An Interactive Multimedia System for Parkinson's Patient Rehabilitation

Wenhui Yu, Catherine Vuong, and Todd Ingalls

School of Art, Media and Engineering,
Arizona State University
Tempe, AZ 85287
{Wenhui.Yu,Catherine.Vuong,Todd.Ingalls}@asu.edu

Abstract. This paper describes a novel real-time Multimedia Rehabilitation Environment for the rehabilitation of patients with Parkinson's Disease (PD). The system integrates two well known physical therapy techniques, multimodal sensory cueing and BIG protocol, with visual and auditory feedback to created an engaging mediated environment. The environment has been designed to fulfill the both the needs of the physical therapist and the patient.

Keywords: Parkinson's Disease, Physical Therapy, Mediated Rehabilitation, Sensory Cueing, Multimodal Feedback, Virtual Environment.

1 Introduction

Parkinson's disease (PD) is a progressive neurodegenerative disease that affects nearly 1% of the elderly population [11]. It is characterized by akineisa (impaired initiation of movement), bradykinesia (reduced amplitude and velocity of movement), tremor, rigidity, and postural instability [6][18].The symptom are believed to be caused by the degeneration of the dopaminergic nigrostriatal pathway, a major pathway supplying dopamine to the striatum [6].

Currently, the standard treatment is L-3, 4-dihydroxyphenylalanine (Levodopa or L-DOPA) therapy. L-Dopa has been shown to improve the motor symptoms and life expectancy after the onset of PD. However, these benefits are not permanent; typically, within five years the gains begin to wear off and produce negative side effects [5]. Neurosurgery, which destroys a small portion of the brain, and deep brain stimulation are both treatment possibilities if L-Dopa becomes ineffective; but these are expensive and contain significant risk [6].

Given the side affects of the medication, physical therapy can be utilized to delay the need for drug interventions or used simultaneously to reduce the side effects. Our team has designed and developed a Parkinson's Multimedia Rehabilitation System that combines physical therapy techniques, sensory cueing [2][3][9][12][21][20][21] and the BIG protocol [3][7][8], with visual and auditory feedback to create an engaging mediated environment.

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2 Background

Sensory cueing, generally in reference to visual and auditory cues, is the use of external stimuli to facilitate movement. For example, of visual cues can be markers or lines on the floor to encourage PD patients to take bigger steps. This has been shown to increase stride length and stride length regulation in PD patients [2][19][20][21]. Auditory cues, such as music or a metronome, has been shown to increase cadence (rhythm) and velocity in PD patients [10][17][19].

The BIG protocol is the use of large amplitude movements to encourage patients to move "bigger" [3][7][8]. Although this technique encourages larger than normal movement it is believed to have carryover effects that increase the amplitude of general movement in PD patients'.

Multimedia rehabilitation systems have started to become more widespread with examples in stroke, cognitive rehabilitation, balance and, telerehabiliation [13][14][16]. One approach has been through the use of traditional Virtual Reality (VR) and Virtual Environments (VE) for motor training [13][16][23]. Similar approaches have long been suggested for PD and some earlier studies were promising [1][4]; however, recent literature points to some unforeseen problems. In recent literature, while using VE that replicates activities of daily (i.e. walking in a kitchen, supermarket, or classroom), using a full head mounted display, PD patients experienced hallucinations (i.e. children sitting in the desks when there were no children in VE) during the "off" phase of L-Dopa therapy. None of the hallucinations were the same and not all PD patients experienced it. This should not present an issue as we are not replicating activities of daily living or using a full head view display.

In this paper we will describe the design and development of a real-time Parkinson's Multimedia Rehabilitation System. We will describe the integration of sensory cueing techniques and the BIG protocol with visual and auditory feedback used to create an engaging environment for rehabilitation.

3 User Needs and Strategies

In order to create a system that meets both the needs of the physical therapist and of the PD patients we have identified a series of needs which are described below.

3.1 Physical Therapist Needs

After discussion with a PD occupational physical therapist and literature review, we have broken the requirements into three main categories that we believe fulfill the needs of the therapist:

3.1.1 Usable in a Clinical Space

Our current system works within our laboratory setting, however, we hope that future revisions of our system can be implemented in a clinical setting. We are trying to implement a system that is cost effective and space efficient. We therefore be limited the number of computers, projectors, projection screens, and active space in our environment with this need in mind.

Treats the Symptoms of PD. In the development of the system, we targeted the symptoms associated with akinesia (impaired initiation of movement) and bradykinesia (reduced amplitude and velocity of movement). These symptoms not only result in hypokinetic (reduced movement) movement characteristic to PD but also contribute gait irregularities such as difficulty in stride length regulation, regular cadence (rhythm), and low velocity [6][19]. As a result the following need were identified:

- BIG and Faster: The system was designed to ameliorate the symptoms related to bradykinesia by encouraging larger and faster movements. The system tasks integrates the amplitude-based whole body exercise tasks and speed to promote the patient's ability to reach and step as far and fast as possible.
- Accuracy and Timing: The system was designed to alleviate the kinetic symptoms associated with akinesia and bradykinesia by increasing accuracy and timing of a patients' reaching and stepping. To do this the accuracy measurements were made flexible and reasonably tolerant to meet the needs of the patient. Focus was placed on timing, faster reaction and fluidity of movement.
- Repetitive and Variable: The tasks presented to patients in the system were designed to be either repetitive or variable. Repetitive tasks (a single task repeated over and over) can help patients learn new movement patterns. Variable tasks (multiple task mixed together) can allow patients to learn how to transition from one movement pattern to another and provide variation in the task.

3.2 Patient Needs

The needs of patients were also taken into consideration. To meet the needs of the patient the system was designed to be engaging, immersive, and adaptable.

Engaging and Immersive. The effectiveness of the environment is based upon the active participation of the patient. During a long-term repetitive exercise session, patients can easily become physically tired and mentally bored. Thus, it is necessary to design an engaging and immersive environment, which can help patients remain attentive and motivated.

Adaptable. Given that patients may get frustrated when failing to reach/step the target the system must be adaptable. It must be able to push the patients limits, but adaptable so that patients do not become frustrated with the task.

4 System Design

In this system, the location of the patient's hands, feet, and torso are mapped directly to an avatar. Patients are asked to control this avatar to complete movement tasks in the game, projected on the screen. The environment integrates sensory cueing into game-like mediated instruction. Patients are given feedback based on accuracy and timing of movement performance.

Fig. 1. Displaying the sky scenario, in which the avatar stands on the cloud to reach falling stars. This environment provides several different scenarios, with different scenes (i.e. galaxy, sky, spaceship), sets of falling object objects (stars, rain, alien), and avatars, to engage patients.

This environment include 11 different simultaneous reaching/stepping patterns the patient can perform. They include: 1) RH, 2) LH, 3) RF, 4) LF, 5) RH/LH, 6) RH/RF, 7) LH/LF, 8) RH/LF, 9) LH/RF, 10) RH/LH/RF, 11) RH/LH/LF; where RH stands for right hand reach, LH for left hand reach, RF for right foot step and LF for left foot step. These patterns can either be performed individually (i.e. patient does 20 RH reaches) or in some combination (i.e. patient does 20 random RH, LH, RF, or LF reaches/steps). This flexibility, in determining the movement patterns, will allow the physical therapist to modify the tasks to either be repetitive or variable and adaptable (see Section 3.1.3 and Section 3.2.2) depending on the physical therapy needs of the patient.

The aim of the system is to motivate patients to follow these visual cues to reach or step on the expected positions in sync with music. In following sections we will describe the structure of the system, including: the composition, the integration of sensory cueing, feedback, and the BIG protocol, and how it addresses the needs of the physical therapist and the needs of the patient.

4.1 System Structure

The system is composed of an active space and the application. The active space is the physical space in which the patient interacts with the game. The application, is the software responsible for creating the virtual interactions between game and the patient. The application receives input data through a motion capture system and provides output through either sensory cueing or feedback via projector and speakers in the active space.

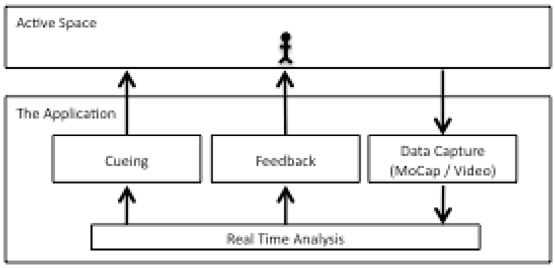

Fig. 2. High Level Design of the Environment

4.2 Data Capture

The system uses a 10 near-infrared camera Motion Analysis System to capture the location of the patient's hand, feet and torso. The data from the cameras are processed using EVaRT software (Motion Analysis Corp, Santa Rosa, CA) . The systems capture patient movement by tracking retro-reflective markers attached to the patient; each marker corresponds to anatomical labels in the EVaRT software. The overall system is run at a rate of 100 motion capture frames per second.

4.3 Sensory Cueing

In this subsection, we will detail how visual and auditory cueing are used to facilitate movement, particularly larger or BIG movement.

Visual Cueing. In the system, patients reach or step toward visual cues (as described in introduction to the section). The location of the visual cues are relative patients' arm/leg length with respect to the center of the screen.

There are several cues in this environment, which are divided into two categories: task and body cues. The first set of cues, task cues, help inform the patients of their task within the environment, this can be seen in Figure 3. These cues include: 1) starting cues, 2) target cues, 3) return cues and 4) moving cues.

The task cues are used as follows for each reach/step. A starting cue appears at the top of the screen, which informs the patient that the moving cue will appear there. Moving cues scroll downward from the top of the screen and pass over stationary semi-transparent target cues. The patient must reach (or step on) the target cue when the moving and target cue overlap. The moving cue attaches to the avatar and the avatar must return the moving the cue to the return cue. Once the avatar has reach the return cue, the moving cue disappears; thus completing the moving task.

This environment can be adapted to encourage larger movement by adjusting the location of the target cue, while the speed of the moving cue can be used to encourage faster movement.

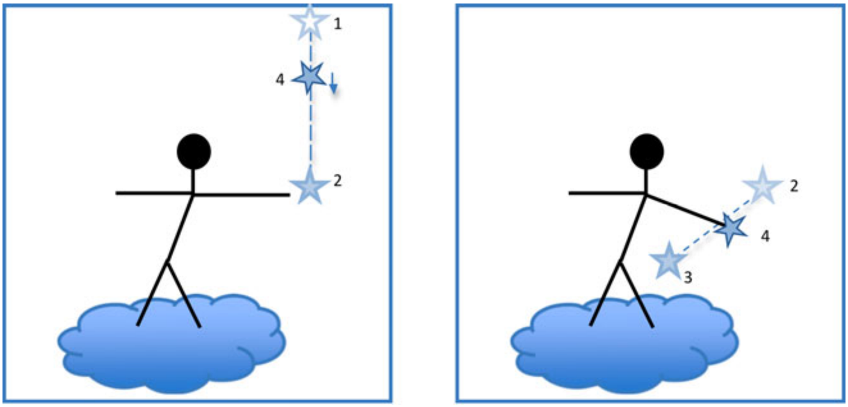

Fig. 3. Visual Task Cues for the Environment. In A, the Avatar is reaching toward the target cue (2). In B, the avatar has reached the target cue (2) and is now returning to the return cue (3). The cues in this figure are: (1) starting cue, identifies the horizontal location the target cue will appear, (2) target cue, the location the avatar is to reach, (3) return cue, the location the avatar is to return after reaching the target cue and (4) moving cue. At first, the moving cue scrolls down from the starting cue to the target cue. If avatar reaches the moving cue at the target cue position successfully then, the moving cue attaches to the hand/foot of the avatar. The moving cue will disappear once the avatar reaches the return cue. For clarity, the visualization in this figure have been reduce to a stick figure; an example of the actual visualization can be seen in Figure 1.

The second set of cues are body cues. Body cues are attached to each appendage and informs the patient which limb must or can move to reach/step on the target cue; this can be seen in Figure 4. This will be implemented using a traffic light color scheme. Green means the limb is involved in the reach and therefore must move to reach the target. Yellow means to reach the target the limb may move as a result of the reach. Red mean that this limb is not involved in the reach and therefore should not be moved; this will prevent patients from walking back and forth to reach targets.

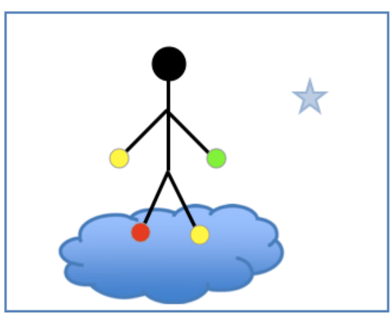

Fig. 4. Visual Body Cues for the Environment. In this example, the patient is asked to reach with the right hand to the falling star. To perform this task the patient has to move his/her right hand (in green). The patient should not move his/her left foot (in red). The movement of the left hand and right foot is not relevant to the task, thus it is also in yellow. For clarity, the visualization in this figure have been reduce to a stick figure; an example of the actual visualization can be seen in Figure 1.

Auditory Cueing. In this system, music with a strong tempo is played in the background to improve cadence and timing. The tempo of the music can be increased or decreased to encourage faster or slower movement. The slower tempo can be used if movement difficulty or fatigue arises; it can be also used to vary the movement task.

4.4 Sensory Feedback

In this system, feedback is given based on the successful completion of movement task (Knowledge of Results, KR) and on whether the movement is being performed correctly (Knowledge of Performance, KP).

As stated in Section 4.3.1, the task is to: 1) reach the moving cue as it passes over the target cue and 2) then to return the moving cue to the return cue. For both part 1 and 2 of the task, feedback is given based on whether the participant successfully completed the task or KR. In part 1, if the participant successfully reaches the moving cue as it passes over the target cue (within a given timing tolerance level), the moving cue shimmers, a happy melody is played, and the moving cue attaches to the limb of the avatar. Now, the shimmering moving cue can only be removed by returning it to the return cue, or second part of the task. In part 2, when the participant returns the shimmering moving cue to the return cue, the moving cue disappears. The timing tolerance level can be adjusted to improve timing, accuracy, or alleviate frustration.

In addition, patients are be given feedback based on whether they are performing the task correctly; this feedback has been integrated into the body cues (using the traffic light system). For example, if they are asked to reach with the right hand, they are not to move their left foot. The right hand will be green, the left foot will be red, and the right foot and left hand will be yellow, see Figure 4. If during this task, the patient moved the a red limb (or in this case, the left foot) the limb will start flashing; until the movement is stopped. The feedback also works in the opposite direction, if a patient does not move the green limb (or in this case, the right hand) the limb will start flashing. This feedback is designed to stop the participant from walking back-and-forth across the space to reach the target and to prevent the participant from forgetting to reach/step for a target currently on the screen.

5 Conclusion

In this paper we described the design and development of a novel real-time Parkinson's Mediated Rehabilitation Environment that integrates sensory cueing techniques and the BIG protocol with visual and auditory feedback to create an engaging environment. Sensory cueing, informed by the BIG protocol, was used to encourage bigger and faster movement.

We believe the system has been designed to meet most of the user needs. In the coming months, we would like to perform a preliminary pilot study on able-bodied and PD participants. We plan to collect and analyze low-level movement data to further classify and analyze the movement dysfunction of PD.

The advantage of the current system is we can collect highly accurate movement data which we can used to analyze the effectiveness of the system. However, for future iterations and clinical implementation, this system should be simplified. We believe this setup can be simplified to use a single infrared camera instead of a Motion Capture System. The camera can be setup to capture the patient's silhouette, which can be used in place of the avatar in our system.

The system, as described, only provides rehabilitation in a single plane. To extend the system to a 3D environment, we have begun to explore the possibility of creating a floor based system; we believe two systems can be combined to create a 3D environment. This system can also be simplified to use a minimal number of cameras to capture movement from two different planes of movement, as an alternate solution.

Current literature has shown the high rate of success with visual and auditory cues in the lower extremities, particularly with respect to gait. However, it has not described the usefulness in the upper extremities. Therefore, future research should explore whether visual cues can increase the amplitude of movement in the upper and lower extremities in PD patients over the course of the physical therapy. We believe the usage of sensory cueing and the BIG protocol within a mediated environment has endless possibilities that we plan to explore.

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