Applying Gaming Principles to Virtual Environments for Upper Extremity Therapy Games

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***Abstract*—Home-based care modalities may yield many advantages in therapy and rehabilitation. Virtual systems for rehabilitation are an emerging technology that may be used to enhance the effectiveness of home-based care while simultaneously increasing the number of patients that physical therapists can provide care for. In this paper, we discuss a system that utilizes game design principles to develop a therapy game for upper extremity rehabilitation. We provide an overview of the system and show evidence based on assessments from adults and children using our virtual environment. Results indicate that the system we have developed can engage and encourage the target demographic by adhering to principles common in successful entertainment games.**

Keywords-cerebral palsy; virtual reality; rehabilitation; upper extremity

I. Introduction

Rehabilitation for people with motor disorders or with acquired injuries is crucial for recovery and maintaining an adequate quality of life. Once a patient leaves clinical therapy, there remains a need for continuation of rehabilitation in the home [1], [2]. To decrease the load and increase the efficiency of physical or occupational therapists, many have also recognized the need for home-based rehabilitation programs to increase the quality of life in patients with musculoskeletal conditions [1], [3], [4]. For these home-based rehabilitation programs, engagement is key to ensuring compliance to the therapeutic objectives. In recent years, virtual systems have been shown as an effective means to this end [5], [6].

Prior research has shown that virtual systems can be an effective means of functional recovery in upper limb rehabilitation [5–7]. Virtual systems can be used to provide, not only the therapist with useful data, but also to give the patient much needed feedback on performance and encourage activity [6], [8–10]. Patients can be prompted in real-time to improve their performance by having the virtual environment immediately provide feedback to the individual. Feedback on performance is crucial to motor learning and is also an effective means for allowing the patient to feel productive during the intervention [5].

Computer and video games are inherently appealing; as witnessed by its associated multi-billion dollar industry [11]. Prior research in game design principles have analyzed the various tenants employed by very successful and popular games and there relation to pedagogy [12–15]. Of course, a primary desired benefit of virtual rehabilitation games is that they are appealing and consequently engaging. Since rehabilitation and therapy of the upper extremity is an extension of learning (i.e. motor learning), these prior studies yield relevant results to our assessment.

We seek to develop a system that is engaging and helps to encourage patients to continue therapy from home once away from the clinical setting. As such, in this paper we discuss an upper extremity rehabilitation system that engages individuals by employing gaming principles in its design. We provide an overview of the system and assess the degree to which the developed virtual rehabilitation system adheres to the game design principles. The working hypothesis is that, adherence to gaming principles should correspondingly allow for a dramatic increase in compliance and utilization of the system in the home environment.

II. Incorporating Game Design in Therapy Games

A. The Virtual Rehabilitation Therapy Game

In [16], the SuperPop VR™ game, a virtual system for upper extremity rehabilitation, was presented. SuperPop VR™ was developed to work on any general-purpose computer system running a Windows 64-bit operating system. A 3D depth camera, the Microsoft Kinect™, was also used to acquire the user's joint positions in the Cartesian plane in order to provide assessment of clinical outcome measures during game play. When playing SuperPop, the user sees virtual bubbles surrounding them on a screen (Figure 1). We have adapted the SuperPop game to implement a rhythmic stimulation therapy (presented in detail in [17]) in order to increase engagement. The goal of the SuperPop Music game is to pop as many bubbles as possible in a certain amount of time by moving the hand close to the center of the bubble. A song is played with an overlying rhythmic beat, or metronome tone, during game-play. The users are instructed to move to the beat as they reach between bubbles. Game sessions can be customized to the capabilities of the user by changing game parameters, which correspond to difficulty level. In the following section, we discuss game design principles and adherence to these principles in the SuperPop Music game.

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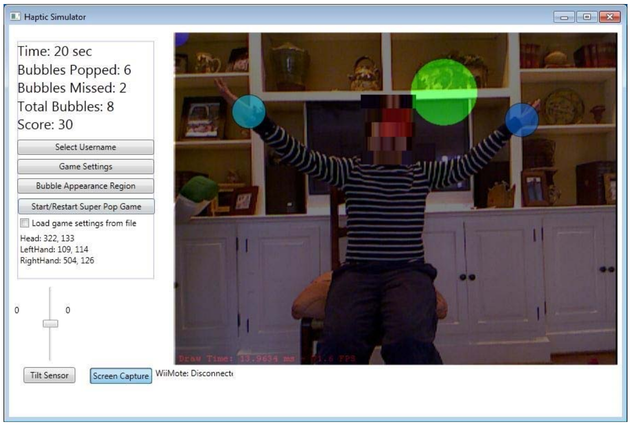

Figure 1. Screenshot of the SuperPop VR™ Game

B. Game Design Principles

In previous studies focused on virtual systems used in therapy, motivation and high interest are noted as key components necessary for compliance [18]. In-home virtual systems provide the added advantage in that children are able to attempt new movements without embarrassment or the risks associated with trying in real life scenarios. In [18], it was shown that children who played virtual reality games spoke of their increased confidence and new opportunities. The author suggests that this alludes to the game providing an increase in engagement and also provides an opportunity to gain increased control over motor function. In [12], Ibrahim and Jaafar analyze and make a comparison between a few different design frameworks for educational games, and then introduce their own, which not only considers game design and pedagogy, but also highlights the importance of learning content modeling. McGinnis [14] also takes a similar stance and looks to use some of these key gaming principles in electronic learning. In [13], Rosario and Widmeyer introduce their set of twelve design principles for gaming-learning environments based on previous work in this field. Whitton [15] looks at engagement and motivation of games in terms of five fundamental principles defined through analyses of games designed for entertainment. By assessing the prior research in this area of game design principles and their role in learning, the framework we employ is derived from the following common key principles: In-Game Story, Easy to Use Interface, Interactive-Feedback, Encourage Exploration, and Sense of Achievement. These principles were used to develop and assess our system's ability to effect engagement and encouragement among participants.

1) In-Game Story

An engaging story or context is crucial when trying to draw players into a play scenario. A story invites the player to become immersed in a virtual experience through the eyes of a character/avatar. Since many of the individuals using our system are anticipated to be children, the game story employed in our virtual system is the simple exercise of popping bubbles to the rhythm of a song. The song, itself, provides a musical storyline which enables therapy interventions to be accessible to a larger demographic of patients with disorders that affect their motor skills. The game interface is designed in such a way that game-play may be initiated with little effort from the patient after a therapist has set all desired game parameters. In the SuperPop Music game, the avatar is the player's own image embedded within the virtual environment (Figure 1).

2) Easy to Use Interface

The user interface (UI) is the means by which the player (and clinician) can communicate to and navigate around the game environment. It must be intuitive and easy to understand. A complicated UI could frustrate a player into abandoning the game entirely and lose interest in playing. The player's concentration should be geared to how to beat the game, not how to learn its interface. For the individual playing the game, the interface employed is that of mediated reality wherein virtual elements are overlaid in the physical, real-world. For the clinician, the system employs a UI (Figure 2) that allows the therapist to select the parameters of any game such that they match with the patient's capabilities, thus also ensuring easy interaction for the user.

3) Interactive-Feedback

The game should be designed to provide immediate feedback to the player such that the player can be made aware of any mistakes or successes that the player has prompted. Through such feedback, the player can reflect on the actions that have led them to that state, which in turn can help the player understand and better master the game. Feedback can be received in different forms: visually (through text or graphics), haptically, or through auditory channels [19]. By using multiple modes of communication, the player can experience a greater sense of realism and immersion. Our mediated reality interface is designed so that the user may get immediate visual feedback based on their direct manipulation of the virtual elements in the game. The goal is indicated through auditory feedback by a rhythmic cue that initiates each successive set of bubbles. In addition, text-based visual feedback is provided using a scoring board (Figure 3). Scores are representative of positive and negative feedback based on game-play performance where positive points, associated with positive reinforcement, are awarded for successful bubble pops before the bubbles disappear and negative points reflect an unsuccessful attempt and is associated with negative reinforcement.

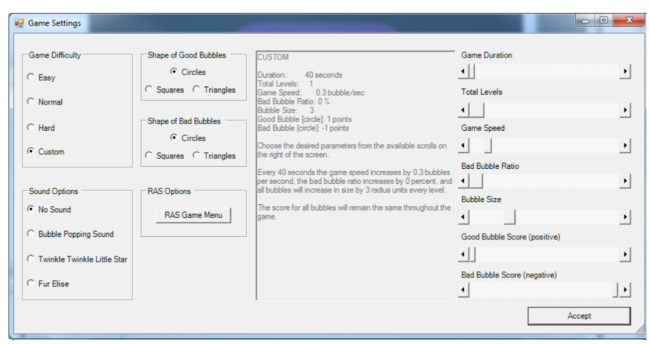

Figure 2. Screenshot of the user interface employed by the therapist

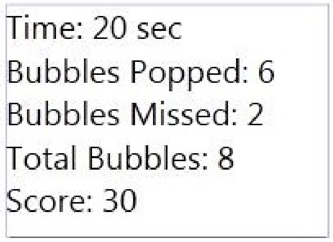

Figure 3. Score board used to provide visual, text-based, feedback to the user

4) Encourage Exploration

The game should encourage the player to explore and become familiar with his/her capabilities within the game. By playing around within the environment, the player gains better control over his/her avatar and a better handle on the game's constraints. And by becoming more familiar with their character/avatar, players can become immersed in the virtual world. Generally, as an incentive to explore, some type of reward (indirect or direct) should be given to the player. In our game, the player is not only being encouraged to increase the skills of their avatar, but their real-world counterpart as well. We seek to encourage exploration of new upper extremity movements that might have otherwise not been explored. The player is rewarded for each successful bubble pop through a scoring system, as discussed prior.

5) Sense of Achievement

Players should be rewarded throughout the game to encourage their continuous participation and further mastery of the game. These rewards serve as an incentive to both keep the player engaged in the current game and encourage them to revisit the game in order to master levels for greater rewards. The rewards also function as markers or milestones to award players for their game performance. To enable this concept, our virtual rehabilitation system contains 3 separate indications of performance: bubbles popped, bubbles missed, and score (Figure 3). These parameters provide the necessary feedback for the player to gauge their own success on performance. These indicators also allow for and encourage the users to explore new reaching motions in order to pop the bubbles without the dangers of attempting these new motions in a real world setting. These rewards and indicators offer what we believe to be an appropriate means to yield feelings of achievement in the player.

Our goal in combining these elements of game design in our virtual rehabilitation systems was to provide a grounded mechanism to encourage and engage the individual in home-based therapy sessions. In the next section, we discuss assessment of our game system implementation through the use of surveys and a quantitative measure of performance.

III. Results

We recruited 19 adults and 7 children to interact with our virtual system. All adult participants signed informed consent forms, whereas parents signed parental consent forms (with verbal assents provided by the children). The age group of the adult participants was between 18 and 32 and included 6 female and 13 male participants. Each participant was asked to interact with the virtual rehabilitation system at least four times. Each interaction was timed to last 40 seconds. At the conclusion of the set of interactions, participants were given survey questions to evaluate their experience.

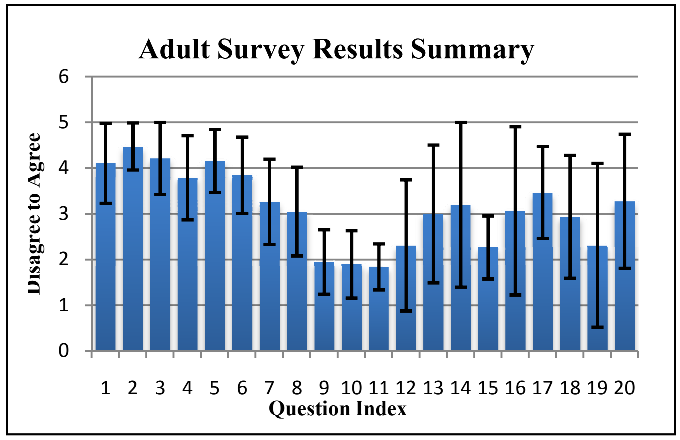

Figure 4. Results of the survey given for the adult test . The blue bars are the average answer which range from "Strongly Agree" (5) to "Strongly Disagree" (1) – a typical 5-pt. Likert scale. The black lines represent the +/- standard deviation over the mean.

A. Adults

The survey questions provided to the adults included 20 questions which used a 5-point Likert scale with the choices: Strongly Agree (5), Agree (4), Neutral (3), Disagree (2), and Strongly Disagree (1). The survey presented a broad range of questions inquiring about the SuperPop Music game and the user's prior experience. Table 1 lists the questions presented in the survey, the question number, the average answer (AVG), and the standard deviation (STD). It should be noted that in the table we are only reporting questions of STD less than 1.0 since they are considered of most significance. Figure 3

TABLE I. ADULT SURVEY DATA SUMMARY

#	Question	AVG	STD
1	I have a lot of experience playing video or computer games.	4.11	0.88
2	The game interface is easy to understand.	4.47	0.51
3	The rules of the game are clear from the current presentation.	4.21	0.79
4	I found it nice to see myself in the game.	3.79	0.92
5	I enjoyed playing the game overall.	4.16	0.69
6	I think I performed well in the game.	3.84	0.83
7	I would like to play this game more often.	3.26	0.93
8	The game was so engaging that I lost track of the time.	3.05	0.97
9	The game was too fast. I would have liked to play a slower version of the game.	1.95	0.71
10	The game was too difficult. I would have liked to play an easier version of the game.	1.89	0.74
11	I found it hard to play the game by moving my arms.	1.84	0.50
12	I popped the bubbles faster when the music was playing.	2.27	0.69
13	The metronome tone allowed me to keep my focus.	3.47	1.00

depicts a summary of the results from the survey given to each of the 19 adult participants in the assessment.

Based on the data with least variation, we can glean from this information that the participants, on average, were experienced in game play (Q1). They also thought the game to be intuitive and lacking in ambiguity (Q2-Q3). On average, the users mostly disagree that the game was too fast or too difficult or that it was difficult to play by moving their arms around (Q9-Q11). These results support the principles of encouraging exploration, ease of use, and the effectiveness of the in-game story. Most people also were pleased to see themselves appear in the game (Q4) which supports our mediated reality interface and our use of visual feedback. We can glean from the data that the participants, on average, enjoyed playing the game and thought they did well (Q5-Q6). This seems to imply that we have successfully given players a sense of achievement.

They were neutral in whether they would like to play the game more often (Q7) and in that the game was so engaging that they lost track of time (Q8). Participants were also neutral as to whether the metronome tone allowed them to keep focus, but leaned towards agreeing (Q13). Most participants disagreed that they could pop bubbles faster with the music playing (Q12). We can use this information to give insight into our implementation of auditory feedback. In the next iteration we attempted to address these issues.

B. *Children*

Figure 5 presents the data summary for interaction with the children participants. For typical children, the survey questions were paired down for ease of understanding and also to better assess our 5 principles. In Figure 5 we present the summary of the data taken from the surveys presented to 7 typical children (6 female, 1 male) between ages 5 years 6 months and 10 years 4 months in the assessment. Each question was asked on a 5-point Likert scale where 1 corresponds to "Completely Disagree," 2 to "Slightly Disagree," 3 to "Neutral," 4 to "Slightly Agree," and 5 to "Completely Agree." These surveys were given orally by the clinician wherein the clinician deemed the most appropriate selection for the child's response to each question.

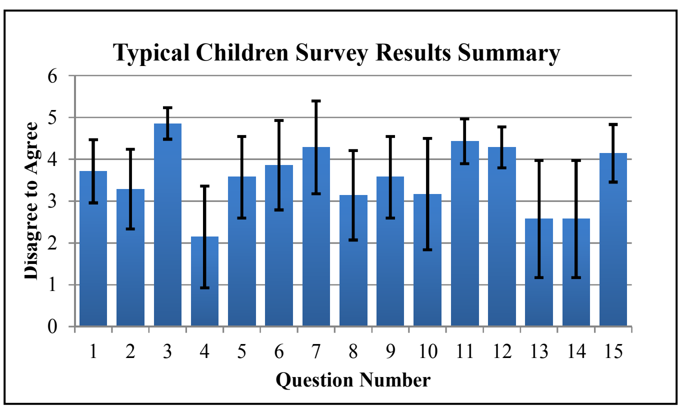

Figure 5. Typical children test survey data summary. The blue bars are the average answer which range from 5 (Agree) to 1 (disagree) – a typical 5-pt. Likert scale. The black lines represent the +/- standard deviation over the mean.

selection for the child's response to each question.

Table 2 shows the list of questions with most significant results from the survey presented to the children during the assessment. We also include the average response (AVG) and standard deviation (STD). We again define results as most significant if their standard deviation is less than or equal to 1.0. Questions with STD greater than 1.0 have been omitted.

Here we present the data from the questionnaire with the most significance. We will refer to each question as Q# to indicate question number, #, in Table 2. In support of our in-game story and visual feedback, most children found the objects in the game to be interesting (Q1) and they also found the objects in the game to be attractive (Q2). Q4 regards the difficulty of movements and may support our adherence to the principle of encouraging exploration of new movements. Most also agreed that they liked playing the game (Q8) and that they would like to play it more often (Q5) which could be indicative of sense of achievement. Ease of use is indicated in Q6-Q7 where the children's responses comment on their understanding of the game, how easy it was to follow, and the intuitiveness of in-game behaviors. In Q3, the children mostly agree that they could hear all of the sound from the game very well. Most agreed the movements used in the game were not too fast or slow (Q4). This data seems to confirm that our implementation of auditory feedback was proven successful.

C. *Between Groups*

During the testing assessment, we gathered joint position data from a Microsoft Kinect 3D depth sensor. Since we have the 3 Cartesian coordinates of the upper extremity joints in 3-space, we are able to calculate joint angles, such as elbow angle and shoulder angle. Range of motion (ROM) of an angle is defined as the difference between maximum and minimum angle. Flexion is a movement, typically in the sagittal plane, that decreases the angle of a joint and reduces the distance between the two bones of the joint. In contrast to this, extension is a movement that increases the angle of a joint and the distance between the bones [20]. Elbow ROM can be defined as the point at which there is maximum flexion to the point where there is maximum extension of the arm at the elbow joint. We use the 3-dimensional angle of the elbow (denoted as Elbow in Table 3 and θ_{3D} in Equation 1) which is

TABLE II. CHILD SURVEY DATA SUMMARY

#	Questions	AVG	STD
1	I found the objects in the game very interesting	3.71	0.76
2	The objects I saw in the game were very attractive	3.29	0.95
3	I could hear all music in the game very well	4.86	0.38
4	The movements used to touch objects in the game were so fast, they were not too easy; but also were not too hard	3.57	0.98
5	I would like to play the game more often	3.57	0.98
6	The request from the game was easy to follow	4.43	0.53
7	It was very logical playing the game by popping the objects	4.29	0.49
8	I like playing the game	4.14	0.69

calculated by the dot product, defined in (1), of the vectors formed by the upper arm ($\boldsymbol{u}$) and the lower arm ($\mathbf{s}$) to define what we refer to as the elbow flexion angle. We report three different angles for the shoulder: the 3-dimensional shoulder angle (S3D), a shoulder abduction angle (SA), and a shoulder flexion angle (SF) which are described as follows.

$$\theta_{3D} = \cos^{-1}\left(\frac{\boldsymbol{s} \cdot \boldsymbol{u}}{|\boldsymbol{s}||\boldsymbol{u}|}\right) \quad (1)$$

The S3D angle is determined using (1) in the same manner as the Elbow 3D angle. Due to the shoulder being a ball-and-socket joint, which is a multiaxial joint wherein movement is allowed in all directions and pivotal rotation [20], we use the clinical definitions of arm motion to describe different types of arm ranges of motion we measure in our study. Since these clinical definitions of motion are restricted to motion on a fixed plane, we must derive our own classification for the unique motion that occurs in normal random reaching.

Abduction is a movement of a limb away from the midline or median plane (a sagittal plane through the midline of the body), generally on the frontal, or coronal plane. In contrast, what is sometimes referred to as the opposite of abduction, adduction is movement toward the midline of the body [20]. The shoulder abduction/adduction ROM (which we will summarily refer to as just shoulder abduction) is defined as the point at which there is maximum abduction to the point at which there is maximum abduction (See Figure 6b). This can be thought of the arm motion used to make a snow angel.
Shoulder flexion/extension ROM (summarily referred to as simply shoulder flexion) is defined as the point at which there is maximum flexion to the point where there is maximum extension of the arm at the shoulder joint (See Figure 6a) [20]. This can be thought of as the motion of the arm from rest in a standing position to straight up in the air as if to give a high five.

We define our shoulder flexion angle as the angle of the shoulder made by projecting the upper arm onto a sagittal plane (perpendicular to the line made by the shoulder joint to the center shoulder joint) versus the coronal plane.

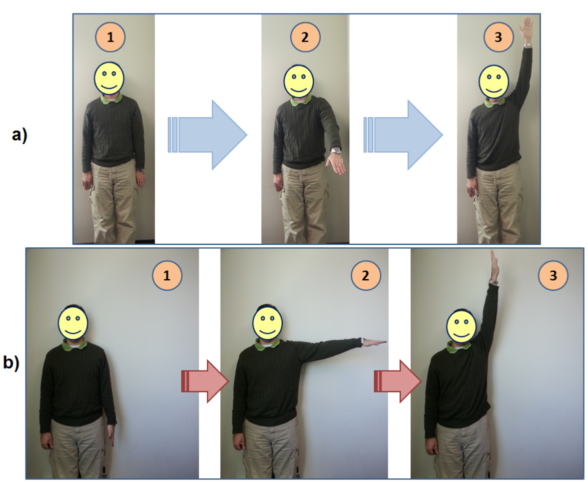

Figure 6. A demonstration of the range of motion of shoulder flexion/extension (a) and shoulder abduction/adduction (b).

Similarly, the shoulder abduction angle is defined as the angle formed by the upper arm projected onto a coronal plane versus the same sagittal plane used for flexion. Numerically these angles are determined by creating a radius using the upper arm and creating a vector projection onto the coronal plane in the case of the abduction angle, or onto the sagittal plane in the case of the flexion angle. A more exhaustive explanation of these calculations can be found in [17] & [21]. The angular data determined by this method was validated in [17], [21], & [22] using a Vicon Motion Capture System.

Since we acquire these angles at a sample rate of about 25 samples per second, we also can determine the angular velocity during each reaching trajectory between the bubbles using a central difference method. By determining the maximum angle in a single trajectory, we acquire the peak angular velocity (denoted PAV in Table 3). From these measurements we determined a significant trend using a two-way t Test statistical analysis that indicates an increase in reaching velocities in the children group (See Table 3). According to [5], peak velocity (and thus by transitivity, peak angular velocity) is typically considered indicative, indirectly, of force of movement, or more appropriately momentum of movement, in the rehabilitative space [5]. These results are supported by previous studies linking movement force and velocity to engagement [23–25]. In these prior studies, a connection was found between engagement during game play and a measure of the amount of motion, dubbed Quantity of Motion (QoM), which used velocity and force to programmatically discriminate emotional states. As such, we believe that these performance measures indicate a more engaged child group as compared to the adult group.

IV. Discussion

Using our results from the adult surveys and considering the data only with the least deviation (≤1 STD), we take the following main points from the data. Judging our game implementation using the principles defined, we see that the adult game effectively implements the in-game story, provides useful visual feedback, encourages exploration, and offers a sense of achievement. However, this implementation yielded conflicting results on ease of use.

From the results from the child surveys and considering the data only with the least deviation, we can glean the following main points from the data. Again we see support of our in-game story in the children's survey results as well as the visual feedback. From the survey data, the game interface is thought to be easy to use and understand. Based on the children's self-assessment of movement difficulty we believe that our game encourages movement exploration. We believe we addressed the need for auditory feedback. The overall positive responses to questions of appeal of the game and self-assessment support

TABLE III. t Test Comparison Between Children and Adult Groups

Metrics	P-value	t Stat	t Critical	Effect
ELBOW PAV	0.0206	3.1198	2.4470	Reduced
SA PAV	0.0136	3.1512	2.3060	Reduced
SF PAV	0.0324	2.6618	2.3646	Reduced
S3D PAV	0.0022	4.4340	2.3060	Reduced

our design's ability to give a sense of achievement.

We saw a direct change in the perception of the game speed between the groups and we expected this since we made the tempo exactly equal to the child's natural tempo. These results coupled with the findings in the comparison between the children versus the adults regarding the significant higher trend of peak angular velocities in the child group lead us to believe that children were very engaged in the game-play. This is crucial for an effective therapeutic treatment as we have found from our review of the literature.

We also observed that throughout the experimental sessions that all the users were concentrated and focused during game-play. This further supports that the children were engaged during game-play.

V. CONCLUSIONS

Overall from the results of our surveys, our observations, and the kinetic data, we believe that we have developed a system that adheres to the game design principles presented, which is indicative of an effective game for use in a therapeutic regime. Further testing is needed to prove the system's effectiveness in improving motor function, but this testing is also warranted based on the findings we present and the findings of others. The results presented here will form a basis for future tests using this system. Preliminary evaluations of the system have been performed with children with CP, the results of which are forthcoming.

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