Individuals with visual impairments have significantly higher levels of obesity and often exhibit delays in motor development, caused by a general lack of opportunities to be physically active. Tactile/audio based exergames that only involve motions of the dominant arm have been successfully explored to engage individuals with visual impairments into physical activity. This paper presents an accessible exergame called Pet-N-Punch that can be played using one or two arms. A user study with 12 children who were blind showed that they were able to achieve light to moderate physical activity, but no significant difference in energy expenditure was detected between both versions. The two arm version had a significantly higher error rate than the one arm version, which shows that the two arm version has a significantly higher cognitive load. Players were found to be able to respond to tactile/audio cues within 2500ms.

Keywords: Health, Exergames, Visual Impairments, Haptics

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

1 INTRODUCTION

There is considerable evidence that the overweight and obesity rates are higher among persons with disabilities than among the general population [10]. Compared to children and adolescents in other disability groups, those with visual impairments have been identified to be the most inactive, with 39% classified as sedentary and only 27% classified as active [24].

Individuals with visual impairments do not have the same opportunities to participate in physical activities that yield adequate fitness and a healthy standard of living as their sighted peers [18]. Children with visual impairments have limited access to physical education, recreation, and athletic programs because of: (1) limited social opportunities, such as lack of exercise partners or sighted guides with whom to exercise [33]; (2) fear of injury while exercising [19] and safety concerns of parents and teachers [23]; and (3) self barriers, such as fear of being made fun of while exercising [30], and a general lack of exercise opportunities [20].

Video games have been identified as a contributing factor to children’s increasingly sedentary behavior and associated higher levels of obesity [35], however, a new genre of video games, called exergames, has the potential to turn couch potatoes into jumping beans [29]. Exergames are video games that use upper and/or lower-body gestures, such as steps, punches, and kicks to provide their players with an immersive experience that engages them into physical activity and gross motor skill development [17]. Studies with exergames show that they stimulate greater energy expenditure than when playing sedentary video games [12, 15, 16]. Exergames vary significantly in the amount of physical activity that is required to play them and a recent meta analysis [8] of exergame studies found that exergames that involve whole-body movements, such as dance-based games, yield significantly higher energy expenditures than exergames that only involve dominant upper limb movements, such as Nintendo Wii games [1]. Because exergames simulate real physical activities [9] they involve spatial-temporal challenges that rely upon the visual sense [21]. The motions that players need to provide, such as kicks, punches, steps or swings, and when to provide the gesture are typically indicated in the game with visual cues. Players who are blind are unable to see these cues and are unable to play exergames.

When compared with regular physical activities, exergames have some attractive properties for individuals with visual impairments because: (1) exergames can be played independently; and (2) exergames are performed in place, which significantly minimizes the risk of injury.

Previous studies with two accessible exergames, VI Tennis [26] and VI Bowling [27], have explored the use of non-visual feedback, e.g., vibrotactile and audio cues to enable users with visual impairments to play exergames. The games are played using the dominant arm using a commercial off-the-shelf motion sensing controller. VI Tennis was able to engage its players into moderate intensity (e.g., walking), which is high enough to contribute to the daily-recommended amount of physical activity for adults, but it is not high enough for children who are recommended to spend a significant amount of time daily in vigorous physical activity (e.g., running), as they have higher metabolic rates than adults [34].

This paper presents Pet-N-Punch, an exergame that utilizes a Whac-A-Mole style gameplay and which can be played either using one or two arms. Pet-N-Punch provides audio and tactile cues as to indicate what motions to provide and when. Using a user study with 12 blind children we investigated whether the two arm version yielded larger active energy expenditure than the one arm version. This paper is organized as follows. The next section provides background information. Section 3 discusses the experiences with two previous tactile/audio exergames. Section 4 discusses the design of Pet-N-Punch. Section 5 outlines details of the user study and Section 6 presents the results. Section 7 discusses results and Section 8 outlines areas for future research and the paper is concluded in...
2 Background

People with visual impairments (VI) can exercise by participating in adapted physical activities. Physical activity is typically a combination of eye-body (sensorimotor) and muscle (cerebellar) control [11]. Tennis and baseball are typically sensorimotor based activities as they require the player to sense the state of the game (i.e., the position of the ball and the opponent) and use that information to properly perform an action (swing and hit the ball to the proper location). These sports are also known as open sports by adapted sports researchers [22]. Open sports contain many variables that change often within the game. Tennis contains the ball and the opponent’s position. Running on a treadmill and cycling on a stationary bicycle are primarily cerebellar as the muscle movements are constant. Also known as closed sports, these activities do not contain many variables that change often. A person with VI has issues participating in most sensorimotor activities as they rely heavily on vision. Activities such as cycling or running can be performed by a person with VI, however, it usually requires the use of a sighted guide (as in assisted running) or a sighted pilot (as in tandem cycling) to perform the sensorimotor piece of the exercise while the person with VI performs the cerebellar activity (running or pedalling). Few unaided sensorimotor activities exist for those with VI. Games such as beep baseball and goal ball utilize special balls and equipment that emit sounds in order to substitute for the missing visuals and rely on ear-body coordination. Studies have shown that people with VI prefer adapted sensorimotor activities to cerebellar activities [20], however, they are more difficult to make accessible. The ability to participate in sensorimotor activities contributes to normalization [31].

Exergames rely on non-traditional input devices. Exergames such as Dance Dance Revolution utilize dance mats, where a large mat is placed on the floor and players must place their feet on symbols on that mat which match the corresponding symbol displayed on the screen. Wii Fit utilizes motion sensing controllers and players must mimic the motions displayed on the screen by their virtual character. Xbox Kinect utilizes a video camera that places the actual player in the middle of the game and it is the players responsibility to move his body in such a way to interact with the virtual objects on the screen by kicking or punching.

Players who are legally blind or have low vision may be able to play existing commercially available exergames. Increasing the contrast, or displaying on a large projected screen may provide enough of a visual such that a player with low vision would be able to sense the visuals cues and perform the desired actions. However, a player with no vision cannot rely on visuals at all. The visuals in exergames are important as they tell the player what to do and when to do it [37]. Exergames also contain sounds relevant to the game play, but they are typically played as a result of something that has happened, not as a cue to the player to do something.

Video games have been adapted for people with visual impairments. Typically these games replace the necessary visuals with audio. Sound effects can complement the graphics, but they also can be enhanced to provide more detailed spatial audio to assist those with VI. Using the left/right/front/back speakers can enhance the virtual representation such that a person with VI can picture the state of the game. In addition to spatial cues, game state cues can be represented as additional audio cues as shown in Battleship SV [32], a Battleship game modified for players who are visually impaired. This game utilized speech synthesis to provide spoken information to the user about the results of each turn and in game navigation. An audio technique called sonification, uses earcons or sound radar to assist those with VI as demonstrated in the game Audio Quake [7].

Substituting visuals with audio can be invasive as exergames are often played in social contexts [28] where players are playing with friends or family and the reliance on audio can interfere with socialization. Also, music is present in most exergames [13] and adding additional sounds might interfere with the music [36]. Removing the music or any other original sounds may subtract from the game play experience. Games such as Blind Hero [36] and Rock Vibe [6] replace visuals with vibrations in adapted versions of Guitar Hero and Rock Band.

Physical feedback is an important piece of exergaming. In a study involving a martial arts game [13] where the players participated in the game by performing real martial arts moves being interpreted by a camera, players found the biggest drawback of the game was the lack of physical feedback, which could be given through the use of a tactile device contained within a game controller.

3 Previous Work

Two studies have been completed involving exergames designed for people with VI and they have indicated a potential for being a useful means to encourage physical activity, however, they have also shown some deficiencies. In VI Tennis [26], players played a virtual game of tennis based on Wii Sports Tennis with no display and sent input to the game by swinging a motion sensing controller in a tennis like fashion. Two versions of VI Tennis were evaluated, (1) a game that provided only haptic cues and (2) a game that provided both haptic and audio cues. Player performance and player preference sided with the game that provided both haptic and audio cues. VI Tennis was evaluated with children with VI and was shown to encourage physical activity. The average energy expenditure (AEE) was found to be 16.9 kJ/min ($\sigma$=7.4). According to the United States Center For Disease Control, participants in the study on average were able to achieve enough physical activity to be considered healthy for adults, but not enough to be considered healthy for children.

Several deficiencies were noted in the VI Tennis study. Players were only utilizing their dominant arm, which leaves the possibility that more physical activity is possible if a player uses more of his body. A second issue was errors. Players were not penalized for swinging too early. As long as a swing occurred in the required time frame the ball would be hit. For players who desired to do well but did not quite understand the required timing, this resulted in players just swinging constantly. Although this technique created physical activity, it did not create an enjoyable game. In order for the physical activity to be meaningful, it must be performed over a long period of time. A game that can be won by swinging wildly would probably not have a lot of replay value and thus may not be the best choice when promoting physical activity.

In VI Bowling [27], players participate in a virtual game of bowling based on Wii Sports Bowling by sending input to the game through a motion sensing controller. Players would mimic a bowling motion and the game would validate the player’s throw. A particular challenge when developing a game such as this is showing the player where the pins are located. With no display present, a technique called Tactile Dowseing was developed to give a representation of where the pins were located so that a player could aim in the correct direction. Tactile dowseing varied haptic pulses in a Geiger counter like fashion to indicate the location of the bowling pins. Players were able to utilize the tactile dowseing successfully and this demonstrated players’ ability to adapt to different types of haptic cues. VI Bowling was evaluated with adults with VI and created an AEE of 4.61 kJ/min ($\sigma$=1.62).

One issue with bowling was the self-paced nature of the game. This allowed players to take their time and aim correctly, however it also had an effect on their energy expenditure. Although this closely followed the real game of bowling where players can take as much time as needed, it may have had a negative affect on the amount of physical activity.
4 Game Design

We seek to design a game for people with VI that promotes physical activity. To advance on previous studies by encouraging more physical activity, the difference in physical activity of utilizing both arms, as opposed to just the player’s dominate arm will be evaluated. Also, the response times will be evaluated to determine the optimum rate at which a player can respond to non-visual cues in an exergame.

4.1 Game Play

In order to analyze the accuracy and energy expenditure between an exergame utilizing only the dominate arm, and an exergame that utilizes motions performed by both arms, a game was created from scratch. The goal was to create a game that was fun to play and provided a means to encourage physical activity to a person with VI. Based on the results from previous work, the game needed to utilize both haptic and audio cues in order to have a higher success rate of performing the motions. It also needed to be non-self paced to encourage physical activity at a known rate. And finally it should create a fun gameplay experience with the potential for a high replay rate.

The game created, called Pet-N-Punch, is a VI accessible version of a game similar to the amusement game Whac-A-Mole. In Whac-A-Mole, a player swings a large padded hammer onto the head of moles as they pop out of a playing field consisting of five holes. Players are awarded points if the moles are hit on the head when they are out of their holes. This game is difficult to play by a person with VI as the outcome of the game is directly connected to the player’s ability to visually sense where the mole is on the playing field and then successfully hit it on the head.

Pet -N-Punch is a virtual representation of Whac-A-Mole adapted to be playable by a person with VI. No graphical interface was needed as the players interact with the game by means of sounds and vibrations only. Two modes of play were available, one with one hammer held in the player’s dominate hand, and a second mode where a player holds a hammer in each hand. Players were asked to help a farmer rid his farm of rodents by smacking them on the head with their hammer(s) which were motion sensing controllers. Players were alerted to the presence of rodents by two modalities: (1) The sound of a rodent, and (2) tactile feedback through the rumble in the controller. In order to avoid players simply swinging wildly, cats were also present within the playing field and players were penalized if cats were hit on the head. Collectively, cats and rodents will be referred to as creatures.

The game begins with an in game tutorial informing the players of the basic situation (a farmer with a rodent problem) and how the player could help (hit the rodent on the head). The farmer asks the player to swing down hard with his controller to hit the rodent on the head. The threshold for detecting a rodent hit was set high in order to encourage large motions. The player cannot start the game until the farmer is satisfied with the intensity of the player’s swing. This allows the player to get a feel for how big and fast of a motion is needed to succeed in the game. The required motion for successfully hitting a rodent is two quick downward swings in succession. The farmer also notifies the player about his cats that are in the fields as well. The farmer instructs the player to not smack the cats on the head when they are encountered, but to gently pet the cat. Once again, the player must perform the correct motion of petting the cat prior to moving onto the real game.

The farmer also informs the player that the rodents are eating his carrots and it is the player’s mission to prevent the carrots from being eaten. The fields start with 100 carrots. Every time a player does not correctly hit a rodent, or hits a cat on the head instead of petting it, one carrot would be deducted from the score. At the conclusion of the game, a higher number of carrots remaining represents a successful run through the game. If a player did not correctly hit the rodent, audio feedback of a carrot being eaten was played in order to notify the player the rodent was not successfully hit. If a player swung hard when a cat was present, a sound of a cat in pain was played, once again to signal an incorrect motion was performed through the use of audio feedback. The length of the audio cues were 1.5 seconds for a rodent, and 0.5 seconds for the cat. Although the rodent sound was 1.5 seconds, it was initially loud, and then faded out. In the event of a timeout occurring and the creature sound still being played, the sound was immediately stopped. The sounds used in the game were either recorded specifically for this game or used from royalty free audio repositories.

Players performing correct moves were presented with haptic and audio feedback as well. A player correctly hitting a rodent on the head would feel the rumble stop, as well as an sound indicating the rodent was hit correctly. Petting a cat correctly would result in the sound of a cat purring. No tactile feedback was given to the correct petting of a cat as the tactile cue to pet the cat was a short buzz as opposed to the constant buzzing of the rodents. Players were also presented with audio feedback by hearing a whipping sound when the motion of a hard downward swing was detected. This helped the players determine their process through defeating a rodent because they would need to hear the swing sound twice. The sound of the second hit was at a slightly higher pitch than the sound of the first hit to allow the players to get into a rhythm of hitting the rodents. There was no audio feedback for the motion of petting a cat except for the sound of the cat purring when the motion was successfully completed.

4.2 Technical Implementation

The motion sensing controller used in this study is the Nintendo WiiMote. This inexpensive controller contains a 3 axis accelerometer which was used to determine motion. These controllers are readily available and were chosen not only for their technical abilities but for their low cost and availability to the general public. At the conclusion of the study, the game was made available for a free download and cost and ease of use were taken into consideration when choosing an input device. Players held one or two WiiMotes in their hands based on which version of the game they were playing. The software runs on a computer running Windows XP, Vista, or Windows 7 equipped with bluetooth in order to communicate with the WiiMote. All cues are either audio or haptic based, so there is no display needed to play the game. The software was written in C++ using MS Visual Studio Express, and the WiiYourself open source library [4] to communicate with the WiiMotes.

The determination of a correct or incorrect motion was based on a running average of the z axis measurements from the accelerometer in the WiiMote. The WiiMote was polled every 33 milliseconds and the z axis values were recorded. Kalman Filtering helps in removing noise read from the accelerometers, however the idea was to look for large motions, so these types of filters were not used.

The technique for determining motion is as follows. The WiiYourself library returns the value of each of the three accelerometers in the range of +/- 3 g. The last five reads (165ms) of the z axis accelerometer were stored for analysis to determine the swing type. If the current value was less than the previous value, a downward direction was detected. Once a value was larger than the previous value, a complete swing was detected as the direction has changed. At that point, the type of swing was determined to be a hard swing, a soft swing, or neither. In order to ignore small fluctuations in movement due to a persons natural movements, once a change in direction was detected, the total range of motion since the last change in direction was analyzed. If the summations of the deltas of the last five reads was greater than 0.9375 g then a downward movement was detected. Next, the highest value within the last five reads was checked against hard coded thresholds. If the highest value was between 1.125 g and 0.1875 g, a soft hit was detected. If it was
higher than 1.183 g, a hard hit was detected. Any motion outside of these ranges was ignored. Initially an autocalibration mode was introduced to customize the game for each player’s technique, but it was dropped as players could swing softly in the calibration section of the game and in turn make the rest of the game easier. The hard coded thresholds were determined by making the desired motions and recording the accelerometer values.

When a player was presented with a rodent, the controller would rumble continuously until either the player performed the correct motion and successfully hit the rodent, or the time window for hitting the rodent expired. A cat’s arrival into the playing field was represented by a short 250 millisecond rumble on the player’s controller. The duration of the haptic cue was varied as opposed to varying the haptic intensity due to the capabilities of the vibrotactile motor contained within the WiiMote. The WiiMote is only capable of providing a constant vibration at 250 Hz.

In the two arm version of the game, the haptic cue was targeted to the arm that was required to perform the motion. Each creature encountered was also paired with an audio cue. In the two arm version of the game, these cues were directional, meaning the sound was played either through the right or left speaker at the same time the corresponding controller would rumble. In order to be sure the players were holding the controller in the correct hand, the controller in the right hand would be used to start the game, and the tutorial would expect the player to swing with the right controller. The controllers contain 4 LEDs that were also encoded with unique identifiers for right and left hands which could be observed and corrected if necessary by the game administrators.

The game was broken down into two parts to determine how the players would react to different response requirements. The first part of the game gradually decreased the time between creatures. The second part of the game kept the time between creatures at a constant rate, but gradually decreased the necessary reaction time. The actual values for each level can be seen in Figure 2. The levels of the game were created this way to encourage physical activity within timing constraints and to also determine what the minimum response time the players were capable of. The average reaction time could have been measured by recording the reaction times of the players without requiring the player to respond within a certain amount of time. Using this method, the player would have no incentive to respond as fast as possible, thus the declining reaction time requirement was introduced as it provided an incentive to the player to respond as quickly as possible and the error rates would identify the timing constraints when it became more difficult to respond.

The time between creatures was the time the game waited after either the player successfully completed the required action, or the reaction timeout expired. The reaction timeout timer was started as soon as the audio and haptic cues were started, not when they were completed.

The total game play consisted of 10 minutes of play through 11 levels, each one progressively harder than the previous. The timing of events on each level was consistent between both versions of the game. The only difference between the two versions was that the two arm version alternated between creatures appearing on the left and right side of the body at a predetermined and random sequence. Although the sequence was generated randomly, all players played the same random sequence.

With the exception of the first two levels, each level was for 60 seconds in duration. At the completion of each level, the farmer would announce the number of carrots left in his fields to keep the players up to date on the progress being made. The farmer would also audibly note the level number before the start of each level. Levels 1 and 2 were just 30 seconds each. These levels would be considered introductory levels where the player learns exactly how to play the game. In level 1, the player would only encounter rodents. This allows the player to have an opportunity to fine tune the swing technique for hitting rodents. Level 2 was comprised completely of cats. This allows for the player to practice the petting motion. The remaining levels are mixed with both cats and rodents at the rate of 20% cats and 80% rodents.

5 User Study
Pet-N-Punch was evaluated in July 2010 at Camp Abilities (Figure 1), a developmental sports camp for children who are visually impaired, blind or deaf/blind held annually at the College of Brockport in New York. The goal of this study was to promote physical activity in a fun way and to identify the differences in accuracy and physical activity between a one handed VI accessible exergame and a VI accessible exergame requiring motions from both arms. This study seeks to analyze the following:

- **H0**: Error rates will be significantly higher in a game utilizing both arms as opposed to a game utilizing only the dominate arm.
- **H1**: The energy expenditure will be significantly higher in a game utilizing movements of both arms as opposed to a game utilizing only the dominate arm.

5.1 Participants
Twelve children (Table 1) who were identified as B1 by the US Association of Blind Athletes, participated in the study over the course of two days. B1 athletes are completely blind with no functional vision, B2 athletes have travel vision and B3 athletes are legally blind. Parents and participants consented to the study prior to participation. To prevent errors in data recording due to familiarity of the game, the full group was broken down into two smaller groups and students were randomly placed into each group. Group A played the two arm version on day one and the dominate arm version on day two. Group B played the games in the reverse order with the

<table>
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Figure 2: Delay/Response Time Vs Level
dominate arm game being played on day one and the two arm version on day two.

Participants played the game for ten minutes in a closed off room with only their camp counselor and a game administrator present. Prior to the study commencing on day one, the players’ height, weight, and age were recorded. After the study, participants were escorted to an isolated room. In this room, they sat with only their camp counselor present and rested for 10 minutes. The heart rate monitor remained active and their resting heart rate was measured and used as a baseline to determine the heart rate increase. The resting heart rate was taken after the study due to camp schedules not providing an opportunity to acquire the data prior to the study. Players also completed a subjective survey at the conclusion of the study.

5.2 Physical Activity Measurement

Players were equipped with an accelerometer worn on each wrist to monitor the amount of motion for each arm and to not interfere with gameplay. Although the players were not required to swing their non-dominant arm in the dominant arm version of the game, they were still equipped with an accelerometer on each wrist to provide a comparison. A measure of physical activity intensity level is known as a MET (metabolic equivalent intensity level), and the Actical accelerometers computed this number by using their validated children’s energy expenditure algorithm [2] after analyzing the motions of the players.

Players also wore a wireless heart rate monitor attached via a small harness across their chest to measure their heart rate throughout the game. The data from the heart rate monitor was collected in real time and contained the current beats per minute (bpm) of the player at one second intervals.

6 Results

6.1 Error Rates

In order to determine the accuracy of a game using both arms when compared to a game using only the dominant arm, success rates were calculated. The success rate is the number of correct motions performed divided by the total number of motions required. The data (Figure 3) shows the difference between success rates of the dominant arm vs the two arm version of this game. A Wilcoxon signed-rank test showed there was significant difference ($Z_{2.12} = 2.325 \ p < 0.05$) in decline between the two modes. This causes us to accept H0. Although the results were similar, the success rates for the two arm version were consistently lower. The additional complexity of deciding which arm to move created a more difficult game. As the required response time decreased to 500 milliseconds, error rates jumped to 25% and 50% for the dominant arm and the full body versions of the game. Errors in level 2 were higher than other levels. This level was 100% cats, and the increase in errors can be attributed to the learning curve of players finding the correct range of motion for petting the cats. Too slow of a motion would not be detected, and too quick of a motion would be considered too hard. As compared to the rodent motion which could be performed by simply swinging very fast.

Figures 4 and 5 analyze the different kinds of errors encountered during game play. A non successful round was the result of 1 out of 2 scenarios, timeouts and errors. An error is represented by a player either swinging soft when he should have been swinging hard, swinging hard when he should have been swinging soft, or swinging with the wrong hand. A timeout is an error condition where the required action was not completed within the time allotted. Figures 4 and 5 show the break down of the types of errors for both the dominant arm and the two arm versions of the game. Timeouts were a higher percentage of the errors on the two handed version when compared with the percentage of timeouts on the one handed version. A paired 2 sample $t$-test with $\alpha$ set to 0.05 showed there was significant difference ($T_{2.12} = 5.81 \ p < 0.05$) between the two. This could be a result of the player needing to make a decision of which arm to move and how to move it as opposed to just how to move it. Both saw an increase in timeouts in the last round largely due to the player not being able to perform the required actions in the shortened time constraints.

To see if the drop in performance in the last level was significant, the performance of levels 1-11 were compared to just the performance of level 11. The dominant arm version of the game showed a success rate of 91.7% ($\sigma=6.3$) for levels 1-11 and a success rate of 75% for the last level. A similar trend was observed for the 2 arm version of the game where the success rate was 87.4% ($\sigma=14$) for
levels 1-11 and a success rate of 51.2% for the last level. A paired 2 sample t-test with \( \alpha \) set to 0.05 showed significant difference in performance in both the 1 handed (\( T_{2,11} = 8.71 \ p < 0.05 \)) and 2 handed (\( T_{2,11} = 9.30 \ p < 0.05 \)) versions of the game for level 11 when compared to all levels. Looking a little closer at the jump in error rates for the last level of the two arm version, 47% of the timeouts were due to the player successfully performing the first of two required hits. 53% of the timeouts were due to the player not successfully performing the first of the two hits. This shows that a response time of 500 milliseconds may be not be enough time for a person to correctly interact with the game.

6.2 Physical Activity

The activity intensity data was determined directly from the accelerometers worn on the wrists. Two sets of data were recorded (one for each wrist) and that data was averaged. The Actical accelerometers directly provide an activity intensity value in METs. The accelerometers are initialized with the players’ height, weight, sex, and age and those parameters are taken into consideration within the Actical software when generating the data. The MET value is assigned a number between 0.9 (sleeping) and 18 (running) [5]. General MET categories consist of light intensity (1.1-2.9 METs), moderate (3.0-5.9 METs), and vigorous (6.0+METs).

The data (Figure 6) shows an increase of activity intensity until the later levels in the game, which may be related to accuracy. Although outliers in the study did achieve physical activity considered to be vigorous, a majority of the participants fell within the light to moderate range. The AEE was found to be 11.72 kJ/min (\( \sigma = 1.07 \)) for the dominate arm version and 10.79 kJ/min (\( \sigma = 1.05 \)) for the two arm version. The amount of physical activity generated in this study can be equated to the range of activity between walking and playing volley ball [5]. There was a significant increase (\( Z_{2,12} = 2.28 \ p < 0.05 \)) in energy expenditure between the start and the end of the game. The energy expenditure difference between the dominate arm version of the game and the two arm version of the game showed no significant difference (\( Z_{2,11} = 0.53 \ p > 0.05 \)). This causes us to reject H1.

According to the American Heart Association (AHA), the resting heart rate of a child should be between 70 and 100 beats per minute (bpm) [3]. Participants in this study had their resting heart rate recorded at the conclusion of the study, and all had resting heart rates that fell within this range. Since all participants had different resting heart rates, the data was normalized as a percentage increase based on the resting heart rate. All of the heart rate readings for each one minute interval were averaged together and used as a comparison to the resting heart rate. As shown in Figure 7, participants demonstrated heart rate increases throughout both versions of the game, however the average variation between the dominate arm and the two arm versions of the game was only 2%. The heart rate showed a higher increase after the five minute mark. This suggests that the quicker required response times had a direct effect on the heart rate.

6.3 Player Survey Results

Participants in the study were asked 18 questions designed to find an enjoyment level based on a Physical Activity Enjoyment Scale (PACES) [14]. The questions were answered on a 1 (lowest) to 8 (highest) Likert scale, and the maximum total score is 144 with the minimum being 18. Some of the questions included, "It is no fun vs It is a lot of fun, I enjoy it vs I hate it, I feel bored vs interested". The results of the survey found the average score to be 131.3 (13.42) which indicates a strong interest in playing the games. This is an important result because any long term health benefits attributed to repeated plays of the game can only be determined if the player has a desire to play the game repeatedly.

7 DISCUSSION

7.1 Visual Observations

One of the goals of this study was to remove the ability for a player to constantly swing wildly and succeed in the game. The placement of cats into the mix was one way this was achieved. Players wanted to not hit the cats hard because they would lose points in the game. This was probably enough of an incentive, but also the children appeared to form relationships with the cats. By observation only, the kids would wince, or verbally announce sadness when a cat would be hit too hard. Whether the threat of losing points or the threat of hitting a cat was more of an incentive is unknown, but the combination of the two seemed to work well.

7.2 Physical Activity

The physical activity based on the accelerometer data went down in the last levels. This can be attributed to the game moving too quickly for the players to correctly keep up. As the players were making error after error, they would pause to get back in sequence with the game. The activity intensity was not significantly different between the dominate arm version and the two arm version of the game. Although both arms were in motion, they were never in motion at the same time, in effect the same number of motions were required for each version of the game. Another possible explanation for the similarity of the energy expenditure between the dominate arm and the two arm version of the game is the concept of Rocking and Self Stimulation. A study [25] has shown that 29% of children with visual impairments exhibit some form of motion through body rocking or hand movements that are not necessary to perform the task at hand. These extra motions could create more physical activity for the dominate arm version of the game when compared with a user who does not exhibit these features.
The AEE from this study was larger than VI Bowling and smaller than VI Tennis. Since Pet-N-Punch was not self paced, having a larger AEE than VI Bowling was expected. Having a smaller AEE than VI Tennis, could be because of several factors. In VI Tennis, players could succeed by swinging constantly, where as in Pet-N-Punch they would be penalized for such a play style. Another difference could have been the style of swing. Both games had similar thresholds for determining motion, however players in the VI Tennis game may have made larger motions due to previous knowledge of how to swing a real tennis racquet. The Pet-N-Punch in game tutorial taught the player how to swing and players may have learned a shorter swing style than used in VI Tennis. And finally, the cats randomly placed throughout the levels required players to use less motion when they were encountered.

In contrast to the accelerometer data, the heart rate data indicates a constant increase throughout the game. This could be related to the players mental intensity as they have a strong desire to succeed which keeps the heart rate up, while the motions go down as the player attempts to correct his mistakes.

7.3 Accuracy
The accuracy of the game showed significant difference between the two versions of the game. The accuracy of the two arm version was significantly lower than the accuracy of the dominate arm version. The last level was significantly lower when compared to the other levels. This shows that whether the player is required to decide which arm to move (two arm version) or the player already knows which arm to move (dominate arm version) 500 milliseconds is an unreasonable amount of time to expect the player to react and perform the desired actions.

Errors (performing the incorrect motion) were a higher percentage of errors when compared to timeouts (not performing the correct motion in the required time) in the one handed version of the game. With the exception of the last level, the two arm version saw the inverse with timeouts being more popular than errors. This could be an effect of the player waiting to react, instead of already being ready. With the dominate arm version of the game the player already had the knowledge as to which arm to move next, the player simply had to wait to determine the type of motion. The two arm version of the game required the player to determine both the motion and the arm. This decision time could have resulted in a slower reaction time.

An analysis of the timeouts in the last level show that the timeouts were roughly split when looking at timeouts that were due to not performing the first part of the required action and timeouts that occurred due to the player not performing any part of the required action. This suggests that 500 ms is not enough time for a player to perceive and recognize a cue, and then perform the desired action - even if that action is only to swing down quickly once. Games requiring action from a player using only non-visual modalities should give the player more than 500 ms to react to a cue.

7.4 Maximizing Results
One of the goals of this study was to find the point when accuracy and physical activity were both at their peaks. By maximizing both of them, an exergame can be created that is fun to play, and achieves high levels of physical activity. Looking at all the data combined, it seems as though there is a point where physical activity and accuracy are both maximized. This point occurred at the 8 minute mark for both the dominate arm and the two arm version of the game. This suggests for this game the optimum delay between events is 500 milliseconds, and the optimum required response time is around 2500 milliseconds. At this point, the physical activity is highest as well as the success rates. Although faster response times are possible, at this value players were not required to pause and wait to get in sequence with the game, and they were able to exert more amounts of physical activity than previous levels.

7.5 Socialization
Although socialization was not specifically measured, it was observed. This game was only a one player game, but the score (number of carrots remaining in the fields) was announced at the end of the game. After playing the game, the children could be heard discussing their scores. They wanted to have the highest score and to hear who had the highest score.

8 Future Work
8.1 Higher Activity Intensity
Players were able to achieve light to moderate physical activity. In addition to using both arms at once, utilizing the legs or requiring larger motions may help promote more physical activity. Another opportunity for higher activity intensity would be to require more complicated movements. In this study the player was required to perform two quick movements for each cue perceived, if the player was required to make more movements for each cue the activity intensity could be higher.

8.2 Health Benefits
The results indicate that exergames may be a viable form of exercise for people with visual impairments. They do show in increase in physical activity, however it is unknown what the long term effects of utilizing exergames as a method for people with visual impairments to exercise will be. The study shows that exergames may be a method to overcome the three barriers associated with lack of physical activity for people with visual impairments (dependence, safety, and self-imposed). The game contains elements to increase the playability, and a long term study will determine the overall health benefits as well as the replay value.

8.3 Socialization
Video games may contribute to the socialization of people with visual impairments. A multiplayer exergame may also increase the physical activity as players will compete against each other. In addition to achieving a high score, players may have the incentive of competing and defeating their opponent. This could result in a higher energy expenditure as the player exerts more energy in order to win. A multiplayer exergame for people with visual impairments should be created to examine how the social aspect will affect energy expenditure. It was observed that the participants in this study shared their scores with each other, and that could create competition.

9 Conclusion
This paper presents Pet-N-Punch an approach to use tactile/audio cues that indicate motions to one or both arms in order to engage children with visual impairments into physical activity. A study with 12 children who are visually impaired found they were, on average, able to achieve light to moderate levels of physical activity, however a version of the game involving both arms showed no significant difference in physical activity when compared to a version of the game involving the dominate arm only. Although the energy expenditure was not high, the game stimulates active behaviors; players were on their feet performing basic motor control and movement skills, which, considering the limited exercise opportunities available for children who are blind, should be encouraged over inactive sedentary behavior. Optimum values for accuracy and physical activity were found to be consistent and will be used in future game designs. Subjective surveys showed a very strong interest in this game and that could contribute to a higher replay rate and to long term benefits.