VI-Bowling: A Tactile Spatial Exergame for Individuals with Visual Impairments

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ABSTRACT

Lack of sight forms a significant barrier to participate in physical activity. Consequently, individuals with visual impairments are at greater risk for developing serious health problems, such as obesity. Exergames are video games that provide physical exercise. For individuals with visual impairments, exergames have the potential to reduce health disparities as they may be safer to play and can be played without the help of others. This paper presents VI Bowling, a tactile/audio exergame that can be played using an inexpensive motion-sensing controller. VI Bowling explores tactile dowsing: a novel technique for performing spatial sensorimotor challenges, which can be used for motor learning. VI Bowling was evaluated with six blind adults. All players enjoyed VI Bowling and the challenge tactile dowsing provided. Players could throw their ball with an average error of 9.76 degrees using tactile dowsing. Participants achieved an average active energy expenditure of 4.61 kJ/Min while playing VI Bowling, which is comparable to walking.

Keywords

Health, Exergames, Visual Impairments, Haptics

Categories and Subject Descriptors

H.5.2 [**User Interfaces**]: *Haptic I/O*

General Terms

Human Factors, Performance

1. INTRODUCTION

Individuals with visual impairments have fewer opportunities to engage in physical activities that provide the amounts and kinds of stimulation to maintain adequate fitness and to support a healthy standard of living [21]. Consequently, they suffer from health problems such as fatigue, obesity [24], deconditioning, and pain that are all considered preventable [26]. Poor self-rated health has been linked to higher suicide rates among adults with visual impairments [8]. Obesity is recognized as a national problem as recent studies show that the current generation of children in the US are expected to have shorter life expectancies than their parents as they develop obesity related illnesses, such as diabetes and heart diseases, at a younger age than their non obese peers [12]. Obesity among elderly is also on the rise, and as their number is expected to increase over the next decade, so will the number of obesity induced premature deaths [11]. Efforts to reverse or attenuate these increasing levels of obesity have been only marginally effective. Obese elderly are also twice as likely to lose their sight [18], due to an increased chance of developing cataracts, the main cause for blindness. Loss of sight has further identified to significantly reduce their remaining years of life [19].

Barriers to physical activity that individuals with visual impairments face include the following: (1) social opportunities, such as lack of exercise partners or sighted guides with whom to exercise [28]; (2) safety concerns and fear of injury while exercising [21]; and (3) self barriers, such as fear of being ridiculed when exercising, a general lack of activities to choose from, and not knowing what to do [29].

Though video games have been identified to be a contributing factor to obesity [14], a new generation of video games called *exergames* have been found to stimulate greater energy expenditure than when playing sedentary video games [16]. Exergames have the potential to reduce health disparities [25], as they have some unique properties that could allow for individuals with visual impairments to overcome the barriers to physical activity they face 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; and (3) the ability to play the same games as their peers, either alone or with their peers and family, could increase socialization and normalization.

Access to exergames could significantly increase existing exercise opportunities for individuals with visual impairments [25], yet existing exergames rely upon their players to be able to perceive visual cues that indicate what input to provide and when [32]. This paper presents VI Bowling, an exergame that can be played using vibrotactile and audio cues. The next section provides background and discusses related work. Section 3 discusses the design of VI Bowling and introduces tactile dowsing. Section 4 presents the results of a user study conducted with six individuals with visual impairments and section 5 discusses the results. Section 6 outlines areas for future research and the paper is concluded in Section 7.

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2. BACKGROUND AND RELATED WORK

Many adapted physical activities for individuals with visual impairments pair a user with visual impairments with a sighted guide [20]. 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 users with visual impairments can perform sensorimotor skills and adapted physical education researchers have therefore called for the inclusion of users with visual impairments in sensorimotor skill activities [20]. Sensorimotor-based physical activities are difficult to adapt, as they are mostly visio-spatial [22].

Exergames have generated mass appeal, largely due to commercial availability of affordable hardware, advances in controller technology, increased ease of use, and the opportunity to exercise at home with family or friends. Popular commercial exergaming titles 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) Sony's EyeToy Kinetic which superimposes animated objects to be punched and kicked over a video image of the player captured with an external camera; and (3) Nintendo's Wii Sports and Wii Fit in which players emulate sports and fitness through gesture recognition using a motion sensitive controller called a Wii Remote.

Though exergames have been criticized for yielding energy expenditures not as high as traditional forms of exercise [16], recent studies show that exergames achieve moderate-to-vigorous-physical-activity (MVPA) [9, 30, 15], the amount of physical activity that yields health benefits [1]. Exergames have further been identified to improve balance [5], participation in physical exercise [9], and socialization skills [6].

Playing exergames is a challenge for players who are visually impaired, as exergames typically only provide visual cues, which the player must interpret to determine what to do. For example, dance games such as Dance Dance Revolution use visual cues that scrolls down the screen that indicates in which direction the player must step and when. Though exergames provide audio feedback, this generally doesn't contain sufficient information to determine *what* input to provide and *when* [32].

This limitation affects players who are legally blind and totally blind more than players who are partially sighted or those with low vision, as these individuals have been identified to be able to play existing exergames through small modifications, such as increasing the contrast or volume of the game [13]. Games for individuals who are blind predominantly use audio based sensory substitution techniques [4] such as speech, (spatial) audio cues or sonification [32].

In previous work, two limitations of using audio sensory substitution techniques to exergames were identified:

- Exergames are often played in *social contexts* [6], e.g., with family or friends where the use of audio may interfere with being able to socialize.
- *Music* plays a facilitating role in dance or combat based exergames as the input the player needs to provide is typically matched with the rhythm and beats of the song. Audio may interfere with the music, which players may find to be detrimental to their gameplay experience [31].

Because no accessible exergames existed, the use of tactile feedback was explored in two projects to identify whether it could be a suitable sensory substitution technique.

Figure 1: Participants with visual impairments playing Blind Hero (left); and VI Tennis (right).

Blind Hero [31] is an accessible version of the pattern matching music game Guitar Hero in which players play rock music using a guitar shaped controller (See Figure 1). Due to the presence of music, Blind Hero provides vibrotactile cues provided with a haptic glove that indicate what input to provide and when. User studies with three blind players showed they could successfully play the game and they could memorize input sequences using vibrotactile feedback.

VI Tennis [25] is a tennis-based exergame that implements the gameplay of a popular exergame (Wii Sports). VI Tennis simulates playing tennis using a motion sensitive controller (see Figure 1). VI Tennis provides vibrotactile and audio cues that indicate what input to provide. A unimodal (audio) and a multimodal (vibrotactile/audio) version of VI Tennis were evaluated at a sports camp for blind children, with 13 children. No significant difference between both versions of the game was detected with regard to active energy expenditure (AEE), e.g., the average AEE for participants for both versions was 9.6 kJ/Min. Players' performance and attitudes towards the multimodal version were significantly higher than the unimodal version, which demonstrated the feasibility of vibrotactile feedback as an effective sensory substitution technique for exergames.

The user study with VI Tennis revealed that congenitally blind children often lack cognitive models of how the game of tennis is played. Their measured active energy expenditure was lower, due to their inexperience with performing the expected motions correctly. Decreasing the sensitivity of the controls or implementing an approach for motor learning was suggested to aid the independent use of exergames [25].

Exergames involve sensorimotor skills that are spatial-temporal and which predominantly rely on vision. VI Tennis is an exception as it only has a temporal skill component, as players only control when to swing their racket. Because it is important to include individuals with visual impairments in performing sensorimotor activities [20] that involve both temporal and spatial challenges, the next section presents an approach called tactile dowsing, which allows players with visual impairments to perform spatial challenges using vibrotactile feedback.

3. DESIGN OF VI BOWLING

Bowling is an anaerobic physical activity in which players score points by rolling a bowling ball along a flat surface into standing wooden objects called pins. This sport is primarily visual-spatial as players aim and throw their bowling ball into a particular direction to strike the pins. Bowling is self paced and it's temporal challenge is relatively small, which makes bowling a good candidate physical activity for exploring exclusively how spatial challenges in exergames can be made accessible to users with visual impairments.

The amount of active energy expenditure that a player can achieve with an exergame is directly related to the gameplay experience [7]. An exergame that is not fun to play is unlikely to engage the player in physical activity for long periods of time. Factors that have identified to contribute to the gameplay experience are different types of stimuli, rules, and behavioral requirements [2]. These factors are intrinsically determined by the nature of the exergame, such as the sport it emulates, but also reinforcement mechanisms used, such as rewards, points, and positive visual and audio feedback. To insulate the research on exploring techniques for making spatial challenges accessible from these intricate game dependencies, the gameplay of an existing exergame was implemented, rather than developing a new game from scratch with unproven gameplay.

Ten-pin bowling exists as an exergame as part of the popular Nintendo Wii Sports exergame (see Figure 2), which is played with a Wii Remote. Wii Bowling has been found to yield an average active energy expenditure of 11.7 kJ/min [16], which is of high enough intensity to contribute towards the recommended daily amount of exercise in adults [1]. Because Wii Bowling was found to be particular successful in promoting regular exercise among senior citizens [17], an accessible version of this exergame could be attractive to individuals with visual impairments, as elderly constitute a significant portion of the population of visually impaired.

The core gameplay mechanics of Wii Bowling consist of the following two discrete consecutive steps:

1. Players `aim` where to throw their ball by manipulating a visual cue with the arrow keys on their Wii remote (see Figure 2). This is primarily a spatial challenge that depends on the visual feedback that the game provides on how many pins are still standing up.

2. Players `throw` the ball using the Wii remote using a motion that resembles how bowling is played. The player raises the Wii remote up in front of them while holding the trigger button on the controller using their index finger. The player then moves the Wii remote down alongside their body backwards and then swings the controller forward. Players then release their bowling ball by releasing the trigger button on their controller. This is primarily a temporal challenge, as the game does not take into account the direction in which the controller is moved. Players can add spin to their ball by twisting the Wii remote to the left or to the right as they release the ball.

Players repeat these two steps twice (two balls per frame) and typically a game consist of ten frames. Players can play against up to 8 friends where Wii remotes can be passed around between players. Once the ball has been thrown, it can end up as a gutter ball or successfully strike a number of pins down.

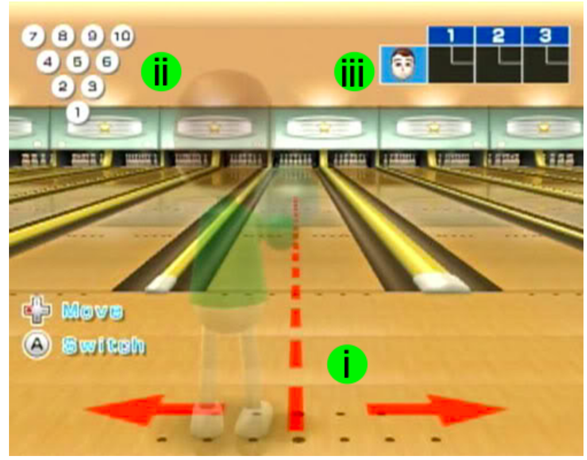

Figure 2: Wii Sports Bowling: The red line (i) indicates the direction in which the ball will be thrown and users can shift this direction using the arrow keys on their controller. (ii) shows the grouping of the pins and (iii) shows the current score.

An initial analysis of the gameplay shows that the player primarily engages into physical activity during the second step where the player throws the ball. To make this game accessible it is important to make the first step efficient because the faster players are able to aim their throw the faster they can play the game, which may yield a higher total AEE. Because Wii Sports is closed source, a PC game was created called Visually Impaired (VI) Bowling, which implements the gameplay of Wii Bowling.

3.1 Controls

Similar to Wii bowling, VI Bowling uses a Wii remote. The Wii remote is an inexpensive controller, which features an infra red (IR) optical sensor, a 3-axis linear accelerometer, a speaker, a rumble (vibrotactile) feature, and an expansion port for additional input devices. The timing of the controls of VI Bowling was based on Wii Bowling, yet the threshold for detecting a throw was set higher than in Wii Bowling. This was done based on the previous experiences with VI Tennis. VI Tennis's controls were modeled after Wii Tennis. In the user study some children developed shortcut motions with a lower AEE than the motions that were taught to them (See section 2). The sensitivity of the controls in Wii Sports are relatively forgiving to appeal to a mass audience, yet players are engaged into higher physical activity if a larger size of detected motion is required for throwing the ball, which also avoids shortcut motions.

3.2 Sensory Substitution

To analyze how Wii Bowling could be made playable using non-visual feedback, the modalities and types of feedback that Wii Bowling provides to the player were identified (See Figure 3).

Wii Bowling provides visual, audio and tactile feedback. For example, visual information includes the visualization of the pins (see Figure 2b), the ball and the lane. Audio feedback includes the sound of the ball rolling, and the ball striking the pins. Different sounds are played depending on the number of pins hit.

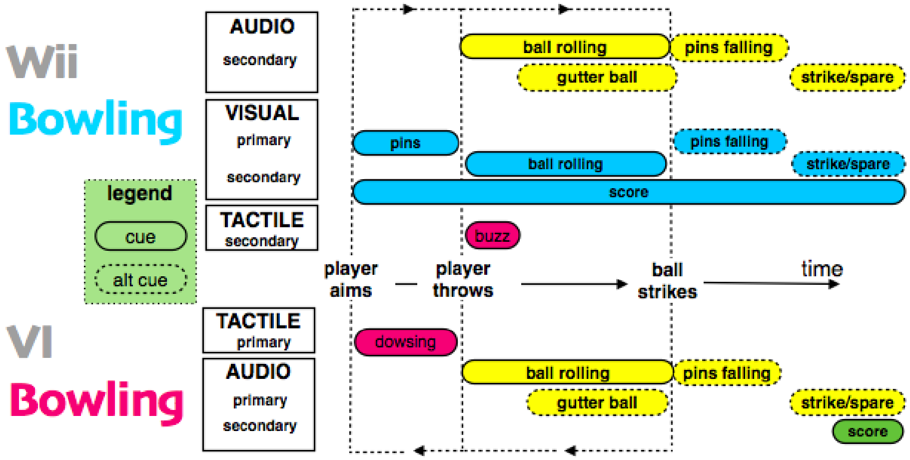

Figure 3: Sensory substitution map which shows the primary and secondary cues for audio, visual and tactile modalities in Wii Bowling (top) and VI Bowling (bottom). Dashed events indicate alternative cue events.

Two types of feedback [32] are distinguished:

- `Primary` cues require the player to respond in a certain way as such indicate *what* to do and *when*. In Wii Bowling this is the visualization of the pins as it indicates to the player where to throw the ball.
- `Secondary` cues are not essential to be able to perceive to be able to play the game such as reinforcement feedback [2] used to state the outcome of a particular player action, e.g., the sound of the ball rolling as well as a vibrotactile buzz confirm to the player that the ball was thrown.

Cues can further be discrete, such as the sound of the ball striking the pin or continuous such as the visualization of the pins. An overview of all feedback is provided in Figure 3. Dashed events indicate alternative cues where two different events can be provided, for example, a strike versus a gutter ball have different feedback associated with them.

To successfully play a game, players must be able to perceive primary cues [32]. Consequently to make a game accessible to someone with a sensory disability, primary cues presented in an absent modality need to be substituted with cues from a compensatory modality [4]. It is hypothesized that when a primary cue is presented in multiple modalities, a cue from the absent modality can be omitted without affecting the ability to play the game [25]. The game may be played with lower performance- because multimodal cues presented simultaneously can be detected at lower thresholds, faster and more accurately than when presented separately in each modality [23]. Sensory substitution is especially challenging for visual impairments due to the limited spatial and temporal resolutions of audio and tactile modalities [4]. Video games further require quick responses from their players, which limits the use of complex encoding schemes, as it may not allow for players to be able to distinguish such cues fast enough.

From the abundance of visual cues that games typically present, often only a small subset of cues in a different modality can be feasibly interpreted by a player with a visual impairment. Often significant tradeoffs with regard to the gameplay must be made, which may be detrimental to the overall game experience [32]. Because the game of bowling is self-paced, no fast responses are required from its players, however the use of audio is limited due to the socialization constraints that were discussed in Section 2. VI Bowling was iteratively developed where feedback from one individual with a visual impairment who play tested our game was incorporated. VI Bowling was implemented using a systematic approach that was developed for VI Tennis [25]:

1. **Implement primary and secondary audio and tactile cues**. The existing audio and tactile cues of Wii Bowling were implemented (see Figure 3 top). For the audio cues creative commons licensed sounds were used. As the spatial challenge part is entirely visual this part was excluded from the game and instead the computer randomly aimed for the player. Due to the multimodal encoding of cues such as the location and speed of the ball, the number of pins hit, and what type of ball the player has rolled (strike/spare), leaving their visual representation out was not found to significantly affect players' ability to play the game. Play testing revealed that although different audio cues are used to indicate different numbers of pins being hit, it was difficult to determine exactly how many pins were hit.
2. **Substitute primary unimodal visual cues**. Because players' score is only represented visually, speech cues were added that convey the number of pins hit after each throw and score after each frame (see Figure 3 bottom). Though the use of audio should be minimized due to social constraints of exergaming, the use of speech is motivated as score and number of pins hit are most easily interpreted as speech rather than other forms of audio or haptic feedback. When the player throws a strike or spare, the number of pins hit is not conveyed, as the player can already deduce this.

After the second iteration the temporal part of Wii bowling was found to be playable. However, playing the game using random aim offers very little challenge to the player, as the player does not exert any control over how many pins are being hit, which is the most important challenge of bowling. This emphasizes the importance of exploring techniques for making spatial challenges accessible, as these often affect the elements of gameplay that are the most fun to perform.

Figure 4: Tactile dowsing: the player moves the Wii remote in the horizontal plane (left); The closer the Wii remote points to the target direction the more continuous the perception of vibrotactile feedback will feel (right).

3.3 Tactile Dowsing

The spatial challenge of Wii bowling contains of two steps:

- `Determine` where to throw the ball, which is a cognitive step. Based on the pins that are still standing up, players will most likely aim towards the location where the majority of the remaining pins are, or in case of a split (only the outer pins remain standing) they may try to throw an effect ball directed towards one of the remaining pins.
- `Align` a visual cue using the arrow keys on the controller with the direction in which the player wants to throw their ball which is a physical step (see Figure 2).

These steps together take a few seconds. After aiming the player throws the ball. Wii Bowling does not take into account the direction in which the Wii remote is swung, only that a motion of significant magnitude was detected before releasing the trigger on the controller. Though several strategies could be employed to make each step individually accessible using non visual feedback, a novel technique called *tactile dowsing* was developed that provides a tactile-spatial challenge that combines both steps into an efficient step that can point out a direction to the player.

Tactile devices for indication of a direction have primarily been explored in navigation of visually impaired, some examples include: belts [10], vests [27] or handheld devices [3]. None of these solutions are commercially available nor can they be easily used while exercising due to their size and weight. Instead the tactile capabilities of the Wii remote were explored as it contains a vibrotactor that provides feedback with a fixed frequency of 250Hz, which can be varied only by pulsing the motor activation. Though the tactile spatial resolution of a Wii remote is limited, an abundance of tactile receptors makes fingertips the most sensitive to vibrotactile feedback [4]. Due to its low cost this solution has potential for large-scale implementation.

Tactile dowsing combines the features of an infrared optical sensor and a vibrotactor in one integrated handheld device, i.e., the Wii remote. Players use the Wii remote like a dowsing rod to find the target direction. A form of haptification is used; a tactile window of 19.3° is defined on both sides of the target direction. Players move the Wii remote in the horizontal plane until they enter the tactile window. VI Bowling will then start pulsing the vibrotactor for $100ms$ with 2500 ms delays. This delay is decreased linearly with 125 ms for every 1° of error. Players find the direction of error by moving the Wii remote in a direction to determine if the pulse delay is increasing or decreasing. To find the target direction, the player needs to point the Wii remote such to maximize the continuity of the vibrotactile signal.

A wireless IR emitter peripheral (Wii Sensor bar) is used to detect the direction in which the Wii remote is pointing. This sensor bar has five IR LEDs at each end of the bar. The light emitted from each end of the Sensor Bar is focused onto the Wii remote's optical sensor as two dots on a 1024x768 canvas, if it is visible within 16ft of the sensor. The distance between the sensed dots can be used to calculate the distance and the orientation of the Wii remote to the sensor bar. For VI bowling, the IR Emitter bar was modified to light only one block of IR LEDs, which is enough to determine the direction in which the Wii remote is pointing and makes it easier to disambiguate which dot is sensed. After tactile dowsing, the player proceeds with throwing the ball.

In Wii Bowling, no sensor bar is used and the direction the ball will go is only determined by twisting the Wii remote at the end of the throw. VI Bowling significantly deviates from Wii Bowling as the direction the ball will travel is determined by the angle between the target direction and the direction the Wii remote is pointing at when the player releases the ball. This was implemented specifically to investigate whether tactile dowsing can be used to support a simple form motor learning. The procedure for motor learning in bowling works as follows: (1) the player finds a target direction using tactile dowsing by holding the controller in front of the player; (2) the player then moves the Wii remote down alongside their body backwards and then swings the controller forward until it points in the target direction (See Figure 6). When the player releases the trigger key, VI bowling records the X value of the sensed dot.

Depending on how far the recorded value is off the target the ball will go either left or right. For the first throw of the frame the target direction is at the center of the sensor bar. A strike is any throw within 3.8° of the target. To get one pin down, the player must throw within 19.3° of the target or else the player will throw a gutter ball. The number of pins knocked down is determined by the accuracy of the throw and is distributed linearly from 1 to 10 throughout the tactile window. These values for the degrees were determined through play testing. In Wii Bowling the magnitude of the throw affects how many pins are hit. To evaluate the accuracy of tactile dowsing the speed of the ball was made constant, to avoid any inaccuracies due to vigorous motions. The target direction for the second throw of the frame is adjusted to point out the error of the player in the first throw. If the player's first throw was to the right of the target, the target position for the second throw is to the left representing the center of the remaining pins. Due to the sensory substitution, certain gameplay elements were simplified, e.g., in Wii Bowling it is possible to have a space between the remaining pins, i.e., a split. VI Bowling ensures remaining pins are clustered, as it would be difficult to indicate the location of two disjunct groups of pins using tactile dowsing. To accommodate dowsing, the tactile cue that indicates a successful throw (see Figure 3) was removed.

Table 1: Participants' characteristics and results

User ID	P1	P2	P3	P4	P5	P6	$\bar{x}$	σ
Gender	M	F	F	M	M	M	-	-
Age ($years$)	30	43	61	77	81	45	58	21
Impairment	L	T	T	L	L	L	-	-
Height (cm)	168	160	154	182	177	183	169	11.3
Weight (kg)	79.3	49.9	60.3	79.3	74.3	81.6	70.8	12.8
BMI (kg/m^2)	28.2	19.5	25.1	23.9	26.5	24.6	24.6	2.94
Score	86	94	130	122	219	143	132	47
Time (s)	532	573	250	281	322	273	371	142
AEE (kJ/min)	6.63	4.97	3.82	6.30	3.10	2.80	4.61	1.62

4. USER STUDY

The goal of the user study was to assess: (1) if VI Bowling is a fun activity to perform; (2) whether it can engage its players into physical activity; and whether (3) tactile dowsing can be used for motor learning.

4.1 Participants

VI Bowling was evaluated with six adults with visual impairments, who were recruited using the email list of the Reno/Tahoe chapter of the Nevada Federation of the Blind. Participants' height and weight was measured using standard anthropometric techniques. Two participants were totally blind (T) and the rest legally blind (L). Three participants were classified to be overweight according to the Center for Disease Control and Prevention's (CDC) definitions. Table 1 lists an overview of the participants' characteristics.

4.2 Instrumentation & Experimental Trial

Active energy expenditure was captured through an Actical omnidirectional accelerometer worn on the participant's wrist. Accelerometers have been successfully used to estimate the energy expenditure of activity [30] and they don't impede players' ability to play the game [25]. VI Bowling records the player's score and throwing accuracy in a log file. Prior to playing participants could familiarize themselves with the controller and learn how to play the game using a brief five minute tutorial, which included a practice session. Players were then equipped with an accelerometer on their dominant arm, which was initialized using their weight, height, age and sex. Players were positioned about 5 ft from the sensor bar and played ten frames.

4.3 Results

Participants achieved an average active energy expenditure (AAE) of 4.61 (σ=1.62) kJ/Min, which is significantly lower than what ($8/12 kJ/Min$) was achieved in previous studies with children playing Wii bowling [15, 16]. These values are not MVPA, which is defined as higher than 9 $kJ/\ Min$ for adults [1]. Lower AEE is explained due to a different population as well as that the spatial challenge in VI Bowling takes longer to perform than in Wii Bowling. Figure 5 shows a combined graph of the dowsing time, e.g., the time it took to find the target direction and the average number of pins hit per frame. The overall average dowsing time per frame is 8.78 (σ=8.34) seconds, and though no comparative data was collected for Wii bowling this visual-spatial challenge typically takes a few seconds. Though dowsing time appears to decrease over the ten frames, no significant difference between the times of the first three and the last three frames could be detected ($T_{2,34} = 0.28$ $p > 0.05$). A contributing factor to this could be that players did not feel pressured to quickly find the target direction, as bowling is self-paced. If the total tactile dowsing time is subtracted from the total playing time, and AEE is reassessed using the times participants were actually physically active (throwing) an AEE of 9.19(σ=5.68) kJ/Min can be found which is considered MVPA for adults. The average aiming error measured at the end of each throw was 9.76°(σ=6.23). Though direction found during tactile dowsing phase was not recorded, all participants were observed to always find the maximum continuous intensity before throwing. Average number of pins hit each frame is a function of throwing accuracy, therefore this score used to assess the accuracy of tactile dowsing based motor learning. Due to the non-parametric nature of the data, number of pins hit was dichotomized (1 if number of pins was 10, and else 0). A McNemar test using a 2x2 contingency table compared the first three frames versus the last three frames and showed that participants became more accurate with throwing as they significantly increased their ability to finish a frame with all pins knocked down over the course of the game ($\chi^2{}_{2,34} = 0.02$ $p < 0.05$).

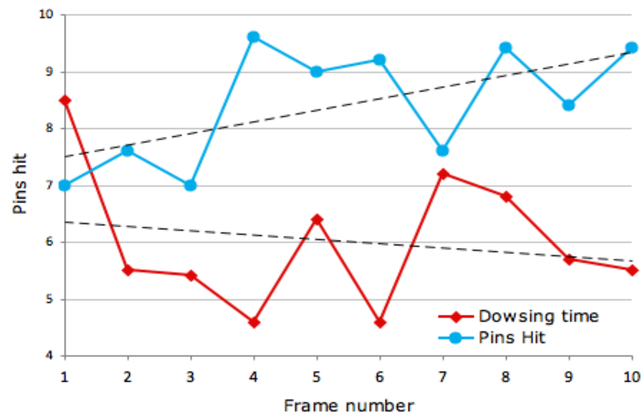

Figure 5: Combined graph showing average dowsing time and average number of pins hit per frame.

4.4 Qualitative Analysis

Participants were interviewed using a questionnaire after the test to determine the usability and playability of VI Bowling. First participants' exercise behavior and experience with bowling was identified, then they were then asked to rate the features of VI Bowling on a 5-point Likert scale (ranging from strongly disagree (1) to strongly agree (5)) and then they could make suggestions for improving VI Bowling. All participants had played bowling before but none had played Wii bowling or a Wii game. P2 and P3 did not exercise regularly and the other participants primarily engaged in walking. P2 and P3 did not consider themselves fit and P1 did not know if he was fit. All participants liked VI Bowling (M=5.0, σ=0.0) and found the game easy to play (M=4.6, σ=0.52) and the tutorial easy to follow (M=4.8, σ=0.41). The tactile dowsing was found to be challenging (M=4.5, σ=0.55) and all participants except one believed this game could help them exercise (M=4, σ=1.55).

Participants made the following suggestions for improving Wii Bowling: (P1; P2) adding a multiplayer option; (P5) using spatial audio to indicate where the pins were hit; (P5) adding more environmental sounds, such as a cheering crowd when the player hits a strike or spare; and (P6) tactile feedback should be provided more gradually over a larger range.

5. DISCUSSION AND FUTURE WORK

5.1 Active Energy Expenditure

The CDC recommends adults engage in MVPA for 150 minutes a week to remain fit [1]. VI Bowling provides light physical activity that is comparable to walking and hence it does not significantly contribute to this recommendation. These findings corroborate with results from an earlier study conducted with Wii Bowling with children [16], though physical activity levels that define MVPA for children are higher than for adults, as children have higher metabolic rates than adults. Due to the sensory substitution, it can be argued whether the visual-spatial challenge in Wii Bowling and the tactile-spatial challenge in VI Bowling are equivalent, however, the latter takes longer to perform. Over ten frames a significant increase in accuracy was detected, but no significant decrease in dowsing time. Two solution strategies can be explored to increase AEE: (1) make it easier to find the target direction by increasing the tactile range of the sweet spot; and (2) incorporate the size of the motion made with the Wii remote to affect the number of pins hit. This may yield more vigorous throws but these may be more inaccurate. Regardless, VI Bowling stimulates positive activity behavior; players are on their feet performing basic motor control and movement skills, which -considering the limited existing exercise opportunities that individuals with visual impairments have- should be encouraged over inactive sedentary behavior.

5.2 Tactile Dowsing based Motor Learning

Using tactile dowsing, players were able to make a motion with their arm in the target direction with an average error of 9.76°. In VI Bowling tactile dowsing implements a relatively simple form of motor learning because players do not receive feedback on whether the motion that was made was correct, e.g., players can make a thrust motion or a swinging motion with their arm and both have the same result. For motor learning, tactile dowsing could potentially be used to point out different stages of the desired motion. Depending on the type of motion, this approach cannot be implemented using one sensor bar, as it requires a line of sight. Multiple sensor bars would be required, which introduces a new problem, as sensor bars are difficult to distinguish from each other. An alternative is to facilitate tactile dowsing using the Wii remote's built in accelerometer, but as low cost accelerometers are prone to fuzzy input, this may not be accurate enough for tactile dowsing. No qualitative comparison was made between a version of VI Bowling with and without tactile dowsing, but participants liked the challenge tactile dowsing provides. None of the participants found tactile dowsing too hard or too easy. The target direction for the second throw (if there was any) only varied in a relatively small range, which may have allowed for some memorization of the target direction for the first throw. Future work will evaluate the ability of tactile dowsing to point out varying target directions within a full 360° range. Tactile dowsing could be used for indoor navigation or to make other physical activities accessible that have some aiming component such as baseball.

5.3 Temporal-Spatial Challenges

VI Bowling only contains a tactile-spatial challenge and VI Tennis [25] contains only a tactile-temporal challenge.

Figure 6: User with visual impairment performing dowsing (left); and throwing (right) in VI Bowling.

As most physical activities are a combination of spatial and temporal challenges, future work will combine elements of gameplay to create an exergame with a temporal-spatial challenge, which may be more challenging to play. For example, VI Tennis could be extended with a spatial challenge where players use tactile dowsing to determine whether the player must hit a forehand or a backhand. VI Tennis can engage players with visual impairments into MVPA and as moderate exercise has a facilitating effect on sensory and motor processes, higher tactile dowsing performances may be observed.

5.4 Barriers to Physical Activity

Individuals with visual impairments face barriers to participate into physical activities. VI Bowling and VI Tennis are available for free on our website `http://www.vifit.org`. A long-term study will evaluate whether access to exergames can overcome these barriers and whether exergames are viable alternatives to existing physical activities. In our user study participants were only able to play VI Bowling for a total of ten frames. Attitudes towards VI Bowling may be different if individuals with visual impairments are able to play this game over a longer period of time.

6. CONCLUSION

This paper presents VI Bowling, an exergame for players who are visually impaired. VI Bowling explores tactile dowsing, a novel technique for making spatial sensorimotor challenges in exergames accessible. Players use a low-cost motion-sensing controller as a dowsing rod to find the direction in which to throw their bowling ball using vibrotactile feedback, which can be used to support a simple form of motor learning. VI Bowling was evaluated with six adults who were blind. All participants enjoyed playing VI Bowling, and the amount of physical activity achieved with VI Bowling is comparable to walking. Solutions to increase physical activity include: (1) making it easier to find the direction; (2) combining the tactile-spatial challenge with a temporal challenge; and (3) incorporating the size of motion made with the controller to affect the number of pins hit. The user study demonstrated the feasibility of tactile dowsing for motor learning and future work will continue exploring tactile dowsing for other kinds of spatial activities.

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