Case study using virtual rehabilitation for a patient with fear of falling due to diabetic peripheral neuropathy

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ABSTRACT

The purpose of this case study is to report the effects of using virtual rehabilitation (VR) to facilitate improvement of gait stability and endurance in a patient recovering from diabetic neuropathy who also experienced fear of falling. Timed Up and Go (TUG) testing revealed objective improvements and the subject's gait appeared more stable and fluid. She reported increased confidence in walking and endorsed increased confidence on the Activity-specific Balance Confidence Scale (ABC). This study also establishes how VR games can be inexpensively made and tailored to specific therapy needs since games were made by undergraduate Computer Science students for credit.

1. INTRODUCTION

Diabetic peripheral neuropathy (DPN) can be a challenging illness to treat in physical therapy due to the combination of sensory and motor loss, neuropathic pain, and fatigue. Additionally, common comorbidities such as depression, anxiety, fear of falling, motivation, and executive dysfunction can also affect recovery. Skilled therapy providing safe repetitious exercises can both enhance motor recovery as well as provide adaptive strategies. People generally utilize a combination of somatosensory, vestibular, and visual systems to maintain balance (Wotseney & Joy, 1997). The loss of one of these systems places a greater burden on the remaining two systems. In this case study, the subject exhibited impaired sensory abilities and therefore, she had to rely more on her vestibular and visual systems to maintain her balance. This reliance on only two systems can be very challenging to therapists and patients, leading to increased fear of falling and ineffectual gait. While repetitious therapeutic exercises have been shown to facilitate recovery, fear of falling can greatly diminish a patient's motivation and effort. While still relatively a young field, VR is at the cutting edge of rehabilitation research. Recently, Zhen et al. (2016) performed a large meta-analysis with conclusions that support the use of VR to improve balance after stroke. However, few studies have examined the use of VR for those who have a fear of falling. Some of our previous research using the Wii Balance Board showed significant benefit over traditional therapies for those in pain (Ramchandani, 2008). It was thought that the engaging and diverting aspects of the games distracted the patients from their level of discomfort, allowing the subjects to stand and participate in therapy for longer periods of time with increased effort and engagement. Unfortunately, the Wii Balance Board system does not have the flexibility to be used with wheelchair users or those requiring assistive devices. Thus, we developed our own games which primarily image the torso, arms, and neck positions and are much less affected by assistive devices and can be used while seated.

2. METHODS

2.1 *Subject*

The subject was a 60 year old female with a history of hypertension and poorly controlled insulin-dependent diabetes mellitus who experienced an acute onset of DPN resulting in lower extremity pain, impaired lower extremity proprioception, and lower extremity diabetic amyotrophy characterized by weakness followed by wasting of pelvifemoral muscles. Over the course of her recovery, her motor abilities recovered at a faster pace than her sensory abilities. Prior to beginning physical therapy (PT), she primarily was using a wheelchair for transportation but was able to use a front wheeled walker (FFW) for short distances. Using the FWW, her gait was slow and deliberate, and she reported a fear of falling. She was participating in outpatient PT sessions and as an adjunct, she also participated in six sessions of VR.

2.2 Hardware

The Microsoft Kinect v1sensor 3d motion sensitive camera was used as the input device. The LiteGait® (Mobility Research), which was used only for her first session, is an adjustable weight bearing device in which the patient is harnessed for safe gait training.

2.3 Software

All games were created in the second author's facility and under his guidance. Games were designed with the input of physical and occupational therapists as to specific movement that would be beneficial. Games were made by senior level undergraduate Computer Science students as part of a senior project for partial class credit. SDL (Simple DirectMedia Layer) was used for sound and data was stored in MongoDB database, using JSON (JavaScript Object Notation). The web server was built using Flask and JavaScript and data was sent between game and server using secure shell (SSH) encryption.

2.4 Games

- *Coin Game*. This game was developed using Microsoft XNA Game Studio. In this game, a player guides a car along a roller coaster type track amassing coins and avoiding obstacles. The player manipulates the car with lateral leans to the right, middle, or center lanes. Leaning forward is used to duck below obstacles and leaning backwards is used to jump, allowing the therapist to address anterior/posterior as well as lateral balance. Auditory and visual cues such as arrows appear prior to an obstacle, thus requiring the player to attend to the signs as well as to the track. Coins are placed evenly on left and right sides of the track to elicit equal attention, and it is possible to view data afterwards to evaluate a player's movements.
- *Boat Game*. This game was developed using OGRE (Object-oriented Graphics Rendering Engine) for graphics and SDL was used for sound. The player guides a boat through a maze of icebergs in search of targets with forward and backward movements and left and right leaning. The player may lift either arm to shoot a laser beam at the target as can be seen in the left aspect of figure 1. This game can be used to challenge balance when arms are raised.
- *Plane Game*. This game was developed using OGRE for graphics and SDL for sound. A player moves their torso laterally to fly a plane while avoiding buildings and hitting targets as in the right aspect of Figure 1. As the game progresses, levels become increasingly faster and feedback includes number of targets hit.

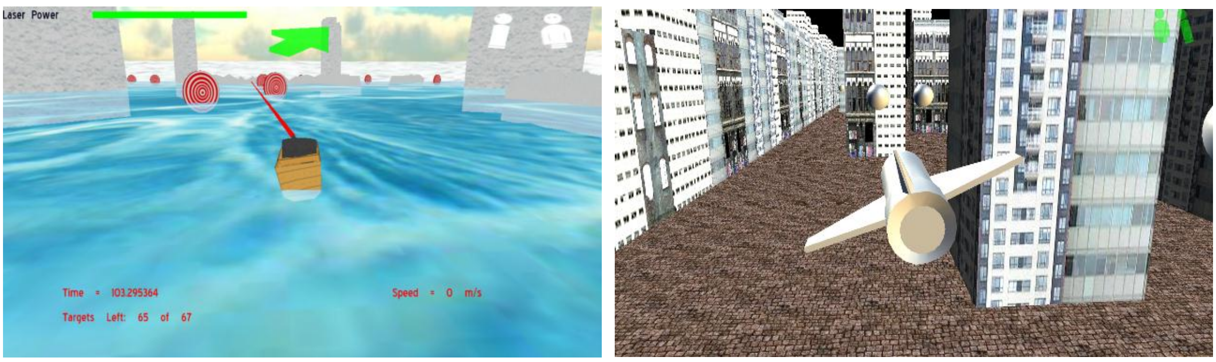

Figure 1. *Screen capture of Boat game (left) and Plane game (right).*

2.5 Procedure

The subject participated in six 45 minute long VR sessions with breaks provided as needed based on the subject's request or therapist's decision. Games were selected to address particular issues that the physical therapist wanted to address and the Plane, Coin, and Boat games were played on various sessions. During the first session, she was supported (but bearing her full weight) by the LiteGait device which was primarily used as a safety precaution and to increase her confidence. She was harnessed facing the Kinect sensor and bobby pins

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were used to hold down straps which would otherwise interfere with the sensor device. Halfway through this session the LiteGait was discontinued, and she used a FWW with her physical therapist guarding her. For following sessions, she used the FWW with diminishing reliance, and no assistive device was used on the final session. The TUG was assessed during the second session, before and after VR, with the subject using either a FWW or single point cane (SPC). The Activities-specific Balance Confidence (ABC) Scale (Powell, 1995) was administered prior to initiating physical therapy and at the end of treatment. The ABC is a self-rating measurement in which subjects rate their perceived confidence on 16 items such as their ability to walk down stairs, stand on a chair, or walk down a ramp.

3. RESULTS

3.1 Objective

This case study was non-planned, and data was analyzed retrospectively. As seen in Figure 2, the subject exhibited improvement in pre/post TUG testing using the FWW (24 seconds pre and 20 seconds post) and the SPC (31 seconds pre and 25 seconds post). She was also timed using no assistive device following VR at 26 seconds, but was unable to so before the VR session due to fear of falling and instability. While game scores were not recorded, her advancement in terms of increased game difficulty (such as increased speed of playing) also served as markers of her improvement. The subject also exhibited increasing standing and playing times over the course of the VR sessions. At the beginning of her starting treatment, chart notes reported that the subject was only able to walk for five minutes at a time and required a 30 minute rest break. For her final session, she was able to play for 45 minutes with no break. In terms of results of ABC evaluation, she reported increased confidence in her balance with an average 31.25% confidence while using a FWW prior to starting VR training and an average 85.3% confidence using no assistive device post VR training.

3.2 Subjective

The subject exhibited improved quality of her movements which were initially stiff and robotic-like but became smooth and fluid, and she moved in a faster manner over the course of her training. She exhibited one loss of balance during her first VR session (while in the LiteGait), but she was able to right herself. When asked about this experience after the session she reported, “I forgot to be scared.” At the beginning of the second VR session she reported, “I felt so much more confident and energized last session!” According to chart notes from that session, the subject exhibited “improved balance and decreased reliance on assistive devices after VR” and also noted that the subject moved faster and more confidently with improved balance.

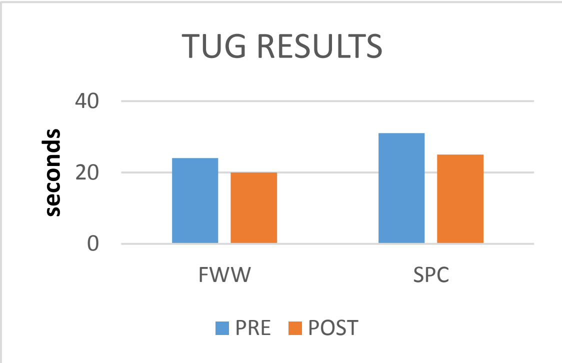

Figure 2. *Results of pre and post VR TUG testing in seconds*.

4. DISCUSSION

These results support that VR can be a useful adjunct to traditional PT, increase the engagement of the subject while providing repetitious therapeutic exercises, and help to increase balance confidence. Based on TUG testing, this subject’s speed of gait improved after VR training. While practice effects cannot be ruled out, the quality of her gait also improved, suggesting that VR contributed to her improvement. She also exhibited improved endurance with each session and completed successfully more challenging levels. Additionally, her realization during the games that she was able to lose and recover her balance seemed to be a significant boost to her confidence. Moreover, chart notes reported that the subject’s gait became “smooth and faster,” and the subject reported improved confidence and energy. Similar to Ramchandani’s (2008) theory that playing video games during therapy can be distracting from pain, we postulate that VR may have diverted the subject’s attention away from her fear of falling and improved her balance confidence. Additionally, this subject clearly enjoyed the games and perceived them as fun. This aspect, of course, is a central tenet to game theory which is that we are more likely to engage in activities we enjoy. This principle was central in designing our games. We attempt to incorporate therapeutic movements into a fun and engaging atmosphere. This positive distraction and competitive aspect are clearly important drives, and she consistently reported her desire to improve upon a previous score or level. The element that these games yield concrete scores for players to notice their improvement and set goals is also a central component of game theory, and we have previously shown how these aspects helped a stroke patient better appreciate his improvement (Carroll, 2016) as he was more trusting of improving game scores than his therapists reports of improvement.

Recently, Shema (2014) postulated that VR may help with the cognitive and motoric aspects of walking. For this study, 60 diverse subjects underwent VR training which consisted of walking on a treadmill while negotiating virtual obstacles. The authors postulated that VR differs from typical balance training, as it contains cognitive aspects of planning with constant adaptation and shifting of attention under varying motor conditions. While executive dysfunction is a more common comorbidity of diabetes, our subject exhibited no evidence of cognitive or executive dysfunction. However, there were substantial cognitive demands used in the games for this study in that the games required divided attention and multitasking (Coin game), spatial memory and upper extremity coordination (Boat game), and speed of processing (Plane game). It is interesting to consider that the cognitive aspects of our games may have also helped with her balance, and that engaging in challenging cognitive abilities during PT may be a useful therapeutic activity for those experiencing DPN. This study also demonstrates how VR games can be made inexpensively and tailored to specific therapy needs. These games were made by undergraduate Computer Science students receiving class credit for their projects. At the beginning of each class, therapists are consulted as to particular skills and movements that would be most beneficial to their patients. Various game scenarios are also discussed to ensure that the final product is both fun and therapeutic. To summarize, VR allows for multiple repetitions of desired movement that would be monotonous in more traditional therapies but can be achieved in a fun and novel way. The competitive aspects of playing games also increase motivation and provide concrete signs of improvement to further propel effort in therapy. Illnesses such as DPN may have complex and intersecting comorbidities such as difficult pain management, depression, anxiety, executive dysfunction and fear of falling which may impair a patient's full benefit from therapy. The use of VR for these and other comorbidities may be a useful therapeutic endeavor.

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