, M., Lieberman, L., and Hand, K. Beliefs about physical activity among children who are visually impaired and their parents. *Journal of Visual Impairment and Blindness 100*, 4 (2006), 223–234.

[29] Van Erp, J. Guidelines for the use of vibro-tactile displays in human computer interaction. In *Proceedings of EuroHaptics* (2002), pp. 18–22.

[30] Warden, S. J., Fuchs, R. K., Castillo, A. B., Nelson, I. R., and Turner, C. H. Exercise when young provides lifelong benefits to bone structure and strength. *J Bone Miner Res 22*, 2 (Feb 2007), 251–9.

[31] Yang, S., and Foley, J. T. Comparison of mvpa while playing ddr and eyetoy. *Research Quarterly for Exercise and Sport 79*, 1 (2008), 17.

[32] Yuan, B., and Folmer, E. Blind hero: enabling guitar hero for the visually impaired. In *Assets '08: Proc. of the 10th international ACM SIGACCESS conference on Computers and accessibility* (New York, NY, USA, 2008), ACM, pp. 169–176.

[33] Yuan, B., Folmer, E., and Harris, F. C. Game accessibility; a survey. *Universal Access in the Information Society 10*, 1 (2010), 88–111.