Engaging Children in Play Therapy: The Coupling of Virtual Reality (VR) Games With Social Robotics

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Abstract. Individuals who have impairments in their motor skills typically engage in rehabilitation protocols to improve the recovery of their motor functions. In general, engaging in physical therapy can be tedious and difficult, which can result in demotivating the individual. This is especially true for children who are more susceptible to frustration. Thus, different virtual reality environments and play therapy systems have been developed with the goal of increasing the motivation of individuals engaged in physical therapy. However, although previously developed systems have proven to be effective for the general population, the majority of these systems are not focused on engaging children. Given this motivation, we discuss two technologies that have been shown to positively engage children who are undergoing physical therapy. The first is called the *Super Pop VR^{TM}* game; a virtual reality environment that not only increases the child's motivation to continue with his/her therapy exercises, but also provides feedback and tracking of patient performance during game play. The second technology integrates robotics into the virtual gaming scenario through social engagement in order to further maintain the child's attention when engaged with the system. Results from preliminary studies with typically-developing children have shown their effectiveness. In this chapter, we discuss the functions and advantages of these technologies, and their potential for being integrated into the child's intervention protocol.

Keywords: Serious games, Physical Therapy and Rehabilitation, Play Therapy, Social Robotics, Darwin-OP, and *Super Pop VR^{TM}*.

1 Introduction

Upper-arm motor impairments affect a number of population demographics, from children living with cerebral palsy [1] to adults recovering from stroke. In the clinical setting, the most effective means to improve recovery of motor function is through rehabilitation which involves intense, repetitive engagement of the respective limb. Unfortunately, due to a number of factors, including increases in medical costs, reduction in paid benefits, and limits on time available for therapists to provide quality one-on-one sessions, there is a growing need to introduce low-cost rehabilitation systems into the home environment. These systems must not only be designed to engage patients into the rehabilitation protocol established by the therapist, but also provide accurate and appropriate feedback on and tracking of patient performance. This desire for engaging home-based rehabilitation systems is especially prevalent when addressing the therapeutic needs of children with physical and/or cognitive impairments [2].

Pediatric physical therapy differs from adult therapy in that children typically cannot (or may not be willing to) follow direct instructions required of a therapy routine. As such, clinicians typically incorporate therapy in play to provide an engaging and motivational intervention that may enhance the child's participation in the therapy session. No one will argue about how important play is during childhood. The role of play in the development of children has been extensively studied, and a large body of work exists to discuss the importance and nature of play in children [3]. As such, these alternative technologies for engaging children with disabilities in rehabilitation should have a key requirement of incorporating concepts of play within their design.

One of the key factors in play, which is also shown to be a determinant for effecting compliance in rehabilitation is engagement. To effect engagement and/or motivation, one such promising technology that has been gaining momentum in recent years is the coupling of virtual reality games with robot-assisted rehabilitation. Virtual reality (VR) refers to a computer technology that creates a three-dimensional (3D) virtual context and virtual objects that allow for interactions by the user [4]. These gaming scenarios enable robust changes in motor task difficulty level, as well as effect the quantity/quality of the feedback on performance, which have been shown as key factors that influence engagement and thus adherence. In [5], Colombo et al. showed that game like scenarios in conjunction with a robot-assisted rehabilitation device helped motivate users through score keeping, in which the scoring mechanism was coupled with the individual’s achieved range of motion (ROM). In [6], a case study provided preliminary evidence that using custom-made VR rehabilitation games with a robotic ankle orthosis can be clinically more beneficial than the same rehabilitation in the absence of the VR games. Similarly, in [7] a ten patient study showed that a VR robot-assisted therapy approach induced a motor output effect that was considered comparable to those obtained with conventional approaches in the presence of a human therapist for patients different neurological gait disorders. Finally, in [8], the Gentle/s system was shown as an appealing device that, when coupled with VR technology, can provide robot mediated motor tasks in a three dimensional space. Although this is just a sampling of the current efforts in this domain, the common theme has been to increase motivation for robot-assisted rehabilitation through the use of interactive gaming. Although preliminary evidence shows that most of these VR-robotics coupled systems are effective, what is missing is their focus on engaging children. As such, this chapter discusses the use of VR and robotics to assist in the rehabilitation process of children who are undergoing physical therapy.

We segment this chapter into two primary technologies that, once integrated, provide an integrated system for this domain. Section 2 provides an overview of the state-of-the-art in gaming and robotics. Section 3 discusses a VR system that can provide feedback and tracking of patient performance during game play. Section 4 details a pilot study that integrates robotics into the VR gaming scenario through social engagement, whereas Section 5 provides concluding remarks and a summary of next steps.

2 Related Work

Although there are very few research efforts focused on using integrated virtual reality-robotic systems for children, there has been growing interest in research involving therapeutic play between robots and children [2]. KASPAR [9], a child-sized robot for engaging children with autism, utilizes expressions and gestures to communicate with its human partner. Another robot designed to teach social interaction skills is CosmoBot [10], a commercially-available telerehabilitation robot that enables a therapist to record robot movements to enable the performance of repetitive and predictable motions, which adheres to a specified behavioral skill. In [11], researchers utilize a humanoid robotic doll, named Robota, to engage children with autism in imitation-based games. In a related domain, teleoperated robots have been shown to enable achievement of play-related tasks that go beyond the child's own manipulation capabilities. In [12], a teleoperated robot called PlayROB was developed to enable children with physical disabilities to play with LEGO bricks. The "Handy" robot in [13] was used to assist children with cerebral palsy in performing a variety of tasks such as eating and brushing teeth. In a pilot study, the authors showed how the robot could be used to enable drawing. Cook et al. [14] also showed the use of robot arms for assisting children in play related tasks.

With respect to virtual reality (VR) systems, alone, there have been a number of pilot studies that have focused on children in recent years. Reid et al. [15] conducted a study to show the benefits of a VR system for children with cerebral palsy. Her studies suggest that a virtual environment allows for increased play engagement and the opportunity for children to practice control over their movements. Bryanton et al. [16] showed that using VR systems to guide exercises may enhance exercise effectiveness. This work focused on the rehabilitation of lower-body motor skills (i.e. ankle dorsiflexion movements in chair-sitting and long-sitting). The results of these studies reported that children have better control of ankle dorsiflexion and show greater interest in doing the same exercise when presented to them through a VR system than as a stand-alone exercise. Golomb et al. [17] investigated whether an in-home remotely monitored VR videogame can help improve hand function and forearm bone health in an adolescent with hemiplegic cerebral palsy. In [18], researchers used a Wii console to augment the rehabilitation of an adolescent with cerebral palsy, whereas in [19], a motion-capturing product called the EyeToy was used to provide a relatively low-cost in-home virtual environment.

Although the feasibility of VR systems has shown to have positive outcomes in the children-rehabilitation domain, there is still a lack of automating feedback on patient performance through these systems. On the other hand, robotic devices, which has been shown to provide a concrete method for objectively recording and assessing the performance of a patient through repeatable and quantifiable metrics (position, trajectory, interaction force/impedance) [20], has not been well-integrated in the child-rehabilitation domain. As such, in this chapter we discuss technologies that enable the design of an integrated VR-robotic system for child-rehabilitation.

3 A Virtual Reality Game for Upper-Arm Rehabilitation

3.1 Introduction

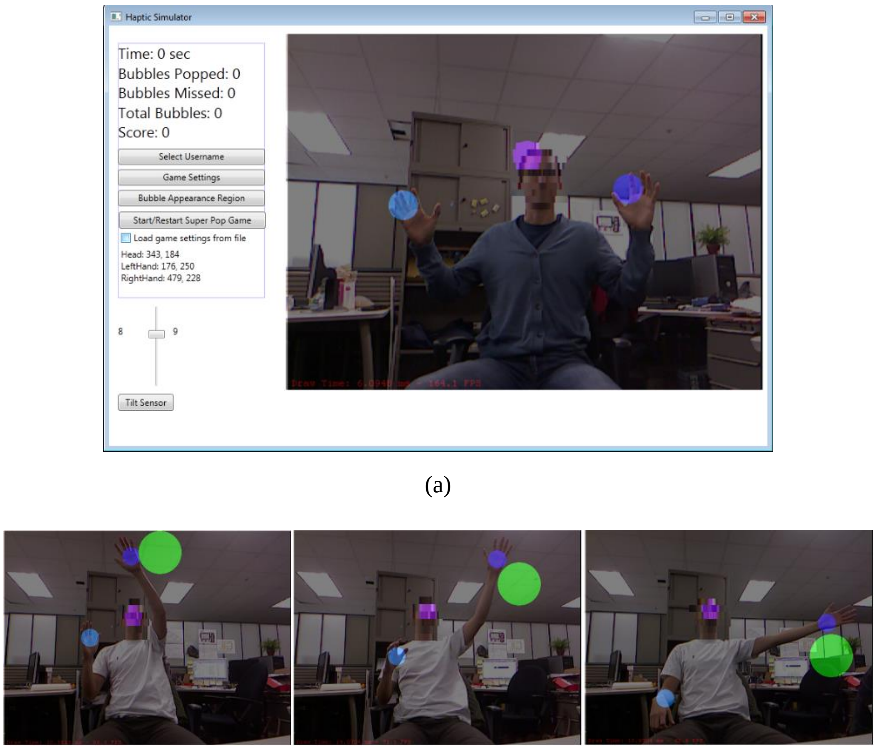
Virtual reality (VR) environments play an important role in the rehabilitation field. Therapists and researchers have studied its importance in physical therapy interventions for people with different conditions such as stroke, Parkinson's disease, and cerebral palsy. Unfortunately, most of these VR systems do not integrate clinical assessment of outcome measures as an automated objective of the system. In addition, most of these systems do not allow real-time adjustment of the system characteristics that is necessary to individualize the intervention. Previous research has shown that VR environments present many benefits in the rehabilitation of individuals with motor skill disorders. Not only do they improve compliance for individuals working with their exercises [21], but they also enhance exercise effectiveness [16]. In this section, we discuss a VR system that integrates clinical assessment of outcome measures, as well as allows individualization of the rehabilitation protocol through real-time adjustment of game parameters. In the subsequent section, we then segway into discussion of the robotics platform, and show methods for robot integration into the gaming scenario.

3.2 Objective

While there have been a number of VR systems developed for use as part of physical therapy interventions for children with motor skill disorders, most do not incorporate a formal method of evaluating the subjects' upper-body motor skills in real-time and in the comfort of their own home. Taking into consideration the limitations of previously developed systems, the goal of our low-cost VR gaming system is to function as an in-home rehabilitation tool for individuals with any motor skills disorder that is user-friendly for both the user and the healthcare professional. The two key features of the system are: 1) the ability to individualize the rehabilitation protocol through adaptation of game settings, and 2) the ability to autonomously record and assess rehabilitation outcome measures for providing feedback to the therapist in real-time. Individualization is achieved through an adaptable user interface that allows the therapist to select desired game settings to match the rehabilitation objectives customized to the user's capabilities. In addition, unlike common entertainment systems, while users are engaged in repetitive movements during game play, the system is capable of analyzing the user's upper-body movements in real-time. Interaction with the game yields an assessment of outcome measures by quantifying the kinematic parameters that describe human movement. Some of these parameters include range of motion (ROM), movement smoothness, and deviation from path.

3.3 Description of Overall System

The VR system consists of a virtual game developed to work on any general-purpose computer system running a Windows 64-bit operating system, and a three-dimensional (3D) depth camera. The camera is used to track the user's upper-body movements and map them into the presented virtual environment. For our application, we utilize the Microsoft Kinect 3D camera [22] along with an open source SDK that provides the necessary functions for tracking upper-body human movement. Beyond the basic requirements of a computer system to run the game and a 3D depth camera, there is no need for additional equipment like gloves or helmets. In addition, the users are free to move their entire bodies without being restricted to traditional computer inputs (e.g. keyboard and mouse).



Time: 0 sec
Bubbles Popped: 0
Bubbles Missed: 0
Total Bubbles: 0
Score: 0

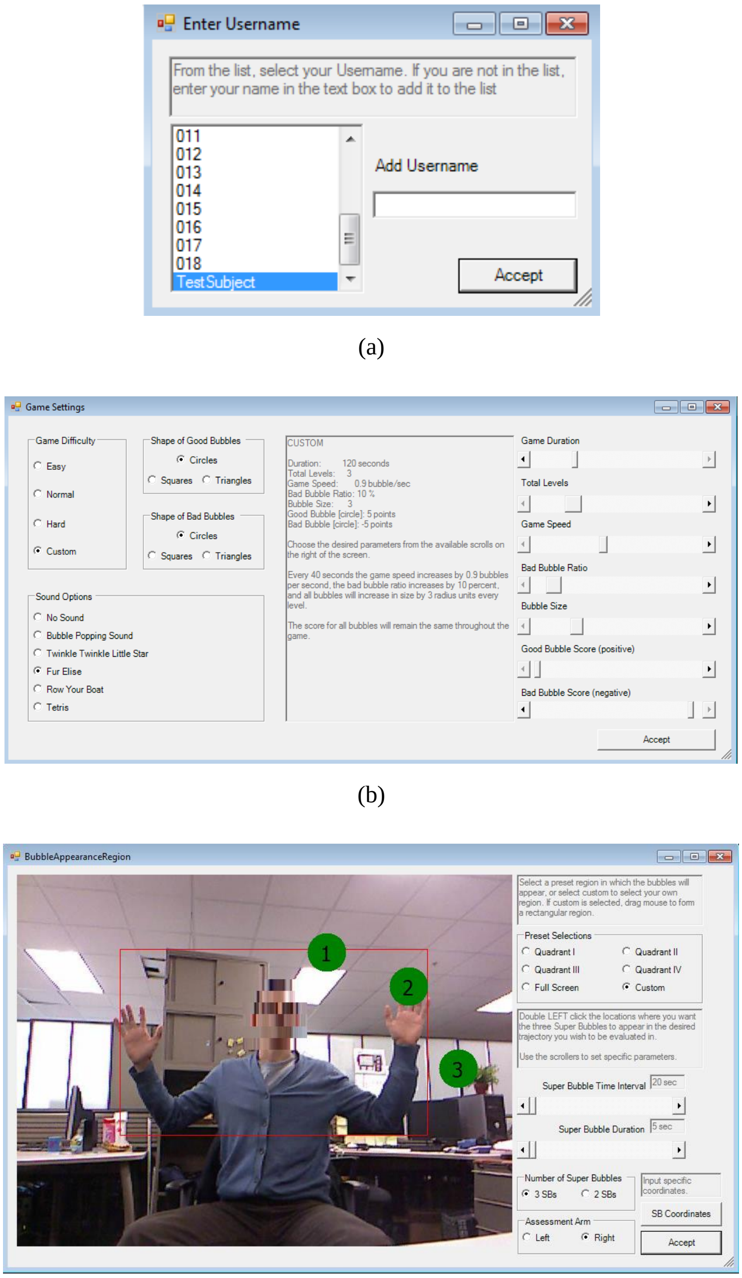
☐ Load game settings from file

Head: 343, 184
LeftHand: 176, 250
RightHand: 479, 228

(a)

(b)

Fig. 1. (a) Main graphical user interface of the *Super Pop VR*^{TM} game. (b) Example of a 90° trajectory created by the position of the three super bubbles.



Enter Username

From the list, select your Username. If you are not in the list, enter your name in the text box to add it to the list

011
012
013
014
015
016
017
018
Test Subject

(a)

Game Settings

Game Difficulty
○ Easy
○ Normal
○ Hard
● Custom

Shape of Good Bubbles
● Circles
○ Squares ○ Triangles

Shape of Bad Bubbles
● Circles
○ Squares ○ Triangles

Sound Options
○ No Sound
○ Bubble Popping Sound
○ Twinkle Twinkle Little Star
● Fur Elise
○ Row Your Boat
○ Tetris

CUSTOM

Duration: 120 seconds
Total Levels: 3
Game Speed: 0.9 bubble/sec
Bad Bubble Ratio: 10 %
Bubble Size: 3
Good Bubble [circle]: 5 points
Bad Bubble [circle]: -5 points

Choose the desired parameters from the available scrolls on the right of the screen.

Every 40 seconds the game speed increases by 0.9 bubbles per second, the bad bubble ratio increases by 10 percent, and all bubbles will increase in size by 3 radius units every level.

The score for all bubbles will remain the same throughout the game.

(b)

BubbleAppearanceRegion

Select a preset region in which the bubbles will appear, or select custom to select your own region. If custom is selected, drag mouse to form a rectangular region.

Preset Selections
○ Quadrant I ○ Quadrant II
○ Quadrant III ○ Quadrant IV
○ Full Screen ● Custom

Double LEFT click the locations where you want the three Super Bubbles to appear in the desired trajectory you wish to be evaluated in.

Use the scrollers to set specific parameters.

Super Bubble Time Interval: 20 sec
Super Bubble Duration: 5 sec

Number of Super Bubbles
● 3 SBs ○ 2 SBs

Assessment Arm
○ Left ● Right

Input specific coordinates.

(c)

Fig. 2. Secondary graphical user interfaces accessed by pressing the corresponding buttons on the main GUI: (a) 'Select Username', (b) 'Game Settings', and (c) 'Bubble Appearance Region'.

The developed VR application is called ***Super Pop VR™*** [23]. When playing, the user is immersed in a virtual world where virtual bubbles (represented by colored circles, squares, and/or triangles) appear on the screen surrounding the user. The goal of the game is to pop as many bubbles as possible in a certain amount of time by moving a hand over the center of the bubble. The 3D depth camera is used to track the skeleton of the user in order to determine the coordinates of the hand joints. Two blue markers follow the user's hands in order to provide feedback to the user on the exact position of their hand as recognized by the system (Fig. 1a). The user is instructed to pop the yellow (good) bubbles and to avoid the red (bad) bubbles. Moreover, there is a set of green bubbles called Super Bubbles (SBs) that are worth double the points as the yellow bubbles. Based on the user's intervention protocol established by the therapist, a certain amount of time is specified in which all yellow and red bubbles on screen get erased and a set of two or three SBs appear on their own one by one. Each set of SBs highlights the trajectory that the therapist will use to evaluate the users rehabilitation outcome metrics. For example, three SBs may be placed such that a 90^0 motion is created forcing the user to follow this 90^0 trajectory (example shown in Fig. 1b). These sets of SBs are used to determine the point in time where the system captures and stores the user's upper-body joint coordinates. This information is used to evaluate the user's movements by calculating the relevant kinematic parameters. After playing the game for a given period of time, the therapist can analyze the results of the assessment in order to track the user's progress and to evaluate areas that may need improvement.

Figure 1a also shows the main graphical user interface (GUI) that the user sees once a game starts. Besides showing the virtual environment, the main interface also depicts the user's progress during game play. In addition, four main buttons are located at the left side of the GUI: 'Select Username', 'Game Settings', 'Bubble Appearance Region', and 'Start/Restart Super Pop Game'. When pressed, the first three buttons access secondary GUIs that provide the therapist options for customizing the intervention protocol of the game (Fig. 2).

The 'Select Username' GUI lets the therapist assign individual usernames or IDs in order to enable the system to be used by multiple users (Fig. 2a). The 'Game Settings' GUI offers the option to choose from three different game difficulties with hardcoded parameters (Easy, Normal, and Hard) as well as a Custom option (Fig. 2b). The Custom option enables the therapist to provide their own combination of game settings depending on the needs of the user. Finally, the 'Bubble Appearance Region' GUI shows a snapshot of the subject taken by the camera when the corresponding button is pressed. In this interface, the therapist can select the workable region in which regular bubbles will appear and the position of the SBs based on the placement of the subject from the shown snapshot. Fig. 2c shows the workable region as a red rectangle and the SBs as green circles. Given that all users are of different heights and all have different arm reach, this interface allows for personalized sessions accommodating the different body structures of the users. The therapist can also select the SB display/appearance interval duration, the number of SBs used for the protocol, and identify the arm to be assessed.

The combination of options and features provided by the different interfaces provide the therapist the freedom to match the level of difficulty of the game to the user's capacity. For example, if the experimental protocol is designed to improve the user's maximum range of motion (ROM), the therapist would position three SBs such that they are spaced with a slightly greater angle than the user's effective ROM. This way, through practicing the specified repetitive motion that will appear throughout the game, the user will progressively increase his/her ROM given that he/she will need to reach the next SB.

Game sessions can also be individualized to the capabilities of the user by customizing the difficulty level. The difficulty of each game can be set by selecting different combinations of the following parameters: game duration in seconds, total number of levels, game speed in bubbles per second (rate at which the bubbles appear on screen), bad bubble ratio, bubble size, good bubble score, and bad bubble score. These parameters serve different purposes in the rehabilitation protocols. For example, the size of the bubbles is linked to the accuracy of the user. Intervention protocols designed for users with poor accuracy will include larger bubbles. Similarly, the speed of the bubbles is linked to how developed the symptoms of the users are. Users with more developed symptoms usually have slower movements, thus their intervention protocols will include games with a slower pace.

All the game levels have equally distributed durations determined by dividing the total game duration by the total amount of levels. At each passing level, the game increases its difficulty by: increasing the game speed by the selected value, increasing the bad bubble ratio by the selected value, and/or decreasing the bubble radius by the selected size value. The shape and the scores for the bubbles remain constant throughout the game. It's important to mention that all selected settings are saved for future games and associated with the username/ID such that the therapist doesn't have to change the settings for each game and can later correlate the results and progress to the corresponding individual.

3.4 Description of Real-Time Kinematic Assessment

In addition to the customization feature, the game has the ability to assess the user's upper-body movements by analyzing the trajectory of the upper-body joints in time. This information is not only used to track the user's progress, but also to identify the parameters that the user may need improvement on.

The user's upper-body movements are mathematically described by certain kinematic parameters related to limb movements. The parameters of interest are: shoulder and elbow ROM, movement time, movement smoothness, deviation from path, shoulder and elbow angular velocity, and movement speed. All parameters are calculated using the user's joint coordinates that are captured and stored at each frame while he/she pops the SBs. The system starts capturing the relevant data when the user pops the first SB in a given sequence. Similarly, the system stops capturing the data after the user pops the last SB in the same sequence. These two points in time define the initial and final positions of the user's joints. Each SB sequence containing the user's relevant kinematic data is assessed, and the algorithm returns the result for each one.

Table 1. Kinematic Parameteres used for assessinf user's upper body movements.

Kinematic Parameters	Definition	Method
Range of Motion	The angle created by the corresponding joint.	Dot Product
Movement Time	The total amount of time needed to move between the initial and final positions.	Fitt's Law [24]
Movement Smoothness	Measures how jittery the user's movements are.	Movement Units [25]
Deviation from Path	Measures how close/far the user's movements are from the defined path between the inital and final positions.	Robot Kinematics
Angular Velocity	Measures how fast/slow the user moves the corresponding joint.	Jacobian Matrix
Movement Speed	Measure's how fast/slow the user's movements are. The system measures the speed of the wrist.	Jacobian Matrix

The methods that are used for calculating the different parameters depend on the definition and their purpose. Table 1 shows a brief description of the parameters and the corresponding general method for making the calculations.

Through individualization and feedback, the resulting VR game is not only user friendly and provides motivation for users to practice their recommended exercises in their homes, but it also provides a kinematic algorithm that assesses the user's movements without interrupting the progress of the game. An example of its use in a pilot study with children is now discussed.

3.5 Pilot Study with Children

Preliminary experiments were conducted to show that the *Super Pop VR*^{TM} game is enjoyable, encouraging, and user-friendly. Given that this work is primarily focused in the rehabilitation for children who have cerebral palsy, the selected demographic for these experiments were children. Seven children (mean age m=7.71, standard deviation σ=1.48, Male: 2, Female: 5) played the game and answered some questions regarding their experience. The participants were instructed to play the game for 60 seconds each. Keeping in mind that the purpose of these experiments was to show that the game is motivating and user-friendly, the game settings were selected such that the game was not too hard yet not too easy. Table 2 shows the overall selected game settings. The instructions given by the experimenter was strictly scripted to avoid any influence it might cause to the participant's experience. The script was as follows:

Table 2. Selected *Super Pop VR*^{TM} game settings for the preliminary experiments.

Game Duration	60 seconds
Total Levels	3
Game Speed	0.6 bubbles / second
Bad Bubble Ratio	10 %
Bubble Size	3
Good Bubble Points	5 points
Bad Bubble Points	-5 points
Super Bubble Time Interval	20 seconds
Super Bubble Duration	5 seconds

> *Hello, today we're going to play a game with the Kinect camera. The purpose of the game is to pop as many bubbles as you can in one minute. To pop a bubble just hover one of your hands over it using the blue markers that are following your hands. You want to pop the yellow and green bubbles which are worth five and ten points respectively, but avoid the red bubbles because these will take away five points from your score. After you complete the game, I will ask you some questions about your experience with the game.*

On a 5-point Likert scale, from disagree (1) to agree (5), post-experiment surveys report that children participants, in general, enjoyed playing the game. Table 3 shows the statements made in the survey. Moreover, Fig. 3 shows the averages and standard deviations of the participants' responses to these statements. It is important to recognize that only seven children participated in this preliminary study and the results were used primarily as feedback. The survey includes positive and negative statements about the game, which have the goal of identifying potential areas that could be improved for a better experience when playing the game.

The most noted positive feedback was obtained from questions 1, 4, and 21. The participants felt that they could see their movements very well in the screen (mean response m=4.1, standard deviation σ=1.1), hear all the music in the game very well (m=4.9, σ=0.4), and liked playing the game overall (m=4.1, σ=0.7) respectively. Given that the mean values are relatively high and standard deviation values are relatively low, these results suggest that the participants not only enjoy the game, but also recognize that the game is functioning properly – at least in terms of tracking the user's movements and playing the sounds when the user pops the bubbles.

On the other hand, questions 5 and 12 pointed out some areas where we can improve the functionality and likability factor of the game. These questions revealed that the participants didn't find the music very attractive (mean response m=3.1, standard deviation σ=1.3), and would like the capability to play the game together with more friends at the same time (m=4.3, standard deviation σ=1.1) respectively. There were scattered responses for the statement concerning the attractiveness of the music played when popping the different bubbles. To deal with this variation in response, our current version of the game now provides the option of selecting any desired sound file from the user's hard drive, in addition to the already provided sound options from different known songs such as: 'Twinkle, Twinkle, Litle Star', 'Row Row your Boat', and 'Für Elise'. Regarding the multiplayer option, we're convinced that adding the capability for two or more people to play at the same time will increase the game's motivation factor. Moreover, the user will see better results as opposed to playing the game alone. Hidding et al. [26] reported that group therapy yields better results than individual therapy in improving thoracolumbar mobility and fitness. Based on these results, we hypothesize that playing the game with other people at the same will also yield better therapy results in terms of increasing movement speed and accuracy, and decreasing movement jitteriness.

In addition to being motivating and user-friendly, the *Super Pop VR*^{TM} game is also capable of outputting accurate outcome measures. A separate study showed that the system is able to correctly measure the user's shoulder ROM with an error of less than 5% [23]. The system's ability to output accurate results, the system's ability to individualize the intervention protocols of the users, and the fact that the system is user-friendly and enjoyable, results in a system that can serve the therapy needs of individuals with upper-body motor impairments such as children who have cerebral palsy.

Given these positive outcomes, we now discuss approaches based on prior efforts in the social robotics domain to incorporate robots in the gaming scenario as a method to increase the engagement factor for long-term adherence.

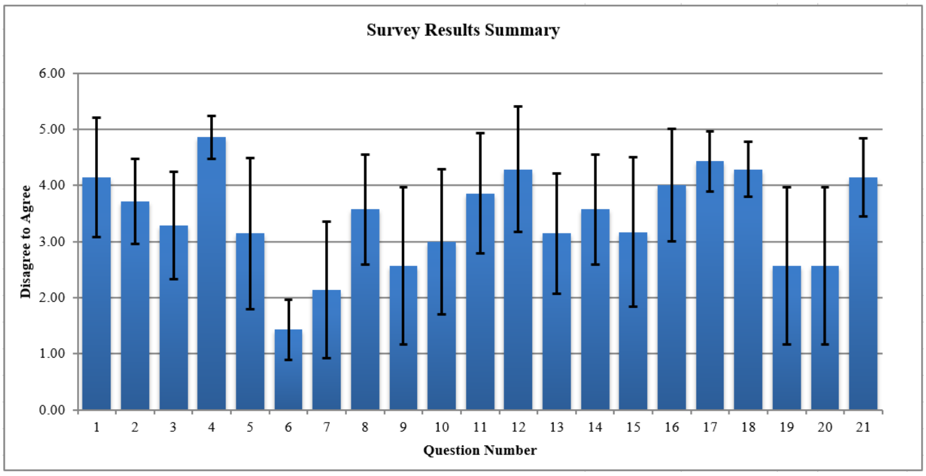


Fig. 3. Averages and standard deviation results from the participant's responses to the survey's statements.

Table 3. Survey stataments presented to the participants after the played the game.

#	**Statements**
1	I could see all my movements from the screen very well.
2	I found the objects in the game very interesting.
3	The objects I saw in the game were very attractive.
4	I could hear all music in the game very well.
5	The music I heard out of the game was very attractive.
6	I could not hear where all of the sounds out of the game came from.
7	The movements to play the game were too hard.
8	The movements used to touch objects in the game were fast, they were not too easy, but also were not too hard.
9	I must still learn a lot before I can play the game well.
10	I could predict what was going to happen after I had made a movement.
11	I had the feeling I could accomplish the game.
12	I would find it nice if I could play the game together with more friends at the same time.
13	The game was so attractive that I lost all count of time.
14	I would like to play the game more often.
15	The game training is less fin than regular computer/video games.
16	The request from the game was easy to understand.
17	The request from the game was easy to follow.
18	It was very logical playing the game by popping the objects.
19	I found it hard to follow the game by moving my hands.
20	I became more tired from playing with the game than from the regular computer/video games.
21	I like playing the game.

4 Integration of Social Robotics in Gaming Scenarios

Socially assistive robotics, defined as robots that provide assistance to human users primarily through social interaction [27], continues to grow as a viable method for a multitude of assistive tasks ranging from robot-assisted therapy to eldercare. Through the use of social cues, socially assistive robotics can enable long-term relationships between the robot and the child that drastically increases the child's motivation to complete a task [28]. In addition, ample studies have shown that the effect of being perceived as a social interaction partner can be enhanced by a physical robotic embodiment [29]. These characteristics are ideally suited for providing motivation to a child interacting with a robot in a therapeutic gaming environment. Generally speaking, children are more attracted to a robot when the robot exhibits positive feedback [30], [31] and are more motivated when the robot uses appropriate behavioral techniques to reengage [32]. As such, we follow the theme of socially assistive robotics by utilizing a robotic system to engage the child during a gaming scenario through social interaction. In order to accomplish this goal, we examine two techniques: engagement through behavioral interaction and learning from gaming demonstration.

4.1 Engagement through Behavioral Interaction

In most clinical settings, therapists are able to observe a child's engagement in real-time and employ strategies to reengage the student, which, in effect, improves attention, involvement and motivation in the rehabilitation protocol. In general, clinicians are able to engage by implementing behavioral cues such as direction of attention, facial expressions, proximity, and responsiveness to the child's activity. This behavioral engagement is deemed as a crucial component in home-based rehabilitation, especially given absence of the clinician in the child's home environment.

For the socially assistive robotic agent, we utilize the DARwIn-OP platform (Darwin) (Fig. 4) [33]. To enable interaction with the human, Darwin is programmed with a range of verbal and nonverbal behaviors. The nonverbal behaviors, or gestures, for the robotic agent included eye gaze, head nods/shakes, and body movements. Table 4 shows a sample of the nonverbal behaviors used in this investigation, and Fig. 5 shows three snapshots of the *head scratch* gesture. A total of eight gestural behaviors were programmed onto the humanoid platform. The verbal behaviors enable Darwin to provide socially supportive phrases for reengagement as the child interacts during a virtual scenario. During the utterance of verbal phrases, Darwin turns his gaze towards the child when speaking; otherwise, he remains looking at the virtual screen. The goal of the verbal phrases is to encourage the individual based on their current performance within the virtual scenario. It is very important that the phrases are socially supportive and convey the message that the child and Darwin are interacting together as a team. There is a dialogue established between the individual and Darwin, and not a unidirectional knowledge flow (i.e. Darwin is not giving instructions or issuing commands to the child). This open dialogue integrating socially supportive phrases between teacher and individual is ideal for optimal learning and engagement [30]. A sample of these socially supportive phrases is shown in Table 5.

Table 4. Sample of Nonverbal Behaviors from the Robotic Agent

Gesture	Behavioral Meaning	Description of Motion
Conversation	Body movements used to engage children while talking	Head nods and both arms move outward while maintaining eye contact
Head Nod	Back-channel signal meaning continue; okay; yes	Head moves in an up and down motion
Head Shake	Negative connotation; sad; no	Head moves from side to side while facing the ground
Tri-gaze	Eye contact distributed between three things	Eye contact the screen, child, then workstation for 3 seconds each
Head Scratch	Confusion; lost	Arm/hand moves back and forth next to head
Fast Arm	Positive connotation; approval; excitement	Arm is bent and raised next to head; arm then quickly moves downward
Hand Wave	Hello; goodbye	Arm is bent and raised next to head; forearm moves back and forth
Eye Contact	Attention is directed towards an object	Head (eyes) is aligned with a specified target

Table 5. Sample of Verbal Responses from the Robotic Agent.

Interaction	Speed	Phrase
Correct	Fast	“Fantastic!”
		“Awesome!”
		“You’re really good at this.”
	Slow	“This is hard, but we’re doing great.”
		“Thanks for all your hard work.”
		“You’re doing great! I had trouble with that one too.”
Incorrect	Fast	“Hang in there. We’re almost done.”
		“Can you slow down a little so we can do it together?”
		“Please wait for me. You’re leaving me behind.”
	Slow	“This part is very challenging.”
		“Don’t sweat it. We’ll get the next one.”
		“Don’t worry. I had trouble with that one too.”
None	Inactive	“Are you still there?”
		“Don’t forget about me over here.”
		“Don’t give up on me. Come on, let’s keep going.”

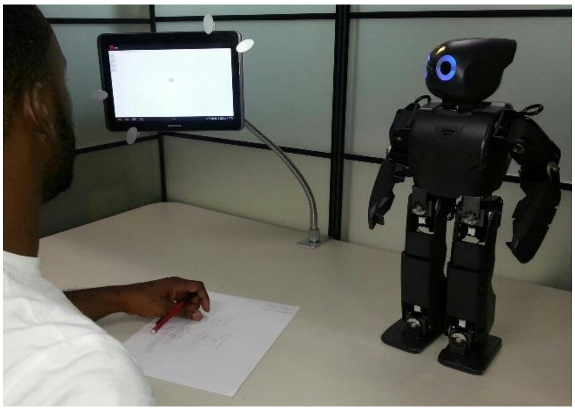
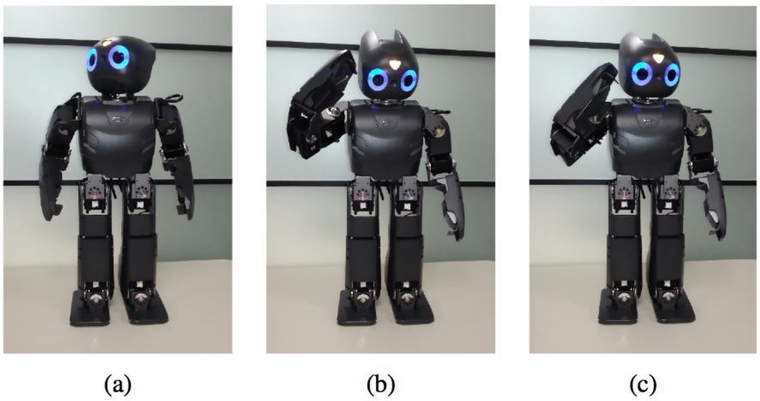


Fig. 4. The Robot Agent Darwin.



(a) (b) (c)

Fig. 5. The head scratch gesture broken down into three parts. (a) Initial Position - Darwin is standing and has eye contact with the tablet-based test. (b) Darwin's right arm scratches his head. His head is down and eye contact is with the pencil and paper. (c) Darwin's arm stops moving, and his head moves up to make eye contact with the subject. He then returns to the initial position.

4.2 Pilot Study with Children

To evaluate the ability of the robotic agent to engage children during interaction with a virtual environment, we employed a between-groups design for this study [34]. To guarantee that the skills are evenly distributed between the robot engagement groups (None, Verbal, Nonverbal, Mixture), the children were selected at random. A total of 20 children between the ages of 15 and 16 years old (mean age m=15.5, standard deviation σ=0.51, Male: 12, Female: 8) took part in this experiment. Our experiment involved one factor type of behavioral interaction, with four levels. Each level is defined as follows:

- **None:** Represents the control group. No agent is present.

- **Verbal:** The agent will say socially supportive phrases for reengagement as the child navigates through the virtual environment. He will gaze towards the child when speaking to him/her.
- **Nonverbal:** The agent will use only gestures for reengagement as the child navigates through the virtual environment.
- **Mixture of Both:** The agent will use both gestures and phrases for reengagement as the child navigates through the virtual environment.

At the start of the virtual scenario, Darwin gives a verbal introduction along with gestures to introduce himself and the activity that the children are about to perform. As each child advances through the scenario, his or her progress is communicated to Darwin. Essentially, every action completed is sent to Darwin, as well as the time intervals taken to navigate through the scenario. In the cases where the child may take a long time to complete a task, it is necessary to interrupt this inactivity (eliminate idle time) and effectively increase engagement. Once the child's progress and speed are communicated to Darwin, he will respond appropriately based on the behavioral interaction type (verbal, nonverbal, or both).

Depending on the child's state, Darwin provides the children cues that are either verbal, nonverbal, or a combination of the two (depending on the experimental group). For both verbal and nonverbal behaviors, the behavior was selected at random based on the message sent to Darwin. For the engagement type that incorporates both verbal and nonverbal cues, the gestures and phrases were scripted and paired prior to Darwin's random selection. As such, we were able to expand Darwin's library of verbal and nonverbal cues by pairing the same phrase with multiple gestures. Although a phrase when it stands alone may mean one thing, by adding a gesture, the underline meaning of the message can be altered. Upon execution of a pair, both the gesture and the phrase are performed simultaneously. For example, if the message sent to Darwin states that the virtual-child interaction behavior was completed too slowly, he may say, "You're doing great! I had trouble with that one too," while nodding his head.

We look to validate the hypothesis that the use of a robot agent can increase the quality of interaction in a virtual environment by adaptively engaging with the child. Adaptive engagement is based on the concept that the engagement model is driven by identification of the child's behavioral state. To prove or disprove this hypothesis, we looked at the responses from an exit survey. After task completion, we asked them to rate their agreement with a series of statements on a 5-level Likert scale that ranged from 1 (Disagree) to 5 (Agree). Table 6 shows the average response to each question and the p-values from the ANOVA tests, which are separated by test groups.

By monitoring the child, Darwin was able to effectively maintain the child's attention, although there was a statistically significant variance in how appropriate the children deemed Darwin's reactions to be during the interaction. The nonverbal group thought Darwin's actions were not appropriate with a score of 1.8 (Slightly Disagree = 2; $\sigma = 0.84$), while the remaining groups had an average score of 4.3 (Slightly Agree = 4; $\sigma = 0.99$). The lack of understanding of Darwin's actions was interpreted as him not giving any feedback at all, which resulted in a more unpleasant virtual reality (VR) experience.

Because boredom is often associated with poorer engagement [35], it is important to note that there was a statistically significant variance in how bored the subject deemed him- or herself to be throughout the scenario. For both the verbal group and the group with a mixture of verbal and nonverbal cues, the average response to the question on boredom during the test was 1.8 (Slightly Disagree = 2; σ = 1.07). The nonverbal group followed with a score of 3.4 (Neutral = 3; σ = 1.52), while the group with no agent was the most bored with a score of 4.6 (Agree = 5; σ = 0.55). This shows that the verbal group and the group with both verbal and nonverbal cues were able to minimize boredom the best when compared to the other groups.

Interestingly enough, although two of the children stated that Darwin was a distraction, the survey question that asked if Darwin was a distraction showed otherwise across these groups. The average score across all groups with Darwin present was 2.3 (Slightly Disagree = 2; σ = 1.35). Overall, the children enjoyed interacting with the system when Darwin was present. The children in the group with both verbal and nonverbal cues enjoyed interacting with the virtual environment the most with a score of 4.4 (Slightly Agree = 4; σ = 0.89). The verbal group followed with a score of 4.0 (Slightly Agree = 4; σ = 1.41). Next, the nonverbal group followed with a score of 3.2 (Neutral = 3; σ = 1.48). However, when Darwin was not present, the children did not seem to enjoy the virtual environment as much with a score of 2.2 (Slightly Disagree = 2; σ = 1.30).

In conclusion, across all behavioral interaction types – verbal, nonverbal, and both – the children enjoyed Darwin's presence. A mixture of both cues and verbal cues only tend to have the least amount of boredom associated with it, which is ideal for a richer virtual environment and higher levels of engagement. On the contrary, the group having no robot agent present enjoyed the scenario the least and experienced the most boredom. Overall, the use of only nonverbal cues such as gestures shows no significant trends when compared to verbal cues; therefore, this works suggests that verbal behavioral cues is ideal for enhancing performance and increasing engagement in a virtual environment.

Table 6. Statistical Analysis of Survey Responses

Question	Verbal	Nonverbal	Both	No Agent	p-value
I was frequently bored	1.8	3.4	1.8	4.6	0.002*
I enjoyed the virtual environment	4.0	3.2	4.4	2.2	0.07
Darwin reacted appropriately	4.2	1.8	4.4	n/a	0.002*
Darwin distracted me	2.4	2.8	1.8	n/a	0.53

*Statistically significant.

4.3 Learning from Gaming Demonstration

The role of robot learning for child-based engagement in a therapy scenario is to increase the duration of the child's interaction by incorporating the concept of turn-taking. Studies have shown that when children are required to teach others, they themselves become more engaged in the task [36]. In this work, we utilize a case-based learning approach in which a robotic platform observes the child's motions during game play, generates an appropriate behavior, and then engages with its child partner as a learner. This learning response is accomplished by utilizing a mimicking process in which the child and robot take turns in accomplishing a goal, thereby motivating and stimulating the social behavior of the participant.

Our robot learns from the user by first observing the user, storing information about their situation-action responses (further defined as a case), and then retrieving these cases to execute a corresponding behavior. The child engages to teach the gaming task to the robot in a shared workspace and intuitively monitors the robot's behavior and progress in real time. In this setting, the teacher (child) is able to interrupt and correct the robot's behavior at the moment the learning is taking place, thus providing a means to continuously engage the child in the protocol of the game. We utilize a method called case-based reasoning to enable this collaborative teaching/learning process.

Case-based reasoning (CBR) is a human memory and cognition methodology that solves new problems based on the solutions of similar past problems [37]. By comparing the current task to some past task cases stored in memory, the best solution is retrieved and adapted to the current task. The first phase of CBR is acquiring knowledge, i.e., training the case base. During this phase, the system observes the game performed by the child and generates a case (problem-solution pair) for each demonstration, which is then saved in the case base. The problems are given as game states, such as game-object information and game score. The solution is extracted from the person's behavior towards a given problem. In the second phase when a new problem is introduced, the most similar past problem and its solution are retrieved from the case base. When measuring a similarity between two cases, the distance is computed as a sum of weighted distances between each problem feature. Our system provides the tool to autonomously train this similarity metric through pattern recognition. Next is the reuse step in which the retrieved solution is adapted to the current task. We use a method of averaging the solution over multiple retrieved solutions with a Gaussian distance kernel. As the case base expands and demonstration improves, deviation of the retrieved solutions decreases. During the last phase, the new problem-solution pair is revised and retained in the case base. The full algorithm is as depicted in Fig. 6 [38].

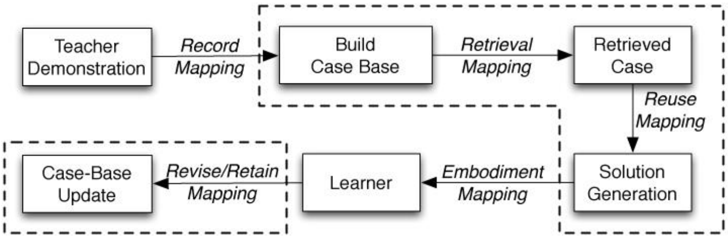


Fig. 6. Steps of case-based reasoning (CBR) incorporated within the overall structure of recording and encoding demonstrations, retrieving and reusing cases, and mapping a generated behavior to the robot's embodiment. CBR steps are depicted inside dashed boxes.

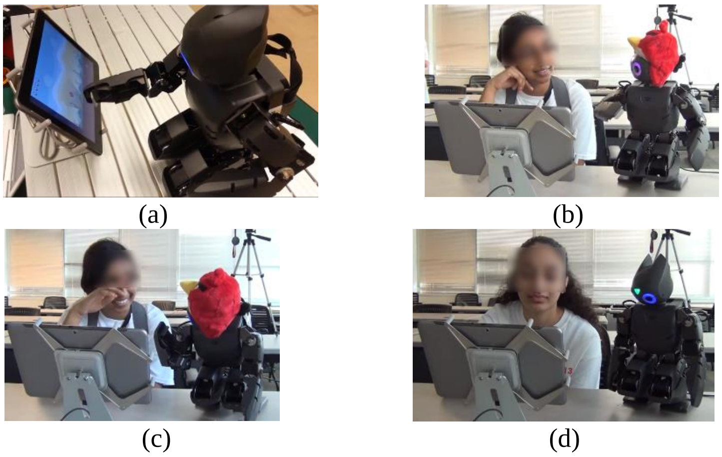
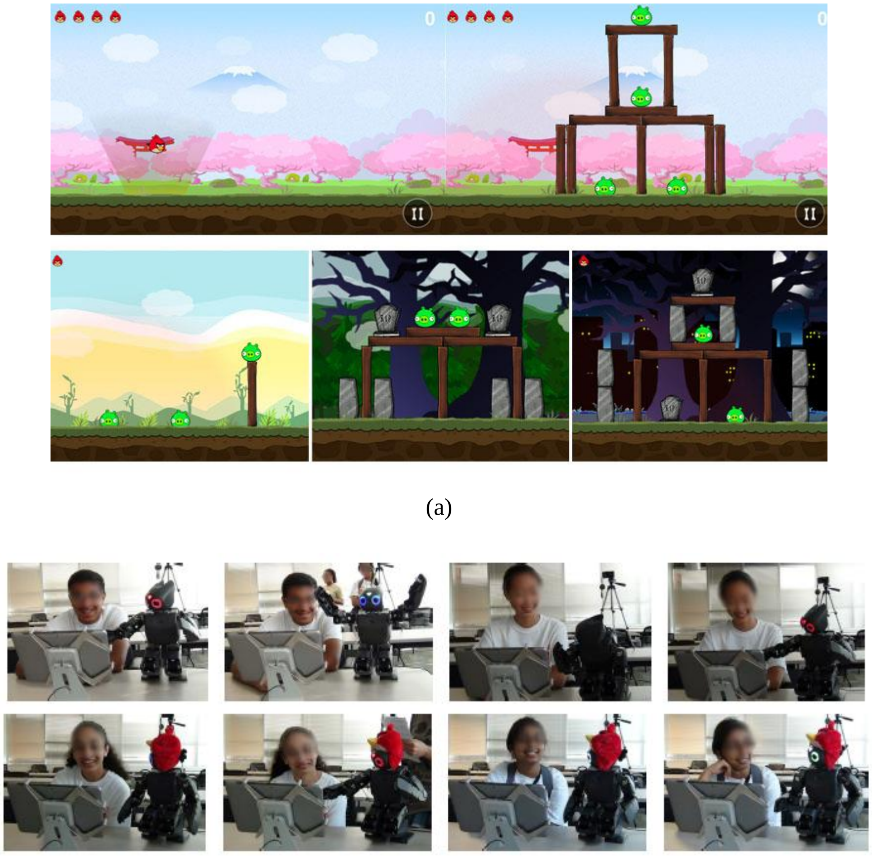

(a) (b) (c) (d)

Fig. 7. Darwin's behavior is reproduced from the retrieved experiences. (a) Darwin interacting with a virtual environment through wireless communication, (b) making eye contact and providing feedback after the participant's demonstration, (c) encouraging the participant, and (d) expressing sadness after an unsuccessful attempt.

For task interaction, the retrieved case and its solution are used to reproduce the task behavior on a robotic platform through a mapping from the adapted solution to the robot's state and action space. This includes generating synthesized gestures that triggers actions within the virtual environment. Darwin also generates a combination of speech and gesture primitives that, as discussed in Section 4.1, enable engagement through behavioral interaction (Fig. 7).

4.4 Pilot Study with Children

For validation, we engaged 33 participants (mean age m=18.27, standard deviation σ=8.56) including 19 children (m=12.26, σ=4.24), some with special needs, to teach a virtual game shown in Fig. 8 to our robot, Darwin. We analyzed data collected during various trials during a two-month period.



(a)

(b)

Fig. 8. (a) The game used in the experiment, and (b) shots of experiment conducted in an open-house styled setting with a group of local school children.

For the experiment, participants were asked to teach the robot how to interact with a virtual game. The instruction given by the experimenter was strictly scripted to avoid any influence it might cause to the participant's experience. The script was as follows:

> *Now, I'd like you to teach Darwin to play the same game. Just teach him in the same manner you would teach your younger sibling. Provide Darwin with demonstrations how to solve each level. Whenever you reach out to provide demonstration to Darwin, he will wait for his turn. Continue teaching each level until you are satisfied that Darwin had learned the level well enough, or think Darwin had stopped learning. Later, I want you to show me what you have taught Darwin, and collaboratively solve each level with him. Darwin may or may not try to communicate with you, and he may not use human language. Afterwards, I will ask you some questions about your experience teaching a task to Darwin.*

The growth progress of the case base and any interaction with the tablet was logged, and two video cameras were placed to record the whole evaluation session. Later, the log was used to evaluate the system, and the videos were analyzed for interaction studies.

First, the learning performance of the robot is determined. In Table 6, the performance of generated solutions is compared with varying k (number of retrieved cases). Distances are computed between a newly introduced problem and problems in the case base using the robot's retrieval method. Then the performance of each retrieved and adapted solution is evaluated using a logarithm of the earned game score. As computed, the average number of demonstrations given to the robot is: m = 29.17, σ = 10.25. It was also observed that the participants utilized other forms of natural interactions though the robot only could learn from actual demonstrations of game play. These natural forms of interaction were measured as the length of time when an eye contact was made or when vocal/gestural-interaction behaviors were observed. These interactions were then categorized into instructive and non-instructive interactions in Table 7(a). On average, participants, spent 5 minutes and 42 seconds without the robot and 24 minutes and 5 seconds with the robot playing the game. The more significant measurement is the ratio of how much social interactions were initiated during these sessions. When the robot wasn't present, these interactions were observed as forms of utterances or calling out to other people. Compared to 3.22% social-behavior occurrence without the robot, participants dedicated 34.81% of their time exhibiting social cues when the robot was present. Detailed break down of the social interactions toward the robot is depicted in Table 7(b). Note that these cues are often observed simultaneously with one another, and the measurement ratio is calculated against the total time of the interaction. On a 5-point Likert scale, from strongly disagree (1) to strongly agree (5), post-experiment survey reports that the participants felt their robot was socially interacting with them (m=4.7); was socially communicating with them (m=3.72); thought Darwin was learning from them (m=4.33) similar to their friends (m=4.01); and thought the robot enhanced their overall experience with the virtual game (m=4.8) (Fig. 9).

Table 7. Performance of case-retrieval method using k-nearest neighbors measured by the resulting game score when the generated solution was applied.

Mean Performance (log(score)) of Case-retrieval Methods

k	*log(score)*
1	4.14±2.23
2	4.02±2.02
3	4.13±1.72
4	3.96±1.46
5	3.11±1.87
6	2.79±0.92

Table 8. (a) Average time and ratio of social-interaction occurrences with and without the robot. (b) Detailed social cues exhibited towards the robot.

(a)

	Without Robot	With Robot
Avg. total time of interaction	342 sec	1445 sec
Avg. time of social interaction	11 sec	503 sec
Percentage of social interaction	3.22%	34.81%

(b)

Social interaction	Percentage
Eye contact / Gaze	22.72%
Gestural interaction	14.20%
Vocal interaction	28.66%
Instructive	36.50%
Non-instructive	63.50%

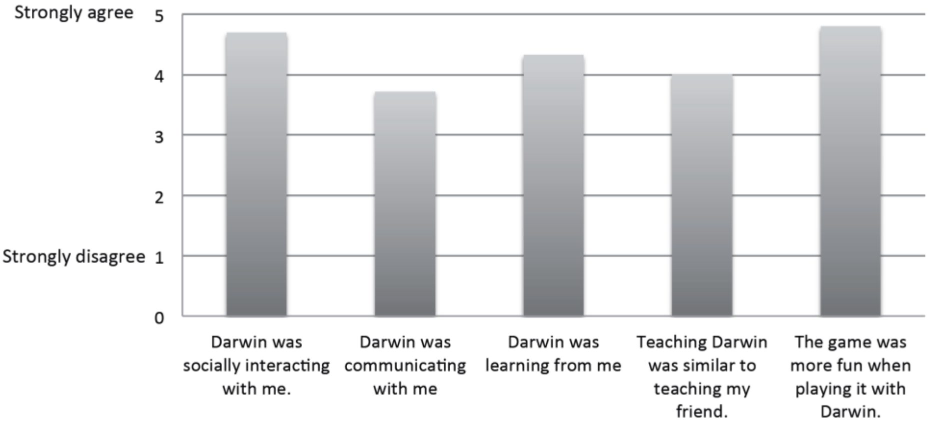


Fig. 9. On a five-point Likert scale, from strongly disagree (1) to strongly agree (5), post-experiment survey reports that the participants felt their robot was socially interacting with them and enhanced their overall experience with the task.

5 Discussion and Future Work

Although there are very few research efforts focused on using integrated VR-robotic systems for children, the work presented in this chapter discusses various approaches and preliminary results showing the use of these systems in therapeutic play. There are many compelling reasons for utilizing robots in virtual reality (VR) gaming scenarios, ranging from augmenting the capabilities of children with motor impairments to increasing engagement of such children. Although much of the presented work is encouraging, we still need more quantitative results to validate the benefits of utilizing VR-robotic systems in pediatric therapy settings. These quantitative results should show the clear benefits achieved from children with disabilities interacting with the coupled virtual-robotic system. Additional substantial quantitative evidence, as well as longitudinal studies that demonstrate the effectiveness of the system, is still necessary.

The overall research presented herein brings up several interesting observations regarding the use of VR-robotic systems in pediatric therapy. Many prior papers in the domain of assistive technologies for children with disabilities discuss the difficulty of performing studies involving children. Common reasons included distraction from outside stimuli and the wide variances found in children's abilities. Another observation is the emphasis that many other researchers placed on robustness and iteration in design. For example, in many prior studies, perhaps due to the novelty of the robot, children would interact with the robots in unexpected ways. Although we emphasize individualization with respect to our system, these identified issues still need to be considered in improving the design of the system discussed in this chapter.

The pilot studies with children, as discussed in this chapter, have provided us sufficient baseline evidence to understand both the limitations of the system, as well as those attributes that are essential for establishing long-term adherence to a rehabilitation protocol. Future efforts will focus on enhancing the autonomy of the system such that the virtual system adapts in direct correlation to adaptation of the robot's social behaviors. This will ensure that both components correlate and grow with the capabilities of the child, as well as ensure the system is continuously engaging. Also, since our focused demographic is children with disabilities, our next set of trials will focus on engaging children with cerebral palsy in the experimental protocol.

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References

1. Bax, M., Goldstein, M., Rosenbaum, P., Leviton, A., and Paneth, N.: Proposed definition and classification of cerebral palsy. In: Developmental Medicine & Child Neurology, Vol. 47, No. 8, pp. 571-576, (April 2005).
2. Howard, A.: Robots Learn to Play: Robots Emerging Role in Pediatric Therapy. In: 26th Int. Florida Artificial Intelligence Research Society Conference, (May 2013).
3. Piaget J., "Play, Dreams and Imitation in Childhood." London: Rout-ledge and Kegan Paul Ltd. (1951).
4. Chen, Y., Kang, L., Chuang, T., Doong, J., Lee, S., Sai, M.T., Jeng, S., and Sung, W.: Use of Virtual Reality to Improve Upper-Extremity Control in Children with Cerebral Palsy: A Single-Subject Design. In: Physical Therapy: Journal of the American Physical Therapy Association, Vol. 87, No. 11, pp. 1440-1454, (2007).

5. Colombo, R., Pisano, F., Mazzone, A., Delconte, C., Micera, S.,Carrozza, M., Dario, P., and Minuco, G.: Design strategies to improve patient motivation during robot-aided rehabilitation. In: Journal of NeuroEngineering and Rehabilitation, (2006).
6. Cioi, D., Kale, A., Burdea, G., Engsberg, J., Janes, W., Ross, S.: Ankle control and strength training for children with cerebral palsy using the Rutgers Ankle CP: a case study. In: IEEE Int Conf Rehabil Robot, (2011)
7. Brütsch, K., Schuler, T., Koenig, A., Zimmerli, L., Koeneke, S.M., Lünenburger, L., Riener, R., Jäncke, L., Meyer-Heim, A.: Influence of virtual reality soccer game on walking performance in robotic assisted gait training for children. In: J Neuroeng Rehabil. 7:15, (2010).
8. Loureiro, R., Amirabdollahian, F., Topping, M., Driessen, B., Harwin, W.: Upper Limb Robot Mediated Stroke Therapy Gentle/s Approach. Autonomous Robots, pp. 15:35–51, doi: 10.1023/A:1024436732030, (2003).
9. Dautenhahn, K., et. al.: KASPAR - A Minimally Expressive Humanoid Robot for Human-Robot Interaction Research. In: Applied Bionics and Biomechanics 6(3): 369-397, (2009).
10. Brisben, A., Safos, C., Lockerd, A., Vice, J., and Lathan, C.: The CosmoBot System: Evaluating its Usability in Therapy Sessions with Children Diagnosed with Cerebral Palsy. http://web.mit.edu/zoz/Public/AnthroTronix-ROMAN2005.pdf, (2005).
11. Dautenhahn, K., and Billard, A.: Games children with autism can play with Robota, a humanoid robotic doll. In: Cambridge Workshop on Universal Access and Assistive Technology, pp. 179–190, (2002).
12. Kronreif, G., Prazak, B., Mina, S., Kornfeld, M., Meindl, M., and Furst, F.: Playrob - robot-assisted playing for children with severe physical disabilities. In: IEEE 9th International Conference on Rehabilitation Robotics, (2005).
13. Topping, M.: An overview of the development of handy 1, a rehabilitation robot to assist the severely disabled. In: Journal of Intelligent and Robotic Systems, 34(3), (July 2002_.
14. Cook, A.M., Meng, M.Q., Gu, J.J., and Howery, K.: Development of a robotic device for facilitating learning by children who have severe disabilities. In: Neural Systems and Rehabilitation Engineering, 10(3):178–187, (2002).
15. Reid, D.: Benefits of a virtual play rehabilitation environment for children with cerebral palsy on perceptions of self-efficacy: a pilot study. In: Pediatric Rehabilitation, Vol. 5, No. 3, pp. 141-48, (2002).
16. Bryanton, C., Bossé, J., Brien, M., McLean, J., Mccormick, A., and Sveistrup, H.: Feasibility, Motivation, and selective Motor Control: Virtual Reality Compared to Conventional Home Exercise in Children with Cerebral Palsy. In: CyberPsycology & Behavior, Vol. 9, No. 2, pp. 123-128, (2006)
17. Golomb, M., McDonald, B., Warden, S., Yonkman, J., Saykin, A., Shirley, B., Huber, M., Rabin, B., AbdelBaky, M., Nwosu, M., Barkat-Masth, M., and Burdea, G.: In-Home Virtual Reality Videogame Telerehabilitation in Adolescents With Hemiplegic Cerebral Palsy. In: Archives of Physical Medicine and Rehabilitation, Vol. 91, No. 1, pp. 1-8, (2010).
18. Deutsch, J., Borbely, M., Filler, J., Huhn, K., and Guarrera-Bowlby, P.: Use of a Low-Cost, Commercially Available Gaming Console (Wii) for Rehablitation of an Adolescent With Cerebral Palsy. In: Physical Therapy: Journal of the American Physical Therapy Association, Vol. 88, No. 10, pp. 1196-1207, (2008).
19. Jannink, M., Van Der Wilden, G., Navis, D., Visser, G., Gussinklo, J., and Ijzerman, M.: A Low-Cost Video Game Applied for Training of Upper Extremity Function in Children with Cerebral Palsy: A Pilot Study. In: CyberPsychology & Behavior, Vol. 11, No. 1, pp. 27-32, (2008)

20. Brooks,D., and Howard, A.,: Quantifying Upper-Arm Rehabilitation Metrics for Children through Interaction with a Humanoid Robot. In: Applied Bionics and Biomechanics, Vol. 9(2), pgs. 157-172, (2012).
21. Reid, D.: The influence of virtual reality on playfulness in children with cerebral palsy: A pilot study. In: Occupational Therapy International, Vol. 11, No. 3, pp. 131-144, (2004).
22. Zhang, Z.: Microsoft Kinect Sensor and Its Effect. In: IEEE Multimedia, Vol. 19, No. 2, pp. 4-10, (2012).
23. García-Vergara, S., Chen, Y.P., and Howard, A.: Super Pop VR^{TM}: an Adaptable Virtual Reality Game for Upper-Body Rehabilitation. In: 5th International Conference on Virtual, Augmented, and Mixed Reality held as part of HCI International, Vol. 8022, pp. 44-49, (2013).
24. Mackenzie, I.S.: Movement Time Prediction in Human-Computer Interfaces: A Brief Tour on Fitt’s Law. In: Proceedings Graphics Interface, Vol. 92, pp. 140-150, (1992).
25. Hofsten, C.: Structuring of early reaching movements: a longitudinal study. In: Journal of motor behavior, Vol. 23, No. 4, pp. 280-92, (1991).
26. Hidding, A., van der Linden, S., Boers, M., Gielen, X., de Witte, L., Kester, A., Dijkmans, B., and Boolenburgh, D.: Is group physical therapy superior to individualized therapy in ankylosing spondylitis? A randomized controlled trial. In: Arthritis & Rheumatism, American College of Rheumatology, Vol. 6, No. 3, pp. 117-125, (1993).
27. Feil-Seifer, D., and Matarić, M.J.: Defining Socially Assistive Robotics. In: IEEE International Conference on Rehabilitation Robotics (ICORR-05), Chicago, IL, 465-468, (2005).
28. Kidd, C., and Breazeal, C.: Robots at home: Understanding long-term human-robot interaction. In: IROS, pp. 3230–3235, (2008).
29. Powers, A., Kiesler, S., Fussell, S., and Torre, C.: Comparing a computer agent with a humanoid robot. In: HRI, pp. 145–152, (March 2007).
30. Saerbeck, M., Schut, T., Bartneck, C., and Janse, M.: Expressive robots in education: Varying the degree of social supportive behavior of a robotic tutor. In: CHI, pp. 1613–1622, (2010).
31. Park, E., Kim, K., and Pobil, A.: The effects of a robot instructor’s positive vs. negative feedbacks on attraction and acceptance towards the robot in classroom. In: ICSR, pp. 135–141, (2011).
32. Szafir, D., and Mutlu, B.: Pay attention! Designing adaptive agents that monitor and improve user engagement. In: CHI, (May 2012).
33. Ha, I., Tamura, Y., Asama, H., Han, J., and Hong, D.: Development of open humanoid platform darwin-op. In: SICE, pp. 2178–2181, (2011).
34. Brown, L., and Howard, A. Engaging Children in Math Education using a Socially Interactive Humanoid Robot. In: IEEE-RAS International Conference on Humanoid Robots, Atlanta, GA, (2013).
35. Baker, R., D’Mello, S., Mercedes, M., Rodrigo, T., and Graesser, A.: Better to be frustrated than bored: The incidence, persistence, and impact of learners’ cognitive–affective states during interactions with three different computer-based learning environments. In: International Journal of Human-Computer Studies, pp. 223–241, (2010).
36. Gartner, Alan. "Children Teach Children: Learning by Teaching." Harper & Row, New York (1971).
37. Kolodner, Janet L. "An introduction to case-based reasoning." *Artificial Intelligence Review* 6, no. 1 (1992): 3-34.
38. Park, H.W., Howard, A.: Case-Based Reasoning for Planning Turn-Taking Strategy with a Therapeutic Robot Playmate. In: IEEE Int. Conf. on Biomedical Robotics and Biomechatronics, pgs. 40-45, Japan, (Sept. 2010).